Recent Results of New Institutional Economics as a basis for Analyzing Common Pool Resources

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This paper tries to draw some main lines in the abundant literature on economic analysis of Common Pool Resources. Some promising articles likely to pave the way to future research are more precisely presented.
The review is organized as follows. The first section proposes a definition of a Common Pool Resource (CPR) and the approach mainly chosen by economists to study this issue. The next section presents the problems existing in a CPR context, and especially how they differ from public goods problems. Then, different models using non cooperative theory are presented: these models help explain the possibility of some degree of cooperation for a given rule. The next section summarizes the rather small analysis made on the negotiation on rules. Finally, an assessment of the link between theory and practice facilitate the proposition of some perspectives for future research.

1 What is a Common Pool Resource ?

Economic theory generally defines only two types of goods:
◦ **private goods**, which verify the principle of competition: the good consumed by an agent cannot by used by another;
◦ **public goods**, which do not follow this principle: "the use by an agent does not limit the use by other agents, there is not destruction linked to use" (Laffont, 1985). For these public goods, a distinction is usually made between those goods for which exclusion is possible (for example, sports clubs), and those for whom it is impossible (e.g. National Defence).
Ostrom et al. (1994) propose to use also this distinction for the private goods. A Common Pool Resource (CPR) is hence a set of private goods (fishes, trees...), for which it is both difficult (but not impossible) to exclude from use and for which the cost of defining individual rights is prohibitive. Figure (1) presents the different kinds of possible goods.
CPRs can be distinguished according to the level of control on use: the situation is one of open access if there is no rule to limit the use, and there may exist many different degrees of regulation over the access (fig. 1).
A simple example of a CPR is a fish resource: even if the fish in itself is a private good, groups of fishes are mobile and of unknown size. It is hence very difficult to share such a resource into individual rights.
On figure (1) are also presented club goods, which do not create any competition in their use but whose access is easily controlled (for example a sports club).

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	No limitation in access	Limited access to resource			
		Property rights difficult to set up			Property rights easily defined
Rivalry in use	**CPR** **Private good in free access**	**CPR** **weakly regulated**	**Regulated CPR** →	**completely regulated**	**Private good**
No rivalry in use	**Public good**	**Club good**			

Figure 1: a typology of goods

1.1 The problem for Collective Action

The fundamental problem for a CPR, also called the "1/n" problem or free rider problem is the following: in a group of n agents, each agent bares $1/n^{th}$ of the marginal negative externality of his effort through the collective good, while he profits completely of this effort. Or, in an equivalent way, he sees only $1/n^{th}$ of the benefits of his action to cater for the collective good while he bares its full cost.

This problem can be mainly divided into two sub-domains: the under-provision of the collective good and the over-investment for the use of the resource (Ostrom et al., 1994).

As a matter of fact, these problems are simply externality problems, which cannot be solved by defining individual property rights because it has been assumed by definition that in a CPR context, the set up of such rights would be prohibitively costly.

Let's give two examples to illustrate this problem. First, the famous common pasture as described by Hardin (1968), where the collective optimum would consist in having, for example, only 100 sheep grazing in the field. Nevertheless, this optimal situation given, each shepherd sees his immediate interest in adding one more sheep but only perceives partially the reduce in the field productivity because of the over-grazing. Without a control of herds size, the shepherds choices lead to an equilibrium situation of, for example, 150 sheep, which is not efficient on a collective point of view, as it diminishes the joint welfare of all.

In the same way, when an irrigation scheme has to be repaired, each farmer sees the total cost of his effort for mending it but sees only partially the gains his action brings.

Besides, one can note that this problem of externality exists even if the users are identical.

1.2 A bad initial paradigm for analysis...

The article written by Hardin (1968), **The tragedy of the commons**, considered that, because of the "1/n" problem, every common pool resource was dedicated to over-exploitation. The idea beneath is the Prisoner's Dilemma. Hardin used the term of "tragedy" in the sense of something ineluctable, which imposes its own logic to each player...of course, the term became famous because of its other meanings. Hardin thought that the only solutions to avoid the Tragedy of the Commons were nationalization or the definition of individual transferable rights.

As a matter of fact, Hardin considered that a Common Pool Resource is necessarily an open access resource. For the last fifteen years, most of articles on that subject positioned

themselves against such a simplistic assimilation.
Nevertheless, **most of these articles remain in the initial paradigm, that is to say that agents act on their own, without any possibility to create common management rules in a bottom-up process.**
Economists have tried to explain that the Tragedy of the Commons could be prevented:
- either by showing that some situations could be modelled by others games than the Prisoner's Dilemma;
- or by keeping the initial structure of the Prisoner's Dilemma, and inserting it in a more global structure (existence of morals, games repeated for an unknown duration, etc.).

By doing this, these studies do not take into account the ability of users to create their rules. In the context of the Prisoner's Dilemma, they search the parameters of the game that will be such that players internalize more the externalities (c.f. discussion of the impact of heterogeneity hereafter).
The economic research on CPR has hence, for its major part, allowed to propose different approaches to estimate to which level players are taking into account the externalities, for a given rule.
In 1966, Harsanyi proposed a boundary line between cooperative and non-cooperative games: in a cooperative game, an engagement is not revocable. Even if this definition is still problematic (Schmidt, 2001), it allows to explicit the paradigm which is used in most part of CPR analysis: it is considered that (i) players cannot make propositions that would engage them irrevocably and (ii) they cannot create the conditions that would allow such non revocable propositions.
The analysis of CPRs, as it has been mainly done, is based on a very restrictive approach that will not be able to explain the success or the failure of a management of a given problem inside a CPR.

1.3 ...but results can nevertheless be used!

The use of economic theory on CPRs cannot be made without a theory of negotiation that would analyze the different possible management rules that users could set up.
The different existing theories (cooperative game theory, bargaining theory) propose an explanation of how players adopt a position depending on what they estimate they expect to win or loose from a given rule.
Is it immediate to calculate the impact of a given management rule on the gains of a given type of agent? It is often not the case, since rules usually let a room for players to manoeuvre: it is very difficult to set up rules that will completely regulate the CPR use.
Finally, the collective impact of such individual rooms for manoeuvre can be described as a non cooperative game...and this brings back again the initial paradigm. Moreover, every cooperative game is founded on a non cooperative one, corresponding to the choice of entering the negotiation or not.
Therefore, the former approach is structurally insufficient, but it provides a necessary base to elaborate a theory of negotiations concerning CPRs.

Why use game theory?
If the CPR problem is above all a problem of externalities, why not use first the tools of the Environmental Economics, such as the Pigouvian tax?
A first general response is that in many CPR situations, even if players are ready to pay the costs corresponding to the production of the resource (for example, the energy costs for an

irrigation scheme), they would not accept the use of an inciting tax, whatever would be the repartition of the products of such taxes. This attitude can stem from the rejection of price as a signal of scarcity, but it can also come from the fact that the system of perception and redistribution is seen as non transparent and unreliable.
Another reason is that, in the context of a CPR, since it is difficult to define exactly individual rights, it may also be costly to estimate the exact marginal damage or benefit of the action of one agent.

2 What are the specificities of externality problems in CPRs compared to those of public goods?

2.1 Two externality problems

The problem of externalities not taken into account exists at two different levels in the context of a CPR.

a) The provision of the common good

Agents must invest to create or maintain the resource which will be collectively available or the means to use it (an irrigation scheme, for example). There is hence the free rider problem of under-provision.

This problem of not taking into account the positive externality of provision is not specific to CPRs, since it exists also for all public goods. Holmstrom (1982) studied the provision for a public good by a group of agents, with a moral hazard in team. He showed that there does not exist an allocation rule that could both be a Nash equilibrium over the agents choices and attain the Pareto optimum[1]. He showed also that, with collective penalties, it is possible to approach as close as desired the optimum..., but of course these collective penalties are not politically acceptable!

b) The appropriation

Agents must choose a rule to allocate the resource. The difference between the CPR appropriation problem and the one of congestion of a public good is that, in the first case, agents must make an effort, or investment, in order to use the resource: the collective potential inefficiency stems from the risk of a too big effort for the appropriation of the common good, which will lead to a bad rate of return for the initial investment.

2.2 A generic model for public and common goods

The theoretical results linking the structure of the game and the importance of externalities for a common good or a public one are close. Bardhan et al. (2000) proposed a general setting which allows to both represent public and common goods, depending on the parameters of the model. In order to estimate the impact of heterogeneity between agents on collective action, they built a generic model that I think interesting to present here.
Suppose that each agent is endowed with an initial wealth which he can invest in a private good k_i, or in the contribution x_i for the production of a collective good. Depending on his

[1] A Pareto optimum is a situation where it is impossible to increase one agent's profit without decreasing the profit of at least another agent

effort x_i and the total effort made by all agents $X = \sum_j x_j$, this agent can profit by the collective good at the following level:

$$Z_i = (\frac{x_i}{X})^\theta X^\gamma \quad (1)$$

with $0 \leq \theta \leq 1$ and $0 \leq \gamma \leq 1$.
The term $(\frac{x_i}{X})^\theta$ of equation (1) represents hence a congestion effect in consumption, i.e. a negative externality indexed by θ. The other term, X^γ, stands for the positive externality on the production of the public good. It is possible to consider that if the congestion term is dominant ($\theta > \gamma$) then the collective good is a common good, while in the other case, it can be considered as a public good ($\theta < \gamma$) (fig. 2).
In order to illustrate this model, let's take the example of an irrigation scheme. On one hand, suppose that the scheme is in poor state, due for instance to seepage losses occurring on the canal. Farmers can individually provide for the repair of these canals. The externality produced by each individual action is hence positive, the situation is one of a "public" good ($\theta < \gamma$). On the other hand, suppose now that the scheme brings a given amount of water. Every farmer could then damage the canals passing close to his field during the night, in order to get more water. Doing this, the farmer only augments his proportional share of water relatively to other farmers. The congestion term is hence dominant: $\theta > \gamma$.
Finally, the private good k_i and the collective good Z_i are inputs of a Cobb-Douglas production function:

$$Y_i = k_i^\alpha Z_i^\beta$$

which constitute a direct measure of the agent's utility. The rate of return is supposed to be decreasing: $\alpha + \beta \leq 1$.
Depending on the respective values of θ and γ, the model leads to a public good, a private one or a common one (fig. 2).

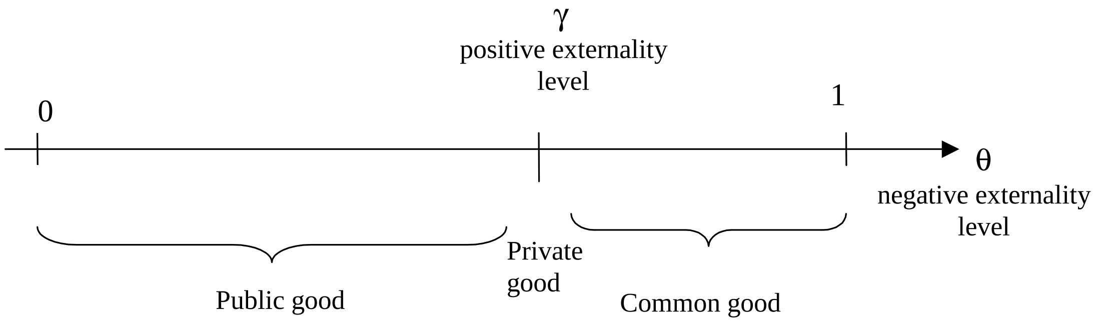

Figure 2: nature of the collective good depending on the parameters of the production function in Bardhan et al. (2000)

Bardhan et al. showed that the Nash equilibrium for a common good ($\theta > \gamma$) corresponded to an over-investment while for a public good ($\theta < \gamma$), it amounted to an insufficient provision. This model proposes an elegant mathematical synthesis of externality problems for public and common goods. Its interpretation is nevertheless delicate: the effort x_i can be either at the origin of a positive externality of production, or a negative one, but never both at the same time. The interest of such model stems mainly from the provision of a common mathematical base for CPRs and public goods, which, for example, allows the derivation of common results about the impact of heterogeneity on the global production of the good.

3 Explaining cooperation by using non cooperative games

This section presents an assessment of the different works devoted to CPR analysis, which tried to describe the conditions that would lead to an efficient collective action, for a given management rule, that is to say in a non cooperative setting. As it has been described above, cooperation can be explained using approaches that are positioned at different levels of analysis:
1) the game outcomes associated with the situation or, in a more realistic way, the shape of the production function;
2) the size of the group;
3) the game structure, and especially its potential repetition;
4) the possible existence of behavior norms;
5) interdependencies between the appropriation problem and the provision one.
The following presentation is based on these 5 items, keeping this order.

3.1 Links between parameters of the game and the level of cooperation

An important part of the economic literature on Common Goods has tried to explicit the structural links between some parameters and the low provision or over investment for the common good.
This review first describes the impact of the general form of the game on the efficiency of collective action (subsection *a*). Then, it addresses a question that has mobilized a lot of studies: the influence of heterogeneity on some parameters inside a given group of agents (subsection *b*). Finally, a short analysis will consider the impact of average value of some characteristics (subsection *c*).

3.1.1 The impact of the outcomes structure or of the shape of the production function on the level of cooperation

The structure of the Prisoner's Dilemma is such that the only Nash equilibrium of the game corresponds to the situation where players do not cooperate; moreover it is an equilibrium with dominant strategies, i.e. each player decides not to cooperate whatever the strategy of the other player.
Both Ostrom et al. (1994) and Baland and Platteau (1996) proposed to replace the initial Prisoner's Dilemma in the more general framework of games in their strategic forms between 2 players. They also showed that other types of games can furnish a relevant analysis in the context of a CPR.
For example, sometimes the situation can be accurately described by an insurance game (which should have better been named convention game). Suppose, for example, that two fishers share a lake and that they can choose between fishing with a net or fishing using dynamite. Fishing using dynamite is preferred by nobody because such a kind of technique

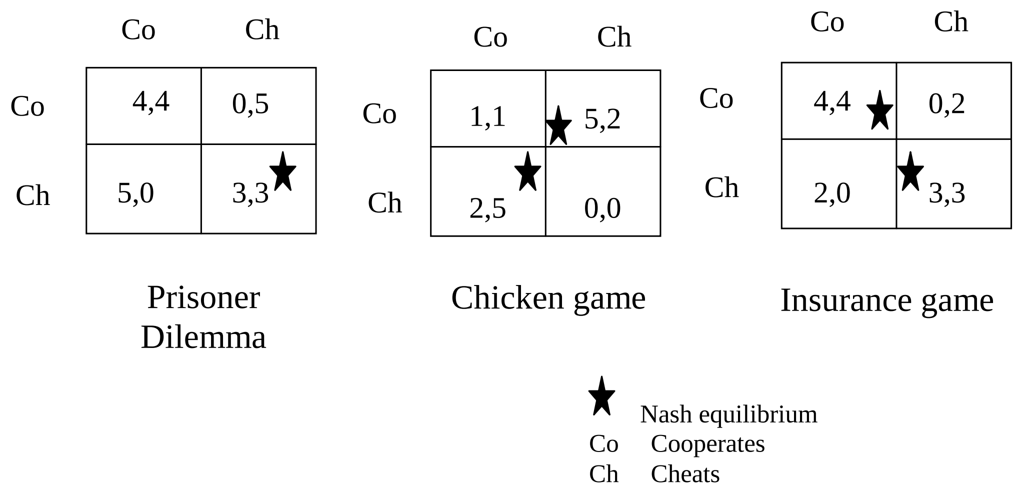

Figure 3: different types of 2 players games

destroys the stock of fishes in the short term. Nevertheless, if one fisher chooses to fish using dynamite, the other will choose the same technique.
Another example is the one named "chicken game". Here, two farmers share a common irrigation pump. It is necessary for one of them at least to wake up during the night in order to check that the pump functions well. If one decides to do the control, the other will decide to remain in his bed..., and reciprocally.
The figure (3) presents the different Nash equilibria (using pure strategies) associated to the Prisoner's Dilemma or to the 2 other former examples. For the 3 games, the numbers written in the matrixes are gains, i.e. it corresponds to years of "liberty" in the case of the Prisoner's Dilemma.

The study of 2 players game in strategic form leads hence to a typology where it is possible to place the Prisoner's Dilemma. Therefore, in the general form of symmetric 2 players games (table 1), the Prisoner's Dilemma can be defined with $b < d < a < c$ (Ostrom et al., 1994). Ostrom et al. (1994) presented the different possible types of games depending on the respective values of these coefficients, and how they can be used to represent a given CPR problem. In the same way, Heckathorn (1993) established a typology of 2 players games when these players have to contribute to the provision of a public good.
Besides, according to Ostrom (1990), the interest of a corpus of management rules (including controls and mechanisms for sanctions) is to transform a Prisoner's Dilemma into a coordination game, of which the Pareto optimum is one of the Nash equilibria, i.e. is self enforcing.

3.1.2 The impact of heterogeneity on Collective Action

Three types of heterogeneity[2] can be defined:
◦ one on *the social position and the kind of interest for the resource*;
◦ one on *the ability to make an effort*, the parameter of heterogeneity being for example the area put under crops, the size of the fishing boat, etc;

[2] I prefer to use the term heterogeneity rather than inequality, the latter referring to normative criteria

Table 1: general structure of 2 players games

		player 2	
		cooperates	does not cooperate
player 1	cooperates	(a,a)	(b,c)
	does not cooperate	(c,b)	(d,d)

○ and finally one on *the ability to profit by the resource*, the parameter of heterogeneity being here for instance the tail or end position in an irrigation scheme, or the fishing technology used.
Concerning the first type of heterogeneity, different authors agree on the idea that differences of social origin and types of use of the resource will impede the building of a common knowledge on the resource and hence will complicate the setting up of structures of regulation (Baland and Platteau, 1996 and Varughese and Ostrom, 2001). Simulations of experimental economics made by Cardenas (2000) showed that, when users interest on a CPR was of the same kind, their "social heterogeneity" lessened their capacity to cooperate.

As for the other sources of heterogeneity, **the initial and pioneering idea was proposed by Olson (1965): heterogeneity will increase the level of Collective Action because the richer users or the more able ones will have a greater share of the marginal collective profit, and hence they will be more eager to cooperate.** Different researches made afterwards showed that things were not so clear cut on the field.
As a matter of fact, there is a double effect of heterogeneity on the $1/n^{th}$ problem, according to Baland and Platteau (1999). First, as Olson argued, an increase in heterogeneity will make rich users internalize more the consequences of their actions and hence they will more provide for the collective good. But, on the other hand, this increase will diminish the (already small) propensity of poor users to take into account the positive externality they may create. It is necessary to look on a case by case basis how these two effects combine.
Many authors proposed simple non cooperative models to explore the impact of heterogeneity on the efficiency of the management of a CPR (Baland and Platteau, 1997, 1998, 1999, Dayton-Johnson and Bardhan, 2001, Bardhan, 2000 among others). Two main ideas can be drawn from these studies.

Regarding the provision of a good or its appropriation, when users get an income from the common good that is linear with the studied parameter of heterogeneity, models show that, whatever the kind of heterogeneity, the overall result is ambiguous.
Moreover, a certain number of articles showed, in a more or less implicit way, that ***for a problem of furniture or appropriation, when agents interest grows in a convex way (resp. concave) with the parameter of heterogeneity, then an increase in heterogeneity will lead to a better (resp. smaller) collective action*** (fig. 4). This proposition is also stated, but not demonstrated, in Cardenas (2000).

The question then becomes: ***in what cases is the "heterogeneity function" (i.e. the relationship between the revenues and the parameter of heterogeneity) concave, linear, convex, or even with a U shape or an inverse U shape?***.

The set of at first very sparse different approaches on the subject could perhaps constitute the base for a ***typology of the different possible functions of heterogeneity*** depending on the type of heterogeneity and the context of the CPR.

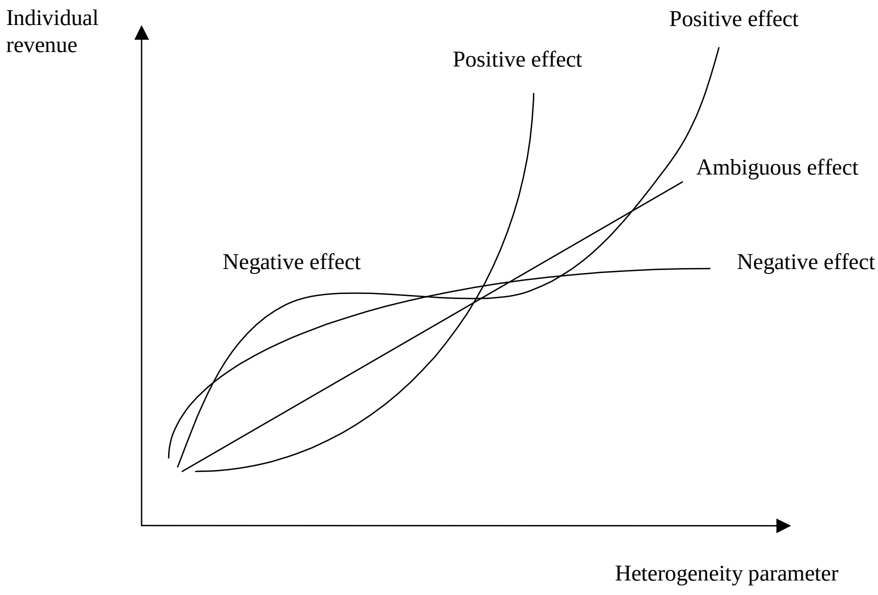

Figure 4: the effect on the total value created with a CPR depending on the relationship between the individual revenue and the parameter of heterogeneity

Among all models dealing with heterogeneity, some other results and interesting ideas can be presented here.

α) heterogeneity on the ability to make an effort

This capacity to make an effort is often studied from the point of view of the ability to make an initial investment: some agents are hence more constrained than others regarding this initial investment.

The increase in the heterogeneity regarding the ability to make an effort does not lead to a bigger marginal outcome for the more able agents: hence, the impact of such heterogeneity is generally unknown.

Moreover, the neutrality theorem that states that a wealth redistribution does not change the total amount of provision for a public good (Bergstrom et al., 1986) cannot be used here because CPRs are not pure public goods and because a redistribution often implies a change in the number of contributors (Baland and Platteau, 1996).

Such a result is proved by Baland and Platteau, both for a provision problem (1997) and for an appropriation problem (1999). In the latter article, they took the example of a community of fishers that has to share a fishing zone. Fishers can choose the number of boats they will buy. Heterogeneity in the ability to invest can then lead to an increase in the collective action, that is to say to limit the total number of boats at sea, compared to the homogeneous situation. ***Furthermore, in some cases, the increase in this heterogeneity can lead to a Pareto augmentation, i.e.***

even the fishers that become more constrained in their ability to invest see their gains increased.

The relationship between the outcome an agent draws from the CPR and the parameter of heterogeneity is not necessarily constant on the domain of the parameter's possible values. For instance, Dayton-Johnson and Bardhan (2001) used a simple model of fishing on a two period basis: the Pareto optimum is not to fish anything during the first period so that the stock will be the biggest possible during the second period. The efficiency is then a U-shaped function of heterogeneity: total income decreases then increases with the level of heterogeneity. In the same way, in the model describing a common setting for public and common goods presented at the beginning of the paper, the total profit decreases with heterogeneity for a public good sufficiently impure (that is to say that θ is far enough from 0)(Bardhan et al., 2000). In the other cases (common good, almost pure good), the two outcomes are possible.

β) heterogeneity on the ability to profit by the resource

Here, the situation described is one where, for the same effort made, agents will draw a profit (or more generally some utility) that will be different from one agent to another.

Regarding the provision of the resource, when discount rates for the future are different, heterogeneity has an ambiguous effect on the provision of the resource (Baland and Platteau, 1997). In the same way, as regards the appropriation problem, Baland and Platteau (1999) showed on the example of the choice of fishing technology, that heterogeneity on the number of fishing boats owned by fishers has an ambiguous effect on collective action. In the two former examples, the heterogeneity function is indeed linear.

About the question of the impact of heterogeneity on the ability to profit by the resource on collective action, econometric analyses provide diverging results. An econometric analysis on Mexican irrigation schemes (Dayton-Johnson, 2000b) showed that the heterogeneity regarding possessed areas had an ambiguous effect on the total income, while another econometric study on 48 irrigation communities in India (Bardhan, 2000) showed that cooperation level is negatively correlated to homogeneousness of possessed areas, the proximity of cities and market integration, and positively correlated with the small size of the group.

Figure (5) presents a basic classification of models dealing with heterogeneity, according to the shape of the heterogeneity function.

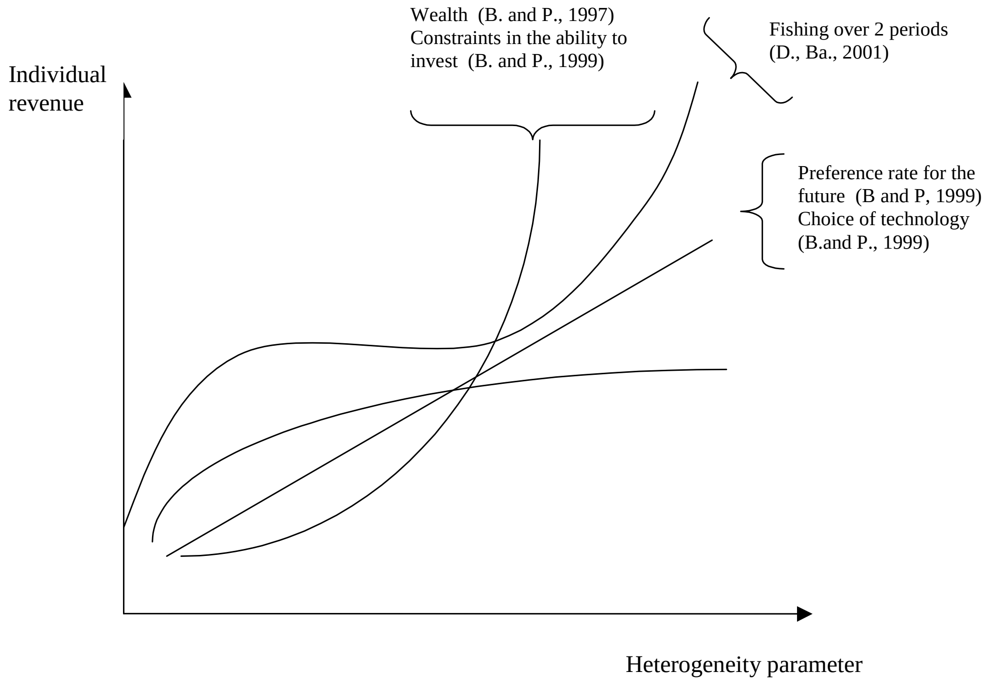

Figure 5: different models describing the impact of heterogeneity, depending on the shape of the heterogeneity function (B., P. stands for Baland and Plateau, D. for Dayton-Johnson, Ba. for Bardhan)

3.1.3 The impact of average characteristics on the level of cooperation

While the former section dealt with the **variance** of parameters of the system, this section looks at the influence of the ***average value*** of such characteristics.
Both theoretical models and experimental results showed that the average wealth could be a facilitating as much as a limiting factor for collective action (Cardenas, 2000).
Nevertheless, when a change leads to an evolution of the group's social cohesion, its impact on cooperation can often be determined. Hence, during simulations of experimental economics made by Cardenas (2000) with Colombian farmers, the poor farmers were the more able to go away from the Nash equilibrium of over-investment. Indeed, these farmers are used to deal with CPRs situation while rich farmers, owners of their parcels, are not often concerned with problems of a "Tragedy of the Commons" nature.

3.2 The size of the group

Here also, the first idea initially put forward is one by Olson, arguing that the smaller the group, the better will be the level of cooperation.
Nevertheless, according to Ostrom (2000b), the size of the group has an influence on many variables (transaction costs, control costs, share of every agent) and therefore it is not possible to propose general theoretical predictions on the impact of the size of the group on collective action.
In the same way, according to Wade (Baland and Platteau, 1996), there is no optimal size pertinent in any case. More than the technical parameters such as the basin size, what counts is the social structure and especially the preexisting authority. Wittfogel (1956) and

Baland and Platteau (1996) gave examples of very organized and structured societies where CPRs were managed efficiently on a extended area.
Farrell and Scotchmer (1998) analyzed the case of a set of agents heterogeneous in their ability to invest for production but who can benefit from increasing returns to scale by gathering themselves. They showed that the best users will group, then the second best users will do the same, etc. The groups created are too small and of different composition compared to the optimal partition. The inefficiency stems here from the ability of such groups to exclude the less able agents. This theoretical approach can explain, for instance, how fisher groups share their investment regarding the search of fishes.

3.3 Repetition during time

If the number of repetitions of the game is either unknown or infinite, a high number of cooperative strategies can be Nash equilibria, and this both in a 2 or in a n players context (Fudenberg and Tirole, 1991). Generally speaking, these strategies are of the "tit for tat" form, i.e an initial cooperation associated with a temporary or definitive punishment in front of a partner who would have cheated.

3.4 Trying to formalize the existence of norms

Many simulations based on experimental economics showed that agents behaviors could not be completely explained by the sole rational choice of the best strategy in a non cooperative setting.

- The efficiency of informal discussions is not taken into account
The game models do not incorporate the "cheap talks" which allow agents to learn about each other.

- The existence of moral behaviors
The set up of mechanisms of sanctions is a public good: it is subjected to the problem of free riding. The theory predicts hence an under provision of this "good", nevertheless in many simulations based on experimental economics, users who are given the possibility to set systems of sanctions are ready to pay for their implementation costs.
Another experiment confirms this argument. Suppose that 2 players A and B receive a certain amount of money, let say for instance 100. The sharing process is the following: first, A decides what share of the 100 he takes for himself and what he leaves for player B. Then, player B can decide either to accept player A's proposition or to refuse, and in the latter case both player will receive nothing. Practically, on average, B refuses if his share is lower than 30 while, theoretically, he should accept any strictly positive amount of money granted by A.
Finally, in his experimental economics simulations made with Colombian peasants, Cardenas (2000) showed that agents cooperated better if they could discuss face-to-face between each step of the game, than if there existed an external regulation system consisting in a random audit of players actions. Face-to-face discussions allows for a better efficiency of resource management even if they do not lead to any verifiable commitment. The preceding theories fail to explain such a result.

There is hence situations where players prove to have a kind of morale that transforms the initial gains into subjective ones. Two main questions can therefore be asked:

- **What kind of statute the morale has to be given in game models?**
- **What are the situations where players have moral behavior and what are the ones when they do not?**

Two sketches of answer have been proposed recently: first the evolutionary game theory, then a classification of information categories mobilized by agents.

3.4.1 Contributions from the evolutionary game theory

In the setting of evolutionary game theory, each agent uses a **given strategy**, for example a moral sense that induces him to systematically cooperate.

The population of the game is composed of agents using different strategies. These agents meet on a random basis and then play a given game. At the end of the period, the agents who have gathered the best profits will have their overall share in the population augmented. When such approach is applied in biology, the usual interpretation is that the groups that get the best gains will reproduce better than others. **When applied to economics, a simple interpretation is that, at the end of each period, a certain number of agents will change their minds and hence their strategies, and this will occur proportionally to the relative gains between the different strategies.**

Hence, according to this point of view, agents are not able to estimate the efficiency of all possible strategies but they can see the strategy used by others and they can change their minds: it is an interesting way to take into account a bounded rationality.

Then, an evolutionary stable strategy is defined as a strategy that, when played by the whole population, is able to "resist" the invasion of agents using a different strategy (Weibull, 1995 and 1999). A Nash equilibrium in mixed strategy corresponds hence simply to a situation of equilibrium between two populations playing different strategies.

Sugden (1986, cited by Baland and Platteau, 1996) showed that, in a situation based on a Prisoner's Dilemma game, the *tit for tat* strategy is evolutionary stable: it is able to impose itself on ever cooperating agents or always cheating ones.

Bester and Güth (1998) defined an "indirect" evolutionary theory: they propose to modify the gains of the game (for instance the Prisoner's Dilemma structure) depending on the "moral" cost or benefit for an agent to cooperate or cheat[3]. Bester and Güth studied the interaction between 2 players who choose each one a certain amount of effort (x for agent 1, y for agent 2), with a mutual externality that can be either positive or negative. Altruism is represented by the fact that users can take into account, in their utility function, a share ($1-\alpha$ for player 1, $1-\beta$ for player 2) of the partner profit. Hence, the more altruism is important, the more players will be able to come close to the Pareto optimum (fig. 6).

Next, Bester and Güth tried to understand whether a strictly positive level of altruism can be evolutionary stable. The idea underlying their demonstration is the following one. If player 1 is more altruist, then 2 knows that 1 will take more into account his proper choice and hence will increase his own effort. Therefore, if the externality is positive, the increase in effort made by 2 will be beneficial for 1, otherwise if it is negative, the increase will be harmful for 1.

The result is that, with a positive externality, a certain strictly positive level of altruism is the only evolutionary stable strategy, while if the externality proves to be negative, only selfishness will be evolutionary stable.

[3]The idea of using a "morale" to solve a problem of the Prisoner's dilemma type was mentioned by Hardin in 1968 but he had rejected it, considering it as unrealistic.

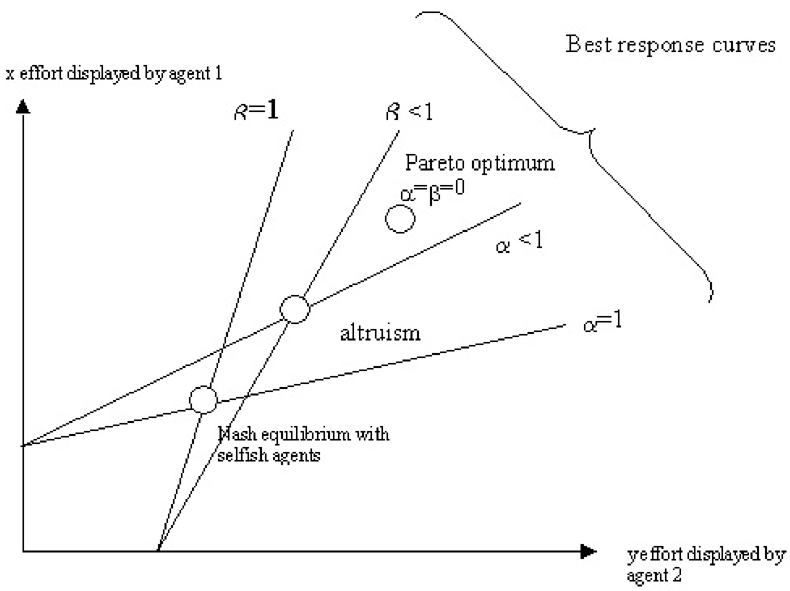

Figure 6: response curves and equilibria in a game between 2 players who can be altruist (from Bester and Güth, 1998)

Nevertheless, in case of a positive externality, when the population is initially composed of selfish and altruist people, if agents know only the proportion of both types, then the altruist type will decline. **This result can explain the importance on the field and during experimental economics simulations, of cheap talks before each agent takes his own decision.**
According to Cardenas and Ostrom (2001), hence, three elements can mainly explain cooperation:
- the kind of situation (for example a repeated game);
- when there is a certain probability to meet people from the same type;
- when institutions set up give a non monetary bonus for cooperating (prestige, reputation, etc.).

This theoretical approach can explain the interest of setting up institutions for cooperation, because they (i) create social norms, (ii) gather information on the agents types, (iii) design systems for rewards and punishments.

3.4.2 The use of norms depends of the context of the game

Cardenas and Ostrom (2001) proposed the distribution of the different layers of information used by an agent in the following manner (fig. 7):
◦ **the static game layer**
It corresponds to the level of the matrix of possible actions and gains.
◦ **the dynamic game layer**
This level corresponds to the information gathered during previous games.
◦ **the group layer**
This layer gathers information possessed on others and especially their propensity to cooperate.
◦ **the individual's layer**

It amounts to the fact of taking into account the importance of cooperating or not, when one makes a decision.

Depending on the structure of the game and of course the available layers, a player will put forward a given layer of information to take his decision, because gathering information on other players (layers 2 and 3: outcomes of previous games, behaviors of players outside the game) may have a cost.
Hence, in the case of a perfect market or, in a Coase theorem approach, when transaction costs are null, only the first layer will be taken into account. On the other hand, when transaction costs necessary for the establishment of contracts reducing the amount of externalities are important, the presence of externalities will lead the agent to mobilize other layers of information. The agent will be ready to take time to have informal discussions with other players, in order to estimate whether they have morals that induce them to preferably cooperate, even if these discussions do not lead to any verifiable commitment afterwards.
Depending on the different layers of information gathered, the player will modify the initial "objective" gains into "subjective" ones, which for instance will transform an initial Prisoner's Dilemma structure into an Insurance game or a Chicken game.

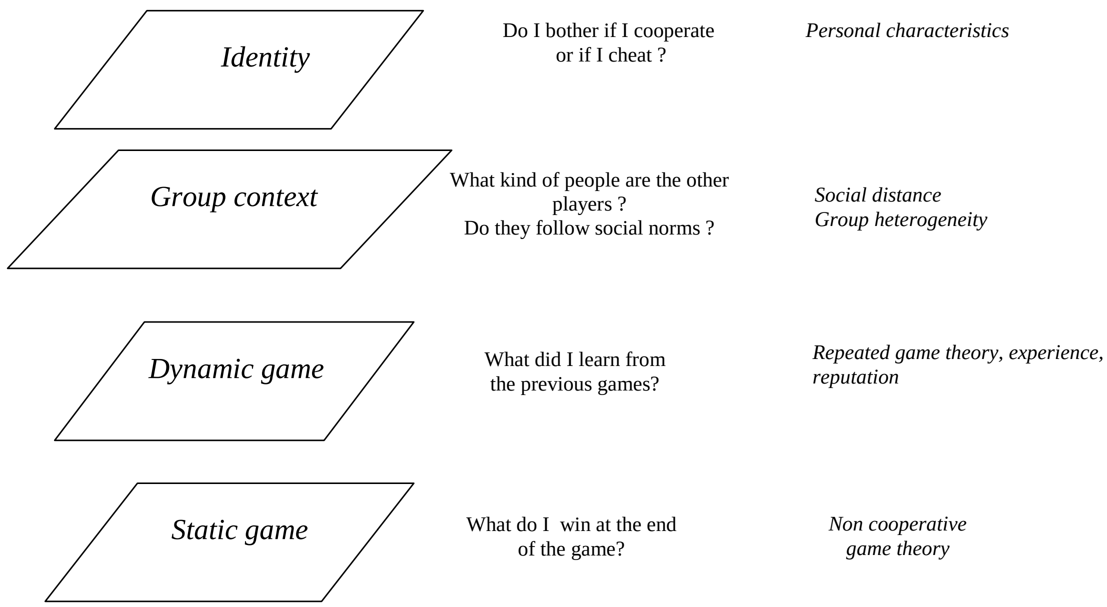

Figure 7: the different layers of information used by a player (from Cardenas and Ostrom, 2001)

3.5 The joint study of problems of under-provision and over-investment

3.5.1 Acting so that incentives for under-effort and over-effort combine

In some Japanese fisheries, mutualization of revenues creates an incitation for sharing the technical knowledge, but also limits the problem of over-investment (Gaspart and Seki, 2000). This over-investment inherent to any fishing activity is indeed compensated by the incentive to behave as a free rider regarding the collective production.
In the same manner, Schott (2001) searches for the optimal size for fishers regrouping in order that the sum of these two opposite effects leads to an optimal fishing effort. According to him, a main advantage of such an approach is that there is no need to redefine property rights.
As a matter of fact, if players maximize their profits, then only counts the tax they have to pay, and therefore this system is equivalent to a Pigouvian tax: if the tax level is low, there is an over-investment problem while a too big tax pressure will lead to an under-investment outcome. There hence exists a certain rate of tax (i.e. a certain amount of profit redistribution) which allows to attain the collective optimum. The model with profit sharing differs only by the fact that the value earned from taxes is redistributed, which is politically desirable.

3.5.2 The necessary congruency between provision and allocation rules

Dayton-Johnson (2000a) studied 48 Mexican irrigated schemes. He showed, as Ostrom (1992) did, the necessary congruency between maintenance costs sharing rules and water allocation rules.
In the same way, De Janvry et al. (1992) proposed a model where agents can both choose the level of provision and of appropriation. Furthermore, they can coordinate themselves in order to limit the over-investment on appropriation, but the implementation of control mechanisms is costly. Depending on the agreed level of control mechanism and hence global investment for appropriation, agents will choose the amount of effort they give for the provision of the resource.

4 The negotiation on the rules to manage CPRs

4.1 Few results

One possible way to tackle the question of negotiation is cooperative game theory. The main area to apply such theory on environmental issues is the negotiation on "global commons", since there is no supra-national state which would be able to dictate the relevant solution. On the other hand, the use of cooperative games for the study of CPRs is small for the moment.
Gardner et al. (2000) studied the proportional limitation rules in order to decrease the over exploitation of a CPR. They determined the level of reduction that will be voted by the majority rule.
Walker et al. (2000) have set up a simulation of experimental economics where players take individually from the CPR. Starting form an initial non regulated situation, players have the possibility to propose a resource allocation, then the different propositions are put under

vote, which can be either the majority or the unanimity rule. The vote of such rules can considerably increase the global efficiency, unanimity vote being itself more efficient that the majority rule.
Funaki and Yamato (1999) looked at the capacity for identical players to avoid the Tragedy of the Commons. They showed that the existence of a core was linked to the hypothesis each coalition makes on the possibility of coordination of other players outside the coalition.
∘ If each coalition make optimistic forecasting, i.e. thinks that outsiders will coordinate themselves (and hence reduce their total exploitation of the resource), then the core may be empty.
∘ On the other hand, if each coalition makes pessimistic assumptions, i.e. thinks that the set of outsiders will lead to the worst result, then the core always exists.
As a mater of fact, "pessimistic" and "optimistic" situations are related to two important concepts of cooperative game theory (theories α and β, c.f. Shubik, 1982). The result proposed by Funaki and Yamato is very simple, nevertheless it is a very promising one regarding the use of cooperative game models to analyze CPRs.

4.2 The impact of heterogeneity

The analysis of the impact of heterogeneity on the results of a negotiation is by nature different from the one about the impact of heterogeneity on the level of cooperation for a given allocation rule. Indeed, the increase of the provision for the resource is always beneficial for all agents, as well as the decrease of the level of appropriation. On the other hand, regarding the creation of regulation rules, it is generally necessary to compare two situations: an initial unregulated one and a potential regulated one. The shift from one situation to the other can lead to a decrease in outcomes for a certain subset of the agents.
Regarding the heterogeneity stemming from the ability to make an effort, there is no result to our knowledge.
As for the heterogeneity on the ability to profit by the resource, the general idea is that, if the regulation leads to a better collective valorization, it happens sometimes that an agent valuing the resource better than others loses during the shift towards a regulated situation, for example one based on uniform quotas. This situation is all the more likely than the group is unequal.
The possibility to make some monetary transfers can theoretically solve this problem. Nevertheless, in many cases, these transfers will not be used because of a lack of definition of rights or for cultural reasons.
From his study of 48 Mexican irrigation schemes, Dayton-Johnson (2000b) compared different rules and showed that the heterogeneity regarding the size of owned areas is positively correlated with the fact that the Community chooses an allocation rule based on a proportional basis.

In order to conclude, **regarding the creation of rules, the regulated situation can profit by or on the contrary be unfavorable for rich agents, compared to the unregulated situation: the results are almost always ambiguous.**

5 To what extent do game theoretic models represent observed behaviors?

A general conclusion can be proposed: **the Nash equilibrium gives an accurate description of collective interactions both in real case studies and in experimental economics simulations, when agents cannot communicate and, more generally, when a "social capital" is difficult to create** (Ostrom, 2000a and 2000 in McGinnis).
Besides, Ito et al. (1995) pointed out that, in some cases, an observed global investment greater than the Nash equilibrium can be explained by the assumption that agents do not maximize their own profit but rather try to maximize the difference between their revenue and the one of others.

Nevertheless, case studies as well as experimental economics simulations show that the present theory fails to take into account the two following facts.
- A still not enough bounded rationality
If the Nash equilibrium provides an accurate description of the strategies taken as a whole, on the other hand **agents do not play individually the Nash equilibrium strategies**.
Hence, using an experimental economics simulation, Keser and Gardner (1999) showed that students choices lead overall to the Nash equilibrium but that less than 5% of these students really used the Nash equilibrium strategy.
Moreover, the observed behavior is not coherent with the backward induction process that has theoretically to be used in finitely repeated games.
Finally, generally speaking, the theory does not take into account the "trials and errors" process used by individuals.

- The theory has not much dealt with the agents ability to change the management rules.
From a theoretical point of view, the approach proposed by Funaki and Yamato (1999) is very promising but it is still far from being able to illustrate real case studies.

6 The contribution of economic analysis to the debate over CPRs

6.1 Modifying the property regime in order to avoid the Tragedy of the Commons?

Broadly speaking, two approaches were put forward after the Hardin article, in order to avoid the Tragedy of the Commons (Berkes et al., 1989).
◦ The first approach consists in defining **individual transferable property rights**. Of course, any Pareto optimum can be obtained when the market on these rights are perfect and when transaction costs are null. Nevertheless, in a CPR setting, these conditions are not met by definition.
One could also imagine that, when markets on these rights are incomplete, the negotiation can also bring Pareto optima, as proposed by the Coase theorem. Nevertheless, added to the potential problem of the initial definition of rights, the transaction costs must be null and, moreover, it is possible than, with a number of players greater of equal to 3, the negotiation

space has no core (Baland and Platteau, 1996), i.e. there is no agreement for which no coalition does better on its own.
◦ The second approach consists in **nationalizing the resource**: this solution has been widely used in many countries in Africa and Asia in years following the access to independence. But two problems appeared then: a lack of means to control the access on resource and a problem of information asymmetry between the State and users. **In most of cases, nationalization has lead to a real situation of free access.**

What is hence the best institutional solution?
In the ideal situation of no transaction costs and no information asymmetry, both preceding solutions (i.e. nationalization or the definition of transferable property rights) can lead to Pareto optima and hence are equivalent. In the almost totality of real cases, the actual situation is far from this ideal one.
A large economic literature organized around IASCP[4] showed that, in some cases, a management base on a Common Pool Good can be more efficient than either the nationalization or a market based on transferable individual rights.
There is therefore no general solution for the "1/nth" problem that could come from a given property regime. It will hence be necessary to study, on a case by case basis, what is the best property regime belonging to the 3 previously presented options.

6.2 What are the interests and limits of CPRs, especially relating to market failures?

CPRs are of interest in places with a large rate of unemployment: there are often the only resources available for the poorest parts of the population (Baland and Platteau, 1996). Moreover, because there is always a lack of access to credit markets, CPRs management can be used to share the risk between users in certain circumstances (Faysse, 2001).

The resource allocation can also be an occasion for making a **social redistribution**. Ray and Ueda (1996) linked this possibility to the furniture problem for a CPR. The authors studied the case of a public good, for which each agent can decide to provide on his own. This public good will afterwards be distributed so as to maximize a social welfare function. This function can be built with relative weights on efficiency and equity criteria: it may range from utilitarian Bentham function (sum of utilities) to the Rawls egalitarian function (minimum of utilities). Since the Community will always *ex post* allocate the public good so as to maximize the social welfare function, agents will not provide enough *ex ante*. Besides, the more the egalitarian function, the better will be collective action (Ray and Ueda, 1996). In a fishing communities context, Gaspart and Seki (2000) studied institutions which set up a large profit sharing. These institutions lead to an efficient provision of public goods by a sharing of knowledge about the resource and production techniques. Gaspart and Seki showed that these institutions can give birth to social norms that will incite less able agents to work more and more productive ones to work less: hence, such norms help the group revenues to remain homogeneous and therefore stable.

[4]International Association for the Study of Common Property

6.3 To what extent can these theoretical results give an insight into the debate on the best property regime and on the best management structure?

Theoretical models applied to CPRs problems had and still have an impact on the definition of public policies. For instance, the current model about pastures management issued from "New Range Ecology" lead to policies consisting in subsidizing in order to limit losses the shepherds endured during dry years (McCarthy, 2001). The approach proposed by McCarthy showed that such policies will lead automatically to an increase of shepherds risk taking, i.e. an augmentation of cattle density on common ranges. According to her, hence, such insurance policies should be completed by measures to help the set up of management rules at the local level in order to prevent the cattle size from increasing.

6.3.1 Helping the set up of cooperation

The formalization using game theory can help us understand how it is possible to modify the form of the game (possible strategies, matrixes gains) so that cooperation may become a possible issue of the game, i.e. one of the Nash equilibria. For example, for a given allocation rule, it will be valuable to try to shift from a Prisoner's Dilemma situation to an Insurance game one: the problem then just becomes a coordination problem between agents in order to attain the Pareto optimum.

6.3.2 Towards a co-management of CPRs

The theoretical analysis and the implemented policies are orientated more and more towards mixed solutions based on a sharing of responsibilities between the State and local users communities. Baland and Platteau (1996) proposed different cases where State can play a role.
1) It can provide a technical assistance in order to evaluate the impact of considered scenarii and to convince users to take part in the management process. This is for instance the case in the United State, where users often negotiate over an environmental problem while State technical staff provide data on the system (see for example the negotiation on Californian aquifers, Blomquist, 1992).
2) It can give economic incentives, where needed, so that users do not follow a trajectory of destruction of the resource but one that preserves it.
3) The State can provide a legal framework which recognize the decisions taken locally, which is one of the principles put forward by Ostrom (1990) for long enduring CPRs systems. This legal recognition is all the more important that market integration will lead to a weakening of traditional institutions capacities to manage CPRs, this for 3 reasons: (i) traditional institutions authority decreases, (ii) capital and work force become more mobile, (iii) new consuming needs increase the discount rates for the future.
4) The State may solve conflicts that cannot be resolved at the local level, for instance pollution problems between irrigation communities and industries in large basins.
5) Finally, the State can provide a technical and financial assistance for activities of control and sanction.
Moreover, the State cannot always sign contracts directly with all irrigation communities: because of transaction costs, it may be interesting to design intermediate organizations,

for example associations of local communities. This is also another principle proposed by Ostrom (1990), that is to say the definition of nested layers to manage large systems.
Some recent studies (Baland and Platteau, 1996, Edmonds, 2001) presented some examples of successful co-management cases.

7 Perspectives for future research

Among the set of analyses presented above, 3 main directions for theoretical research can be proposed.
a) It will be necessary to incorporate in CPRs management models based on more **bounded rationality** (Ostrom, 2000a and Keser and Gardner, 1999). This theory will have to incorporate norms, i.e. an internal value given by an agent regarding some action, or rules, which are a conception shared among a group that some actions have to be done and that it is necessary to punish the cheaters. For instance, one of the major norm that will have to be taken into account is the "tit for tat" strategy. As for the definition of a social capital, there is nevertheless the risk of signing a "blank check".
b) Many currently used models are based on a 2 players structure, especially the one dealing with heterogeneity. These models over-estimate the impact of each user action on the collective good. It seems more realistic to design models with **n players**, even if their conception is simplified by considering that, for calculating Nash equilibrium, each player does not take into account the impact of his own effort on the global effort made on the resource (i.e. $\frac{dX}{dx_i} \simeq 0$). Results for 2 and n players analysis may be qualitatively very different.
c) On the whole, the analysis made focused mainly on the application of rules, and not much on their choices. **It is necessary to build a negotiation theory applied to the CPRs context**. The approach proposed by Funaki and Yamato (1999) on such issue is a promising one.

Two other perspectives for more applied future research seem also of importance.
d) There is a link to be made between the large literature on environment economics tools (quotas, taxes, permits, etc.) and the economic analysis of CPRs. The last one has concentrated one the regime of property rights and on the influence of the different parameters of the system, but there are few works on the comparison of different classical economic tools in the context of a CPR.
e) Game theoretic models have shown that, depending on the structure of the game, the gains, etc., the outcome could be everything: the spectrum of an unavoidable Tragedy of the Commons seems far away now...Moreover, most of the studies which tried to link observed behavior and theory are based on experimental economics simulations. For these two reasons, it is time to **build models on a case by case basis, from detailed case studies**, using more realistic production functions and game structures.