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THE TRAGEDY OF THE PARK: AN AGENT-BASED MODEL ON ENDOGENOUS AND EXOGENOUS INSTITUTIONS FOR THE MANAGEMENT OF A FOREST

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The tragedy of the park: an agent-based model on endogenous and exogenous institutions for the management of a forest.

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Abstract

Many scholars of common pool resources discovered that institutions may solve the tragedy of the commons. I will address a particular situation of management of natural resources: that of a protected area. In this situation interests differ. Local rural inhabitants care about the quality of their environment, but also need to exploit the resources for livelihood reasons. An external entity, being the State or a donor, or an NGO, or all of them together, decides that there is the need of nature conservation in that area. Because of some evidence of failure of strictly top-down conservationist approach, the external entity decides to apply the concept of participatory conservation: the local inhabitants become stakeholders in the management of the area and they become collectively responsible for conservation, having in turn the right to exploit the resources up to some degree**.** I argue that project designers try to find a solution to nature conservation through the creation of a situation of a commons: creating a community that has rights and duties towards a particular natural area that is endowed with some resources. Many scholars rely mostly on institutions which are endogenously created within the users' community in order to avoid the "tragedy". However, what happens if institutions are imposed? In participatory conservation initiatives the community has collective rights over the resources, and in this sense the issue of endogenous rules for the commons management is relevant. However, the level to which the community should exploit the resource is usually imposed by the external project designers. Using agent-based simulations we develop a theoretical model in order to look at the consequences of an imposed institution on the state of a forest and on the profit of the users, taking into account the possibilities of violating the imposed rules, and that of facing enforcement. We compare the consequences of this imposed institution with those deriving from an endogenously created institution. We will also analyze the interaction between the different kinds of institutions and the individual perceptions of each agent. Many results of the model confirm quantitative and qualitative findings of the literature: the presence of institutions and enforcement improve the management of the resource with respect to an open access situation, with different degree of success depending on the kind of institution in place. The two main counterintuitive findings are the following. First, an exogenous institution imposed by external agents may crowd out agents' intrinsic environmental motivations. Second, when an imposed exogenous institution is in place, the most effective rule is one allowing sufficient degree of access to the resources for the agents, provided that an adequate rule enforcement is implemented.

JEL Code: D02; O13; Q2; Q57

Keywords: participatory conservation, institutions, protected areas, commons, forests, agent based models

1.Introduction

Scholars of the commons widely agree on the possibility that institutions endogenously created by a community of people in order to manage a common pool resource may be able, under certain conditions, to solve the "tragedy" highlighted by Hardin (1968) (Van Laerhoven and Ostrom 2007). This is one of the reasons for the spread of participatory conservation projects worldwide, implemented by many kind of development and conservation agencies. In these projects the local beneficiary community is directly involved in the management of the natural resource that needs preservation. The objective is to obtain at the same time nature conservation and local economic development through the creation of a protected area. However, in many of these experiences where we face a community managing a commons, the aid agency actually imposed on the community the rules about resource exploitation, creating *de facto* the common pool resource and the rules of the game. Therefore in this case we face an exogenous institution rather than an endogenous one. We build an agent-based model in order to explore the impact of different kind of institutions on the state of a simulated forest and on the economic earning of the local loggers community. We also explore the links between individual decision criteria about the forest share that should be logged, the emergence of a community institution and the interplay with an exogenously imposed institution. The paper is structured as follows. In section 2 we explain what participatory conservation is and make reflections about the commons literature and the evolution of conservation strategies. In section 3 we explain the usefulness of agent-based models to explore socio-ecological systems. In section 4 we present the set up of the model. In the sections from 5 to 9 we model the situations respectively of open access, of endogenous institution, of exogenous institution, of presence of cheating and of presence of enforcement. In section 10 we discuss the results and conclude. In the Appendix the variables of the model are explained in detail.

2. The commons and the parks

In order to understand and analyse the phenomenon of community-managed protected areas two streams of literatures can be useful: first, the widely debated literature about the commons and second, some history of protected areas.

Regarding the first issue, with the famous article of 1968 “The tragedy of the commons” Garrett Hardin started a long dispute about the so-called common pool resources: scarce resources which are used collectively by a group of individuals, with different degrees of use regulation. Hardin stated that if several individuals exploit the same resource and each of them has the goal of personal profit maximization, the only possible result will be the overharvesting of the resource, with each of the individuals being worse-off. Hardin (1968) brings as example a shared parcel of land where several herders let their cattle graze. During the following decades many scholars show that the “tragedy” occurs only if the resource is held in an open-access situation, that is to say, property rights and extraction rules are not well defined among the members of the users group (Berkes 1989, Ostrom 1990, Baland and Platteau 1996). If the community members agree on a rule about the extraction of the resource the tragedy of the commons may be avoided. This condition does not necessarily requires the parcelization of the resource into individually owned parts, nor the imposition of rules by a public authority (McKean 2000, Dolšak and Ostrom 2003, Baland and Platteau 1996). These findings have been derived mainly through field research and experimental methods (Ostrom 2010, Janssen et al. 2010, Cardenas 2009). In the literature it is now widely accepted that a community, under appropriate conditions, may be able to find internal regulations leading to a sustainable use of the limited resource, that is, not overcoming its carrying capacity and compatible with its re-growth rate (Van Laerhoven and Ostrom 2007). In one word, institutions may solve the tragedy of the commons (Bravo 2011).

On the other hand, it is interesting to observe some patterns in the evolution of conservation policies. Historically, since the nineteenth century, the original approach to nature conservation has been the so called “fine and fences” attitude: a full prohibition of extraction of the resource which is supposed to be conserved. The resource takes the full status of protected area, which may be marine or terrestrial. In this way the local community is completely excluded from the exploitation of the natural elements of the protected zone.

Over time empirical evidence emerged on the limits of this approach (Haller and Galvin 2008, Alcorn 2005, Dixon and Sherman 1990). The "fines and fences" often are not sufficient to hinder the free-riding phenomenon or the illegal exploitation of the resources to be conserved by member of the local community or by outsiders. This problem has been particularly severe in developing countries, where a high number of individuals and communities still base their livelihood on the extraction of natural resources, through activities like agriculture, livestock raising, harvesting, fishing, logging (Haller and Galvin 2008). Another reason for the difficult applicability of this approach is the poor enforcement capacity, by both public and private agencies (Gibson 1999). Observations from empirical experience, together with the scholar research by Ostrom and others (Berkes 2007) on the possibility of auto-regulation on resource use by the local community, led to the development of the so called "participatory conservation projects" (Alcorn 2005: 40, Murphree 2002). They are also known with the names "Community-Based Natural Resource Management Projects" (CBNM), "Integrated Conservation and Development Projects" (ICDPs), Community-Based Wildlife Management Projects" (CBW). In these projects the local community is organized in an institution involved in the management of the protected area and in turn has the right to exploit its resources up to some degree. The aim is to promote both nature conservation and local economic development (Barrow et al. 2000, Roe et al. 2000, Hughes and Flintan 2001, Garnett et al. 2007, Hsing-Sheng 2007).

Since the 1980s these kinds of projects have spread in developing countries, particularly in those natural areas which seemed to be threatened by economic activities of local inhabitants (Blaikie 2006). The promoters of these projects often used theoretical argument provided by the numerous scholars of the commons: self-organization of a community for the successful and sustainable management of a common pool resource is feasible (Ostrom 1990). Many different kinds of development agencies adopted this participatory approach: governmental organizations, local or international non-governmental organizations (NGOs), conservation organizations. It is interesting to observe that both organizations caring about the environment and about local economic development started to share "in theory" this vision of combining nature protection with fostering of local economic activities through community self-organization (Blaikie 2006, Alcorn 2005, Lowenhaupt Tsing et al. 2005).

The extremely wide spread of these projects, that I will call for convenience "participatory conservation projects" (PC), induced the development of a vast empirical literature (Garnett et al. 2007, Alcorn 2005, Hughes and Flintan 2001). We find a high number of case studies about communities which are collectively responsible for some natural resource (forests, pastures, fisheries,…), reporting both successful and unsuccessful cases (Galvin and Haller 2008, Berkes and Seixas 2004, Vallino 2009, Berkes 2007). Very often the commons which are collectively managed have the status of protected area to some extent.[2] For our purpose "successful" refers to the achievement of two goals. First, the resource to be protected is allowed to renew itself at a sustainable rate. Second, the community improves its standard of living, measured mainly in monetary terms, through the PC project.

Lowenhaupt Tsing et al. (2005) and Alcorn (2005) identify two main kinds of community-based conservation initiatives (CBC): "design mode" and "discovery mode". "'Design mode' refers to situations where outsiders identify a problem and design a solution. This model (…) results in the typical community-based-conservation project supported by Conservation Organizations (…). Designed CBC can lead to co-option and destruction of Little Conservation[3]. 'Discovery mode', on the other hand, refers to situations where outsiders discover that local people have identified a problem and designed a solution, and subsequently assist local communities to legitimate their solution" (Alcorn 2005: 42). Many subsequent case studies and my own field experience (Vallino 2009) appear to confirm this interpretation. We can identify two main classes of PC projects. One class contains situations in which a community asked for the support of some external actors in order to get the recognition of some rights over a resource. The other class involves contexts in which an external actor wanted to create a natural park and to obtain the maximum possible collaboration from the local community. Community-based natural resource management experiences triggered by external project designers and PC coming from more grassroots motivations *are* actually mixed together in the literature (Berkes et al 2004, Dansero 2010, Murphree 2002, Garnett et al 2007). I show this fact also in Table 1.

[2] According to the International Union for Conservation of Nature, a protected area is "an area of land/or sea especially dedicated to the protection and maintenance of biological diversity, and of natural and associated cultural resources, and managed through legal or other effective means". The International Union for Conservation of Nature established six categories of protected areas, according to the degree to which resource extraction is allowed within the conserved zone (IUCN 1994).

[3] Alcorn (2005: 39) defines Little Conservation as a process in which "individuals make choices in their day-to-day lives, in the places where they live". It is opposed to Big Conservation, which, according to this author, means big scale operations and projects carried out by Conservation Organizations.

Table 1. Selected case studies about participatory forest management experiences in different countries, with information about their "designed" or "discovered" mode and their degree of success. "Successful" refers to the achievement of two goals. First, the resource to be protected is allowed to renew itself at a sustainable rate. Second, the community improves its standard of living, measured mainly in monetary terms, through the participatory conservation project.

Case study	Reference	Designed mode	Discovered mode	Successful	Not successful	Main reasons for success or failure
Phong Nha Ke Bang World Heritage, Vietnam	Larsen 2008	X		Half successful. Fair biodiversity conservation but serious livelihood problems.		Under different institutional arrangements *de facto* exclusion of the local communities by the access to forest resources.
Forêt Classée de la Comoé-Lèraba, Burkina Faso	Vallino 2009	X		Half successful. Fair biodiversity conservation but low income.		Local people income decreased because of lack of access to the resources of the Reserve. Decreased people access to the Reserve improved conservation.
Analavelona Forest, Madagascar	Auer 2006		X	X		Endogenously created community based rules and enforcement.
Zombitse Forest, Madagascar	Auer 2006	X			X	Rules imposed by the State and poorly enforced.
Kayapó Indian Nation Forest,	Auer 2006		X	X		Efficient indigenous skills in protecting

Amazonia						forests and extracting resources at a sustainable rate.
Amarakaeri Communal Reserve, Peru	Alvarez et al. 2008		X	Half successful. Good biodiversity conservation but low income.		Local people income decreased because of lack of access to the resources of the Reserve. Decreased people access to the Reserve improved conservation.

Scholars discovered that institutions matter and may solve the tragedy of the commons. Institutions are defined as the sets of rules actually used by the local community (Berkes 2007). They particularly rely on endogenous institutions, that is to say rules that emerge from the community members themselves (Bravo 2011, Agrawal 2007). For this reason, PC project designers focus their effort on the community institution that will manage the threatened natural resource. Moreover, when analyzing the harms of the PC projects, the community institution that manages the resource is often the object of the researches that want to detect the cause of failure of these initiatives. Researchers concentrate on dynamics *within* the community i.e. free riding, elite capture (Platteau 2004, Joiris and Bigombé Logo 2008: 22), or heterogeneity (Leach et al 1999, Ruttan 2008), and on the way in which these dynamics influence the institution.

The question of whether, when we look at a PC project, we are in a “design mode” or rather in a “discovery mode” (Alcorn 2005: 42) is mentioned in the literature. Commons scholars stress the importance of the context of the project and of the inclusion of the local policy arena within a larger institutional setting (Bromley 2008). Ostrom (2007: 15182) explicitly wonders “What is the likely endogenous development of different arrangements, use patterns, and outcomes with or without external financial inducements or imposed rules?” Garnett et al. (2007), in their excellent review on the effectiveness of Integrated Conservation and Development Projects (ICDPs), mention the fact that those seeking biodiversity conservation in poor countries are usually external stakeholders competing first of all with local stakeholders whose livelihood is dependent on the resource itself, but also with many other local or foreign actors. They also briefly recognize that the interaction between a donor agency and the project's beneficiaries involves asymmetric power relations. Moreover, there is a wide literature on the history and politics of ICDPs. Such authors basically argue that the biodiversity conservation concept and the strong focus on community participation both belong to an imposed rhetoric from the developed world to the developing one (Blaikie 2006, Brosius et al 2005, Grove 1989).

However, it is surprising that no authors engaged in a systematic study, neither through statistical testing, nor theoretical modeling, nor case study approach, about whether and how the *origin* of the institution affects the project outcome or the other variables which have been already detected as "relevant".

In one of the most important existing datasets on forest governance, the International Forestry Resources and Institutions (IFRI) research program contains data about several variables which are considered influential for the state of a forest. It includes information about the characteristics of the forest, of the users, the enforcement level and the ownership regime of the forest. However, there is no information about the different stakeholders involved in the forest management or about the presence of a donor agency starting some kind of participatory conservation project.

In the popular Institutional Analysis and Development Framework (IAD) Ostrom (2007) identifies four classes of variables which are decisive in determining the performance of collective management of a common pool resource: features of the resource system, of the resource units, of the users and of the wider governance system. Government and non-government organizations appear only as one of the many features of the category "Governance System" (Ostrom 2007, Agrawal 2007). No particular emphasis is posed on the fact that in most cases such organizations trigger the community-based project itself .

Garnett et al. (2007) draw ten lessons on how to improve the performance of an ICDP. These lessons belongs to five dimensions of a project situation: natural capital, human capital, social capital, built capital and financial capital. None of these lessons mention the importance of the difference between "designed" or "discovered" mode of an ICDP.

More weight should be given to the variable indicating the nature of the institution governing the commons: endogenous or exogenous. This may decisively affect at the origin all the other relevant variables and may (should) completely change the point of view of the researcher. Often an NGO or an external agency creates the situation of a common and a community responsible for that in order to pursue the goal of creating a park (Vallino 2009, Alvarez et al. 2008, Roulet and Assenmaker 2008, Joiris and Bigombé Logo 2008: 25, 28). This is what I call "the tragedy of the park". Garnett et al. (2007) underlines that "those seeking biodiversity conservation in poor countries are usually external stakeholders competing with both local values and other external stakeholders who place greater value on the resources they can extract". Moreover, we find a kind of institutional engineering in participatory conservation projects linked to a protected area (Skjovold 2008, Joiris and Bigombé Logo 2008: 25). External agencies enter communities and set up governance structures with little concern for existing institutional structures. In this situation, individuals have to adapt to the environment created by the NGO. In PC projects, the community has collective rights over the resources, and in this sense the issue of endogenous rules for the commons management is relevant (Poteete and Welch 2004). However, the level at which the community should exploit the resource (the institution) is usually imposed by the external project designers (Galvin and Haller 2008, Dansero 2010, Ezzine de Blas et al. 2011). This fact must be acknowledged when, while studying a commons, a PC project is taken as case study. Moreover, in the empirical and experimental literature the risk is mentioned that imposed institutions crowd out grassroots rules and motivations (Frey 1994, Ostrom 2006, Cardenas 2000, Bowles 2008). The research questions underlying this work are thus the following. Firstly, does the origin of the institution regulating the access to the resource matter in explaining the results of a PC project? Secondly, how does the interaction between individual rules, community endogenous institutions, and exogenously imposed institutions function?

3. Why a model and why agent-based

Adopting a theoretical approach I use the tool of agent based modelling in order to explore the consequences of different kinds of institutions on the state of a forest and on the economic profit of its users. Developing a model allows us to observe if it is true that the origin of the institution regulating the use of the resource strongly influences the behaviour of the users, and consequently the state of the resource together with the users' monetary profit derived by the resource exploitation. Moreover, it allows us to study how general this pattern of relations may be (Epstein 2008). Moreover, a model gives us the possibility to monitor the exact interaction among individual values, endogenous institutions and exogenous institutions.

Agent-based models deal with complex systems. It is assumed that "(...) systems are emergent structures on a macro scale due to interactions between microlevel agents who adapt themselves to their environment" (Janssen 2002: 1). Complex systems do not have a predictable behaviour, however they can offer a chance of observing under what circumstances simple local rules can lead to the emergence of structures at a higher level. Social systems, economies, ecosystems, socio-ecological systems, the nervous system are examples of complex adaptive systems (ibid.). In the present work we are interested in the relationship between people and their environment and in the evolution of the institutions regulating this interaction.

Economists explore ecosystems management in terms of exploitation of ecosystem services from renewable resources. While until the 1970s such research was generally based on static models, in the subsequent decades the tools of dynamic programming, game theory and equilibrium analysis have been widely employed. Irreversibility and uncertainty are key issues in environmental economics, although in the mainstream of this discipline the typical representative agent still has perfect knowledge and utility maximization goals (Janssen 2002). This approach is not useful if we want to study systems characterized by non-convex dynamics and structural uncertainty, or if we have multiple heterogeneous stakeholders interacting with an heterogeneous environment. Socio-ecological systems present the features of complex systems. Equilibria are continuously changing, because of the internal dynamics of the components themselves and due to the interaction between these dynamic elements. Ecological systems need to be resilient in order to be able to withstand the pressures generated by socio-economic systems for a prolongued period of time. This requires learning and adaptive capacity. (Janssen and Ostrom 2006b, Holling 2001, Berkes 2007).

Agent based modelling represents a very useful tool for analyzing this kind of systems.[4] In agent based models we have a number of autonomous heterogeneous interacting agents, which can represent animals, people or organizations (Epstein and Axtell 1996, Conte et al. 1997, Squazzoni 2010). Each agent has both states and rules of behaviour. They are able to combine reactive and proactive behaviour, as humans do in real life; they may perceive and

[4] For a very good review of the role of agent-based model in the social sciences see Squazzoni (2010).

influence the state of the surrounding environment; communicate with other agents, learn, remember, move in the space. They may adopt a satisfying behaviour instead of a maximizing one, in line with the bounded rationality concept (Kahneman 2003). It is possible to take into account random elements of the system. Finally agent based models allow the analyst to observe emergent effects which trigger from the interaction of all the elements at the micro level of the system (Axtell 2000).

There are good reasons for using agent-based modelling for institutional analysis as well. Game theory is a useful tool for studying the choice of strategies within a given set of rules. However, by using this tool, one must assume that a fixed, commonly understood, and followed set of rules is already in place. Evolutionary game theory is also a useful possibility for institutional analysis. However, it focuses on the evolution of strategies rather than rules. Moreover it requires the assumption of a homogeneous set of players facing a homogeneous environment. Agent-based modelling allows us to introduce consistent degrees of heterogeneity both into the attributes of the agents and into their biophysical world, leading to a better theoretical understanding of the process of institutional emergence and change (Janssen and Ostrom 2006).

In general, we can say that agent based models are suitable for analyzing socio-ecological systems for the following reasons. First, agent decisions are based on internal decision rules; this fits with the findings regarding the different types of heuristics in different situations. Second, the clear inclusion of agent interactions reflects the important role of communication in solving social dilemmas. Third, agent-based modelling is appropriate to describe complex adaptive systems and to observe the emergence of phenomena at a higher scale than its parts (Janssen and Ostrom 2006b).

One of the first agent-based models about socio-ecological systems is Bossel and Strobel (1978). In this model agents have cognitive capacity and base their decisions on the state of the global environment using indicators like livelihood needs, security and freedom of action. The state of the world determines the agent's priority, which in turns determines its decision about its behaviour. This process prevents a crisis of the system and leads to satisfactory policies. Another stream of agent-based models belongs to the discipline of ecology and started in the late 1980s. They aim was to systematically study the behaviour of organisms in complex and spatially explicit environments (Grimm, 1999). Bousquet et al. (1994) developed an agent-based model of management of fisheries in the central Niger delta. Based on field

work, an artificial world was created where different scenarios of rules of when and where to fish in a wetland area were analyzed. The aim was to observe the impact on long term viability of the fish resources. Deadman and Gimblett (1994) constructed a model that simulates the behaviour of three types of visitors in a natural park: hikers, bikers, and visitors transported in tour vehicles. The results of hiker interactions with other users is useful for suggesting ideas about alternative recreation management planning.
The work of Lansing and Kremer (1993) is one of the first simulations about collective natural resource management, even if it is not an agent-based simulation. This model is seminal since it provides a formal representation of self-governance. It is about traditional irrigation systems in Bali, Indonesia. It shows that simple bottom-up interactions of farmer groups at village level can lead to a good performance of a very complex large-scale irrigation system (Janssen 2007).

Probably the first work using agent-based models to investigate common pool resources situations was Deadman et al. (2000). They modelled agents that replicated most of the findings of experiments on the same topic, such as the strong effect of communication on cooperation and sustainable use of the resource. System behaviour was not specified in the model, but resulted from the interaction among individual agent choices. It is interesting to note the important role of a "central authority" in the "communication" routine, in order to inform agents of the strategy that best performed in past rounds. The "central authority", although unable to enforce the proposed strategies, represented a rough sketch of an institution. In 2006 the journal *Ecology and Society* dedicated a special issue to empirically based agent-based models and common-pool resources.

4. The model set up

I model different scenarios of a community of people managing a forest. The model is implemented in NetLogo (Wilensky 2005).[5] I use an agent-based model created in Bravo (2011) as the initial scenario. The choice of this model as a starting point is motivated by the fact that it represents a forest which is logged by individual members of a community, according to different criteria. It is assumed that individuals earn money when they log trees.

[5] The NetLogo code is available at http://www.openabm.org/model/3004/version/1

The model gives information about the state of the forest and about the monetary earning of the virtual agents after a certain period of time. These two variables correspond exactly to the observable objectives of participatory conservation projects. For this reason it was convenient to start from this scenario in order to represent a forest governed by different kinds of institutions, some of which aim to represent participatory conservation projects situations.

The focus of the model lies in the relationship between the internal (micro) states of the agents and systems (macro) outcomes. Following North (2005), a strong relationship exists between the value system and the institutional framework that humans apply in order to coordinate their behaviours. Values, as other informal constraints, influence agents behaviour, telling them which is the appropriate action in a given situation. Agents behaviour determines the state of the world. In turn, the macro state of the world, i.e. the competition among agents and the resource condition, influences the agent values and thinking.

The purpose of the model is formalizing the links between individual values that agents hold regarding the desirable state of the resource and the best way to achieve it, and the emergence of institutions containing norms which are binding for the whole agents community. It is an attempt to analyse what happens among personal principles of economic actors, establishment of shared rules and economic and ecological consequences of aggregated actors behaviour.

5. The baseline model: “Open access”

The baseline version of the model represents a community of people logging a forest, in a open access situation. Every member of the community takes decisions about logging or not only according to individual and therefore subjective values and visions of the world and on the basis of his own monetary earning.

In the baseline model, the state of the world has the following features. 100 agents operate on a regular lattice of degree $l = 8$. The lattice has the structure of an m x m toroidal surface, with $m = 50$. The surface is divided in patches. Each patch is a forest area that can be logged in one round. Patches have the attribute *trees*, which belongs to the [0, *max-tree-growth*] interval. It represents the total tree biomass present in a given moment in the patch and, if its value is higher than zero, it takes a green colour. *max-tree-growth* is the maximum possible level of biomass per patch, and it is controlled by an external slider. This choice is made in order to have the possibility to represent different kinds of forest, containing more or less vegetation. At the beginning of the simulation the forest is mature, with the value of *trees* randomly distributed in the [½ *max-tree-growth, max-tree-growth*] interval. If not logged, biomass in each patch grows at the fixed rate of 0.5 units per round up to the point where they reach *max-tree-growth*. If the patch is empty, biomass regrows with a probability depending on the state of the neighbouring patches, according to the function

*growth-prob * ((living-neighbours + 1) / 9)*

where *growth-prob* is the basic regrowth probability and has the value of 0.05, *living-neighbours* is the number of non-empty neighbour patches and 9 means 8 + 1, with 8 being the number of neighbour patches. This means that if all the neighbour patches are green, the regrowth probability of an empty patch is 0.05, while if it is surrounded by empty patches the probability will be 0.005555. This function is used by Janssen et al. (2008) for the "spatial commons experiments". One difference is that here the regrowth probability is strictly above zero because of mechanisms, assumed to be present, such as the natural recovery capacity due to seed conservation in the soil and seed dispersion by animals.

Each agent has three features. The first is called *reference-trees* and represents a subjective idea about the fraction of the initial tree biomass that should be ideally conserved. It represents a personal level of importance that the agent gives to the environment in general. The value of this variable is heterogeneous among the agents, representing the fact that different people attach different degrees of significance to given issues (Jager and Janssen 2002: 83). At the beginning of each round this is drawn randomly from a normal distribution having mean 0.5 and standard deviation 0.25 and it remains subsequently constant. The second is *minimal-cut* and represents a preference about the minimal level of tree biomass that a patch should have in order to be logged. For every agent it is equal to zero when agents enter the game. This conditions means that at the beginning of the game loggers believe that they can always cut. This variable will update during the simulation according to the state of the forest and to the economic profit of the agent. I will describe this mechanism later. The third feature is the *payoff* : it is assumed that when an agent logs a patch he earns a monetary profit. At the beginning of the simulation payoff is equal to zero for every agent.

The execution of the model operates as follows. Each simulation covers 2000 periods. Each period has 10 rounds. One round corresponds to one "tick" in NetLogo. In every round agents move within the simulated forest and each of them pays a fixed monetary charge. This variable is called *cost* and it is controlled by an external slider. I assume that the exogenous cost parameter represents the general costs of displacement and of monitoring the possibility of logging. I put this parameter as permanently "high" since I assume that poor rural communities have limited technical and technological means to travel and obtain information at a low cost (Vallino 2009, Baland and Platteau 1996).

When an agent arrives on a patch he has to decide if logging or not. If the condition

[trees] of patch-here > minimal-cut

is true, than the agent cuts and the quantity of *trees* is added to his *payoff*. If the condition is not true, the agents controls if any of the neighbor patches has biomass above that threshold. If he finds any, he moves on one of these patches, pays the fixed charge and realizes no earning in the current round. If none of the patches has sufficient biomass, the agents move randomly and earns no profits. The *payoff* of each agent is given by the difference between his earnings and costs.

At the end of each period there is an update of the subjective preferences of each agent about the right threshold of biomass quantity that should be present on a patch in order to decide whether logging or not. I assume here that agents have bounded rationality (Simon 1955, 1959, 1976) and act following a kind of trial-and-error process (Simon and Simon 1962) when they decide whether and how to update their operational values (*minimal-cut*). Moreover this update phase of the simulation deals with the fact that people develop ways of learning and of understanding how a resource system reacts to given behaviours (Jager and Janssen 2002: 89, Hutt 1970). Therefore, in the model the reasoning process of an unsatisfied agent is the following.

If the current *payoff* is higher or equal to that of the previous round, the agent maintains his *minimal-cut*. This means that if the agent is satisfied about his profit from the logging activity, he has no reason to modify his opinion about the importance of preserving part of the forest intact. Otherwise, the agent changes his *minimal-cut* with a probability *q*:

q (payoff - old-payoff) / (abs payoff + abs old-payoff)

where *old-payoff* is the payoff of the previous round and *abs* means "absolute value". A random extraction determines if the agent will actually change his *minimal-cut*. If this happens his *minimal-cut* is modified according to his *reference-trees.* More specifically, if the total number of green patches is higher than the fraction that should ideally be conserved according to the agent's vision (*reference-tree)*, the agent decreases his *minimal-cut* by a random value in the interval [0,9]. If the contrary happens, that is to say, if the total number of green patches is lower than the agent's *reference-tree*, he increases his *minimal-cut* by the same amount. The meaning behind is that agents facing a payoff reduction become unsatisfied and are motivated to modify their subjective values and, therefore, their behavior. If the share of the biomass left is lower than the agent's *reference-trees* (which indicates the share of the forest that should be conserved according to the agent's vision), he attributes the earning reduction to an excessive cutting and will increase his own *minimal-cut*, becoming more "environmentalist", and viceversa. In this way the model is able to represent heterogeneity within agents, which change values, decision making strategies and actions (Jager and Janssen 2002: 83).

This mechanism is consistent with different streams of literature on mental models and human heuristics. Many authors state that individuals merge information from the situation they face (here this means the amount of biomass on a single patch and the amount of the payoff) with pre-existing personal knowledge structures (here this means the degree of importance given to forest preservation – reference-trees – which influences the change in minimal-cut). In this way they shape a mental model that gives them motivation and operational instructions for concrete action (Lynam et al 2012, Jones et al. 2011, Wagner and Hayes 2005). Moreover, scholars agree on the fact that individuals experiencing resource depletion (Janssen and Ostrom 2006: 73) or which are disappointed because of one's and other's behavior (Jager and Janssen 2002: 83, 85) become ready to modify personal environmental values and therefore their action. On the contrary, if the outcome of his action is considered satisfactory, the agent will minimize his effort in the decision-making process, following a logic that Simon (1976) calls "procedural rationality". Therefore he will keep constant both his personal values and his operational rules in deciding his behavior (Jager and Janssen 2002: 85).

At the end of the values update, a selection process among the agents takes place, through the bankruptcy of unsuccessful agents. First, one of the agents with the highest period payoff and one with the lowest payoff in the period are selected. Secondly, a copy of the former (i.e. its *reference-trees*, while *minimal-cut* is always equal to zero when a new agent enters the game) replaces the latter. There is a one per cent probability of "mutation", that is to say "copy errors" or new entrants with innovative values. At the end of the selection process all payoffs are put equal to zero and a new period starts.

The results of the open-access version of the model show a complete depletion of the forest and very low payoffs for the agents. Both the number of green patches and the total biomass are reduced to a small proportion of the initial quantities. The dynamics of the socio-ecological system shows that a strong decline of the biomass in the very first period leads to a temporary increase of the agents' *minimal-cut*. This reflects reality in the sense that an environmental shock gives incentives to individuals to become more sensitive to the fear of resource depletion (Bravo 2011). However this lasts only for a few periods. Subsequently both payoffs and forest indicators go to zero. This temporary inversion of the depletion trend happens because of the different speed of change of the agents' values. While agents can quickly adapt their *minimal-cut* to the new situation in every period, changes in *reference-trees* are driven by the selection process, which involves only one agent per period. At the end of the simulation also the agents' *minimal-cut* and *reference-trees* go to zero. This implies that the selection process leads to the prevalence of the agents with higher earnings, which, in turn, are agents believing that the "correct" state of the forest is one with no trees on it. Since we are in an open access situation, with every agent deciding his behaviour only according to his personal values, agents with a low *minimal-cut* will log always more. At the end the typical tragedy of the commons occurs, with depletion of the forest, as it is shown in Figure 1.

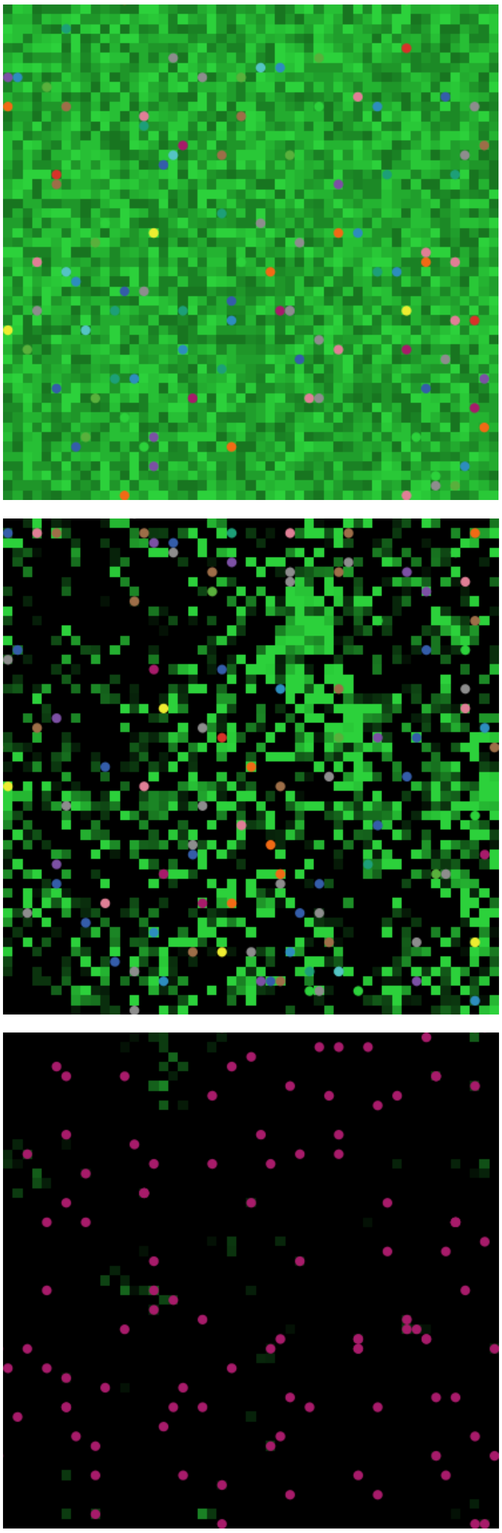

Fig. 1. Examples of the state of the forest in the "Open access" model version represented in the graphic interface of NetLogo. The first image symbolizes the mature forest at the setup phase of the simulation. The different green gradation of the patches stand for the different amount of tree biomass: the darker the patch is, the less tree biomass it contains. Circles stand for loggers. The second image represents the forest after 1,000 rounds. Black colour means that the patch has no trees anymore. The third image is about the depleted forest at the end of the simulation, after 20,000 rounds.

6. The “Endogenous institution” model

In this version of the model one new variable is introduced. At a certain point of the process, agents agree on a shared cutting rule. As explained earlier, an agent is unsatisfied when his current payoff is lower than the one of the previous round. When the number of unsatisfied agents exceeds 2/3 of the population, the mean of the *minimal-cut* of each agent forms the new variable *current-institution*. This new variable indicates the biomass threshold that a patch should contain in order to be logged and this cutting rule becomes compulsory for the whole community. An agent determines his behaviour on the basis of the shared *current-institution* and not anymore on the basis of his personal *minimal-cut*. At this point an additional criterion for agent dissatisfaction is in place: the “distance” between *current-institution* and *minimal-cut*. Therefore if an agent faces a payoff reduction or if his personal “environmental values” are too far from the institutional rule in place, he is unsatisfied. Again, when a high number of unsatisfied agents is reached the institutional rule is updated according to the mean of the agents’ new *minimal-cut*. This new institutional rule will determine agents’ behaviour. Up to now it is assumed that agents, even if unsatisfied, behave accordingly to the institutional rule, without cheating. The possibility of violating the rule will be introduced in following model versions. The relatively high fraction of community members needed to change the institution reflects the fact that, in real situations of management of common pool resources, institutional change is usually costly and a large consensus is needed to reach this goal, at least when there is no subgroup of actors capable of imposing their regulation on the whole community (Singleton and Taylor 1992, Bravo 2011, Janssen and Ostrom 2006: 90). Moreover, it is worth noticing that the sources of dissatisfaction belong to two different categories: one has a monetary nature, while the other concerns the sphere of personal values.

The results of this model version show much higher levels of total biomass and of earning of the agents, if compared with the “Open access” situation. These results are in line with the empirical literature (Bravo 2011, Berkes et al. 2003, Lam 1998, Ostrom 1990, Ostrom et al. 2002, Tang 1992) and show that an institution endogenous to the community may solve the tragedy of the commons. Observing the dynamics of the model it is possible to understand how these results emerged. Unlike the “Open-access” model, the average *reference-tree* of the agents remains constant until the end of the simulation. The establishment of the management institution diminishes the effect of the selection mechanism, even if this is the same than in the previous version of the model. Like in the previous model version, at the beginning of the simulation there is an increase of the average *minimal-cut*. However, here this leads to an increase of the shared institution and all the agents will cut less. The endogenously created institution makes the selection mechanism less effective in allowing the survival of more selfish characters among the agents and the defection of the others. The logging decision is no longer matter of personal *minimal-cut* of the agents, but depends on the system level *current-institution*. More "environmentalist" agents (with higher *minimal-cut*) no longer reach payoffs much lower than the "selfish" ones and therefore they are not excluded from the simulation. This happens because the cutting behaviour does not fluctuate anymore following the heterogeneous *minimal-cut*, therefore the payoffs are more stable as well and the selection mechanism less efficient. This means also that agents with a more "forest-friendly" vision (*reference-trees*) are not so easily excluded by the simulation.

7. Turning the forest into a protected area: an exogenous institution

In this version of the model I represent a situation in which an exogenous entity decides on the cutting threshold. Therefore the variable *current-institution* is not anymore made by the mean of agents' *minimal-cut*. It is now determined by an external slider controlled by the researcher, as it is shown in Figure 2. Its range goes from zero (which means that a patch should contain at least zero biomass in order to be logged) to [*max-tree-growth* – 0.5] (which means that a patch should contain at least its maximum biomass level minus 0.5 units in order to be logged). The meaning behind is that, in the first case, an agent is always allowed to cut, and in the latter case an agent is not allowed to cut at all. In this way it is possible to observe both situations of a "strict" cutting rule (with the *current-institution* slider set to 9) and of a "soft" cutting rule (with the *current-institution* slider set to 2).

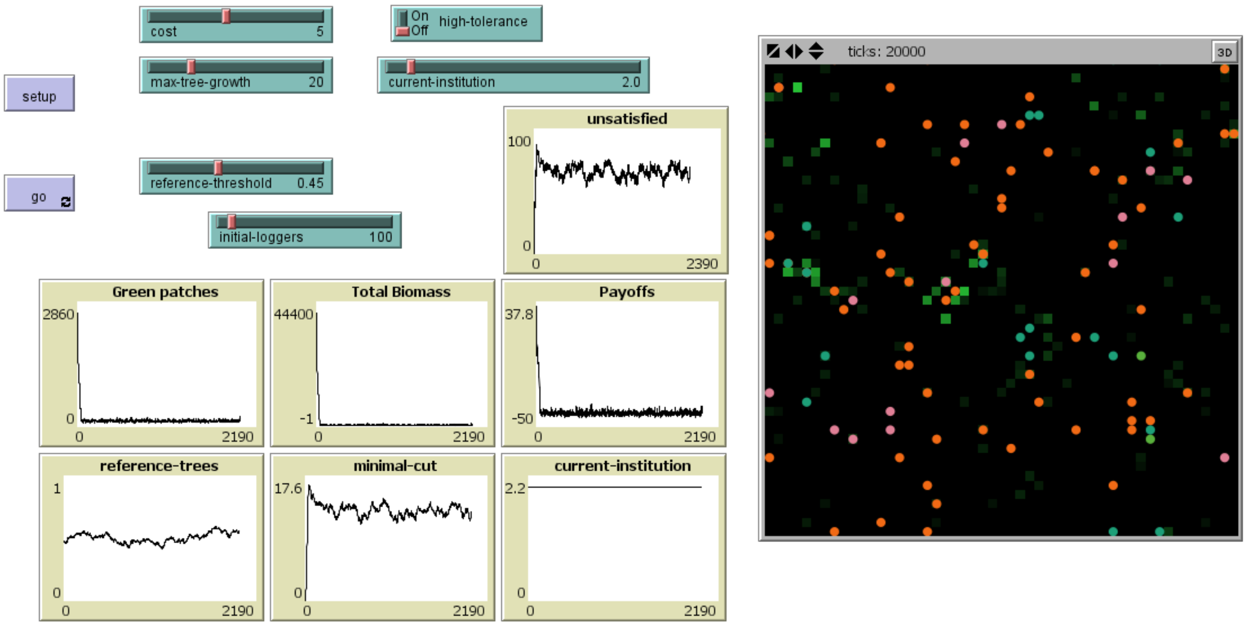

Fig. 2 Interface of the "Exogenous institution" model version. There is an additional slider named "current-institution", which symbolizes the cutting rule decided by an external entity.

When the cutting rule is set to level 9, it represents a classical situation of "fortress" style protected area, where resource extraction is almost completely forbidden (Hayes 2006, Campbell and Vainio-Mattila 2003). The important difference with reality is that at this stage we still assume that cheating does not exists and that every agent follows the imposed cutting rule. In line with common sense intuitions, the results of this simulation show a good state of the forest, but a very low level of agents payoff. Otherwise, if we shift the cutting level to a "soft" rule (level 2), according to which it is possible to cut a high number of patches, the forest is depleted and the payoffs become even negative, because after a certain number of periods agents do not find any more trees to cut. This outcome is similar to that in the open access scenario.

8. Introducing Cheating

At this point the possibility of violating the cutting rules is introduced in the model. In both scenarios, with endogenous and with exogenous institution, agents log a patch either if the cutting rule is fulfilled, or if they are unsatisfied. Again, an agent is unsatisfied either if his current payoff is lower than the one of the previous round, or if the cutting rule is too far away from his personal vision. The formalization of this concept is shown in the code below.

```
ifelse ([trees] of patch-here > current-institution) or (abs (minimal-cut - current-institution) >
tolerance-threshold or payoff-satisfaction = 0)
    [set payoff payoff + [trees] of patch-here
ask patch-here [
      set trees 0
      set pcolor black]
    ]
    [move-turtles]
```

where *turtles* stands for agents.

The only difference between the two settings is that for the endogenous institution version, the *current-institution* is the mean of the individual *minimal-cut*, while in the exogenous institution version it is determined by the external slider. Enforcement has not been introduced yet, therefore the impact of the possibility of violating the rule is very strong, regardless of what kind of institution is in place: in both cases the forest is completely logged and the payoffs of the agents are negative. This results reflect very well studies about participatory conservation projects, either belonging to the "discovery" mode, or to the "designed" one. In most of the cases of forest management free riding is technically feasible. Illegal harvesters are relatively skilled in finding opportunities for logging timber illegally. This is shown in the experience of many "paper parks" created without sufficient attention to the level and the type of monitoring (Gibson et al. 2005). Therefore if any form of control and rule enforcement is completely missing it is likely that forms of personal dissatisfaction lead to free-riding behaviors.

9. Introducing enforcement

At this stage I introduce settings with rule violation and enforcement, regarding both kinds of institutions, exogenous and endogenous. The enforcement intensity is again determined in both cases by an external slider, since I assume that it depends on the availability of resources of the institution in charge, being endogenous or exogenous to the community, and it is not dependent on the performance of the participatory conservation experience. Additionally, agents now face a random probability to be effectively caught after the violation of the rule, as it is shown in the code.

```
ifelse ([trees] of patch-here > current-institution)
  [
        set payoff payoff + [trees] of patch-here
        ask patch-here [
        set trees 0
        set pcolor black]
    ]
  [ifelse (abs (minimal-cut - current-institution) > tolerance-threshold or payoff-satisfaction = 0)
    [
        set payoff payoff + [trees] of patch-here
        ask patch-here [
        set trees 0
        set pcolor black]
        ifelse probability-to-be-caught > enforcement-level
        [show "die" die]
        [move-turtles]
       ]
    [move-turtles]
 ]
```

When the agent enters a patch he logs it if the rule satisfaction condition holds. Otherwise he moves when satisfied, or he logs anyway if he is unsatisfied. If this latter case happens, if the probability to be caught is higher than the enforcement level effectively in place, the agents *dies*, which means he disappears from the next simulation rounds. This can be interpreted as exclusion from the community or as obligation to leave the given economic activity. This intuition is confirmed in Baland and Platteau (1996: 324): "while opting for occasional rule violations, forest users therefore know that guards have a monitoring tendency smaller than one and that, when they actually monitor, the probability of detection of rule-breaking is also smaller than unity". Further research in this field should analyze the consequence on the model results if the punishment is in monetary terms, leading for example to a payoff reduction.

Results clearly show that enforcement matters. This is in line with most of the literature in general about natural resource management (Chhatre and Agrawal 2008, Baland and Platteau 1996, Ostrom 1990, Gibson et al. 2005). Regarding endogenous institutions experiences, results show that at the end of the simulation the forest cover is at 60 percent of its initial level, and payoffs are high. This confirms the results of a high number of studies about community managed common pool resources and the role of enforcement on sustainable management. Chhatre and Agrawal (2008) conducted a statistical analysis of data on 152 forest commons in 9 countries. They examined the relation between local enforcement and forest-related outputs: they discover that in general high levels of local enforcement are associated with a higher probability of forest regeneration. This holds even across different ecological and social contexts, even when a variety of other factors are taken into account. These factors are dependence of user groups on forests, size of forest patches, user group size, and collective action around the forest. Although most of the above factors have a statistically significant relationship to changes in the condition of forests, differences in levels of local enforcement decisively moderate their link with natural resource outcomes. Gibson et al. (2005) stated that although it is generally recognized that enforcement matters in managing a commons, few studies investigate "how rules will actually be enforced (…) when other important factors are analyzed and policies recommended" (ibid.: 275). From an extensive case studies review, they pose one general hypothesis: local users monitoring and enforcement leads to better forest conditions. They find support for this hypothesis when using a large sample of forests' users groups from 12 countries. Through statistical tests they discover that "rule enforcement by the local user group is significantly correlated to forest condition whether or not user groups are formally organized, dependent on the forest for a series of resources, or possess social capital". Baland and Platteau (1996: 323) also report about the effectiveness of local enforcement mechanisms in community forestry in Uttar Pradesh, India. Even if the rule regulators do not have formal legal powers, their influential role in the community turns out to be very powerful in providing incentives to compliance.

The most interesting and counterintuitive outcome of the model regarding exogenous institution experiences, is when the imposed cutting rule is at a "soft" level but enforcement is in place. This could reflect a situation of participatory conservation project, in which the rule about resource extraction is imposed, but without the adoption of a "fortress" approach, that is to say a certain level (low or high) of resource extraction is allowed for the local population (Garnett et al. 2007). The simulation outcomes show very positive results. The number of green patches is 60 percent of the initial level, while the total biomass is at 52 percent of the initial quantity. The agents payoffs are at their highest level up to now.

An interpretation of these results could be that if an external agent, like an NGO, requests to impose a rule, it may be worth imposing a soft one, but investing a lot for monitoring and enforcement of this rule. This solution may be superior than imposing a strict rule if anyway resources for enforcement are not sufficient to monitor it, as it is in the case of many

participatory conservation projects in developing countries. On the one hand this result may be surprising, because, according to the mechanism of the model, one may think that if the rule allows to cut very often, agents will log indiscriminately. On the other, however, the fact that the agents are allowed to log at quite high levels at the beginning of the simulation makes their payoff sufficiently high for avoiding the condition of dissatisfaction. Therefore a low number of agents cheats by cutting anyway because of dissatisfaction. Moreover for those who still violate the rule, the enforcement mechanism is in place. In this way forest depletion is prevented and, consequently, there is always a sufficient amount of trees to further satisfy the agents. The interplay among endogenous institution, exogenous one and enforcement as it is shown in the model reflects also recent findings by Ostrom (2010: 69), who states: "contrary to the presumption that external rules are the only way to make people overcome social dilemmas, experiments in rural settings in Colombia have generated diverse outcomes depending on context. Imposing external rules with low levels of monitoring and enforcement, like typically found in the rural areas where these experiments were conducted, did not improve rates of cooperation within groups as theoretically expected. (…) Lopez et al. (2009) found that letting subjects know how their decisions affected the group in framed field experiments and allowing informal sanctions was more effective than externally imposed regulation".
Similar considerations are also in Baland and Platteau (1996: 345) who state that external sanctions systems are often necessary because of deficiencies of local enforcement mechanisms. In order to reach their goal these mechanisms must be "escalating, flexible and tolerant" and important decisions must be taken publicly.

Some final considerations about the outcomes of the models concern the variables *minimal-cut* and *reference-trees* which represents the personal "environmental" values of the agents. In the last model version, with the exogenous institution and the enforcement, both these variables go to zero, meaning that agents lose their own motivation to preserve some part of the forest. This happens also shifting from the endogenous institution setting to the endogenous institution with the enforcement scenario. This result may confirm some literature based on laboratory and field experiments that show that in particular contexts externally imposed regulation seems to crowd out intrinsic motivation. This is shown for examples by Cardenas et al. (2000) through field experiments in rural Colombia. These authors investigate the effects of external institutions (rules and regulations imposed from outside a community) on behavior in an experimental setting on the field in three rural villages in Colombia. They observe the consequences of external control of environmental quality. Subjects are asked to determine how much time they would like to spend in collecting firewood from a common forest, knowing that this activity may have various adverse effects, in this case for example damaging water quality because of soil erosion. The authors confront a subgroup of subjects with a government-imposed quota on the amount of time that one is allowed to spend collecting wood. This quota is modestly enforced, which is typical of environmental policies or projects in developing countries. Standard economic theory would forecast that the external control will lead to more efficient choices by the individuals. This research presents evidence that such policies may be ineffective mainly because external control crowds out group-regarding behavior in favor if higher self-interest. The interpretation of these findings is very interesting. One may believe that insufficient enforcement of these policies simply renders them ineffective. However their simple existence may trigger crowding-out of socially desirable behavior. Authors suggest the external agencies should concert together with the local community the framing of the regulations, considering their needs and values, in order to avoid, or at least diminish, the crowding-out effect.

Similar reasoning is to be found in Bowles (2008), who, reviewing wide behavioral experiments literature, show how imposed economic incentives may be counterproductive signaling that selfishness is an appropriate behavior. He explains this trend by the fact that people do not act only inspired by economic motivations, but also to make themselves moral and respectable individuals at the eyes of their peer. Therefore, effective policies should combine incentives to the two dimensions of human motivation. Analogous conclusions are derived by Frey (1994).

Ostrom (2006) also concludes her paper by underling that "Unfortunately, some policy advisors have thought that involving the users of a resource in some kind of participatory activity is an easy way to overcome resistance to external programs designed to protect resources. This is *not* the lesson we have learned. Calling resource users to a single meeting and asking them 'to participate' while telling them what a project will do, is just an exogenous change that is likely to crowd out positive endogenous processes (Frey, 1994). These efforts are unlikely to create a setting in which reciprocity and trust can be achieved" (Ostrom 2006, italic in the original).

For the purpose of this work, observing that the setting with the exogenous institution imposing a soft cutting rule and the presence of enforcement leads to very good outcomes in terms of forest state and monetary payoffs, but to the disappearance of intrinsic agents motivations, may pilot us to some interesting conclusions. We are facing the typical crowding-out effect described above. Therefore the success of this institutional setting is likely to be completely "in the hands" of the enforcement. This scenario may be fragile, since resources and effectiveness of monitoring and punishment activities may be fluctuating. Policy makers should invest more in actual exchange of information with the local community and look for mechanisms that actively involve their motivation and values about the importance of environment protection, even if these are heterogeneously distributed among the population and are not always particularly far-sighted. With this I do not mean that local values and perceptions about environmental management are always superior to those of some external actors[6]. I only argue that taking into account local community priorities and weaknesses may turn out to be very effective in terms of the outcome of participatory conservation projects.

10. Conclusions

Through the method of agent-based modeling I create scenarios in which different kinds of institutional arrangements manage a forest commons. I observe the impact that the various institutions have on the "health" of the forest and on the monetary welfare of the forest users, looking also at the consequences of the scenarios on the evolution of the personal environmental values of users. Table 2 summarizes the main results of the simulations.

A part of the outcomes confirms quantitative and qualitative empirical findings from the field and are quite intuitive. Their added value lies in the fact that the related agent-based model offers a formalization of the described processes and allows us to track the mechanisms dynamics. This holds for the following results: In an open access situation we have forest depletion and low profit levels for the forest users. In a situation where the users' community is able to create an endogenous institutions to govern resource extraction from the forest the model shows good outcomes both regarding the state of the forest and the profit levels. If an exogenously determined institution is in place which has the aim of preserving the forest, results show that it will succeed in this goal, however the payoffs of the forest users will be

[6] A discussion about the conservationist vocation of indigenous communities goes beyond the scope of this paper. For an useful introduction into this topic see Baland and Platteau (1996, Chapter 10).

very low, leading to a high number of unsatisfied individuals. The presence of enforcement clearly improve the outcomes, both with endogenous or exogenous institution.
The following results are instead somehow counterintuitive, even if they are supported by important experimental literature. First, an imposed institutional rule from the outside may crowd out intrinsic environmental motivations of the agents. Second, in the exogenous institution setting, the best outcomes in terms of forest condition and agents payoffs are given when the imposed rule is a soft one and enforcement is in place.

Table 2. Summary of the results of the simulations. The first column is the list of the different specifications of the model. The variables of the “Sliders” columns are those determined by sliders which are externally controlled by the researcher: maximum possible level of biomass per patch (“max-tree-growth”); fixed cost faced by agents for displacement and logging (“cost”); level of the exogenous cutting rule (“ExogenInst”). The variables of the “Dependent Variables” column concern the state of the forest and the agents’ features. “Green patches” is a fraction: the number of patches with biomass greater than zero at the end of the simulation over the total number of patches that at the beginning of the simulation had biomass greater than zero. “Total biomass” is a fraction as well. It represents the sum of the biomass of each patch at the end of the simulation over the sum of the biomass of each patch at the beginning. “Payoffs” represents agent’s earning when he logs the patch. “Minimal-cut” is the vision of each agent about the minimal level of tree biomass that a patch should have in order to be. “Reference-trees” is the value of each agent about the fraction of the initial tree biomass that should ideally be conserved. “Payoffs”, “Minimal-cut” and “Reference-trees” values are a mean of the individual values at the end of the simulation. Negative payoffs mean that the agent is not making any profit. Each specification of the model run once.

	Sliders				Dependent variables				
	Max-tree-growth	Cost	ExogenInst		Green Patches	Total biomass	Payoffs	Minimal-cut	Reference-trees
Open access	50	5			0.05	0.09	-40	4	0
Endogenous Institution	50	5			0.52	0.37	9.04	15.18	0.75
Exogenous Institution	50	5	2		0.05	0.01	-35	14	0.4
	50	5	9		0.42	0.28	3	9.3	0.56
Endogenous Institution with rule violation	50	5			0.02	0.005	-39	0	-0.21

Exogenous Institution with rule violation	50	5	2		0.04	0.009	-37	0	-0.16
			9		0.44	0.14	15	0	0.3
Endogenous Institution with rule violation and enforcement	50	5			0.66	0.54	69	0	0.52
Exogenous Institution with rule violation and enforcement	50	5	2		0.65	0.46	63	0	0.3
			9		0.56	0.29	44	0	0.2

Summarizing the findings, after comparing different scenarios in which the forest is managed by different kinds of institutions, the best outcomes in terms of sustainability of forest logging and of earning of community members are essentially found in two kinds of settings. First, when the forest commons is managed by an institutions which has *actually* been created endogenously by the community, which is able to adapt from time to time to changes of the community needs and values, in order to minimize dissatisfaction and therefore incentives to violate the rule, and which provides local monitoring and enforcement. Second, if an imposed institution is in place, without the possibility of updating, it is more effective to choose a "soft" resource extraction rule but invest more in the enforcement of that rule, than imposing a "strict" rule.

Further research would be very useful in two directions. Firstly, building additional variations of the model. Punishment could be turned into payoff reduction for those violating the rule. It would be worth investigating the role of social influence among the agents and its impact on their cheating propensity. It would be also interesting to simulate the so-called buffer zones around protected areas: studies reveal that forcing the concentration of resource extraction in these zones may be counterproductive because resource depletion is reached more rapidly than when extraction is dispersed throughout the whole protected area (Vallino 2009). Secondly, it would be crucial to conduct a field experiment with forest users of some participatory conservation project, in order to introduce actual values in the variables of the model and test the consistency of the intuitions presented in this paper.

Appendix

Table 3. Variables in the simulation in Netlogo.

Variables names in NetLogo	**Features**	**Explanation**
max-pxcor (in "settings")	50	Maximum x coordinate for patches of the mxm toroidal surface
max-pycor (in "settings")	50	Maximum y coordinate for patches of the mxm toroidal surface
trees	Belongs to [0, bmax]. At the beginning of the simulation it is randomly distributed in [1/2 bmax, bmax]	Tree biomass present in a given moment on the patch. x y are the spatial coordinates
max-tree-growth	slider	Maximum possible level of biomass per patch
pcolor	60 + 5 * (trees / max-tree-growth) = the more trees the patch has, the lighter it is.	Colour of the patch
		Re-growing probability of an empty patch
living-neighbors		count neighbors with [trees > 0]
growth-prob	0.05	Basic probability of re-growth in $p = p^* (N+1)/(k+1)$
reference-trees	At the beginning of each run, it is drawn randomly from a normal distribution with mean 0.5 and standard deviation 0.25. It remains constant.	Individual belief of each agent: fraction of the initial tree biomass that should ideally be conserved.

minimal-cut	= 0 when agents enter the game; it is updated frequently.	Individual belief of each agent: minimal level of tree biomass that a patch should have in order to be logged. If it is low, it means you can cut all. If it is high, it means you can not cut. Level of cutting that is able to maintain the actual tree biomass at the desired level.
payoff	= 0 at the beginning of each period; after it depends on agent's actions.	Agent's earning when he logs the patch. In every round: set payoff payoff - cost If he logs: set payoff payoff + [trees] of patch-here
old-payoff		Payoff of the previous round
cost	Slider: [1, 10]	Fixed cost that the agent pays at every round.
q	let q (payoff - old-payoff) / (abs payoff + abs old-payoff)	Probability of changing *minimal-cut* if the *payoff* of the current round is lower than the one of the previous round.
"Total Biomass" (in plots)	sum [trees] of patches	Total biomass in the initial period (sum of bxy) Total biomass in the current period
"Green Patches"(in plots)	count patches with [trees > 0]	
current-institution	At the beginning of the simulation is =0 After, is the average of the agents' *minimal-cut*	Minimum level of tree biomass that a patch should have in order to be logged. If it is low, it means you can cut all. If it is high, it means you can not cut.
current-institution	Slider: the maximum value of the slider is (max-tree-growth – 0.5). When you do setup, netlogo calculates it. After doing setup, you decide the value of the slider.	Exogenously imposed institutionMinimum level of tree biomass that a patch should have in order to be logged. If it is low, it means you can cut all. If it is high, it means you can not cut.

tolerance-threshold	ifelse high-tolerance = true [set tolerance-threshold (2 * max-tree-growth) / 3] [set tolerance-threshold max-tree-growth / 3]	Tolerance level
unsatisfied	count turtles with [abs (minimal-cut - current-institution) > tolerance-threshold or payoff-satisfaction = 0]	
payoff-satisfaction	ask turtles with [payoff < old-payoff] [let q (payoff - old-payoff) / (abs payoff + abs old-payoff) if (- random-float 1) > q [set payoff-satisfaction 0	At the end of each period each agent checks its payoff satisfaction. If the current payoff is lower than the previous one, he changes its *minimal-cut* with probability *q*. A random extraction determines whether he actually changes its belief.
initial-loggers	Slider: [0, 100]	Initial number of agents
enforcement-level	Slider: [0, 100]	Enforcement level
probability-to-be-caught	Random 100	The probability to be caught is random

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