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Paula Andrea Zuluaga Guerra

Modelling of Decision Making in a Common Pool Resource Dilemma with a Dynamic Resource

Directora: María Claudia López

Codirector: Daniel Castillo

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Abstract

This paper presents the results of a system dynamic model that allows the possibility to study the changes in players' extraction behavior when moving from a static field experiment to a dynamic resource simulated through dynamic modeling. We build an artificial experiment based on the results of a static experiment conducted with fishers in the Peruvian Amazon. Our results suggest that the fishers in this experiment used the first norm of reciprocity described by Ostrom (1998), *Always cooperate first; stop cooperating if others do not reciprocate; punish non-cooperators if feasible*. System Dynamics approach allows us to simulate fishers' behavior with a dynamic resource. We found that artificial players did not change their behavior with the introduction of the dynamic resource, therefore depleting it. This result is consistent with evidence found in dynamic experiments and in few fisheries around the world showing that the dynamic resources create misperceptions among the users.

Acknowledgments

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1. Introduction

The way communities govern and manage their natural resources has been a recurring concern addressed by environmental and social scholars. In his seminal article " The Tragedy of the Commons", Hardin (1968), states that communities cannot manage their resources in their own because they are trapped in a situation in which the immediate individual interest do not coincide with the long term commons interests. The author concludes that the only solution to avoid the tragedy of the commons is by the intervention of an external party, either through the State or by privatizing. Years later, Ostrom (1990) reported a series of empirical case studies in which the tragedy did not occur. Moreover, her findings suggested that many communities were able to self-organize and succeeded in preventing the overuse[1].

In order to have a better understanding of how communities govern and manage their resources Ostrom (1990) investigates different institutions around the management of these resources. Institutions are defined as "the prescriptions that humans use to organize all forms of repetitive and structured interactions" (Ostrom, 2005: 3)[2]. In other words, institutions are the rules in the society, or more formally, the humanly devised constraints that articulate and configure social, political and economic interactions (North, 1991). Many studies have shown that a unique institution does not guarantee the conservation of natural resources (Ostrom et al. 2007). Acheson (2006), explains that either private-property regimes, government-controlled resources, or local-level management institutions have failed under certain conditions. Therefore, more studies looking into new institutional arrangements that introduce the particular needs of each situation are needed (Vollan and Ostrom, 2010; Ostrom et al., 2007).

The common pool resources (CPR) are defined by Ostrom (1990) as a resource system (natural or man-made) in which the costs of exclusion of potential beneficiaries are high but not

[1] From the studies Ostrom (1990) exposes, the author characterizes some principles that communities need to have successful processes of self- governance and self-organization. In recent years, some scholars have reviewed these principles (to have a comprehensive understanding refer to Cox et al. (2010))
[2] Between these, there are rules, norms and shared strategies, also known as institutional statements (Ostrom, 2005)

impossible to assume and where the consumption units of one beneficiary are not available for the others in the system after the extraction. These two characteristics are defined by Ostrom (1990) as excludability and subtractabilty. These CPRs are embedded in complex systems that Ostrom (2009) recognizes as Socio-Ecological Systems (SES).

Our objective in this paper is to include the ecological dynamism that characterizes natural resources in the design of CPR experiments in the field, through the construction of a dynamic model. We use dynamic modeling to recreate a series of experiments carried out in Caballo Cocha, in the Peruvian Amazon. In the dynamic model, we replace the static resource used in the experiments with a dynamic resource, in order to analyze changes in the behavior of artificial players[3] in this new scenario. The dynamism of resources and space as well as other institutional factors have not been widely addressed in CPR experiments (Anderies et al., 2011). Few exceptions to this statement are Moxnes (2007); Janssen et al. (2010) and Janssen (2010) among others. In these studies the dynamism and spatiality of resources as well micro-situational variables have been included due to the necessity to increase the relevance of behavioral experiments (Janssen, 2010).However, the use of dynamic experiments in the field is not widely spread due to their complexity and because in most cases they are computer based. In this context, the use of a dynamic model allows scholars to study people's behavior in field experiments (traditionally in static settings), without the challenges of developing dynamic experiments in the field.

In recent years scholars have proposed the use and combination of different methodologies to study socio-ecological systems and CPRs in order to have a more holistic approach to complex realities (Poteete et al., 2010). According to these authors all methodologies have limits and the best way to overcome them, is through a rigorous research combining complementary methods. In this article we use experimental economics together with simulation modeling to study the processes of decision making involved in a CPRs use.

[3] Artificial players are the individuals built in the system dynamic model

According to Smith (1976), experimental economics can be used as a rigorous empirical way for testing hypothesis from the economic theory and represents a fundamental input to the study and analysis of field data. In the past decades, the experimental economics literature in environmental and development issues had generated very valuable and interesting results that cover issues from economic valuation to the creation of economic incentives (Cardenas, 2011; Cherry et al., 2007; Sturm and Weimann, 2006). Regarding resource management, the focal point has been how to solve the social dilemmas incurred by the use (or the provision) of the CPRs and to find the best institutional arrangements for managing the CPRs in each particular case (Cardenas et al., forthcoming). Additionally, the experiments have been used as a pedagogical tool for communities to participate, communicate and discuss about the use and management of their CPRs (Lopez, 2011; Moreno-Sánchez and Maldonado, 2010; Cardenas and Carpenter, 2005; Cardenas et al., 2003). All these authors report that the combination experiments together with participatory methods such as participatory rural appraisal enables participants to make bridges between what happen in reality and what happen in the experiment. According to Moreno Sánchez and Maldonado (2010: 2565), “this is an important aspect of the experiments, especially with respect to fishers that often have low levels of education, such as are generally found in developing countries”.

On the other hand, simulation models have been a tool for understanding individuals and groups behavior in the social dilemmas with CPRs (Deadman, 1999). Among modeling approaches, System Dynamics, is a conceptual and methodological tool based on a systems approach. It is characterized by close boundary systems[4] and feedback loops[5] (Forrester and Collins, 1969). Initially, Forrester (1965) proposed the use of this methodology in industrial engineering to analyze and improve industrial processes and management. A few years later,

[4] This does not mean that the system is not affected by external variables but that those variables do not affect the intrinsic behavior and characteristics of the system (Forrester and Collins, 1969).

[5] Feedbacks are understood as the interactions between the components of the system. All dynamics are explained in terms of two types of feedback loops: positive (or self-reinforcing) and negative (or self-correcting) loops (Sterman, 2000). Feedbacks are composed by stocks and flows (Forrester and Collins, 1969)

Forrester and Collins (1969) used System Dynamics methodology in in urban dynamics. Finally, in more recent years it has been used in environmental and economic development (Meadows et al., 1992; Meadows et al., 1972). Specifically, in environmental sciences it has been used since the 60's, especially for the study of population growth in a finite world (Cavana and Ford, 2004). In this context, Meadows et al. (1972) elaborate the "World3 model" in which they represent the population increase, the agricultural production, the nonrenewable resource depletion, the industrial output and the pollution generation. In 1992, Meadows et al. vary the original global policy assumption of "World3" dynamic model and predict different outcomes, from collapse to sustainability. In other subjects, Ford (2009) explains this method is usefulness in strengthening theories through the models and discovering or learning attributes of the modeled systems. With respect to decision making processes and policies, Stave (2002) explains that System Dynamics has the potential to encourage public participation in environmental decisions making. Regarding SES studies, Castillo and Saysel (2005), state that this method is useful to represents and formalizes feedback processes governing the dynamics of the SES. As well as Dudley (2008), explains that System Dynamics allows researchers to emphasize in changes the SES have over the time.

The main question we want to address in this paper is if the players' extraction behavior in a static experiment changes when facing a dynamic resource simulated through dynamic modeling. To do so we build an artificial experiment[6] based on the results of a static experiment conducted with fishers in Caballo Cocha, in the Peruvian Amazon (Lopez and Walker, 2011).

To our understanding, the only study using both experimental economics and System Dynamics is the one by Castillo and Saysel (2005). In that article, the authors use these methodologies to approach complex realities by elaborating a feedback dynamic model based on the results of a static experiments conducted in Old Providence Island of the Colombian Caribbean with crab hunters and fishermen. The model structure used by the authors is based

[6] Artificial experiment because is built in the model

on Ostrom's behavioral theory of collective action (1998)[7], observations on subject's behavior in their daily life and payoffs during the experiment. We depart from Castillo and Saysel (2005) model and adapt it for the new CPR experiment created by Lopez and Walker (2011). Our analysis goes beyond Castillo and Saysel (2005) in two directions. First, by introducing a dynamic resource into the model as a new input, this was done with the objective to compare the behavior of the artificial players in this setting to the static one. Second we include another loop into the theoretical model that we called Aversion to Inequality. The combination of experimental economics and System Dynamics could help understanding how decision making processes work and how it affects people decisions.

Our results suggest that artificial players do not change their behavior when deciding over a static or a dynamic resource. Due to the dynamic model structure artificial players do not realize fast enough the changes in the resource until it is almost completely depleted. This behavior coincides with different cases of fisheries around the world (FAO, 2008; Berkes et al., 2006; Orensanz et al., 2005; Pauly et al., 2002; Berkes et al., 2001) and with the results obtained in dynamic experiments (Cardenas et al., forthcoming; Castillo et al., 2011; Janssen, 2010; Moreno-Sánchez and Maldonado, 2010). According to the experiment results and the simulations, the Caballo Cocha fishers in the experiment used the first norm of reciprocity described by Ostrom (1998), *Always cooperate first,; stop cooperating if others do not reciprocate; punish non-cooperators if feasible*

This paper is organized as follows. In the second section we present the context describing the local background of the Caballo Cocha fishery, in the third section the experimental design In the fourth section we include the modeling decision making process, the second generation model of Ostrom (1998), the formal simulation models and the validity discussions. In the next section, we present the results of the players' behavior whit a static

[7] The second generation model of rationality is based on the feedback relation between reciprocity, trust and reputation. According to the author, in a social group with individuals using reciprocity rules there is an interest of building and maintaining a reputation of being trustworthy.

resource and with a dynamic resource in six scenarios. In the next section we present the discussion and finally in the last section we conclude.

2. Context

Fisheries in the Amazon are principally located in ecosystems known as floodplains. These ecosystems are defined as the areas periodically flooded by the lateral overflow of rivers, lakes or even by high precipitation or ground waters (Junk and Bayley, 1989). The principal ecological dynamic of these ecosystems is the flood pulse, which determines: the productivity, the biota existence, the annual lakes growth (Junk, 1989) and the reproductive seasons of fish species (Goulding, 1980). The flood pulse dynamic makes of fish species dependent on both terrestrial and aquatic resources (Goulding, 1980). With reference to communities leaving in floodplains, McGrath *et al.* (1993) explains that the flood pulse also determines the survival strategies and the economic activities of those communities.

Between the flood plain ecosystems there are the varzeas, areas periodically flooded by the muddy waters of the Amazon River (Castro and McGrath, 2010), that due to all the characteristics mentioned above are extremely productive. Nevertheless, Castro and McGrath (2010) explain that since 1960 the increasing fish demand and the introduction of new technologies have been raising the pressure on these fisheries.

Caballo Cocha is located in a varzea area in the Peruvian Amazon and is the capital of the Ramon Castilla Province. In 2010 the population was estimated to be around 57.000 inhabitants, predominantly mestizo (Lopez and Walker, 2011). Even though one of the main economic activities is fishing (Lopez and Walker, 2011), the exact number of fishers is unknown. A fishers association was created in 1979, but this association only has 40 active members. In the last years the community has detected the decrease of the fishing resources, especially some species as the *Colossoma macropomum* (Gamitana) o *Arapaima gigas* (Paiche) (Ortiz et al., 2010). According to Ortiz et al. (2010) this decreased is due to the use of new gears (i.e., like small fishing nets) and the limited regulation. Other studies also suggested that this may be happening because of an increasing demand (Barthem et al., 1997)

Caballo Cocha's fishery is mandated in a national level, through several laws: a) the Organic Law for the Sustainable Use of the Natural Resources[8], b) the Law of the Conservation and Sustainable Use of the Biological Diversity[9] and c) the General Fishing Law[10] and its regulation[11]. These laws aim to achieve a sustainable development in fisheries of the country. Regionally, a "Fisheries Management Regulations of the Peruvian Amazon"[12], gives the basis for the conservation of the hydrbiological resources in the Amazon. This management highlights the importance of the research to design management tools. It recognizes the need of specificities of the Fisheries Management Programs according to each fishery. Additionally, it gives a preferential status to communities living in lakes (or *cochas*[13]) for using the hydrobiological resources in these areas. And finally, this regulation determines the permitted season (during heavy rainfalls) for commercial fishing in the lakes and recognizes the importance of the communication and coordination of activities between Peru and the border countries.

At the local level, there is a Management Fishing Plan for Caballo Cocha implemented in 2010[14]. This plan was as a response to conflicts between the "*secretaría de pesca*"[15] and the fishers. The Management Fishing Plan aims to establish principles and regulation measures seeking the sustainable management of some fishing species within (Ortiz et al., 2010).

[8] Law Nº 26821 of Peru
[9] Law N° 26839 of Peru
[10] Law Nº 25977 of Peru
[11] Supreme Decree Nº 012-2001-PE of Peru
[12] Ministerial Resolution Nº 147-2001-PE of Peru
[13] Cocha is a local name for lake (Ortiz et al. (2010).
[14] Implemented by the "secretaría de pesca" and the Colombian NGO Omacha.
[15] Government office in charge of the fishing regulation (Lopez and Walker,2011)

3. Experimental design

Lopez and Walker (2011) created and conducted a new CPR experiment in two different communities of the Peruvian Amazon based on an initial field survey that identifies current rules-in-use and alternative rules suggested by community members and regulators. Their results show that rules promoted by the community and the regulators (when the origin of the rule was not revealed) where more effective in increasing cooperation than rules not crafted at the community level. The experiments had two sets of 10 rounds each one. In the first set of the 10 rounds all the participants were facing the same experiment traditionally recognize as a baseline, then in the second set of 10 rounds the participants were introduced to the different institutional treatments. In this paper we use the results from the first 10 rounds of the experiment.

The CPR experiment conducted by Lopez and Walker (2011) recreate the use of a CPR resource, in this case a lake with y=150 units by 5 users. In each round of the experiment, each person is allowed to withdraw up to n=30 units of the resource knowing that for each unit extracted he will receive 1 unit of experimental currency[16]. Then the units reaming in the resources are shared by all individuals with the following payoffs functions:

g ≤ (y/3), then each individual receives g*0.5.

If g ≤ 2*(y/3), then each individual receives (y/3) *0.5+(g – (y/3))*0.3.

If g > 2*(y/3), then each individual receives (y/3)*0.5+(g – (y/3))*0.3 + ((y/3) – (y – g))*0.1.

This novel experiment includes the need of fishers to use some of the resources from the lake to guarantee their livelihood, for that reason the social optimum is achieved when the group as a whole extracts (*y/3*) resource units, thus 50 units. Thus, there are a multiple combinations of individual decisions that accomplish that optimum. On the other hand the Nash equilibrium is for each individual to extract 30 units.

[16] In the instructions the monitor explained that one unit of experimental currency is equal to 25 cents of a sol (the Peruvian currency)

The experiments were conducted in June 2010 with 160 inhabitants of Caballo Cocha. The recruitment process started one month before the experiments took place through an NGO and the local fishery authorities. Fishers older than 18 years from different zones of Caballo Cocha were invited to participate in a decision making task. The experiments were conducted in several sessions (one session having more than one group), each session lasted on average two hours and a half. In case that two members of the same families showed up to participate, they were not to participate in the same group. After all the participants were distributed in groups, the monitor started to read the instructions aloud. The same protocols were followed in all the sessions. The monitor explained the experiments through the use of posters containing all the forms to be used during the experiment. Subjects were not allowed to communicate in any stage of the experiment and after the experiments started they were seat in such a way that it was impossible to see other people´s forms. After the instructions were finished, all groups had the same three rounds of practice; this allows players to become familiar with the decision setting and the different forms, but also to guarantee that everybody participating in the experiments was getting the same information. People with reading or/and writing difficulties, had field assistants helping them register their decisions, but in no case advising them about what decisions to make.

Table 1 shows the socio-economical characteristics of the participants in the experiments. Among the 160 participants, the mean age was 42.83 years, the mean years of formal education was 7.15, 60% of the participants were male, 85% live meanly from the fishing activity and 30.63% were members of the Jose Olaya Belandra Association.

Subject Characteristics	
Number of participants	160
Percent male	60%
Mean age	42.83
Mean years of formal education	7.15
Percentage of people who mainly live from fishing	85%
Percentage of associated fishermen	30.63%

Table 1. Socio-economic characteristics of the participants in the experiments.

In this paper we take into consideration the extraction decision of the 160 participants over the first 10 rounds of the experiment, thus in total we have 1600 observations. We start our analysis by showing some descriptive statistics about the extraction level in the first ten rounds of the experiment. In table 2, we present the group average extraction and the average individual extraction per round, as well as the standard errors. This first result suggest that individuals were in average extracting 73.362 units, thus more than the 50 units of the social optimum, but less than the 150 units of the Nash equilibrium. This result is consistent with other field experiment on social dilemmas conducted with fishers (Lopez, et al. 2010. Velez et al. 2010), thus extraction levels stand in a level between the social optimum and the Nash equilibrium. Additionally, the group extraction also shows that in the first five rounds of the experiments participants were extracting 72.13 units in average; while in the following five rounds of the experiment the extraction was 74.54 units in average. A t-test determines that these average group extractions were different at the 1% level of significance (p=0.000). This difference may be due to different factors such as learning effect to not cooperate that is widely found in the experiments conducted with students.

For the purpose of this paper and to allow the analysis to be done at the individual level, we assume that the group social optimum of 50 units was to be extracted in an even way; this means that each participant was supposed to extract 10 units. As mentioned before, the average extraction at the group level was higher than the social optimum, then it is not surprising that the average individual extraction we observe is over the 10 rounds of the experiment over the individual social optimum of 10 units.

Round	Average Group Extraction	Standard Error	Average Individual Extraction	Standard Error
1	71.406	1.605	14.281	0.639
2	73.812	1.426	14.766	0.693
3	71.312	1.496	14.350	0.675
4	71.812	1.196	14.363	0.649
5	72.312	1.04	14.463	0.641
6	74.281	1.624	14.856	0.66
7	73.093	1.514	14.619	0.678
8	74.593	1.43	14.918	0.672
9	74.906	1.325	14.981	0.703
10	76.093	1.111	15.219	0.711

Table 2. Average group and individual extractions per round.

In the experiment each participant had the possibility of extracting between 0 and 30 units of the resource in each round. In Figure 1 we present the frequency of each one of the extraction decisions per round. The figure shows that extracting 10 units was the most common decision in rounds 1, 2, 3, 8 and 10, extracting 15 units was the most common decision in rounds 5 and 6 and extracting 20 units was the most common decision in rounds 4 and 7. In round 9 both extracting 10 and 15 units were the most common decisions. Taking into account that communities do cooperate but not always at the optimum (Ostrom, 1998) we define that extracting 15 units is an intermediate cooperation. In this context, in average cooperative decisions were more common than non-cooperative decisions in each round.

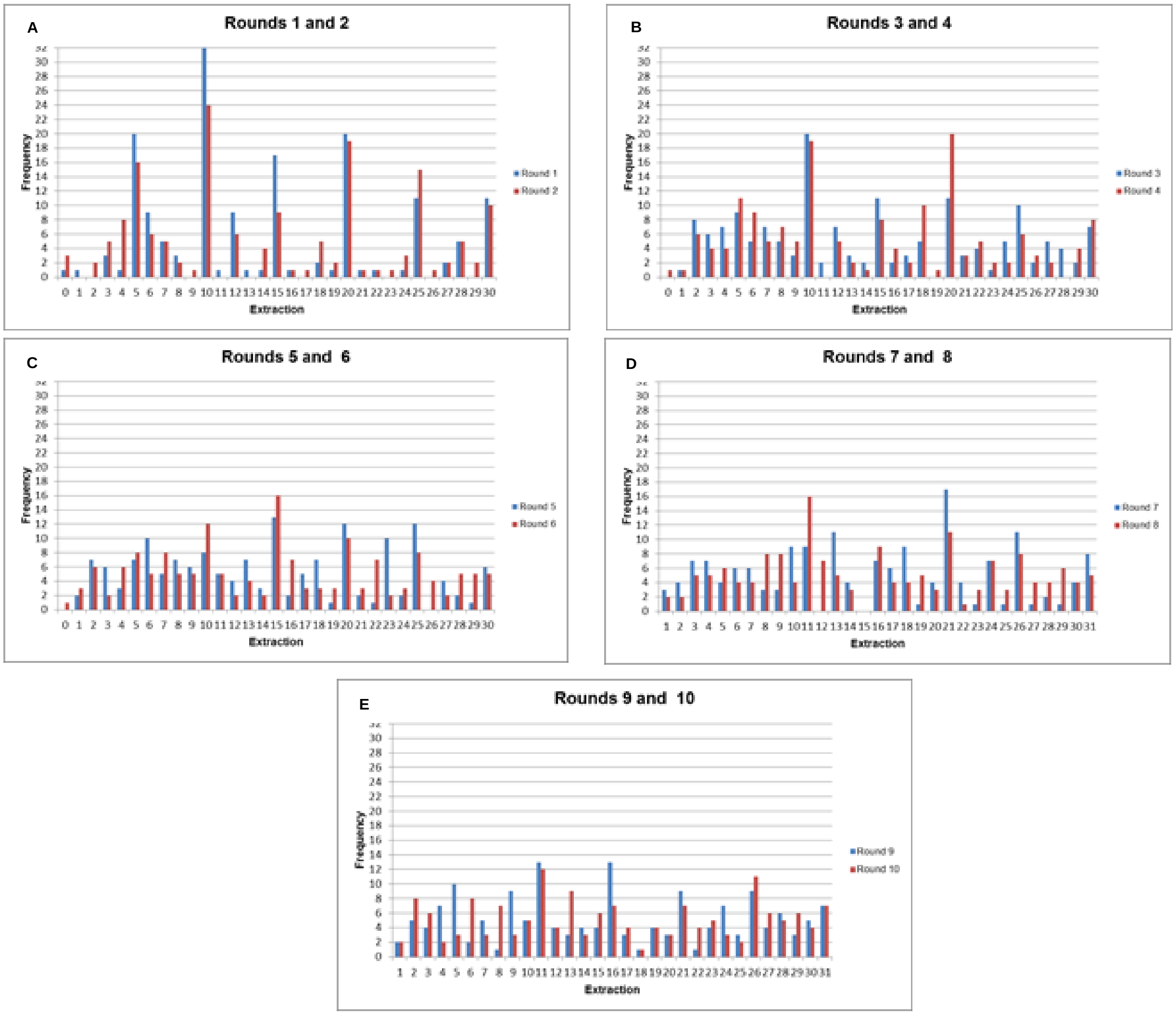


Figure 1. Frequency of Individual Extraction Decisions per round

The individual extraction decision (between 0 and 30) goes in the x axis and the frequency of each one of these extraction decisions in the y axis.

Replicating the same figure but now for the whole ten rounds of the experiment, we observe in Figure 2 that the most frequent individual decision is to extract 10 units, with 165 observations (over 1600), follow by the decision of extracting 20 units, with 136 observations and by the decision of extracting 15 units, with 110 observations. The less frequent decision is extracting 0 units, with 15 observations. There are 659 observations in which the extraction is between 0 and 10 units of the resource and 253 in which the extraction is between 11 and 15 units of the resource and 688 between 16 and 30.

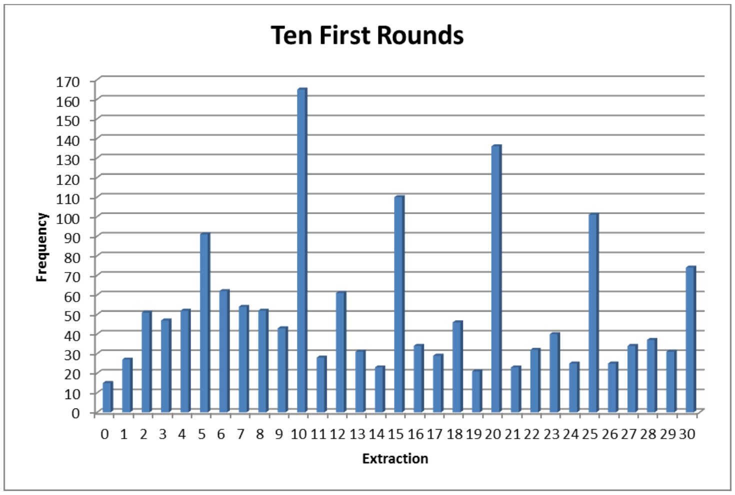


Figure 2. Extraction frequencies during the first ten rounds

4. The Simulation Model

4.1 Modeling Decision Making

Stocks, flows and auxiliary variables are the building blocks of the language in System Dynamic modeling (Castillo and Saycel, 2005). Stocks, symbolized by rectangles, are accumulations that characterize the system state and generate the information in which the decision and actions are based (Sterman, 2000). Flows, symbolized by valves, are the actions or decisions to change the system to a new state in the next unit of time, in this case rounds (Ford, 1999). Auxiliary variables represented with circles, describe the flows and help to perform different operations (Castillo and Saysel, 2005: 424). Additionally to these symbols, as shown in in Figure 3 arrows are also used, these arrows are connectors, not variables, and represent a "causal relation between two variables and carry the information within the model structure" (Castillo and Saysel, 2005: 425).

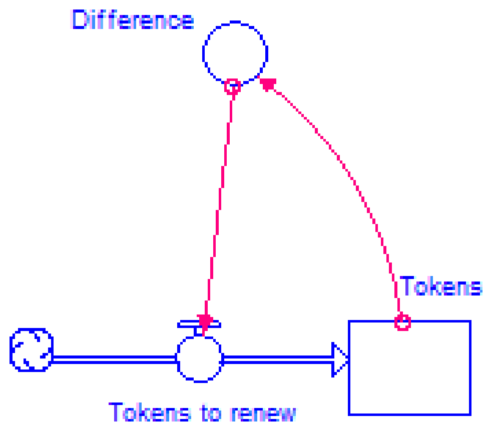


Figure 3. . Elements of the System Dynamic language

Referring to the modeling of the players in the economic experiment, Castillo and Saysel explain that they must be "represented as individuals or as aggregations of decision-making individuals or groups" (2005: 424).

4.2 The Second Generation Model of Rationality

Taking into account that part of our dynamic model is designed based on the Second Generation Model of Rationality of Ostrom (1998), we will explain it briefly. Ostrom (1998) states that in the field when individuals face social dilemmas they do not behave as rational, self-interested agents. Their behavior is dependent on "structural variables"[17], that are determined by the local context, and the use of heuristics rules and norms that individuals learned over their lives. Between these norms we found the reciprocity norms, understood as different strategies that can be used in social dilemmas and that "share the common ingredients that tend to react to the positive actions of others with positive responses and negative actions of others with negative responses" (Ostrom ,1998: 10). "The reciprocity norms posited to help individuals gain larger cooperators' dividends depend upon the willingness of participants to use retribution to

[17] Such as "size of the group, heterogeneity of participants, their dependence on the benefits received, their discount rates , the type and predictability of transformation processes involved, the nesting of organizational levels, monitoring techniques, and the information available to participants" (Ostrom, 1998: 2).

some degree" (Ostrom,1998: 10). The author identifies six types of reciprocity norms exposed further.

The model is based on the core relationship between reciprocity, reputation, cooperation and trust and the "structural variables" affecting this relationship. Figure 4. shows the "link between the trust individuals have in others, the investment others make in trustworthy reputations and the probability that participants will use reciprocity norms" (Ostrom, 1998: 12). The cooperation variable affects and determines the net benefits for a given group. Both trust and reputation are only important in groups of small sizes, such as the case of Caballo Cocha fishery.

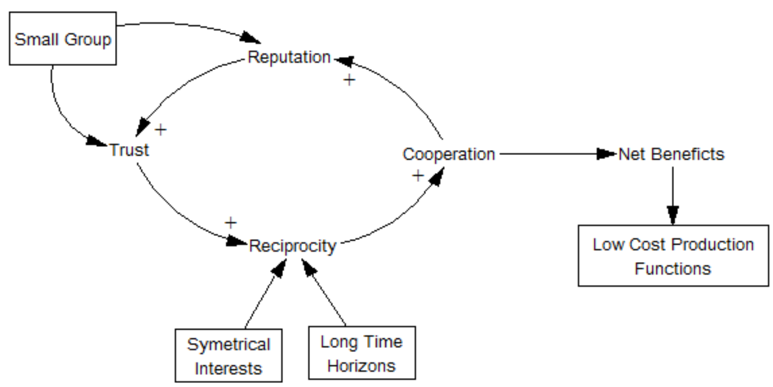


Figure 4. "Core variables of the second-generation model of rationality and structural variables that determine the effectiveness of the theory". Adapted from Ostrom (1998) by Castillo and Saysel (2005)

4.3 Dynamic Model Structure

As explained before the simulation model[18] was built based on Castillo and Saysel (2005) but using the structure of the experiments conducted in Caballo Cocha by Lopez and Walker (2011).Then, the model formalizes the feedback causality between trust, reputation and reciprocity proposed by Ostrom (1998). It characterized as well the feedback causality among other behavioral factors such as temptation to free ride, profit maximization, and awareness of the social dilemma. Additionally, for this paper we introduced another loop, aversion to

[18] The simulation model was done using Powersim Constructor (Powersim, 1999).

inequality, this measure represents the difference between the own earnings and the earnings each individual receive from the resource. The structure of the simulation model includes the individual payoff functions from the experiments presented above, the condition of the resource at each round (the units remaining in the resource after each round) and the individual extraction decision in that particular round. There is not a particular strategy for the players to follow, strategies such as “tit-for-tat” or not cooperating between others, may or may not arise depending on the model structure. The behavior of the artificial players in the model tends to represent the “average” observed individual behavior in the real experiments. As we assume that the theory and the model explain the systemic behavior of the individuals, the model behavior is confronted with the “aggregate” experimental results. Finally, it is important to recognize that the dynamic model does not consider all the factors that could determine the participant’s behavior because it may exclude variables such as the life history of the participants, the incentives they had when participating in the experiments, their relation with the *secretaria de pesca* or the local NGO helping us with the experiments, among others.

With respect to the resource we use two scenarios one static and one dynamic. The former corresponds to the structure from the experiment, and the later includes a simple logistic model of a fish population. The structure of the fish population model is composed by three loops: birth, death and fishing extraction. Thus, the structure is defined in terms of the total population (N), the carrying capacity (k), the population growth rate (r) and the fishing extraction (F). The equation 1 represents the fish population change (N) over time. Using these two scenarios allow us to identify changes in player’s behavior from one scenario to the other.

$$\frac{dN}{dt} = Nr * \left(1 - \frac{N}{K}\right) - F \quad \textbf{(Equation 1)}$$

The Extraction of the artificial players in the model is determined by six loops independently of the structure of the fish population model explained above. These loops are: Reciprocity, Aversion to Inequality, Profit Maximizing, Temptation to Free ride and two

Awareness Building loops. Each one of the loops of the model gives some characteristics of the player personality; *Reciprocity loop* (R1) which affects directly the extraction decision through the *Willingness to Cooperate* variable, it determines how cooperative the player is. The *Temptation to Free ride* loop (B1), which affects directly the extraction decision through the *Temptation to Free ride* variable, it shows how vulnerable to the temptation to free ride he/she is. The *Profit Maximize Effect* loop (R2), which affects directly the extraction decision through the *Maximize Effect* variable, it establishes how important is to maximize his/ her earnings. The *Aversion to Inequality* loop (R3), which affects directly the extraction decision through the *Aversion to Inequality* variable it shapes how important is for he/she to have similar extraction decision as the group. The *Extraction learning* (R4) *and Payoff unlearning* (B4) loops, these two loops affect directly the extraction decision through the *Awareness of the Dilemma* variable, this represents how fast does he/she learn about the social dilemma he/she is facing. Finally, the Individual Extraction is affected by the *Reference Extraction* variable that captures players' average individual extraction of the players during the first ten rounds of the experiment (14.73). In other words, it is the aggregate behavior variable that is the starting point of the artificial players' extraction, so each one of the loops affects this variable value and determines the individual extraction variable per round.

Except for the Reference Extraction, all of the variables used in the Extraction definition are nonlinear functions. These variables are defined by several functions depending of some of the characteristics the players could have according to Ostrom (1998), Castillo and Saysel (2005) and field observations. Figure 5 shows a small sample of the functions used in the model to represent those characteristics in each one of the players. Furthermore, with the inclusion of the different loops in the extraction decision we include what Ostrom (2005) defines as the delta parameters. According to the author delta parameters can be explained as the perceived costs of breaking or following a internal rule an individual has. According to Ostrom (2005:146), "one can further divide these rewards and costs into those that arise from external versus strictly internal sources valuation”. The first type is related with the benefits and costs of establishing a reputation and the second type with the social emotions (such as guilt or shame) an individual has when breaking a rule (Schlüter and Theesfeld, 2010; Ostrom, 2005). Having into account these definitions we can determine that the *Reputation to Cooperate* variable is the only one in our model that is originated by external sources, while the *Willingness to Cooperate*, the *Temptation to Free Ride*, the *Profit Maximize Effect,* the *Aversion to inequality* and the *Awareness of the Dilemma* are originated by internal sources.

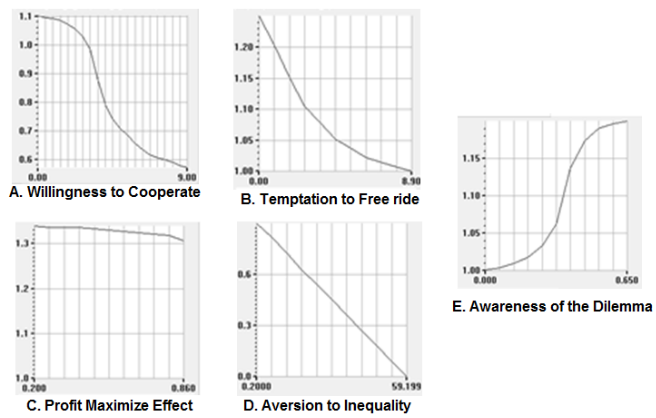


Figure 5. Non-linear functions in extraction calculation for each round.

A. Trust in the others is in the x axis and the *Willingness to Cooperate* in the y axis.
B. Perception of the others’ extraction is in the x axis and the *Temptation to Free ride* in the y axis.
C. The difference between *Actual Individual Payoff* and *Desired Payoff* is in the x axis and the *Profit Maximize Effect* in the y axis.
D. The difference between the *Actual Individual Payoff* and the *Individual Earnings Received from the Resource* is in the x axis and the *Aversion to Inequality* in the y axis.
E. The difference between *Relative Payoff* and *Relative Extraction* is in the x axis and the *Awareness of the Dilemma* is in the y axis

Figure 6 shows four of the six loops that define the model; we observe the different variables included in the model structure, some of which are the stocks. The Reciprocity loop (R1) is a reinforcing or positive feedback loop and is affected by five variables: *Individual Extraction, Group Cooperation, Reputation to Cooperate, Trust in Others and Willingness to Cooperate*. As the *Individual Extraction* variable rises (between 0 and 30 resource units), the cooperation decreases because the players extract more units of the resource. So the *Group Cooperation,* which is the aggregate of individual’s cooperation in each round, decreases as well. As *Group Cooperation* decreases, so does *Reputation to Cooperate*. Therefore, players lose trust in one another and consequently do not to cooperate, reinforcing the decision to extract more. If the level of *Individual Extraction* reduces, *Group Cooperation* increases and so does the *Reputation to cooperate* variable. *Trust in others* increases as well as the *Willingness to Cooperate* does. This last variable is a function determined by the trust the players have in the rest of the group. This function aims to represent the reciprocity level a player can have with respect to the rest of the group. As the reciprocity level increases the player is more able to cooperate and reduces the individual extraction.

According to this, we defined four different functions that represent different levels of *Willingness to Cooperate* (tendencies to reduce the extraction), presented in the validation section. As the player sees that the rest of the group has higher levels of extraction his/her level of trust in others reduces and the willingness to cooperate is low (Figure 5A). As he/she sees that the group extraction decreases his/her trust in others increases, the willingness to cooperate is higher and so the tendency is to reduce the individual extraction (Figure 5A).

The Profit Maximizing loop (R2) is a reinforcing loop that represents the fact that each player compares his/her actual payoffs in that round (*Actual Individual Payoff)* with the maximum payoffs he/she could have in that round (*Desired Payoff*) and take this into account to make his/her extraction decisions. This loop is composed by five variables: *Individual Extraction, Resource Units, Actual Individual Payoff, Difference between Actual Individual Payoff and Desired Payoff* and *Maximizing Effect*. As the *Individual Extraction* gets higher there are fewer units in the CPR so the *Resource Units* variable decreases and the *Actual Individual Payoff* diminishes. If the *Individual Payoff* diminishes, the difference between *Actual Individual Payoff and Desired Payoff* increases and the *Profit Maximize Effect* increases. If the only variable the player would have into account to take the decision of extraction was the *Profit Maximize Effect,* then when it increases the extraction would increase as well. In other words, as individuals perceive that his/ her earnings are decreasing in comparison with the *Desired Payoff* they would tend to extract more units of the resource to reduce this difference.

The *Maximize Effect* variable represents the importance the payoff has for the player; if the earnings are important when taking his/her extraction decision this variable is higher. The *Maximize Effect* variable depends on the difference between the *actual individual payoff* and the *desired individual payoff*. We defined four functions to represent player's profit maximize effect, from a low to a high one, presented in the validation section. In Figure 5C, we characterized a player with an egoistic profile, for this player the value of the difference between the actual payoff and the desired payoff is not important because in any case he/she is extracting in high levels.

The Temptation to Free ride loop (B1) is a balancing or negative feedback loop and consists of three variables: *Individual Extraction, Total Extraction and Temptation to Free ride*. In this loop the player compares his/her extraction in the last round with the group's extraction in that round and uses this information to make an extraction decision in the following round. As the *Individual Extraction* rises the group's *Total Extraction* increases. When the player observes that others are extracting low quantities of the resource the *Temptation to Free ride* increases. If the player has a tendency to free ride he/she would try to extract more units of the resource.

The *Temptation to Free* ride is understood as a tendency individuals may have to take advantage of a cooperative group behavior. If the player has a high temptation to free ride function he/she would try to extract more units of the resource when the total group extraction is low because in this situation his/her payoff would be better. However, when the group has a high extraction level, the incentive to free ride does not play an important role, since none of the player will have the opportunity to improve his/her payoff by rising the extraction. We designed four functions to represent player's temptation to free ride, from a low tendency to a high one, in order to facilitate the comprehension only one of these is reported here. In Figure 5B, we characterized a player with an intermediate tendency, it starts from the highest value when the group's extraction is low but then decreases gradually.

The *Aversion to Inequality* loop (R3) represents the importance for the player of having a similar behavior as the group. The variable is defined in terms of how similar is the individual payoff to the payoff every player receives for the resource. In this context the Aversion to Inequality affects the extraction in three ways. In the first case, when an artificial player perceives that he/she is having more average earnings than the other then she/he will tend to reduce the extraction. In a second case, when an artificial player perceives that he/she is having less average earnings than the other then she/he will tend to increase the extraction. Finally, when the player perceives that he/she is having the same average earnings than the other then the Aversion to Inequality variable is not affecting the extraction decision. This loop is determined by five elements: *Individual Extraction, Resource Units, Individual Earnings Received from the Resource (IER), Actual Individual Payoff and Aversion to Inequality*. Taking into account the experiment structure and the information the players had available[19] at the end of each round, we build a loop in which the players compare his/her *Actual Individual Payoff* with the *Individual Earnings Received from the Resource* in each round. At the individual level, the players do not know the real payoffs the others are making, but at each round they receive from the experimenter the information about the earnings each individual including himself, received from the recourse. As the *Individual Extraction* rises there are fewer *Resource Units* remaining and the *IER* are lower. If the difference between the *Actual Individual Payoff* and the *IER* is higher the *Aversion to Inequality* also increases. If the *Actual Individual Payoff* is bigger than the IER, the player's *Aversion to Inequality* tends to increase If the *Actual Individual Payoff* is lower than the IER, the player's *Aversion to Inequality* tends to decrease. Nevertheless, in this case the effect of this loop in the extraction decision is positive, so if the R3 would have been be the only factor affecting the decision the player would have increase the extraction.

[19] After all the players make their extraction decision, the monitor informed them about the group extraction.

The *Aversion to Inequality* variable is defined in terms of how similar are the individual payoffs to the payoffs of every player. We have two functions for this variable, one for an adverse to inequality player and others for a non-adverse one, in order to facilitate the comprehension only one of these is reported here. In Figure 5D, we can see an adverse to inequality player, the value of the aversion reduces as the difference between the *Actual Individual Payoff* and the *Individual Earnings Received from the Resource* is bigger, so the extraction reduces and the payoff is more similar to the group one.

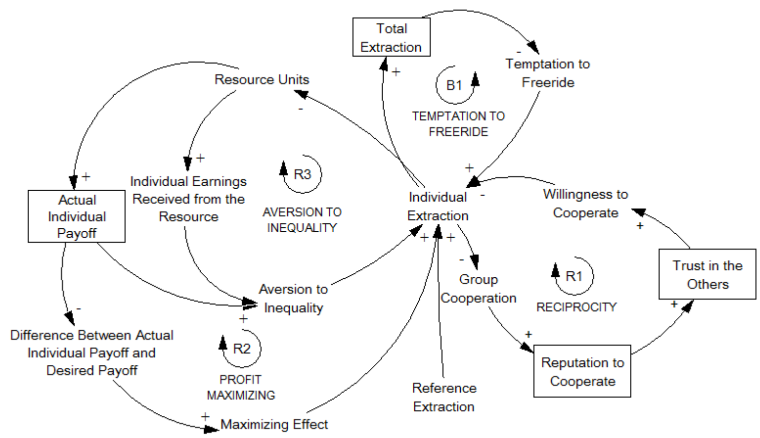


Figure 6. Reciprocity, Temptation to Free ride, Aversion to Inequality and Profit Maximizing feedback loops.

The final two loops are presented in the Figure 7 and represent the capacity the players have to understand and learn about the social dilemma faced in the experiment. The Extraction Learning loop (R4) is a balancing loop that has five elements: *Individual Extraction, Difference Between Total Extraction and Individual Extraction, Difference Between Relative Extraction and Relative Payoff, Awareness of the Social Dilemma* and *Effect of Awareness*. The *Relative Extraction* is explained in terms of the difference between the total extraction of the group and the *Individual Extraction*. As the *Individual Extraction* rises this difference reduces. The *Relative Payoff* depends on the difference between the *Actual Individual Payoff* and the *Desired Payoff.* As the *Relative Extraction* increases, the difference between this variable and the *Relative*

Payoff tends to increases. If this difference increases the players would have a better comprehension of the social dilemma they are facing then the *Effect of Awareness* on the extraction decision increases. The *Effect of Awareness* variable has a negative effect on the extract decision. In other words, if the player was only taking this variable into account he/she would reduce the extraction.

Associated with the *Extraction Learning* loop (B2) there is the *Payoff Unlearning* loop (R3), a reinforcing loop that has six variables: *Individual Extraction, Actual Individual Payoff, Relative Payoff, Difference between Relative Extraction and Relative Payoff, Awareness of the Dilemma and Awareness Effect.* This loop describes the opposite situation of the R4 loop, a player that cannot recognize he/she is facing a social dilemma. As the *Individual Extraction* is higher the *Actual Individual Payoff* increases and so the *Relative Payoff* is higher. If the *Relative Payoff* is higher the difference between this and the *Relative Extraction* is lower. In this case the player does not take into account the social dilemma derived from his extraction decisions because he/she does not perceive it.

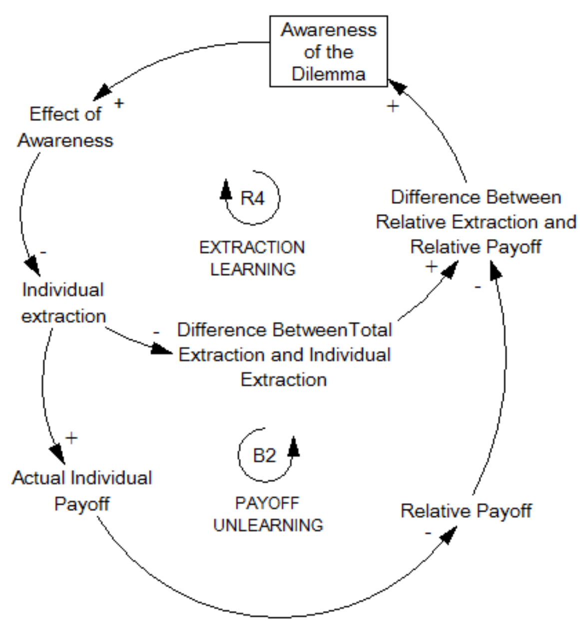


Figure 7. Extracting Learning and Payoff Unlearning feedback loops.

Finally, the *Awareness of the Dilemma* function represents the learning process a player has to understand the social dilemma the experiment proposes. This variable increases until it stabilizes, when the player has a complete understanding of the dilemma (Figure 4E). We establish three types of functions expressing different learning curves, from a player with a fast capacity of learning to a player with a slow capacity, in order to facilitate the comprehension only one of these is reported here. The highest learning curve represents the associated fishers in the field experiments[20] since according to the results of the experiment the associated fishers extracted fewer units than the other players. The average individual extraction of associated fishers was of 13.92 units (s. error of 0.377) compare to 14.38 units (s. error of 13.92) for of the non-associated fishers in the 10 rounds. A t-test determines that these average individual extractions were different at the 1% level of significance (p=0.000). We may think that this behavior happened due to different factors, but one explanation could be that these fishers have a better understanding of the social dilemmas and the benefits of the collective action. This could be one of the reasons to belong to the association and therefore, as Cardenas and Ostrom (2004) state participants bring their own experiences and believes into the experiment. We may say that these associated fishers are behaving in the experiment just as they behave in real life.

4. Model Validation

The validation of the model is a fundamental step in the modeling process (Barlas, 1996). The main purpose of model validation is to have confidence in the structure and parameters of the model in explaining players' behavior in the experiment as well as to generate different behavior tendencies in the artificial agents. The validation takes place for the whole modeling process; nevertheless, formally it occurs after the formulation of the model and before simulating the

[20] This decision was taken according to a hypothesis elaborated after field work: associated fishermen share information and knowledge resulting in an individual learning.

results (Barlas, 1996). The model we present is classified as a causal descriptive model, meaning that the model that represents the way systems behave in some aspects[21] (Barlas,1996).

The validation of the dynamic model is done through Structure Behavior Oriented tests and Behavior Pattern tests. We use Extreme-Condition test and the Sensitivity Behavior test from Structure Behavior tests and among Behavior Pattern tests, we compare the observed average behavior with the simulation results (Barlas,1996).

4.1 Extreme-condition test

The Extreme-Condition test evaluates the dynamic model behavior under extreme values in relevant variables, by comparing the simulation results with the observed results or the theoretical ones (Barlas, 1996). We run the test for multiple variables attempting to replicate always cooperative and never-cooperative players. Table 3 presents the functions used to represent these two players. The *Initial Trus*t variable represents the trust players have in others at the beginning of the experiment. In the dynamic model, this variable is based on the theoretical assumptions proposed by Ostrom (1998), assuming that trust is related with the way individuals see the others and expect something from their actions; in social dilemmas this is expressed by the willingness the players have to cooperate at the beginning of their interactions (Ostrom, 1998). The *Initial Trust* variable varies from zero to ten according to a scale in which zero represents the minimum level of *Initial Trust* and ten the maximum level of *Initial Trust,* we vary the level of trust from one to another simulation in order to represent different players.

A cooperative player has high levels of *Initial Trust,* a high *Willingness to Cooperate*, low *Temptation to Free ride,* low *Profit Maximize Effect*, high *Awareness of the Dilemma* and has

[21] The bounded rationality of players in the experiment.

Aversion to Inequality[22]. The individual extraction of a player with these characteristics is between 1.93 units and 2.25 units along the ten rounds of the simulation. In this simulation we give these characteristics to all of the artificial players. Each player's extraction in this simulation is below the social optimum of ten units per person. In the experiments 30.8% of the observations are bellow ten. According to the dynamic model any observation between 0 and 10 could be classified as cooperation. In this sense the participants taking these decisions may have the characteristics presented before. As in this simulation all of the artificial players have a cooperative profile it was expected that the extraction level was maintained around two units for the whole simulation.

A never-cooperative player has low levels of *Initial Trust,* a low *Willingness to Cooperate*, high *Temptation to Free ride,* high *Profit Maximize Effect*, low *Awareness of the Dilemma* and an *Aversion to Inequality very low.* The average individual extraction observed in the simulation with these characteristics is between 29.30 and 28.12 units in the ten rounds. In the experiments 2.31% of the observations match with an extraction of 28 units and 1.93% with an extraction of 29 units. According to the dynamic model these observations can be classified as non-cooperative ones, in this sense the participants making these decisions may have the characteristics presented above.

[22] According to the model design, players only have two options of functions in the Aversion to Inequality loop: Being adverse or not being adverse

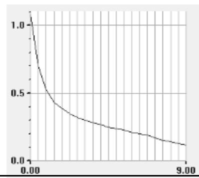
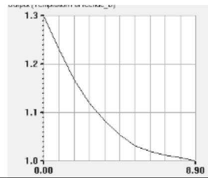
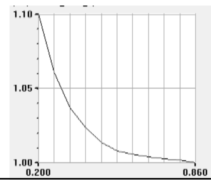
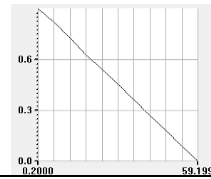
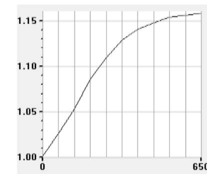
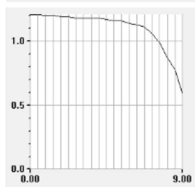
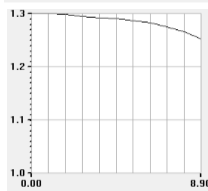
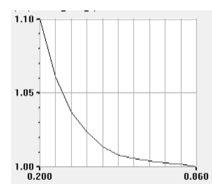
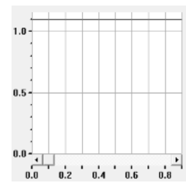
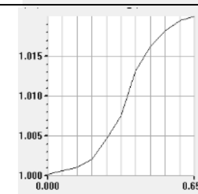
Player	Variable					
	Initial Trust	Willingness to Cooperate	Temptation to Free ride	Maximize Effect	Aversion to Inequality	Awareness of the Dilemma
Cooperative	10					
Non-Cooperative	0					

Table 3. Functions used for a Cooperative and a Non-cooperative player.

A Cooperative player has: Initial trust = 10, High Willingness to Cooperate, Low Temptation to Free ride, Low Maximize Effect, is Averse to Inequality and has a High Awareness of the Dilemma.
A Non-Cooperative player has: Initial Trust = 0, Low Willingness to Cooperate, High Temptation to Free ride, High Maximize Effect, has none Aversion to Inequality and a low Awareness of the dilemma.

The Extreme Behavior test shows that with the assignment of extreme values in all the parameters the extraction observed coincides with the theoretical behavior of an always cooperator individual and a never-cooperator individual. Additionally, the individual extraction results of the simulations in each round were observed in the experiment results as well. With this information we conclude that the dynamic model is well calibrated.

4.2. Sensitivity Behavior test

A Sensitive Behavior test consists in determining the sensitivity the model has with respect to different variables (Barlas, 1996), in this particular case we choose the *Willingness to Cooperate* variable and the *Maximize Effect* variable. The reason to select these variables and its respective loops goes back to two different models of collective action. In the first hand, Hardin (1968), characterizes resources users as selfish individuals trying to maximize their own individual benefits. On the other hand, Ostrom (1998) proves that this is not always the case and raises the importance of the reciprocity norms in resource users' behavior. That being said, we run the test for the Reciprocity loop (R1) and the Profit Maximize loop (R2).

The Sensitivity Behavior test is done through the comparison between the extraction results obtain when modifying the *Willingness to Cooperate* variable in the Reciprocity loop (R1) and when modifying the *Maximize Effect* variable in the Profit Maximize loop (R2) in the base model[23]. In both cases we run the dynamic model for three different values of *Initial Trust*, to represent a player with high *Initial trust,* a player with intermediate *Initial trust* and a player with none *Initial trust.* Figure 8 and 9 show the different functions that *Willingness to Cooperate* and *Maximize Effect* variables could have in the dynamic model. In front of each one of these functions we include the individual extraction results with the static resource scenario; additionally each graphics has three different functions representing the different extraction results as the result of changing the level of trust. Line 1 is the simulation with low *Initial Trust*, line 2 with intermediate *Initial trust* and line 3 with high *Initial Trust.*

Between the *Willingness to Cooperate* functions, the Intermediate (Figure 8A) and the Low functions (Figure 8G) have the same trend in the extraction results. The individual extraction with Low and Intermediate *Initial Trust* has a linear behavior with a tendency to decrease (Figure 8B and 8H). While with High *Initial Trust* (Figure 8E) the individual extraction has a logistic behavior, it starts below the social optimum and then increases until it reaches a point (over the social optimum) in which it stabilizes (Figure 8F). The individual extraction results obtained with the Common (explained before) (Figure 8C) and the High (Figure 8E) *Willingness to Cooperate* functions have the same trends. For both functions, Common and High *Willingness to Cooperate*, the individual extraction observed with High and Intermediate *Initial Trust* has a similar trend (Figure 8D and 8F), a linear behavior and a tendency to increase. With a Low *Initial Trust* the individual extraction starts at high levels and tends to decrease.

[23] The base model is the one that represent the behavior of the players in the experiment.

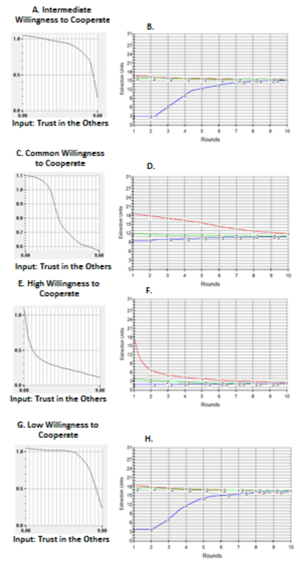


Figure 8. Sensitivity test for Willingness to Cooperate functions.

A. Intermediate Willingness to Cooperate function.
B. Extraction results with Intermediate Willingness to Cooperate with none, intermediate and full Initial Trust.
C. Common Willingness to Cooperate function.
D. Extraction results with Common Willingness to Cooperate function with none, intermediate and full Initial Trust.
E. High Willingness to Cooperate function.
F. Extraction results with High Willingness to Cooperate function with none, intermediate and full Initial Trust.
G. Low Willingness to Cooperate.
H. Extraction results with Low Willingness to Cooperate function with none, intermediate and full Initial Trust.

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trends as shown in Figure 9. For all the functions of *Maximize Effect* (Figure 9A, 9C, 9E and 9G) the individual extractions observed with a Low and an Intermediate *Initial Trust* have similar trends, a linear behavior with a tendency to decrease(Figure 9B, 9D, 9F and 9H). In the other hand, with a High *Initial Trust* the extraction results have a logistic behavior, the extraction starts under the social optimum and then increases until it reaches a point (over the social optimum) in which it stabilizes (Figure 9. B, E, H, J).

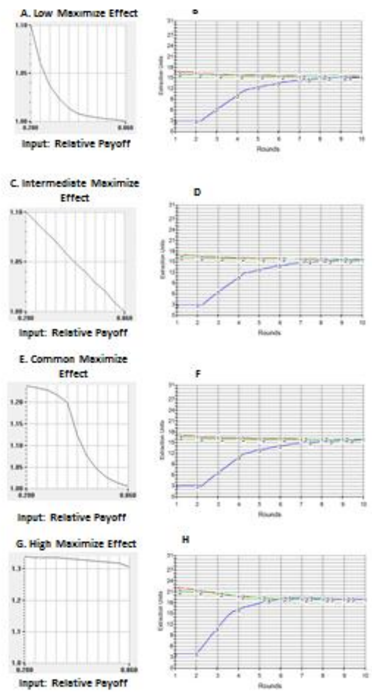

Figure 9. Sensitivity test for Maximize Effect function.

A. Low Maximize Effect function.
B. Extraction results with Low Maximize Effect function with none, intermediate and full Initial Trust.
C. Intermediate Maximize Effect function.
D. Extraction results with Intermediate Maximize Effect function with none, intermediate and full Initial Trust.
E. Common Maximize Effect function.
F. Extraction results with Common Maximize Effect function with none, intermediate and full Initial Trust.
G. High Maximize Effect function.
H. Extraction results with High Maximize Effect function with none, intermediate and full Initial Trust.

The validation results show that the model is more sensitive to the Reciprocity loop (R1) than to the Profit Maximize Loop (R2), so the artificial player's decision is more affected by the relation between reciprocity, reputation and trust described by Ostrom (1998), than by the desire of maximizing earning described by Hardin (1968). This result is coherent with results from field experiments from around the world showing that individuals do not act as merely rational agents (Cardenas 2011; Velez and Lopez, 2011; Velez et al., 2010; Ostrom, 1998). It exists experimental, (Lopez et al., 2010; Velez et al., 2009; Rodríguez-Sickert et al., 2008) and empirical (Agrawal and Gibson, 1999; Ostrom, 1990) evidence showing the importance of reputation, trust and cooperation between natural resource users to manage natural resources in a successfully way.

4.3. Behavior Pattern Tests

The Behavior Pattern tests determine the accuracy of the model in reproducing the real system patterns (Barlas, 1996) or the theoretical predictions. The idea is not to reproduce the exact average extraction behavior that happens during the experiment but to reproduce its general trend. With the dynamic model structure we define a base model that replicates the average extraction results trend in the experiment. Artificial players in the base model have: an *Initial Trust* of 6.7 (high), ii) a Low *Willingness to Cooperate* function, iii) a tendency to free ride as the extraction decreases (Common *Temptation to Free ride*), iv) a Low *Maximize Effect* function, v) *Aversion to Inequality* and vi) an intermediate learning curve of the social dilemma in the experiment (Intermediate *Awareness of the Dilemma)*.

For this test, we compare the average individual extraction in each one of the first ten rounds of the Caballo Cocha experiments and the results obtain in the base model. As shown in table 2 and in figure 10B the average individual extraction in the experiment remains around the same values as the results of the simulation (from fourteen to fifteen resource units). However, in the simulation the extraction increases for round one to four and then decreases after round four (Figure 10A), while in the experiment the extraction has a tendency to increase over the ten rounds. These differences can be due to the fact that in real life the players have different personalities and incentives to cooperate while in the base model all the artificial players have the same characteristics.

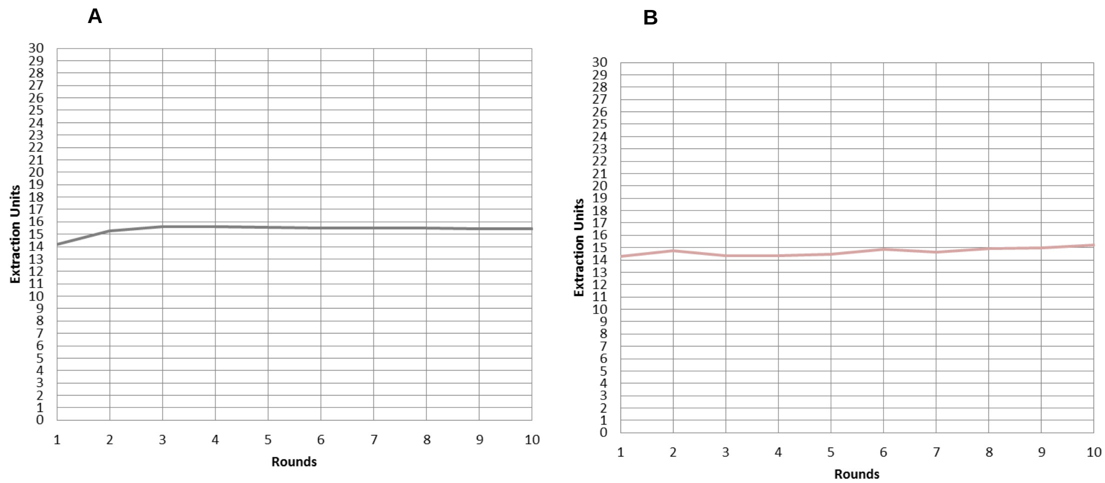

Figure 10. A. Simulated Average Extraction With a Static Resource. B. Real Average Extraction.

5. Results

According to Ostrom (1998), individuals follow different types of reciprocity norms depending on the individuals context. The author formalizes six reciprocity norms that we replicate in the model by selecting different output functions for each one of the loops. All the reciprocity norms are stated and presented through the extraction results. To analyze the extraction in terms of cooperation we use three reference points: the social optimum (10 units), the Nash strategy (30 units) and the intermediate between this two (15). In this sense, we assume that a cooperative player has an extraction of ten units or bellow. According to Ostrom (1998), people do cooperate but usually not at the optimum level so we define an intermediate level of cooperation between 11 at 15 units of extraction. Finally, we define that players with an extraction above 15 units and until 30 units are not cooperative. In the model, each one of the artificial players can follow only one of the reciprocity norms. For purpose of the analysis only one of the players in the group, named as player A, is following each one of the reciprocity norms proposed by Ostrom (line 1 in the figures 11, 12, 13, 14 and 17), while the other 4 players are doing the opposite to each one of the norms depending on the case (line 2, figures 11, 12, 13, 14 and 17).

To represent the reciprocity norms described by Ostrom (1998), we use the different functions that affect the extraction decision in the model. The different functions are not necessarily related with the Reciprocity loop (R1) in the dynamic model, but do help to represent the norms. We vary the values on *Initial Trust* and we use the different functions of *Willingness to Cooperate, Temptation to Free ride, Maximize Effect, Aversion to Inequality* and *Awareness of the Dilemma.* We analyze the extraction results and the cooperation variable for two scenarios, a static and a dynamic resource, for each one of the reciprocity rules. As in the static scenario the resource is always renewing we evaluate the resource condition through the ten rounds simulation only in the dynamic resource scenario.

i) "Always cooperate first, stop cooperating if others do not reciprocate; punish non-cooperators if feasible"

For the static resource, the player A follows the norm i), then he starts with an extraction of 15.57 units that decreases until 13.49 (Figure 11. C line 1). The other four players start the experiment with an extraction of 17.01 and then it decreases to 11.31 units (Figure 11. C line 2). In the simulation with a dynamic resource, the extraction of player A starts at 15.57 and finishes at 10.02 units, the other player's extraction start at 17.01 and finishes at 9.15 units in round 5(Figure 11. B) when the resource is completed depleted (Figure 11. A).

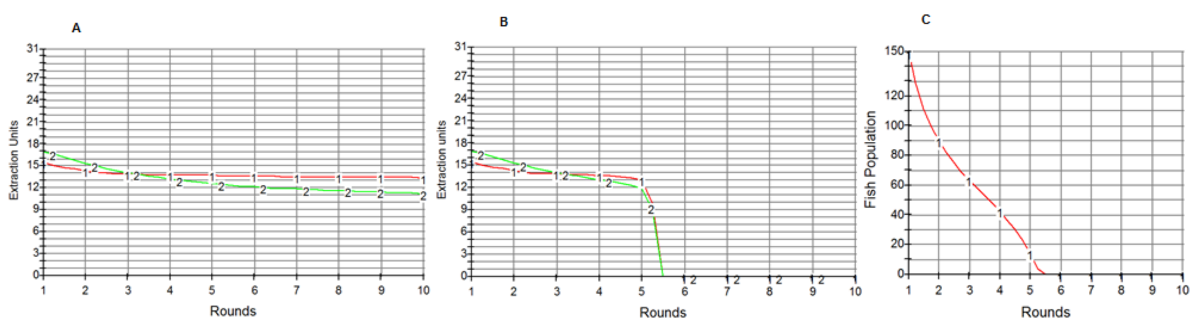

Figure 11. Extraction with the use of norm i.

A. Extraction of player A (line 1) and the other 4 players (line 2) with a static resource.
B. Extraction of player A (line 1) and the other 4 players (line 2) with a dynamic resource.
C. Dynamic resource condition.

In this reputation norm player A has a low *Initial Trust* because according to Ostrom's enunciation for this player the initial trust is not necessary to cooperate. When the *Initial Trust* variable has low values, the players extraction at the beginning of the simulation is the highest possible. In other words, in the model when the *Initial Trust* is low players do not cooperate at the beginning of the simulation. Because of this, the representation of Ostrom's first reciprocity norm (1998) is a difficult task. The results obtained in both simulations show that the extraction of player A is lower than the other player's extraction at the beginning of the simulation. Nevertheless, the difference between A extraction's and the others is just of two units in round one and gets equal at round two. Thus, after round one player A sees that the others are cooperating less than he/she is. Then in the second round all the players start to decrease the extraction, player A only reduces it in two units while the others reduce it around five units. Taking into account that player A is high *Averse to Inequality* and has a Low tendency to free ride; we can deduce that having a higher extraction is more related with a way to punish the others than with a strategy for having higher payoffs.

ii) Cooperate immediately only if one judges others to be trustworthy; stop cooperating if others do not reciprocate; punish non-cooperators if feasible

Player A follows the norm ii) with the static resource he starts with an extraction of 8.96 units, then increases it to 10.24 in round six and finally decreases until 9.79 (Figure 12A. line 1). The other four players start the extraction with 18.01 and then they decrease it until 9.90 units (Figure 12 A. line 2). In the simulation with a dynamic resource the extraction starts at the same level as in the static resource for the player A and the others, nevertheless the resource is depleted in round six (Figure 12C.), with an extraction of 9.50 for A and 11.14 for the others (Figure 12B.)

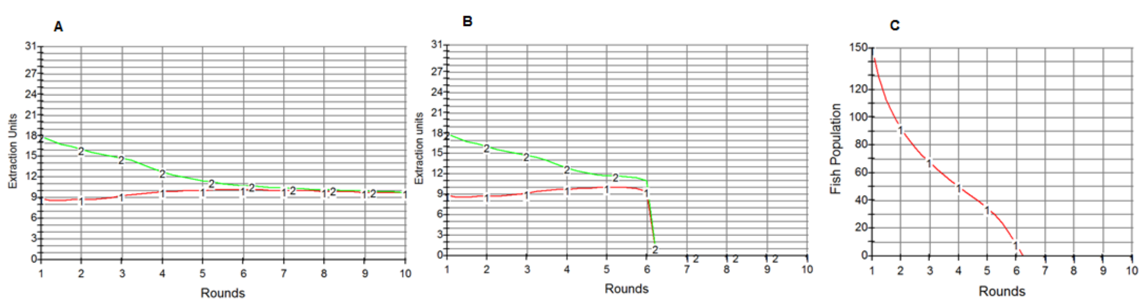

Figure 12. Extraction with the use of norm ii.

A. Extraction of player A (line 1) and the other 4 players (line 2) with a static resource.
B. Extraction of player A (line 1) and the other 4 players (line 2) with a dynamic resource.
C. Dynamic resource condition.

For this norm player A has high *Initial Trust* because the player cooperates since the others players are trustworthy for him/her. With this norm the behavior of the players does not have important changes in the extraction trend between the simulation with a static and with a dynamic resource. Player A starts with an extraction level under the social optimum and then raises it, as this happens the other players have a fast reduction of their extraction levels. The other players have a tendency to cooperate as they see that others are cooperating, which coincide with the observed extraction. In this case, player A is always cooperating so the others reduce the extraction.

iii) Once cooperation is established by others, cooperate oneself; stop cooperating if others do not reciprocate; punish non-cooperators if feasible

The player following the norm starts in the static scenario with an extraction of 17.77 units and decreases it to 10.40 (Figure 13A. , line 1). The other four players start the extraction with 13.62 and then they decrease it to 13.45 units (Figure 13A. , line2). In the dynamic resource scenario player A extraction's start at 17.77 and finishes at 13.57 units, the other players start at 13.45 and finishes at 13.33 units (Figure 13.B line 1 and line 2 respectively). In round five the resource is completely depleted (Figure 13C.).

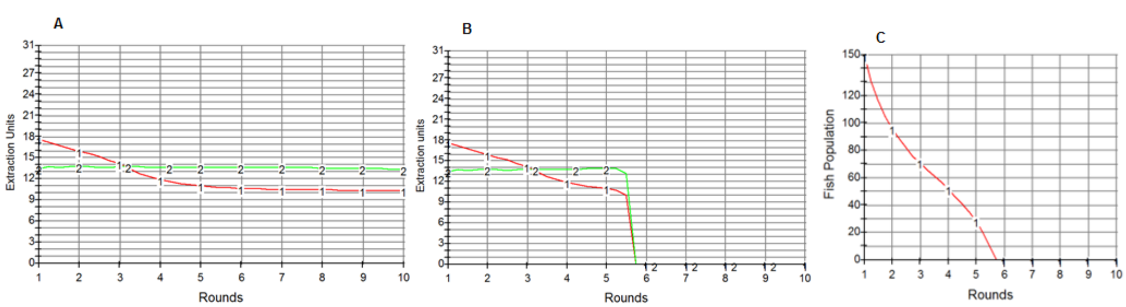

Figure 13. Extraction with the use of norm iii.

A. Extraction of player A (line 1) and the other 4 players (line 2) with a static resource.
B. Extraction of player A (line 1) and the other 4 players (line 2) with a dynamic resource.
C. Dynamic resource condition.

The player A starts with a non-cooperative behavior but as he/she sees that the others are cooperating he/she reduces the extraction until round four in which it stabilizes around ten units. The other players have an extraction of about thirteen units during the ten rounds, even with player A reduction. Taking into account that the other four players trust each other from the beginning, that they have a low tendency to free ride, a low profit maximize effect, a high aversion to inequality and a high comprehension of the dilemma this behavior can signify that changes in A extraction are not big enough for them to perceive the changes in the total extraction.

iv) Never cooperate

The player following the rule iv) starts in the static setting with an extraction of 29.30 units and decreases until 27.47 (Figure 14A. line 1). The other four players start the extraction at 10.08 and then decreases it until 10.76 units (Figure 14A. line 2). In the simulation with a dynamic resource, the players have the same extraction in round 1 as with the static resource, nevertheless the last extraction is 27.47 for player A and 13.35 for the other players (Figure 14B, lines 1 and 2 respectively), the resource is depleted in round four (Figure 14C).

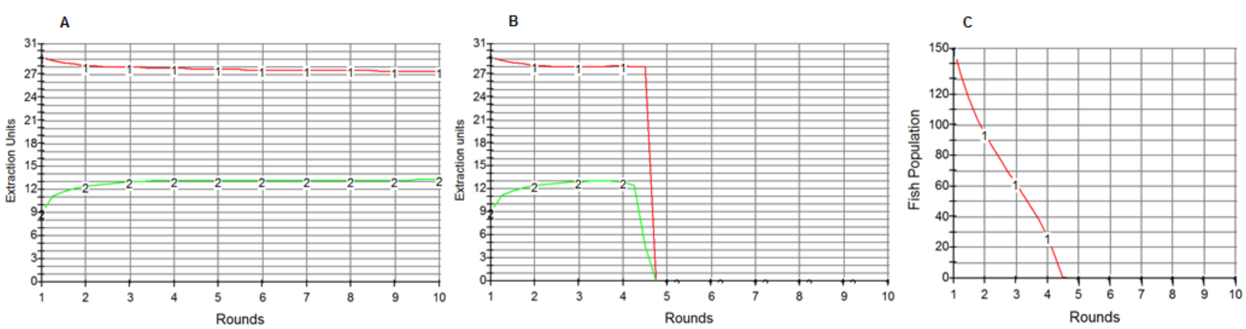

Figure 14. Extraction with the use of norm iv.

A. Extraction of player A (line 1) and the other 4 players (line 2) with a static resource.
B. Extraction of player A (line 1) and the other 4 players (line 2) with a dynamic resource.
C. Dynamic resource condition.

In this case, player A does not cooperate even when the other players have much lower levels of extraction. The other four players are extracting around twelve units during the simulation; they do not rise the extraction even with the high extraction levels of A. This behavior can be explained by the fact in the field experiment players do not know the extraction of each one of the participants, but the group extraction. The average extraction of the group in the dynamic scenario is 76.102 units (of 150 units possible), which is not necessarily interpreted as high extraction levels by one of the other players. Additionally in the simulation, these players have more cooperative personalities than player A.

Comparing the results of the simulations obtain with a static resource and with a dynamic resource, in the second case artificial players depleted the resource so fast that they do not have enough time to react about the situation.

v) Mimic (i) or (ii), but stops cooperating if one can successfully free ride

Mimic (i)

In the model we recreate, the extraction of an artificial player with these characteristics does not coincide with Ostrom's view of this reciprocity norm since the extraction of the player A is never lower than the other player's extractions. In this case, the *Initial Trust* is low therefore the *Temptation to Free ride* variable is dominant in the extraction decision. Then as the extraction of the other players reduces A will tend to extract more units of the resource. In the simulation the extraction of the player with this profile (A) in the static scenario starts with 20.89 units and decreases until 19.23 units (Figure 15A line 1). The other four players start the extraction with 10.22 and then decreases until 9.78 units (Figure 15A line2). With a dynamic resource the behavior is the same until round nine, in which the resource is depleted (Figure 15C). The extraction starts at 20.89 for A and at 10.22 for the others and finishes at 19.34 for A and 4.91 for the others (Figure 15B).

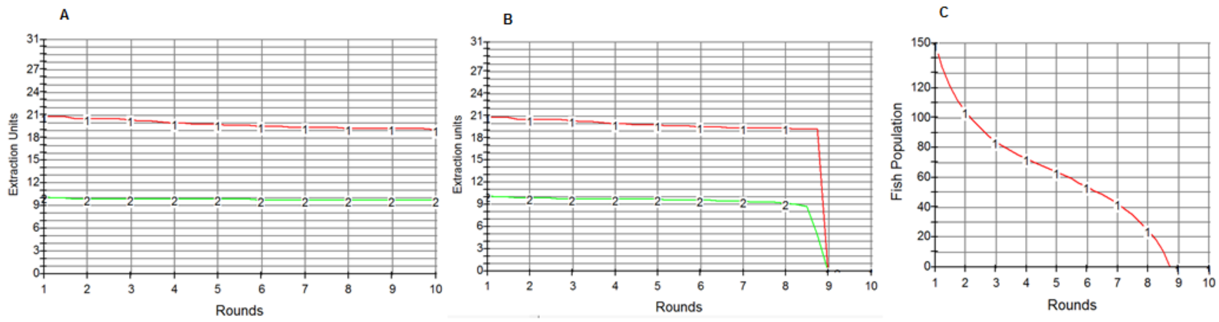

Figure 15. Extraction with the use of norm v: Mimic norm I but stops cooperating if one can successfully free ride.

A. Extraction of player A (line 1) and the other 4 players (line 2) with a static resource.
B. Extraction of player A (line 1) and the other 4 players (line 2) with a dynamic resource.
C. Dynamic resource condition.

As with rule (i) the initial trust path dependence of the model does not allow to have a cooperative behavior at the beginning of the simulation. By having a higher tendency to free ride and being not averse to inequality, player A always has higher levels of extraction than the other players. The other players have an extraction between eleven and fourteen units, with a tendency to decrease the extraction as time passes. As with rule (vi) these players do not respond by extracting more units to A over-extraction.

By comparing the static and the dynamic model dynamic, the players in the dynamic scenario do not change their behavior with respect to the static scenery but in the former case the resource is depleted in round four (Figure 14. C).

Mimic (ii)

The player following this norm starts in the static scenario with an extraction of 12.80 units, then increases it to 15.50 in round five and finally decreases it until 14.03 (Figure 16A. line 1). The other four players start with an average the extraction of 17.32 and then the decrease it to 9.65 units (Figure 16A. line 2). With a dynamic resource the extraction is the same until round five, when the resource is depleted (Figure 16C). In this case the extraction starts at the same level than in the static model but finishes at 15.82 for A and 10.34 for the others (Figure 16B).

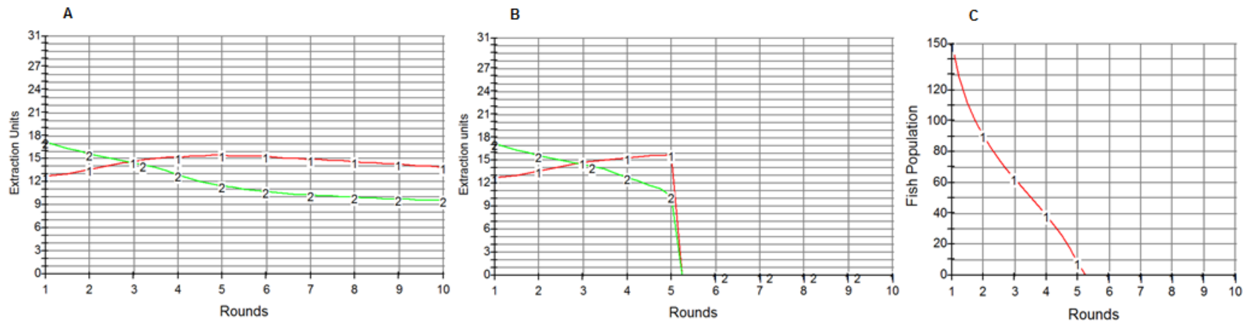

Figure 16. Extraction with the use of norm v: Mimic ii, but stops cooperating if one can successfully free ride .

A. Extraction of player A (line 1) and the other 4 players (line 2) with a static resource.
B. Extraction of player A (line 1) and the other 4 players (line 2) with a dynamic resource.
C. Dynamic resource condition.

Player A starts cooperating while the rest of the players do not cooperate, nevertheless as the other players reduce the extraction, A rises his/her extraction and keep it higher than the others during the rest of the simulation. As the player A has a tendency to free ride, a high value for profit maximizing and he is not averse to inequality it is natural that the extraction rises. The other players have a tendency to cooperate as they see the others are cooperating, in this case they keep reducing the extraction until they reach a level of around the social optimum in both scenarios.

Comparing the simulation with a dynamic resource and with a static resource, the players do not have important changes in their behavior. The players have the same tendency as with a static resource until round eight when the resource is depleted in the dynamic scenario meaning that the players do not see the diminution of the resource.

vi) Always Cooperate (an extremely rare norm in all cultures)

The player A following this norm in the static scenario starts with an extraction of 1.89 units and finishes with 3.57 units in the last round (Figure 17A. line 1). The other four players start the extraction with 17.91 units and then decreases it until 15.02 units (Figure 17A. line2). The extraction of the player in the simulation with a dynamic resource starts at 1.89 and finishes at 3.40, while the others start with an average of 17.91 and finish at 14.33 when the resource is depleted in round six (Figure 17B and 17C).

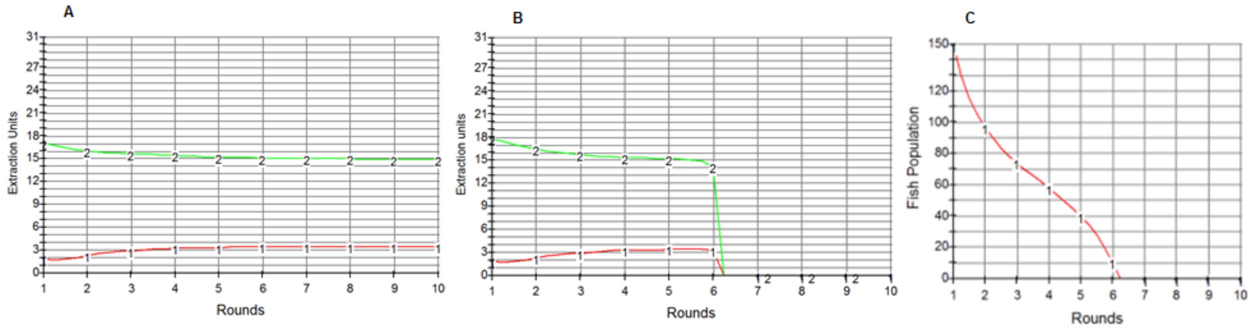

Figure 17. Extraction with the use of norm vi.

A. Extraction of player A (line 1) and the other 4 players (line 2) with a static resource.
B. Extraction of player A (line 1) and the other 4 players (line 2) with a dynamic resource.
C. Dynamic resource condition.

Player A always cooperates without taking into account the others four players behavior, while the others tend to have high levels of extraction. In this case it is possible that as the players only know about the group extraction the behavior of A does not change their perception of it. Player A's personality is not of punishing the non-cooperation or rising the extraction levels, but to cooperate.

Comparing the results obtained with a static resource and the ones with a dynamic resource, the players do not change the extraction levels. The players have the same tendency as with a static resource until round six where the resource is depleted.

6. Discussion

According to Ostrom (1998), individuals who follow reciprocity norms are influenced by their education and cultural legacy among other factors. Since reciprocity norms are learned, individuals can use the different reciprocity norms depending on their background and/or the situation they are facing. In this context, we cannot expect a particular behavior in a group even when the individuals from that group share similar backgrounds as is the case of the participants in the field experiment. Taking into account the results obtained in the experiment for the individual and group extraction we observe that in average participants in the experiments had a cooperative behavior during the first rounds and then try to extract more units. According to Ostrom (1998), the first and/or the second rules correspond with this type of behavior because participants started to cooperate from the beginning of the experiments but as they see others were not cooperating they started to have a non-cooperative behavior. By comparing the results from the experiment with the ones of the simulation we observe that this comparison can suggests that the subjects in the experiment were using the most of all the first norm which is the *Always cooperate first,; stop cooperating if others do not reciprocate; punish non-cooperators if feasible* because participants were having an extraction of 14.281 in round one, 14.766 in round two, 14.350 in round three, 14.363 in round four, in round five 14.463, 14.856 in round six, 14.619 in round seven, 14.918 in round eight, 14.981 in round nine and 15.219 in round ten (average of 14.682 thus closer to a intermediate cooperative behavior). In order to explain this behavior it is important to remember that in the experiment relatives were not allowed to participate in the same group so we can dismiss a family-related trust. According to Ostrom (1998), this norm also known as the strategy of "tit-for-tat" has been the most studied from an evolutionary perspective and it has been determined that the size of the population in which interactions occur must be relatively small, such as the case of Caballo Cocha fishery. On the other hand, the experiments were held with people from the same community so participants knew each other, thus it is possible that players have initial trust in others from the beginning, as well as other regarding preferences that come into play as reputation. According to Cardenas and Ostrom (2004), this situation is expected since participants in the experiments act based on the knowledge they have of the others. We cannot dismiss completely the use of norm two which is *Cooperate immediately only if one judges others to be trustworthy; stop cooperating if others do not reciprocate; punish non-cooperators if feasible.*

In the simulations when the dynamic resource was introduced the resource was depleted in the majority of the cases before the end of the simulation (round 10). Adding up to this and taking into account that the resource model is calibrated to have a maximum sustainable yield at 50 units of the resource (the economic social optimum), we can conclude that the group extraction was over this social optimum in all of the simulated cases and therefore the resource was depleted. In the experiment with a static resource, the results show that the average group extraction in the ten rounds was of 73.36 units, meaning over the social optimum. With reference to the individual extraction, in all the ten rounds, 58,8% of the individual extractions were above 10 units. With this behavior in a dynamic resource scenario, players would deplete the resource before finishing the game because in order to have enough resources until round ten the group extraction needed to be of 50 or bellow. This result may signify that players do not realize the real condition of the dynamic resource stock, and then they do not react fast enough to stop its depletion. This result is consistent with dynamic experiments conducted by Cardenas et al. (forthcoming), Castillo et al. (2011), Moreno-Sánchez and Maldonado (2010)and Moxnes (2007) showing that people has a misperception of the resource dynamics. Cardenas *et al*. (forthcoming) create three experiments one for water, one for forestry and one for fisheries including basic resource dynamics. The authors found that overcoming the temporal and spatial ecological features of the resource dynamics experiment is a difficult task for the players. Castillo et al. (2011), present the results of field experiments in Colombia and Thailand on fishery resources. The authors found that even with high levels of initial trust among the players the resource was depleted. Moreno-Sanchez and Maldonado Moreno (2010) study the behavior of fishermen in a semi-dynamic CPR game under two possible resource scenarios (scarcity and abundance).Depending on the group extraction decisions in each round, the resource may vary from abundant to scarce and vice versa. The authors conclude that when players confront scarcity levels of the resource, they tend to have inefficient extraction strategies because they tend to over extract the resource. Finally, Moxnes (2007) finds that subjects, in his case students, participating in dynamic experiments are not capable to understand the dynamic of the system leading to the destruction of the resource.

This misperception of the condition of the resource goes beyond the experimental setting to the management of fisheries around the world. According to Wilson (1982), in fisheries ecosystems the interaction between different species, the changes of the relative abundance due to many of environmental factors and the lack of knowledge of these factors, constitute a difficulty for resource users to determine the real state of the resource. One of the most challenging difficulties is to determine whether a decrease in the population is consequence of the harvesting or due to environmental factors (Ostrom *et al.* 1994). With reference to environmental factors in Caballo Cocha fishery, the factors and patrons associated with the floods are determinant in fish populations. The knowledge of the varzea ecosystem is still very precarious; in particular in Caballo Cocha the *secretaria de pesca* does not have biological information to assess the fish population. On the other hand, Bravo (2011), explains that in his agent-base model the agents must experience a strong decline of the biomass they are deciding about before changing their behavior. In this sense, in the dynamic scenario artificial players do not receive enough information about the real condition of the resource at each round so they do not perceived its rapid depletion and do not react fast enough to avoid the depletion. The information Caballo Cocha fishers have of the resource is also incomplete, on one hand there is a lack of biological information about the real condition of the fish populations, secondly the fish extraction is not reported by the fishers, then the authorities do not have any records to assess if extraction is increasing over time and finally the number of fishers is unknown. In this context, a study of the real fish population, a census of the fishers and their gears and a monitoring program could help the fishers to have complete information to implement a management plan. In the model, this additional information could be introduced as another loop that regulates the extraction decision.

With respect to the structure, the dynamic model shows a path dependence trend on the initial trust variable hindering the simulation of the first and the fifth reciprocity norms (mimic the first). On the other hand, as the dynamic model is not high sensitive to the Profit Maximize loop, changes in the payoff function are not enough to affect the player's behavior.

As mentioned before, during the experiment players only knew the group's extraction and their own extraction level, then if the extraction of the majority of the group was similar, a very high or very low extraction of one of the participants cannot be perceived. The same situation was happening in the dynamic model since four of the players have the same extraction decision while only player A has a different one. Nevertheless, according to Cardenas and Ostrom (2004) in a CPR context the costs of knowing the individual levels of appropriation would be very high. So the situation observed in both the field experiments and in the decision modeling can be an expected difficulty in real life socio-ecological systems. This difficulty is observed in the Caballo Cocha fishery in which the enforcement of each fisher extraction is not possible because of the high costs this may represent and the lack of technology to do that.

Cardenas an Ostrom (2004) and Cardenas et al. (2002) mention that the heterogeneity of the group with respect to wealth and social position represents a difficulty to overcome social dilemmas. However, the authors also mention that in homogenous groups with a long history of non-cooperative behaviors the cooperation is not an expected outcome in the future. In the experiment 85% of the participants were fishers, which can determine a high grade of homogeneity in the group and the average individual extraction was of 14.68 units, which in our analysis is considered as an intermediate cooperation. With these results, if we use this average individual extraction (Table 2.) to simulate the resource outcome the resource would be depleted before round ten.

Caballo Cocha fishery has been in crisis for a few decades and fishers express their concerns about this situation. In this context, fishers have been recognizing the need of organizing the community to manage the hydro-biological resources. Recently as a response to this situation, the local authorities and the Fishermen Association Jose Olaya Belandra have elaborated a Management Plan that allows a better management of the fishery. In the model we create, we did not allow the possibility of institutional arrangements to appear. However, in the experiments conducted by Lopez and Walker (2011), after round 10 was played an institution was introduced. Different instructions were used, but in general in all cases the extraction level decreased with respect to the first ten rounds, generating better social outputs. This importance of institutions was also reported by Janssen and Ostrom (2008). The authors elaborate a lab experiment in which a group of participants interact between them to extract tokens of a real-time, spatial, renewable resource, finding that without communication the resource was vastly depleted. Nevertheless, when a communication treatment was included many agreements about space distribution and extraction were observed and so the extraction reduces postponing the depletion. Since in our model we did not include any institution, the extraction behavior was only affected by the formalized feedback causalities and the delta parameters. But it is clear that as a extension of this work we may include a new loop or variable that allows artificial players to use institutions as way of achieving extractions closer to the social optimum.

7. Conclusions

This paper presents the results of a system dynamic model that allows the possibility to study the changes in players' extraction behavior when moving from a static field experiment to a dynamic resource simulated through dynamic modeling. To do so we build an artificial experiment based on the results of a static experiment conducted with fishers in Caballo Cocha, in the Peruvian Amazon (Lopez and Walker, 2011) According to the structure of the Caballo Cocha field experiments we formalize the feedback causality between trust, reputation and reciprocity proposed by Ostrom (1998) and other behavioral factors such as temptation to free ride, aversion to inequality, awareness of the dilemma and a profit maximize effect. Subsequently, we integrate a simple logistic model of fish population to allow for the dynamic resource.

One of the main interests of ecologists around the world is the study and comprehension of socio-ecological systems, understood as complex systems in which the human being interact with the natural environment. In this paper we aim to represent some of the main factors that determine this interaction. We formalize the feedback relations between the internal beliefs and values people have when deciding about how to manage a natural resource and how other´s decision may come into play. The methodological approach we use in this paper by combining experimental economics with System Dynamics is useful because the former brings us the possibility to have people´s decisions while the later provides us the possibility to recreate a scenario in which these decisions actually affect a resource with ecological characteristics as it occurs in socio-ecological system.

In the model, artificial players did not change their behavior with the introduction of dynamic resource. This could happen as they do not perceived the changes in the resource because a lack of information. This coincides with the situation of different fisheries around the world in which fishers do not know the real condition of the fish stocks. In Caballo Cocha fishery neither the local authorities nor the fishers know the condition of the fish communities or the extraction levels.

In real life some communities have succeed in managing their resources (Ostrom 1990), nevertheless in our dynamic model, in dynamic experiments conducted with rural populations and students and in fisheries around the word this has not been always observed. In our particular case, the resource was almost always depleted before the 10 round. In this sense, it is important to identify what socio-ecological variables determine the success or of understanding the resource dynamics. It could be the case, that the use of experimental economics with Simulation Modeling could help identifying such factors. It is well prove that institutions have been useful in overcoming the *Tragedy of the Commons*. In this context, an extension of this study will be to craft institutions to address these issues.

Field experiments are designed to address particular questions the researcher may have. Thus they are based on model simplifications that may have some limitations depending on the design and the question that wants to be addressed. Lopez and Walker 2011 aim to understand the effects of different institutions in people´s behavior, therefore they did not include in their model resource dynamics or multi species just to mention some of their limitations. However, in this particular study, when using Dynamic Simulation Modeling we are able to overcome one of these limitations by simulating a dynamic resource.

Additionally, field experiments have been useful as pedagogical tools for the conservation and management of natural resources with communities. With the use of this methodology together with simulation modeling methods the representation of social dilemmas and its consequences may become a powerful tool to work with communities in the management of their resources. Since the simulation models allow the possibility to represent visually the behavior observed in the experiment adding the implications of having a dynamic resource will result in a more illustrative representation of people´s decision. Thus, very useful for management decisions.

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