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by

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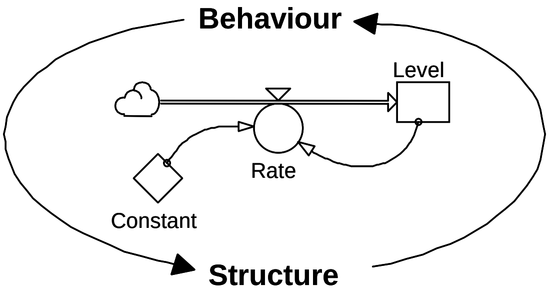

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DYNAMIC SIMULATION MODEL OF COMMON POOL RESOURCE COOPERATION EXPERIMENTS

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ABSTRACT

We investigate the decision rules adopted by individuals in local communities, whose livelihoods depend on common pool resource stocks and who face the cooperation dilemma in their everyday life. For this purpose, field experiments are modeled and the model structure and output are confronted with experimental data and with the relevant theory of collective action proposed by Ostrom (1998). The field experiments analyze the cooperative action among coastal communities in Providence Island (Colombian Caribbean Sea). The simulation model is built according to the principles and methods of *System Dynamics*. The model formalizes the feedback causality among *reputation*, *trust* and *reciprocity* as suggested by Ostrom (1998). Moreover, based on the payoff structure used in the experiments, it considers other behavioral factors such as *temptation to free ride*, *profit maximization*, and a*wareness* of the individuals in feedback perspective. Depending on the initial conditions and parameter values, model behavior replicates major patterns of the experimental data. It reveals path dependent characteristic to the initial *trust* of the individuals in the group. The variables and decision rules built into the model structure provide the basis for a dialogue between the theories of collective action and future experimental designs to test and improve such theories.

Keywords: Common pool resources; Cooperation; Field experiment; System Dynamics; Modeling decision-making.

I. INTRODUCTION

According to the “tragedy of the commons” hypothesis suggested by Gordon (1954) and Hardin (1968), as a rational being, user of a common pool resource tries to maximize her/his own benefits by increasing individual resource extraction. If every actor follows the same rationale, the resource will eventually be overexploited or depleted and will not be able to generate any social benefit in the long term. This problem represents a cooperation dilemma among common pool resource’s (CPR) users where everyone has to extract less and “sacrifice” from their individual short-term benefits in order to improve the social benefits in the long term. Many renewable natural resources, the fisheries, pastures, forestry, groundwater, and others such as biodiversity, the atmospheric ozone and the global atmosphere are common pool resources. The conservation and governance of these resources face the same challenge, the cooperation dilemma. Local and rural communities whose economic livelihood and social development depends strongly on any common resource are also strongly trapped in this dilemma. These types of users usually have to cope with environmental policies that intend to conserve the resources on one hand and with their own livelihood needs on the other.

Traditionally, the proposed solutions to overcome the commons problem have focused on external regulations for extraction and ownership rights (Ostrom, 1990). Those policies have been designed based on the complete rational actor paradigm of neoclassical economic theory (Gintis, 2000). However, during the last 10 years’ research in CPR management and collective action, alternative explanations have been developed to overcome commons problems. Field studies and evidence from all around the world have shown that the “tragedy of the commons” is not unavoidable and people can efficiently cooperate and build institutions to govern common resources. Data from laboratory experiments, which employ game theory and experimental economic approaches, also supported this fact. Such developments have revaluated conventional perspectives in CPR management such as the state intervention and individual property rights, as well as the rational self-interested actor of traditional economics (Ostrom, 1990 and 1998).

For example, in Colombia, a mega-diverse country with 10% of the world's biodiversity (Franco, 1999), environmental management has been decentralized since the late 1980s. Colombia's indigenous population of 700,000 (less than 2% of the total population) has been granted control by Colombia's Constitution of nearly one fourth of the country's land mass. After Earth Summit in Rio de Janeiro in 1992, Colombian government began to build an institutional framework for sustainable development policies by creating the national environmental system (SINA, Sistema Nacional Ambiental) in 1993. SINA was organized according to a decentralized schema, which consists of local environmental agencies, whose purpose is to regulate and monitor the natural resources at local levels. However, in Latin America the decentralization process has faced serious difficulties due to the history of almost two centuries of strong centralized policy making which has created a culture of direct dependence on the government. Currently, local and rural communities under common property regimes manage a high percentage of the biodiversity. Institutions have been set up to promote direct participation of local communities in resource management but the policy instruments have not had much effect on the behavior of the local resource users. On the other hand, the efficiency of state interventions is limited and they do neither guarantee citizen participation nor the desired sustainable use of the resources (Cardenas, 2002).

To design efficient environmental institutions which facilitate the decentralized governance of CPRs, individual incentives being faced by the local communities must be understood (Cardenas, 2002). To understand the institutional failures, which create social inefficiencies and overexploitation of natural renewable resources, a micro level analysis of various incentives and social behavior is particularly important. With this respect, the experimental methods in CPR research have gained considerable popularity since Ostrom et al., 1994 and became a substantial instrument in policy analysis. On the other hand, formal simulation models of decision-making in CPR situations based on multi-agent systems are also emerging as a method, which can assist the experimental studies (for example Deadman, 1999; Jager and Janssen, 2002). Both the laboratory experiments and formal simulation models can be useful in testing the theories of collective action and can improve the scientific policy proposals in the long term. In this paper, we present a dynamic feedback model (*System Dynamics* model) of field experiments in the Old Providence Island of Colombian Caribbean Sea, which builds on

Ostrom's "behavioral theory of collective action" (Ostrom, 1998). Next, we provide a brief background on the behavioral theory of collective action, the experiments and on modeling decision making. Then we'll introduce the formal simulation model. After that, the discussion on model validity and model behavior analysis will follow. We conclude with a discussion on future work.

II. BACKGROUND

Important amount of fieldwork have led to the development of a "second-generation model of rationality", which identifies "the attributes of human behavior that should be included in future formal models" such as *reputation, trust* and *reciprocity* (Ostrom, 1998). According to Ostrom (1998), "the individual attributes that are particularly important in explaining behavior in social dilemmas include the expectations individuals have about other's behavior (trust), the norms individuals learn from socialization and life's experiences (reciprocity), and the identities individuals create that project their intentions and norms (reputation)".

These variables involved in this model are causally related in feedback (Figure 1) and are the driving forces of cooperation, which determine the net benefits generated by the use of the common resource. Cooperation determines the levels of social or net benefits for a given group. The hypothesis depends on the "structural variables" shown in gray boxes. Each of these variables affects particular variables of the feedback relationship. Reputation and trust among the members of a given community are important only when the social group is relatively small, as in the case of local and rural communities. Reciprocity norms develop among community members only if there are relatively homogeneous interests and dependence on the resource as well as relative equality on the available endowments. This process develops in the long term. Low costs of the extraction activity seem to be a condition for the improvement of social benefits through high levels of cooperation. Social interactions in small groups increase the possibility of face-to-face communication and sharing of information about past actions of the individuals, increasing reputation and building trust in others. The more is the communication, the less is the cost of reaching agreements, which is also decreased by the existence of symmetrical interests and resources among individuals. Both influence the development of shared norms, which affects directly the use of reciprocity norms.

The community analyzed in this research satisfies the conditions required by these gray boxes.

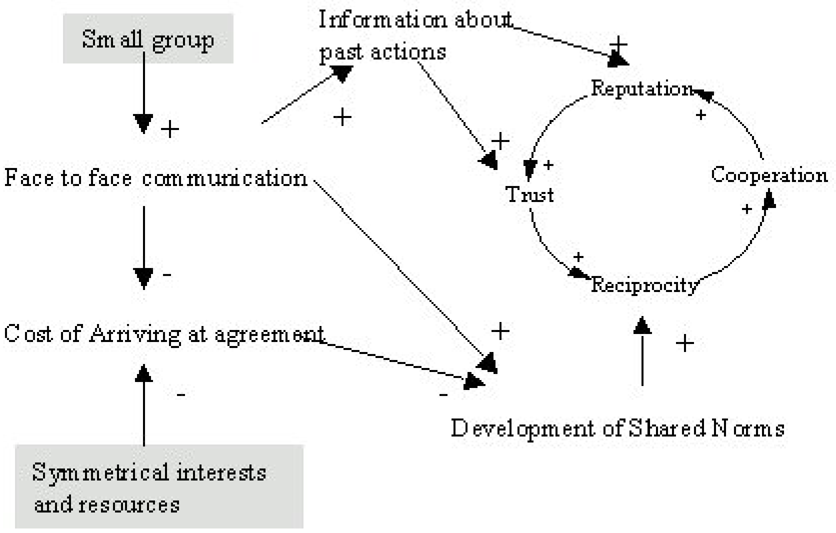

Figure1. Structural variables affecting reputation, trust and reciprocity (adopted from Ostrom, 1998)

According to the predictions of this theory, social groups with these characteristics have high potential to escape from the resource depletion trap. Case studies show that, the most successful communities have self-developed their own rules for the use of common resources. When external regulations have been implemented, they tend to undermine social structures supporting the local institutions.

Ostrom et al., (1994), Ostrom (1998, 2000), Cardenas et al., (2000), Cardenas (2000a) and Lopez (2001) among others have reported important CPR experiments. These results confirm the importance of self-organization and identify communication among individuals as a key factor in reaching agreements and developing rules for the use of the resource. When subjects do not face restrictions and cannot communicate with each other, their decisions tend to be neither pure Nash strategies nor efficient choices, but somewhere between these extremes. The treatments simulating institutional interventions such as taxes and subsidies lead to more selfish and opportunistic behavior. In these treatments, levels of cooperation decreases and the system moves far from social optimum outcomes. Figure 2 illustrates the reference modes inferred from these experimental studies.

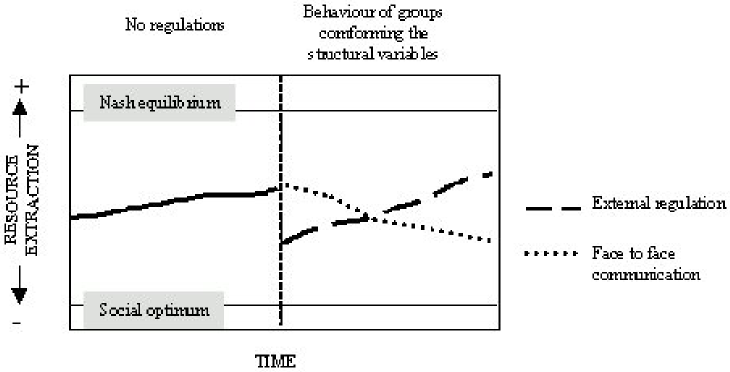

Figure 2. Reference mode inferred from previous experimental research.

Experiments in Old Providence Island

In addition to these theoretical considerations and aggregate experimental evidence, the model structure and behavior analysis in this study is particularly based on the observations during field experiments in the Providence Island of Colombian Caribbean Sea (Cardenas, 2001). These experiments were performed with 80 participants from crab hunter and fisherman communities. These two activities are very important for the economic development of the island inhabitants. The Black Crab (*Gecarcinus ruricola*) has been traditionally harvested to satisfy domestic and tourist demand. During the last 15 years its production has increased to satisfy the increasing demands for trade and tourism. The fisherman manages their marine ecosystems as communal property and they face serious species depletion, like the many other fisheries in the world. According to Valdes et al. (1997) the overexploitation of lobster (Panulirus argus), conch (Strombus gigas) and red snapper (genus: Lutjanus) has pushed fishermen to increase their work hours and to go into farther places.

The purpose of these experiments was to investigate, in the field, the cooperative behavior of resource users under external regulations and communication treatments. A payoffs function was designed in which, individuals derived direct benefits from allocating effort into extracting a resource (fish or crab) for which there is joint access by a group or community. On the other hand, their payoffs were reduced as the aggregate extraction of the group was increased, representing the negative externalities such as the biodiversity loss. According to this payoffs structure, the individuals were confronted with the cooperation dilemma: while cooperation for decreasing extractions increased the social benefits, any individual could free ride to increase her own efforts and own income. The payoffs function is calibrated by Cardenas (2000) and the formulation is shown by Equation 1.

$$60 \times Effort - 2.5 \times Effort^2 + 20 \times 5 \times 8 - 20 \times TotalEffort \quad (1)$$

The parameter values 5 and 8 stand for the number of players and for the Nash strategy (in effort units) respectively. A unit of effort means the time spent in the extractive activity, which can be represented in hours, days, months or years.

Figure 3 illustrates the possible benefits an individual can derive, based on this payoffs function. There are two extreme possibilities from an individual player’s perspective: when the total effort of the 4 others is at its minimum level 4, the individual can derive benefits between 758 $ (Colombian Pesos) to 880 $ depending on 8 alternative extraction units for that round (this is illustrated by the 8 points on the upper inverse parabolic curve). The other extreme is when the 4 others extract at their maximum level in total, 32 (effort units). Then the individual can derive benefits between 198 $ and 320$, represented with the lower inverse parabolic curve. The space between these two extremes depicts all possible alternative benefits for the individual depending on the total group effort. According to this payoffs function, even if an individual doesn’t put any efforts (plays 0 effort units) he still gets benefits due to environmental services from biodiversity. However, according to the rules of the experiment, efforts have to be between 1 and 8.

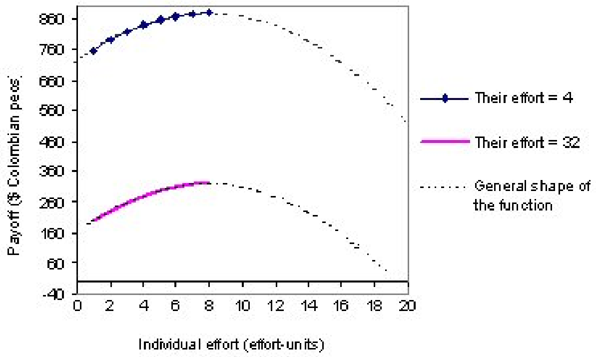

Figure 3. Individual payoffs with respect to individual and group efforts

Throughout the game, all decisions are made individually and privately and only the group's outcome is publicly announced in each round. The experiments are conducted with groups of five players in a finite repeated game of 20 rounds divided in two stages. The first stage (rounds 1-10), for all groups, is under a baseline treatment as a non-cooperative game, where each subject decides on the level of effort to extract units of resource from the commons according to the payoffs incentives described above. In the second stage (rounds 11-20), a new institution is introduced in the form of a regulation aiming to improve social earnings. These are the tax, subsidy or communication treatments.

Figure 4 shows the pooled results with respect to subject groups (crab hunters and fisherman) for the two treatments (tax and communication) for 80 subjects in total. The vertical axis shows the average extraction effort and the horizontal axis shows the rounds of the game. The first ten rounds is the base treatment. For this period, the results of the two treatments are averaged on this graph. For crab hunters, during the base treatment effort level stays around the mean (4 effort units) whit a slightly increasing tendency. At the second stage both the tax and the communication treatments work well, efforts decrease (hence cooperation increases). For the fishermen, during the base treatment, the effort level remains around the mean. At the second stage, tax appears to be a better policy which stabilizes the extractions at a level below the baseline value. The results from communication treatment is highly instable, indicating there is not a reliable agreement among the players.

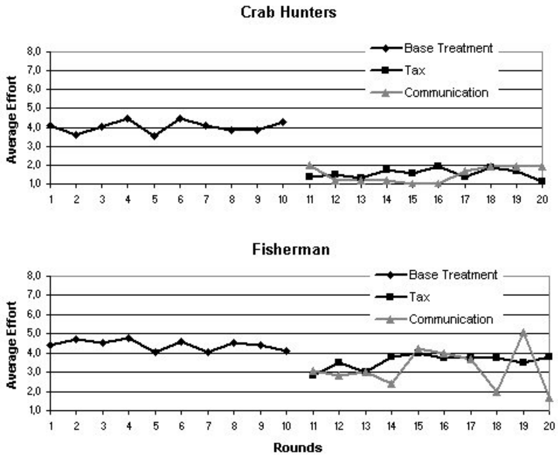

Figure 4. Outcomes from the field experiments in Old Providence Island

Dynamic modeling of decision making

Computer models are emerging as an important complement of extensive field studies and economic laboratory experiments in CPR problems. Jager and Janssen (2002) and Deadman (1999) have both used agent based modeling approach to link common pool resource laboratory experiments with computer models. Though their studies intend to represent the structure of the experiments reported in Ostrom et al. (1994) and discuss the model behavior with respect to these experimental results, they don't benefit from the "behavioral theory of collective action" (Ostrom 1998) as the conceptual framework. Deadman (1999) studies the relationship between individual behavior and group level performance by providing the agents with a return maximizing strategy with several possible options to achieve their goals. The main objective is to explore the possibility of testing theories of individual action and group behavior through computer simulations. The model behaves similar to the group level performance in laboratory experiments, which is characterized by an oscillating pattern due to over investment in the CPR and a subsequent fall in extraction. The author claims this behavior fit as the bases for the verification of the model. Jager and Janssen (2002) use psychological theory of human decision making, which considers basic needs and uncertainty as the driving factors of decisions as opposed to the traditional "rational actor" assumption. Their original objective is to explain the individual's behavior in real experiments as originating from heterogeneity in Social Value Orientations (SVO's) of the participants using the "consumat" approach, a multi-agent simulation method from social psychology. Their model is not able to explain individual patterns of the real experiments. On the other hand, they claim, the statistical fit between simulation data and real experiments observations are not "sufficient proof that the simulation model captures the most relevant dynamics that guide the behavior of the subjects in the Ostrom et al (1994) experiments." (Jager and Janssen, 2002). They call for the necessity of more empirical data. They identify different needs which are important in decision-making, their relative importance, decision maker's Social Value Orientations, cognitive processes subjects use, personality characteristics and the relevant time horizon people use to make a decision. The authors conclude, testing all these factors in experimental settings is a very complex task, therefore the usefulness of simulation models is to provide a practical tool to “test beforehand the relevance of factors and develop hypotheses concerning the effects of varying these factors” (Jager and Janssen, 2002).

The modeling approach of the present study is based on the principles and methods of *System Dynamics* (Forrester 1961; Sterman 2000). System Dynamics is particularly useful in formalizing feedback processes governing the dynamics of socio economic systems. In addition to the representation of physical and institutional structures of the systems, it provides methods for formulating decision rules which represent the behavior of the agents within those systems (Sterman 2000, p. 515). Decision makers may be represented as individuals or as aggregations of decision-making individuals or groups. In these continuous dynamic formulations, the decision makers’ rationality can be limited by separating the actual and available information to the agents, by considering expectations on the future states of the system and by taking into account several other cognitive limitations. Time delay formulations have an essential role in representing these processes. The model structure consists of feedbacks, time delays and nonlinearities, which create dynamic behavior patterns over time.

In this particular case, the existence of feedback processes among the variables such as *reputation, trust,* and *reciprocity* and the others like *temptation to free ride* through the rounds of the experiments; the existence of time delays in building variables such as reputation and trust; and existence of non linear relationships among the factors such as trust and reciprocity (illustrated in Figure 8) makes system dynamics to be an appropriate approach for modeling the experiments. Finally, many variables that need to be considered in this analysis are “*soft variables*”, which lack units but are identified within appropriate scales, like *trust*, for example. The model building practice in system dynamics supports these requirements. Provided that the sensitivity of model behavior is tested with respect to the uncertainty in “*soft variables*”, inclusion of behavioral factors in formal simulation is strongly encouraged. According to Forrester (1961, p. 57), to omit such variables is equivalent to saying that they have zero effect – probably the only value that is known to be wrong. Moreover, there are opportunities for statistical estimation of soft variables. As long as the model structure satisfies the conditions for structural validity and there exists reliable data from extensive field studies, statistical estimation of soft variables are also possible (Sterman 2000, p. 868).

The modeling language consists of building blocks (variables) classified as stocks, flows and auxiliary variables. Stock variables (symbolized by rectangles) represent the state variables and are the accumulations in the system. Flow variables (symbolized by valves) are the decisions, which act to alter the stocks (the sate of the system); they fill or drain the stocks. Auxiliary variables (represented by circles) describe the flows and help to perform several calculations. Connectors (the arrows) are not variables but they point the causal relation between two variables and carry the information within the model structure (Figure 5).

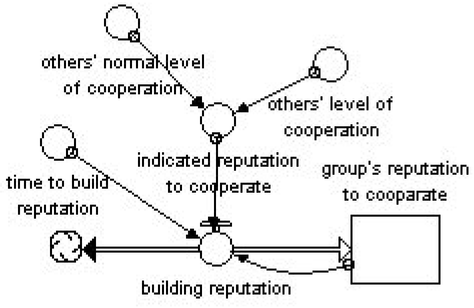

Figure 5. Simple illustrative example of the modeling language

III. MODEL STRUCTURE

The simulation model represents the structure of the field experiments in Providence Island in November 2001, and formalizes the feedback causality among *trust*, *reputation* and *reciprocity* as suggested by Ostrom (1998), "behavioral theory of collective action"[1]. Moreover, based on the payoff structure used in the experiments and direct observation of participants, it considers other behavioral factors such as *temptation to free ride*, *profit maximization*, and *learning* of the individuals in feedback perspective (Castillo, 2002). It is important to note that, no player strategy is built in the model. The agents of the model do not choose out from the predefined strategies such as reciprocate, tit-for-tat, or punish. Such behavior may or may not arise from the structure of the model, which represents the experiment's payoff function and the decision rules

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[1] System dynamics has been used to model and test the dynamic consistency of social theories. Sterman (1985) models Kuhn's theory on the structure of scientific revolutions and illustrates its consistency by simulation tests. For a discussion on the validity of this work, reader can refer to the articles in System Dynamics Review, 8(1), 1992.

of the participants modifying this payoff for each individual. Also, since the model simulates the field experiments, decision-makers stand for those individuals participating in the experiments but, the model attempts to capture the decision rules for the "average" or "aggregate" individual. For this reason, model behavior is confronted with the "aggregate" or "pooled" experimental results.

In the following paragraphs, we describe the model structure from individual player's perspective. However, in the computer simulation model, these loops are coupled for the five players of the experiment; hence, the overall loop structure is more complex. Computer model is implemented on Powersim Constructor (Powersim Corporation, 1999).

The model consists of five loops, which represent the decision rules for each player from an individual player's perspective. These are *Reciprocity*, *Free riding*, *Profit maximization*, *Awareness Building loops*. The decision rules embedded in these loops determine the effort allocated to extract the resource in each round of the experiments. In Figure 6, the first three of these loops are illustrated. According to the reciprocity loop R1, as more effort is allocated by each individual to extract more units of resource, the less will be the cooperation of the group and the less will be the reputation of the group to cooperate. This in turn, will erode the trust in group (*group's trustworthiness* will decrease) and will lead to a less willingness for the individuals to cooperate with the group members. Eventually everybody will tend to increase his or her extraction efforts. This feedback loop is denoted with "R" which stands for a *reinforcing loop* (positive feedback). The main characteristic of "R" loops is that, any change in one of the variables is reinforced through the succession of the causal relations. Later in the behavior analysis section, it is shown that this R1 loop is responsible for the path dependence of the model behavior on the initial trusts of the individuals in the group. According to Ostrom (1998) reputation is built by different identities that individuals create, through their past actions, which project their intentions and norms of behavior. *Group's Reputation to Cooperate* is modeled as a stock variable and it keeps part of the system's inertia. In other words, the group cannot change its reputation in front of a player instantaneously. This variable represents the reputation built by the group with respect to the aggregated past actions expressed with cooperation levels during previous rounds. The trust that each player has in the rest of the group is also modeled as a stock (*Group's trustworthiness*), and formulated as a delay function of *Group's reputation*. The letter "D" on the causal links represents these temporal delays in Figure 6 and Figure 7. The level of trust in the group depends on the group's reputation built through past actions. Although group's cooperation may have decreased, the level of reputation can persist for some rounds. According to the reciprocity loop, the level of cooperation in the group can decrease increasingly or increase increasingly, but the delay in building reputation and trust among the group members avoid immediate shifts in between these two modes of behavior. The stock variables are represented with boxes in the causal diagrams in Figures 6 and 7.

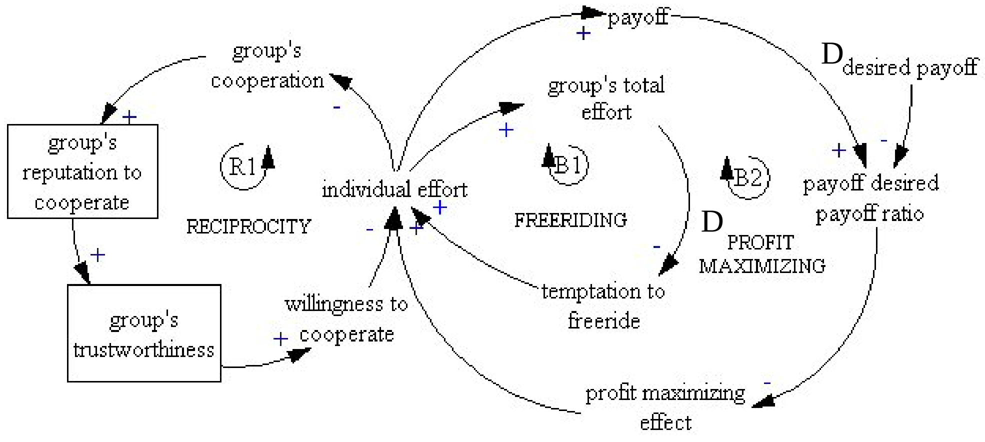

Figure 6. Reciprocity, Free riding and Profit maximization feedback loops

As the individual efforts increase, the total group effort increases. But, when group effort is low, individuals face the opportunity to free ride on others, hence the temptation to free ride is higher. When the individuals tend to free ride, extraction efforts increase. This process is represented by the free riding loop denoted by B1 in Figure 6. In this figure, "B" stands for the *balancing loop* (negative feedback) whose main characteristic is to counteract or balance any change that occur in the value of its variables. Therefore, according to this description, for example, a free riding individual may counteract any decrease in the effort of another individual. The profit maximization loop, B2, represents the profit maximizing behavior of the individuals. According to this balancing loop, as the individual puts less effort on resource extraction, the individual payoff decreases. Then the player becomes less satisfied with her/his payoff compared to the maximum that she/he can receive and tends to increase her/his efforts for extraction through the variable, profit maximization effect.

Figure 7 portrays the *Awareness building loops* that influence the player decisions. According to this hypothesis, individuals learn about the dilemma that they are involved in and adapt their decisions according their level of awareness. The effort-learning loop B3 implies that players learn by comparing their own perceived effort with the perceived group effort. Then, they compare their relative effort (ratio of individual effort to total effort) with their relative payoffs (ratio of individual payoff to maximum payoff). As the ratio of relative effort to relative payoff (effort payoff ratio) is high, the individual better perceives the commons dilemma. The payoff unlearning loop, R2, works under the following assumption: the less is the difference between the perceived individual and maximum payoffs (i.e. the higher the ratio of perceived individual payoff to maximum payoff) the less the player perceives the incentives structure. Finally, the higher the perception of the dilemma the less will be the individual effort the people allocate to harvest the resource. It is important to note that, none of these rules assume rational players who make accurate calculations. The inputs to this decision are delayed perceptions of actual payoff and effort information and the nonlinear formulations reflect a tendency for increased awareness of the dilemma. The overall idea is that, as players see decreased payoffs with increased efforts, they become more aware of the dilemma.

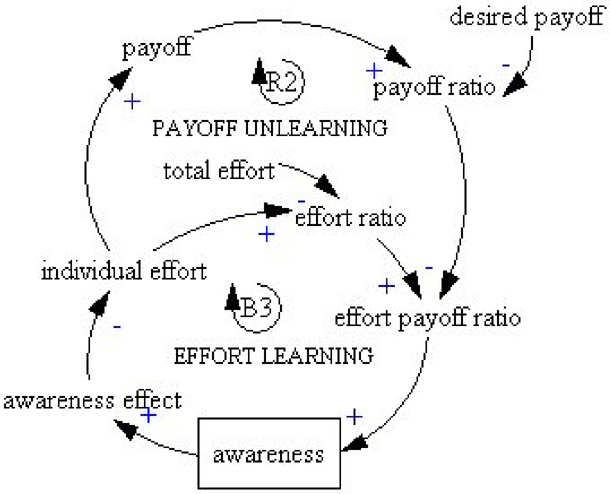

Figure 7. Awareness building loops

The payoff function in the model is identical to that used in the experiments (Equation 1) whose formulation is generic to the games with group externalities. In the model, the effort of an individual is formulated by Equation 2.

$$\mathit{IndividualEffort} = \mathit{ReferenceEffort} \times \mathit{WillingnessToCooperate} \times \mathit{TemptationToFreeride} \times \mathit{ProfitMaximizingEffect} / \mathit{AwarenessOfDilemmaEffect} / \mathit{RiskPerceptionEffect} \tag{2}$$

The entire variables are nonlinear functions, except the model constant R*eference Effort*. The *Reference Effort* for each player represents one of the culturally learned social behavior norms for this type of social dilemmas. This parameter is set at 4 effort-units assuming an intermediate norm between a complete selfish decision (8 effort units) and a full cooperative one (1 effort unit). Therefore, the model adjusts individual efforts around this reference value, based on the weights of the factors involved in the effort formulation.

The effects of reciprocity, temptation to free ride and profit maximization, awareness and risk perception on effort decisions are formulated by several nonlinear functions. The following paragraphs provide a closer look at these formulations.

Willingness to Cooperate

The level of trust of each player in the rest of the group (group’s trustworthiness) affects the effort decision for each round. This effect represents the reciprocity norms a player has. In this sense, the effect has been called *willingness to cooperate*. The nonlinear relationship between group’s trustworthiness and willingness to cooperate is shown in Figure 8. According to this formulation, when group’s trustworthiness is high, the player reciprocates to the group with her/his next decision, by decreasing his extraction effort. As group’s trustworthiness decreases, player’s willingness to reciprocate tends to decrease. At very low levels of trust, player reciprocates by increasing his extractions. As trust approaches its minimum and maximum levels, the reciprocity of the player saturates at certain levels.

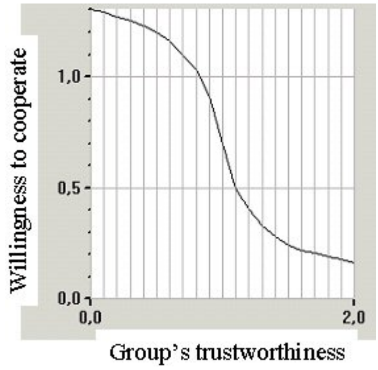

Figure 8. Willingness to cooperate as a function of group's trustworthiness.

Temptation to free ride

Temptation to Free ride aims to capture the free riding incentives present in the experiments. Direct observations during the experiments suggest that, in general, the players give more weight to information related to the group effort than payoffs, which are taken into account in the profit maximizing effect. As the group cooperates and efforts tend to decrease, individual players get the opportunity of free riding on the others. According to the formulation of this behavior in the model, individual checks the ratio of others' effort in the group that he or she perceives with some time delay to some average effort, which is a model constant set as 16 effort units (others' reference or intermediate total effort). Figure 9 portrays temptation to free ride as a function of this ratio. Therefore, as the others' effort decreases below this average, the individual faces a higher temptation to free ride. When others' effort increases above the average, this temptation decreases and free riding behavior is discouraged because the payoffs are considerably low if a free riding strategy is followed.

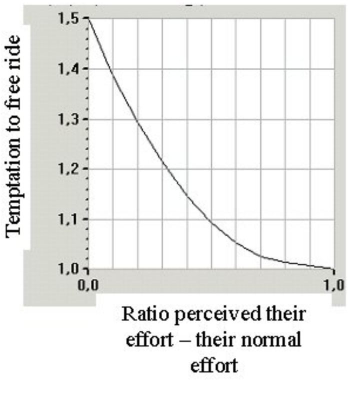

Figure 9. Temptation to free ride as a function of individual and perceived total effort.

Profit Maximizing effect

The function representing the effect of the profit maximization rationality on the effort decision is shown in Figure 10. The ratio of the average payoff perceived by the player over some rounds of the game over the maximum payoff that can be earned by the player in a single round is the input for this function. The maximum payoff is a model constant driven from the payoff function, whose value is 880 $. The higher is the ratio of average perceived payoff to the maximum payoff, the less is the value of this function. As the average perceived payoff approaches to the maximum that can be earned, the value of the function approaches to 1, which is a null effect in multiplication. However, as this ratio reaches to its minimum, the value of the function increases to increase the effort decision in the next round of the experiment.

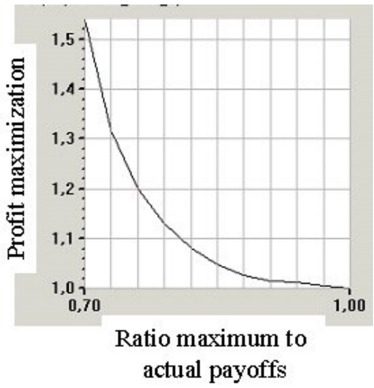

Figure 10. Profit maximization effect as a function of maximum and actual payoffs

Awareness of the Dilemma Effect

This function represents the effect of awareness of the dilemma on effort decisions. Awareness is modeled as a stock variable (accumulation) based on the assumption that, each player learns and adapts to the incentive structure and the actions of others as rounds go on. The individual player’s perception on how much effort he invests relative to the others and how much he can earn relative to the maximum payoff are the key factors in development of this awareness. The inputs to this level are explained while describing the B3 and R2 loops in the previous section. Eventually, the awareness of the dilemma has an effect on the effort of the player, which is depicted in Figure 11. According to this figure, as awareness changes between its minimum and maximum values, its effect on effort decision asymptotically approaches to its minimum and maximum values. This effect first increase at an accelerated rate at the initial state of the learning process and then arrives at a saturation phase as awareness improves.

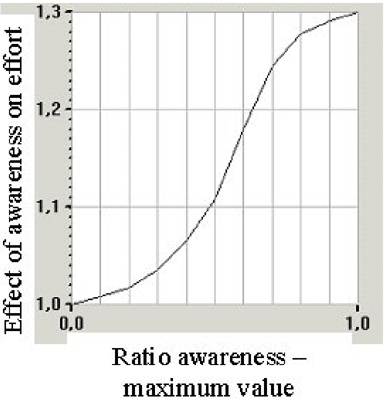

Figure 11. Awareness of the dilemma effect as a function of awareness and maximum awareness

Risk perception effect

Risk averse behavior of the players are modeled with the variable risk perception effect which is a function of risk perception. According to this formulation in Figure 12, as the players perceive higher risk they tend to cut their extraction efforts. Risk averse behavior develops first at an increasing rate and then at a decreasing rate as the risk perception increases.

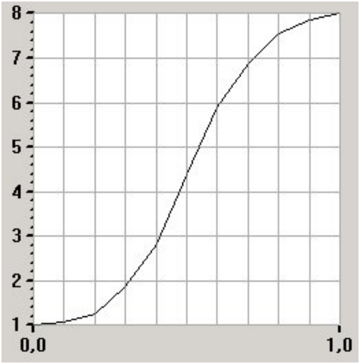

Figure 12. Risk perception effect as a function of risk perception

We described the loop structures and important nonlinear formulations of the model. This structure represents the hypothesis about the causes of the behavior of the players in CPR experiments based on Ostrom 1998 and on laboratory observations. All model details are available in Castillo (2002).

IV. VALIDATION OF THE MODEL

The presented study is a *causal-descriptive* model, which intents to describe how and why the players in the experiments cooperate or not cooperate. The model structure stands for the causal hypothesis describing the behavior of the players over time. Therefore, the validity of this model depends on the validity of its structure, rather than statistical fit between the model output and data. In complex dynamic systems, while radically flawed structures can produce a satisfactory fit between the model output and data (Barlas 1989), perfect structures can yield statistically very poor results if the model is noise driven and/or data are noisy (Forrester 1961, p. 430). Based on these considerations, in system dynamics, there is a crucial distinction between the *validity of the structure* and *behavior validation* (Forrester and Senge 1980; Barlas 1996). Model behavior is calibrated after enough confidence is built on the validity of the structure. To overcome the informal nature of structure validation, Barlas 1989 and Barlas 1996 propose indirect structure tests called *structure-oriented behavior tests*. These tests consist of several simulation experiments, which yield strong information about the validity of the structure. Among the structure-oriented behavior tests, *extreme condition*, *behavior sensitivity* and *phase relationship* tests constitute the minimum set, which are common and easily applicable.

In this section, we illustrate several of these tests and discuss the validity of the model structure. The behavior fit with respect to the experimental results and theoretical predictions is discussed in the next section.

Model behavior under extreme initial trustworthiness

Extreme-condition test involves assigning extreme values to selected parameters and comparing the model-generated behavior to the observed (or anticipated) behavior of the real system under the same extreme condition (Barlas, 1996). The model response is tested under two extreme initial trustworthiness conditions. In these tests, the anticipated behavior represents the assumption about the most likely behavior that would be observed in the experiments. In the first test, all the players enter to the experiment with a complete lack of trust in the rest of the group, i.e. group's trustworthiness in front of all the players are at its minimum. The anticipated behavior is that, all the players will try to increase their efforts without taking care of the group benefits. Namely, they will follow the Nash strategy (8 effort-units) from the very beginning of the experiments. Figure 13 portrays the result of the simulation under this condition with the curve labeled “1”. The model generates behaviors following the Nash strategy during the first three rounds, but after that round, players gradually decrease their efforts down to 6 effort-units. This gradual decrease is because of the learning. As players become more aware of the dilemma, they deviate from the Nash strategy. Though the players are sensible to the learning, since their trusts in the group are very low from the first round, they are not able to improve cooperation below 6 effort-units in their decisions.

The second extreme condition test assumes the individuals enter the experiment with full trust in the group, i.e. the group's trustworthiness in front of all the players are at its maximum. The prediction for the real life situation under this condition is that everybody will make group oriented decisions and the system will stay at the social optimum, which is 1 effort-unit. The model generates exactly this anticipated behavior (Figure 13, curve labeled “2”).

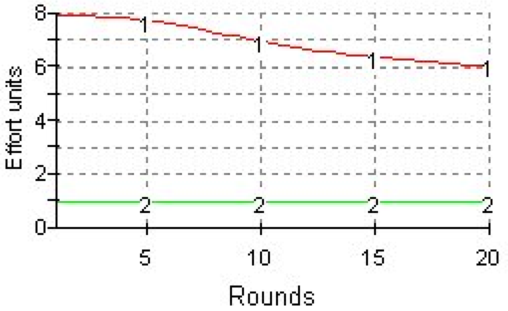

Figure 13. Extreme condition tests for the initial value of *group's trustworthiness*

Behavior Sensitivity to Willingness to Cooperate and Profit Maximizing Behavior

In behavior sensitivity tests, the idea is to determine those parameters to which the model is highly sensitive, and ask if the real system would exhibit similar high sensitivity to the corresponding parameters (Barlas 1996). Here two illustrative examples are given for behavior sensitivity tests: sensitivity to willingness to cooperate and sensitivity to profit maximizing behavior.

Willingness to cooperate represents the reciprocity norms of each player as a response to the trustworthiness of the group. Since this function is a factor in multiplication in the effort equation, its decreased values must be understood as higher willingness to cooperate. Figure 14 shows different possibilities for this function (upper panel). The lower panel of the figure depicts model runs for group's average effort under different functions and different initial values for trust in the group: curves labeled "1" are for minimum initial trust, curves labeled "2" are for intermediate initial trust and curves labeled "3" are for full initial trust.

A high willingness to cooperate (upper left) means, players are responsive to initiate cooperation even though group's trustworthiness is low. This leads the system to the social optimum (lower left). If the willingness to cooperate is medium (upper central left), the system reaches lower levels of effort close to the social optimum (lower central left). If willingness to cooperate is low, i.e. the players require high levels of group's trustworthiness to cooperate (upper central right) the system reaches high levels of effort (lower central right). The type of player who we call as common cooperator (upper right) is responsive to the increase in group's trustworthiness first at an increasing rate, but this response slows down as group's trustworthiness further increases. This formulation assumes that players react to group's trustworthiness by reaching full cooperation or full anti-cooperation at the saturation points of high and low levels of trustworthiness respectively. Then, if this common cooperator starts the game with full initial trust in the group, the system stays in optimum equilibrium (lower right).

The tests show a high sensitivity to willingness to cooperate function. The assumptions behind each function characterize four types of cooperation norms: high, medium, low and common willingness to cooperate. Therefore, the behavior of the model under each of these categories is acceptable and as expected.

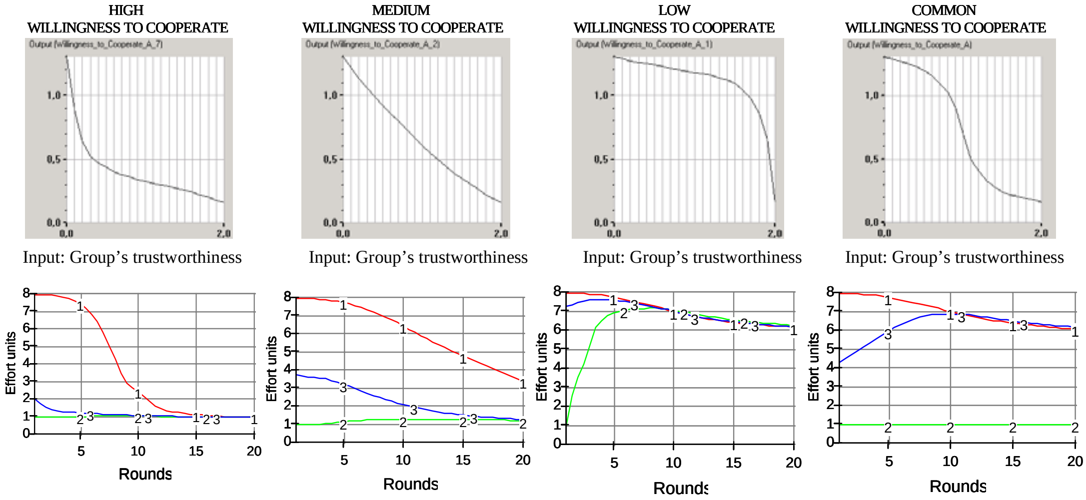

Figure 14. Sensitivity analysis of *willingness to cooperate* function

Temptation to free ride function represents the incentives that players have to free ride on the group. The possibility to follow an opportunistic behavior depends on her/his willingness to cooperate and her/his sensibility to the temptation. In order to carry out a sensitivity test for this function, four players are equipped with common willingness to cooperate (players B, C, D and E depicted by the curves 2,3,4 and 5 in Figure 15) and one with low willingness to cooperate (player A depicted by curve 1 in Figure 15). All players are given the same temptation to free ride function for each run, which are shown in the left panel of Figure 15. The right panel illustrates the corresponding simulation runs. In the three simulations, all the players start with initial maximum conditions of trust in the group.

For the first scenario, where they all are highly sensible to the temptation to free ride (upper left), player A free rides from the very beginning and the rest of the players try to increase their effort because they are “weak” and easily respond to the free riding incentives (upper right). In the real experimental setting, one should also expect that there are “weak” and “strong” individuals in front of this temptation. It means, their internal cooperation rules allow them to resist or not to resist this temptation. This temptation increases as the effort of the rest of the group decreases, in the experiments and in the model structure.

The two lower panels portray two different possibilities of this function and their corresponding runs. The behavior patterns are the same but the maximum effort units reached by the free riding player are different. The model shows sensitivity to temptation to free ride, which is coherent with the assumed behavior of the players in the experiments according to our hypothesis.

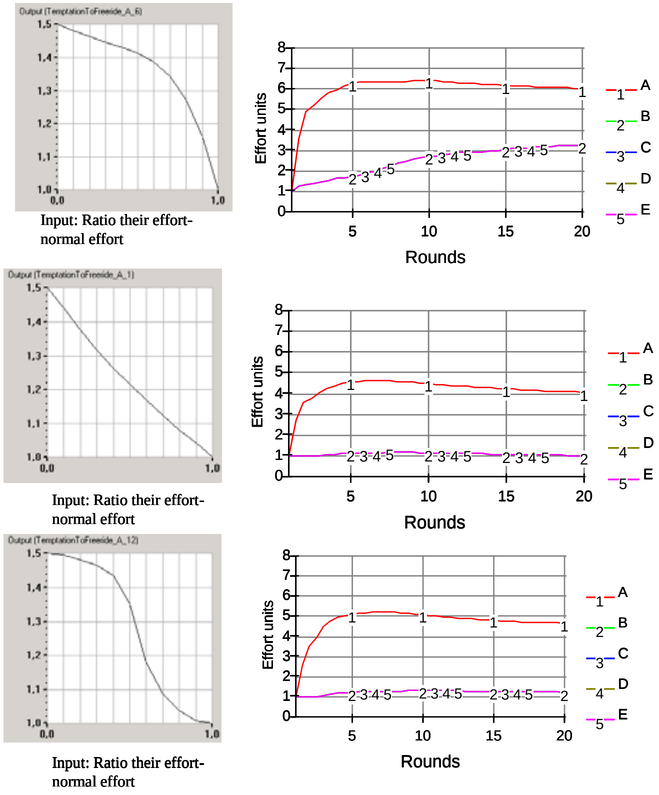

Figure 15. Sensitivity analysis of *temptation to free ride* function

Phase relationships between effort, group's reputation and group's trustworthiness

If certain phase relationships obtained from the model contradict the phase relationships that are observed/expected from the real system, this may indicate a structural flaw in the model (Barlas 1996). Figure 16 illustrates the phase relationship between effort, group's reputation to cooperate and group's trustworthiness. In this run, the players start with medium initial trust in the group. In the first 10 rounds, the group effort increases. In response to this behavior, first, group's reputation to cooperate decreases and consequently, group's trustworthiness decreases as well. From round 10 on, players initiate a decrease in effort due to the learning about the dilemma. Then, group's reputation to cooperate starts to increase with a delay, and later, group's trustworthiness do the same due to information about group actions during the past rounds. The time lag between the behaviors of effort, reputation and trust confirms the expected behavior based on our hypothesis. In real life situation, based on her/his past actions individual builds reputation and it takes time to build trust in her/him. This is consistent with the assumed behavior of these variables in the real experimental setting.

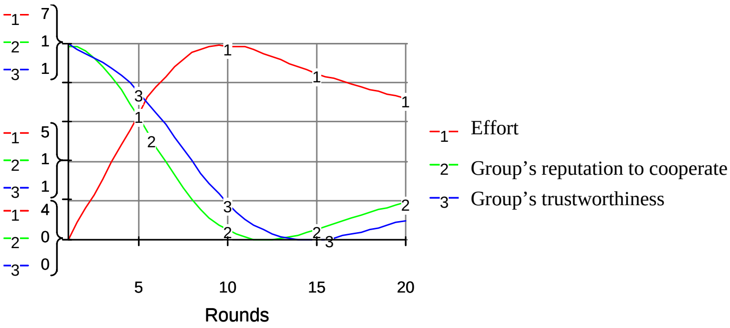

Figure 16. Phase relationship between effort, reputation and trustworthiness

In this section, we presented illustrative examples for the structure oriented behavior tests and discussed the consistency and validity of the model structure. In the next section, we discuss the model behavior with respect to the experimental results and theoretical predictions.

V. BEHAVIOR ANALYSIS

Ostrom (1998, p. 491) identifies six basic norms of reciprocity present in any population of individuals when they face a repeated social dilemma. When heterogeneity in decision making of the players is introduced to the model, it generates the majority of these behavior norms. Castillo (2002) discusses these simulations in detail. Figure 17 illustrates the way the model simulates one of such reciprocity norms: "cooperate immediately only if one judges others to be trustworthy; stop cooperating if others do not reciprocate; punish noncooperators if feasible" Ostrom (1998, p. 491). Figure 16 shows the following situation: players A, B and C start the game with full initial trust and D an E with minimum initial trust. In this run, players A, B and C behave according to this norm. As they see, the group is not cooperating, they start increasing their extraction efforts but, as D and E decreases their efforts and the groups proves to be trustworthy, A, B and C cooperate immediately by lowering their efforts again. The model cannot generate the "punishing" of noncooperators because on the game context individual players cannot perceive the efforts and earnings of other individuals but only has an impression about overall group cooperation.

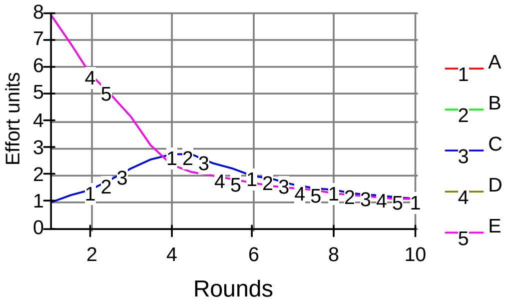

Figure 17. Simulation of a reciprocity norm of Ostrom 1998

Next, we analyze the model outcome focusing on the comparison between real experimental results, theoretical predictions and on the path dependent patterns of behavior found through experimentation with the model. It is important to note that this comparison is made based on "pooled" data, which represents the average behavior of the participants who participated in the three repetitions of the tax treatments and two repetitions of the communication treatment, with respect to two subject groups (fisherman and crab hunters).

Real and simulated decision-making under tax policy

In the simulation model, the tax policy and player's response to inspection are introduced by additional assumptions. Thus, inspection is modeled by a random variable, which detects the inspected player and the behavioral response to inspection is modeled by a stock variable, which represents risk perception. Tax is deduced from the payoffs and the risk perception creates the *risk perception effect* on effort, which is introduced as a variable in Equation 2. Figures 18a and 18b portray the best fit between simulations and real data from the experiments. It is important to note that, the purpose of this analysis is to capture the general trend patterns in data. When the oscillating patterns of data are considered, model behavior is not able to capture this detail. From the present model's perspective, such fluctuations are considered as "noise" for which no causal hypotheses is represented in the model structure. Such behavior can be due to different heuristics used by the players, which don't have any representation in this model.

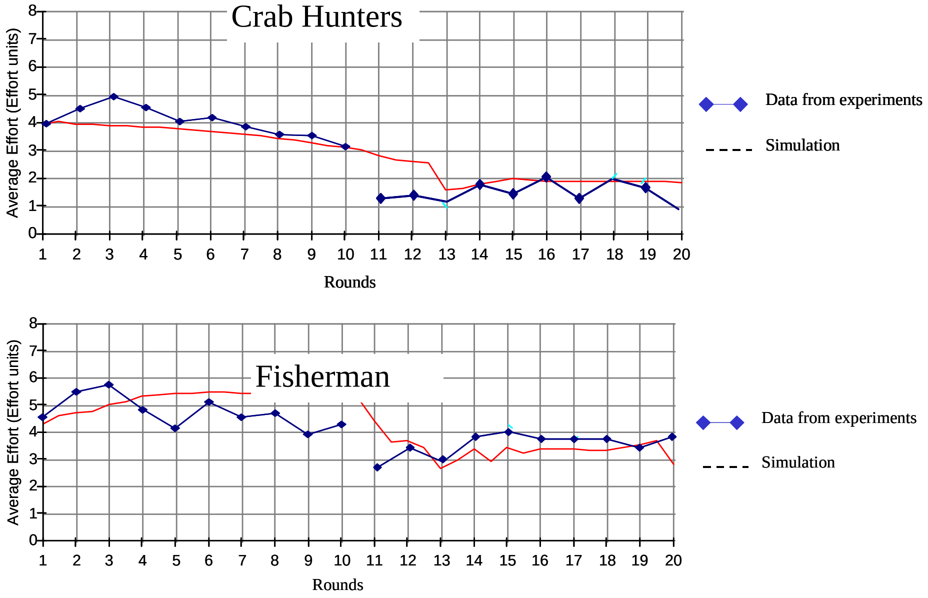

Figure 18. Comparison of model behavior and experimental data for tax policy

In order to achieve the behavior in Figure 17, each player's characteristics were modified; these are specified in Table 1. These characteristics are set by modifying the functions for willingness to cooperate and temptation to free ride, and the initial value of group's trustworthiness. The values in Table 1 characterize the crab hunters as a more cooperative group than the fisherman as mostly being cooperators and as individuals less sensible to the temptation to free ride. This finding may be in line with the field observations, also. Most of the crab hunters are females from adolescents to seniors and children from both sexes. On the other hand, the fisherman community consists of experienced adult and senior males. For the crab hunter community, the general impression from field observations is that their attitude towards cooperation is higher than the fishermen group. Further analysis of the questionnaires filled in by the participants may verify this hypothesis.

Player	Willingness to reciprocate	Temptation to free ride	Initial trust in them
CRAB HUNTERS			
A	Low cooperator	High sensitivity	Medium
B	Common cooperator	Low sensitivity	Medium
C	Common cooperator	Low sensitivity	Medium
D	High cooperator	Low sensitivity	Medium
E	High cooperator	Low sensitivity	Medium
FISHERMEN			
A	Never cooperate	High sensitivity	Medium
B	Low cooperator	High sensitivity	High
C	High cooperator	High sensitivity	High
D	Medium cooperator	High sensitivity	Medium
E	Common cooperator	High sensitivity	High

Table 1. Characteristics of crab hunters and fishermen based on the simulation of tax policy

Real and simulated decision making under communication treatment

In communication treatments, during the second stage (rounds 11 to 20), the participants are allowed to communicate with each other for 3 to 5 minutes in between the rounds but the decisions are still private. In the simulation model, this treatment is introduced by the assumption that, when communication is allowed, the rate of increase in awareness of the players is also increased. Figure 19 illustrates the best fit between the model behavior and data. Again, the model attempts to reproduce the negative trend.

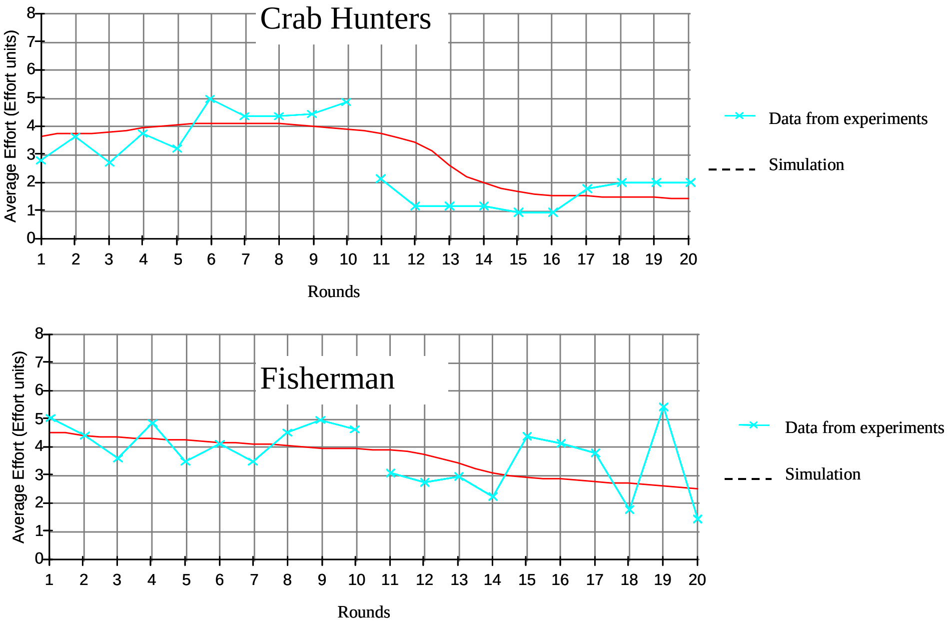

Figure 19. Comparison of model behavior and experimental data for communication treatment

Table 2 shows the characteristics for each player in each group according to this simulation run. In addition to these modifications, in order to achieve a similar behavior pattern for the crab hunters' experiments, the maximum values for the functions "Effect of awareness on effort" and "Effect of communication treatment" are also increased. Based on this finding, one can argue that, this group may have a larger potential for learning during the experiments. The differences in group composition of the fisherman and the crab hunters may imply that people from crab hunters group learn easier and are more willing to cooperate. But of course, such considerations have to be verified by further analysis of the group composition.

Player	Willingness to reciprocate	Temptation to free ride	Initial trust in them
CRAB HUNTERS			
A	Low cooperator	High sensitivity	High
B	High cooperator	Low sensitivity	High
C	Common cooperator	Low sensitivity	High
D	Common cooperator	Low sensitivity	Medium
E	Common cooperator	Low sensitivity	Medium
FISHERMEN			
A	Low cooperator	High sensitivity	Low
B	Common cooperator	High sensitivity	Low
C	Common cooperator	High sensitivity	Medium
D	High cooperator	High sensitivity	Medium
E	High cooperator	High sensitivity	Medium

Table 2. Characteristics of crab hunters and fishermen based on the simulation of communication treatment

Path dependence to group's initial trustworthiness

The model behavior is path dependent to the players' initial values of trust in the group. Path dependence arises in systems dominated by positive feedback where small initial differences can be amplified and the system can be locked into different paths (Sterman 2000, p. 406). Experiments with the model show that system behavior is eventually dominated by the reciprocity loop R1. Figure 20 illustrates this characteristic of the model. For the four runs in this figure, the behavior characteristics of the players are set as equal (the same willingness to cooperate, temptation to free ride, profit maximization and effect of awareness functions) but then, for each run, the initial trust of the players in the group are set as different. For example, for the first run (curve labeled "1"), all players start the game with equal minimum level of trust and for the last run (curve labeled “4”), all the players start with equal maximum level of trust in the group. Runs labeled “2” and “3” illustrate that, a microscopic difference in the initial trust can lead to different paths and different social outcomes.

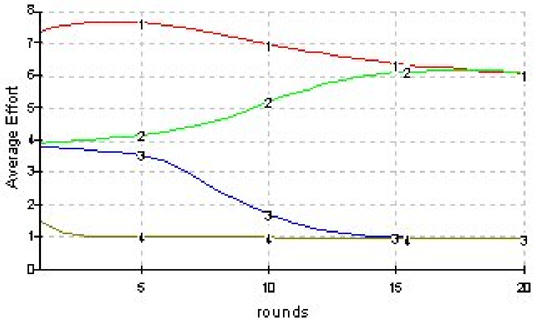

Figure 20. Path dependence pattern: simulations with different initial values of trust

VI. DISCUSSION

Present model shows reasonable response to the structure oriented behavior tests. Depending on the initial parameter values and on the degree of heterogeneity in the decision making of the players (different willingness to reciprocate, temptation to free ride and profit maximization functions) the model can generate a number of behavior norms cited in the literature. These norms can be explained in terms of the causal structure and feedback loop dominance, rather than through model built-in strategies. The model is able to replicate the experimental data for tax and communication treatments and based on this calibration, some behavior characteristics of the players can be identified. With this respect, the present work demonstrates how the decision rules of the players in CPR experiments can be modeled based on the theoretical second-generation model of human behavior using system dynamics approach.

However, yet, the present structure cannot replicate other data form other institution treatments such as subsidies. Also, the experimental results for the tax treatment replicated by the model are in contradiction with the theoretical propositions. Because, although the theoretical prediction suggests gradually increasing extraction efforts under external regulations (shown in Figure 1), neither the data of Old Providence

Experiments nor the present model structure confirms this. In fact, this discrepancy calls for future research both in experimental and modeling perspectives.

According to the hypothesis arising from model behavior analysis, the crab hunters are a more cooperative group than the fishermen. This is a result obtained by the values of the functions fitting the model behavior to the experimental outcomes. Verification of this hypothesis by field survey analysis can further increase the confidence in model structure. This investigation may yield important information about the relation between real life cooperation attitudes and decisions in the experiments. Path dependence of model behavior with respect to trust can be relevant outcome which points to the importance of trust in resource management in local communities. A practical implication would be to design environmental policies, which empower the social relationships and facilitate building trust among the community members.

In more general terms, modeling can be used as a tool to determine the relevant factors in decision making in common pool resource management. Relevant factors identified by model analysis can guide experimental designs. For example, the insights generated through the modeling process concerning the learning process, information available to the players, free riding and profit maximizing incentives are all potential hypothesis to be tested by experiments. Collaboration between experiments and models can be powerful in testing the relevance of factors in decision-making and in improving the knowledge on social behavior. While modeling can be used to identify new problems and generate hypothesis about the causes of observed or desired behavior, which helps new experimental designs, new experimental evidence can help improving the model structures as well. Figure 21 is a simple illustration of this idea. The *experiments* loop represents how knowledge is generated through experimental research. Based on the current knowledge on social behavior, problems are identified, the hypotheses about the problems are tested by experiments and the knowledge is improved by the analysis and reasoning on data. The *formal models* loop illustrates how modeling can be useful in improving knowledge. New hypotheses can be tested by new model structures and insights from model analyses can contribute to the knowledge.

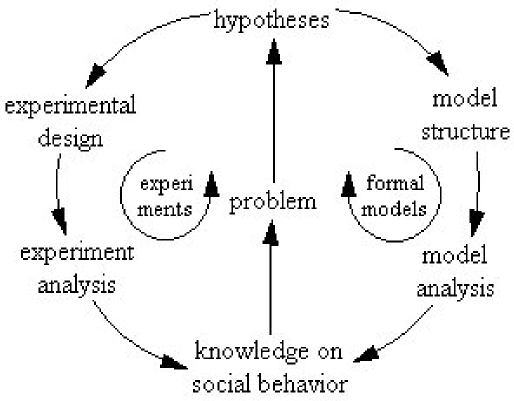

Figure 21. Iteration between laboratory experiments and modeling

Finally, as long as the micro models built to represent laboratory experiments can be extended to case studies for policy research, the external validity of the experiments and their hypothesis can further be tested. This is a challenge for the modelers, for which the aggregation level of the decision rules, incentive structures and resource structures have to be modified to adequately represent real life case problems. In fact, system dynamics is a rich field in policy research. Nevertheless, models of experiments have the potential to serve as the rigorous building blocks of the larger scale policy models of socio-economic systems.

VII. CONCLUSION

A dynamic simulation model of cooperation experiments is presented. The model represents the decision rules and incentives faced by the players in feedback perspective. Model structure is based on the “behavioral theory of collective action”, observations on subject behavior and payoff structures, and the principles and methods of system dynamics. Model structure is validated with structure oriented behavior tests and output is calibrated with respect to experimental data. Model analyses reveal significant insights about the incentives and behavior characteristics of the participants. In collaboration with laboratory experiments, modeling proves to be a useful approach for the micro analysis of decision rules adopted in common pool resource dilemma situations.

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