From Experience to Experiments in Water Management

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Abstract

Thirteen years after the beginning of the democratization process in South Africa, many radical socio-political and institutional transformations have taken place in the country. Unlike during the Apartheid era, natural resource management and governance, particularly in the water sector, is nowadays based on concepts and criteria such as decentralization, economic efficiency, environmental sustainability and social equity. These criteria, which represent the pillars of the South African National Water Act (NWA-1998), are universally recognized as the fundaments of sustainable development and are widely employed in the definition of the environmental policies of the industrialized countries.

To accompany this socio- political revolution, a process of institutional building is taking place in the South African water sector. New organizations, namely the Catchment Management Agencies (CMAs) and the Water Users Associations (WUAs) in charge of local governance of water are being established in the country.

These new organizations urgently need tools, methods, processes that can help them in their difficult task of implementing locally the NWA by promoting the participation of local stakeholders in the process of water management and allocation. In particular, there is a need to gain a better understanding of collective decision mechanisms. In the South African context, participatory approaches – involving local stakeholders, decision-makers and researchers- have been implemented to accompany the water allocation process at catchment scale : the Kat River catchment was used as a pilot study to develop a role-playing game (KatAware –based on multi-agent simulations) accompanying the negotiation between water users on the allocation rules of irrigation water. However, the lessons of this experience are not easily transferable to other sites or situations. The objectives of our work are therefore to assess the impact of the context on the outcome of a collective decision: by identifying the contextual elements influencing most on individual behaviour and on collective action, we could then build negotiation-support tools which are more easily transferable from one context to another.

Introduction

This paper describes and discusses the work of construction and test of an experimental protocol adopting a simplified Role-Playing Game (RPG) to test hypotheses issued from Cooperative Game Theory (CGT). The RPG context refers to the case of common property water allocation among farmers and derives from observations made during a participatory project on water governance in the Kat River Basin (Eastern Cape, South Africa).

During this experience based on an approach called Companion Modelling (ComMod), a RPG called KatAWARE (Farolfi et al., 2008) was developed to reproduce the functioning of a real catchment – the Kat River - and allowed local stakeholders (members of a Water Users Association, WUA) to play around water management in order to :
- understand the complexity of the system;

- understand the relations between agents;
- understand the impact of different water allocation strategies on the water flows, the profits, employment and domestic users' satisfaction;
- build up a catchment strategy within a WUA.

The ComMod process involved local stakeholders to play two sessions of the KatAWARE RPG (Farolfi et al., 2008). Once the ComMod process ended, the RPG outcomes (first session) were compared with theoretical results from a CGT model calibrated on the same data (Dinar et al, 2008). Several similarities resulted from this comparison, even if the complexity and the dynamic nature of the RPG determined differences in absolute terms. In particular, the distribution of the payoffs among the three sub-basins that resulted from the CGT model was similar to the one exhibited as an outcome of the RPG session.

The encouraging, though still vague, results of this first comparison between RPG and CGT outcomes suggested to deepen the analysis in the direction of an experimental use of the RPG in order to test some hypotheses made by the CGT.

To do so, the Kat RPG was simplified and "polished" of all elements needed when used in the context of stakeholders' negotiation support, but not directly related to the CGT hypotheses being tested. Nevertheless, a certain degree of contextualization was maintained:farmers producing cabbage compete for irrigation water, stock of water available in a dam, etc. This simplified RPG was used to conduct contextualized experiments (CE) in the laboratory. The adoption of these CE to test CGT hypotheses triggers an important research question about the use of contextualized tools derived from a negotiation process as a laboratory experiment to test hypotheses. This question is particularly unconventional in the field of Experimental Economics, where experiments are usually conducted in a very de-contextualized way (Eber and Willinger, 2005) in order to avoid different understanding of the context by the players due to their culture, education, experience, personality, which influence their own perception of the context.

A reverse research trajectory would consist of re-building progressively context from a very abstract and de-contextualized experimental protocol. The analysis of the influence of the introduction of contextual elements on players' behaviour would represent an interesting research question. This issue is treated in the last section of the paper.

This document is organized in 3 sections. The origin of the research question is introduced in *Section 1*. *Section 2* presents the theoretical benchmark and the proposed CE to test the theoretical hypotheses. *Section 3* concludes and provides the way forward of this research activity.

Section 1.Origin of the research question

One of the principles of an experiment is to give a study the possibility to be reproduced afterwards. Rouchier (2006) discusses two different approaches that gather empirical data and link them to models and simulations: Experimental Economics, and Companion Modelling (ComMod) (ComMod Group, 2003). The latter approach uses tools such as models and RPG to *"accompany observed social groups when they negotiate over renewable resource issues"*.

A ComMod RPG is a negotiation process that takes place in the field. The 'field', unlike the 'laboratory' used in EE, is an environment that has not been constructed or handled by an

experimenter, who therefore cannot control it. The field is also a complex system. The two main objectives of ComMod RPGs are firstly to understand complex environments, and secondly to support collective decision in complex situations (ComMod Group, 2003). These objectives correspond to a global objective of increasing the knowledge for both the scientist and the stakeholders through a permanent and iterative confrontation between field circumstances and modelling processes.

In some ComMod experiences, like the one in the Kat River, the researcher starts building a first preliminary model to explicit the theoretical *"pre-conceptions"* (Farolfi and Rowntree, 2007). The confrontation of this first model with the stakeholders allows revising and re-building it, taking into account the field situation and the stakeholders' questions and remarks. This dynamic process leads to the construction either of a new model derived from the previous one or a totally new one. Stakeholders learn collectively by creating, modifying and observing simulations (ComMod Group, 2003). Local stakeholders are part of the framing RPG process in the ComMod approach. As a consequence, RPGs developed with ComMod are unique. Therefore, it is impossible to reproduce the same experiment with others players in order to gather data and compare it. Rouchier (2006) stresses that the first and most obvious limit of ComMod RPGs is *"the lack of accumulation of a knowledge that could be generalized to more than one situation"*. Repeatability of the experience is the strength of Experimental Economics, which gets back the standards of the classical experimental approach.

In a ComMod approach, which involves many disciplines in the analysis (e.g. Sociology, Psychology, Economics, etc.) many phenomena could be observed and some could be seen as 'exhibits', consisting in empirical regularities that are discovered and for which, at the time, there are no well-developed theoretical explanations (Sugden, 2005). ComMod RPG could give rise to new research questions derived from the results, but different from the original research framework. An example of emergence of a new research question during a ComMod approach took place in the Kat River project (Farolfi and Rowntree, 2007). This ComMod experience included a RPG played by local stakeholders (members of a WUA) in order to understand the complexity of the system, the relation between agents around water management, and also the impact of the strategies of water allocation in the field in order to build up a common strategy for the WUA. The two RPG sessions played during the ComMod experience allowed observing cooperation among the different players in the use of the water available from the Kat dam, situated upstream the catchment. This observation suggested an attempt of comparison between the results obtained through one of the two RPG sessions and a Cooperative Game Theory (CGT) model calibrated on the same data (Dinar et al., 2008). The comparison showed some similarities about players' behaviours and the distribution of profits (payoffs) among players. It was an encouraging result with regard to the attempt to compare outcomes emerged through both empirical and theoretical approaches. However, these two approaches show many differences that cannot allow concluding definitely about the robustness of such similarities in the outcomes. Replications were therefore needed to verify the soundness of the results. Consequently the idea emerged to construct a "polished", though still contextualized game derived from the RPG used in the Kat to replicate experiments in order to test cooperative behaviour of agents around water allocation.

A common agreement among experimenters in the EE research field is to conduct experiments in a lab and to make the context of the experimental instructions as neutral (decontextualized) as possible. It is argued that, when contextual elements are introduced, the experimenter looses control of the experimental parameters, since players have different

interpretations of a real context. The reasoning is that a real context might contaminate behaviour which possibly makes ambiguous the interpretation of the outcomes (Harrison and List, 2004; Eber and Willinger, 2005). The idea is that the players have a same perception of a general and neutral issue. For example each one could interpret differently an economic context issue, such as two players respectively named 'seller' and 'buyer' in an auction or ultimatum game, or 'monopolist' and 'entrant' in a market game. In a context generalization, they become 'player A' and 'player B' in the experimental instructions (Cooper and Kagel, 2003).

However, it is not strictly true that subjects have the same perception of a neutral context. If the subjects do not understand what the experimental task is about, meaning that they do not know what actions are feasible and what are the consequences of different actions, then control is lost at a basic level (Pillutla and Chen, 1999). Nevertheless, it must also be recognized that inappropriate choice of field referents may trigger uncontrolled psychological motivations. The choice between an abstract context and one with field referents must be guided by the research question (Harrison and List, 2004).

In the ComMod approach, stakeholders are involved in the design of the Role-Playing Game; consequently in order to facilitate the understanding and discussion of the problem at stake, the game is as much "contextualized" as possible.

By using a CE derived from a ComMod experience to run experiments in a laboratory, the question is to verify if such contextualized game can be useful to test theoretical assumptions backing the exhibited phenomena.

Section 2.The theoretical benchmark and the contextualized protocol

Game Theory studies strategic behaviour of decision-makers in situations where one player's decisions affect the other players. The basic assumption of Game Theory is that decision makers are rational players and take into account other decision-makers' rationality to build expectations on their behaviour (Parrachino et al., 2006a). There are two main branches of Game Theory, the first is Non-Cooperative Game Theory and the second is Cooperative Game Theory (CGT). Unlike Non-Cooperative Game Theory, CGT does not focus on the coalition building among players but rather studies the possible results of cooperation. More particularly, CGT objective is to determine what coalition could be formed among the players in a game and how coalition gains are shared among its members. Specifically, CGT focuses on the solutions of the *grand coalition* that includes all the players. Supposing that the players agree to work together on a certain objective, the main question in cooperative game models is how to allocate the earnings of a coalition among its members. Different solution concepts of the payoff sharing issue are developed in CGT and could be provided as a subset (e.g. the Core) or as a one-point (unique) solution (e.g. the Shapley value) (Parrachino et al., 2006a and 2006b; Dasgupta, 2007).

The Shapley value solution vector satisfies individual and group rationality. It is defined such as each player's reward x_i equals a weighted average of the contributions the player makes to each coalition of which he is a member (Parrachino et al., 2006a). The Shapley value (cf. annex) represents a "fair" payoff sharing, taking into account the players' strength and weaknesses (Tisdell and Harrison, 1992).

The protocol building process

The bridge that links a given RPG and its experimental "abstract" version (CE) could be crossed following two directions:
- a "*top-down*" approach that means a degradation (i.e. decontextualization or abstraction) of the context in which the RPG players are initially involved;
- a "*bottom-up*" approach that means to move from an abstract context (as developed in laboratory experiments) onto a contextualized game (Wang, 1996), by adding contextual bricks in order to obtain a RPG (i.e. a contextualized experiment).

The trajectory illustrated so far can be identified as a "top-down" approach, as the RPG KatAWARE was degraded into the CE focusing on CGT issues. A question emerged at this stage: in the degradation process, what factors influence the choice to keep or to leave a given contextual "brick"? Similarly, in a "bottom-up" approach, this question could be seen as the difficulty to choose the bricks and their ordering during the context building process.

What justified the construction of a "contextualized" protocol version for experiments was the fact that Kat Aware in its initial version can be played only in the Kat River context (cf. section 1). Therefore, it needed to be adapted to allow controlled repeatability in other contexts. The new CE could be played in a controlled context (the lab) with players that are not the "Kat" committed stakeholders.

The CE

The experimental set-up aims at testing the Cooperative Game Theory hypotheses that lie behind these results. The protocol mobilizes 5 aspects of a cooperative rationality:

1) Players' rationality (selfishness) and profit maximization;
2) Players' capacity to take advantage of the side payments in coalitions;
3) Players' behaviour in terms of resources (water, land) allocation within a coalition;
4) Players' choice to stay in partial or grand coalition (because of the particular case of this game);
5) If players stay in the grand coalition, allocation of coalition's payoff in comparison with the Shapley values.

The experiment consists of a water resource management game. Water is stored in a dam. Three farmers, cabbage producers, have to require water from the dam if they want to irrigate more area than their initial endowment. The game is a one-shot round, meaning that the farmers play only one period, corresponding to one year.

The CGT model which underlies the game derives from the CGT model used in the Kat River Basin (Dinar et al., 2008).Each farmer has a specific production function but each one initially gets an area endowment set at 20 Ha he may increase up to a maximum of 40 Ha.The farmers have the same initial area endowment (20 Ha) but they have different production functions. Each farmer may increase his cultivated area to a maximum of 40 Ha. If a farmer chooses to increase the cultivated area, he needs water from the dam. In that case, he must demand an additional amount of water from the dam manager (played by the experimenter). Therefore, the farmer's decision is made at two, interrelated, levels: firstly, the cabbage producer eventually demand an additional amount of water from the dam, and then he decides about the additional area to cultivate according to the water allocation decided by the dam manager. The

dam has a capacity of 350 000 m^3 of which 100 000 m^3 must be preserved for domestic consumption and the ecological reserve.

The experiment is composed of three phases. During the **first phase**, the three farmers play as singletons. They choose the area to cultivate and the corresponding water required without communication with the other farmers. During the **second phase**, two farmers play together in a partial coalition whilst the third farmer still plays alone. The partial coalition is presented to the farmers as an "informal group". The farmers forming the partial coalition choose together the area cultivated by each one and the amount of water they require. The profit obtained is common between the two farmers and side-payments are allowed. The side-payments theory is based on the assumption that "the coalitional utility function is expressed in units of a divisible commodity which stores utility, and which can be transferred without losses to the players". If a coalition can obtain a total utility, this utility can be divided among the members of the coalition in any possible way. It is possible to transfer money among the players in order to reallocate the profit gained through the coalition. Such games satisfying these assumptions are called "transferable-utility games" (Parrachino et al., 2006a).

Finally, in the **third phase**, communication is allowed between the three players who play together in a grand coalition. The same cooperative principle as in the second phase with two farmers is generalized to the group including all the farmers. The grand coalition is presented to the players as an "irrigation board", and consequently the farmers in the board manage collectively the water available from the dam.

In the instructions provided to the players, theoretical CGT terms were changed into more colloquial words. For instance, terms as 'partial coalition' and 'grand coalition' were named respectively "informal group decision" and "irrigation board".

This protocol proceeds in a testing phase and is not still fully developed to be implemented in an experimental way.

Section 3.Conclusion and research perspectives

During the participatory project conducted in the Kat River Basin, a ComMod approach was implemented. Stakeholders played a RPG articulated around water management in order to understand the complexity of the local system and to build up a catchment strategy within the local water users association. The ComMod approach exhibited some regularities in the stakeholders' behaviour that seemed worth further investigation. The outcomes of the RPG conducted with local stakeholders in the field were first compared with theoretical results predicted by a Cooperative Game Theory (CGT) model calibrated on the same data. Some similarities in the grand coalition payoff sharing appeared and suggested to deepen this comparison through an *experimental* use of a simplified version of the RPG (i.e. the CE) to test a certain number of hypotheses made by the CGT. The EE approach was chosen because, unlike the ComMod approach used in the Kat, it provides the possibility to reproduce many times the same experiment in order to gather data and capitalize knowledge. However, EE commonly develops experimental protocols which are decontextualized. Consequently, the overall question treated by this research project is whether a contextualized experiment is useful to test theoretical hypotheses, and particularly how to simplify or adapt the context to run valid experiments.

The results obtained through a repeated use of the contextualized experiment were compared with those of the CGT model. The comparison of the results obtained provided insights on the correspondence between hypothetical and real behaviour of players when facing a situation of common pool resource (water) allocation in different conditions of cooperation.

However, the experimental protocol is not completely definite. Some context aspects remain to be discussed. Particularly, in the present game, water is required for free from the dam. This feature was chosen to simplify the experiment.

A fully abstract protocol (AP) is currenltly being developed following the top-down approach presented above. It consists of a three-phases game as the CE: 1) singletons; 2) partial coalitions; 3) grand coalition. In this AP, abstract terms instead of water management specific terms are used. For instance, the dam is identified with a "common-pool", water becomes "tokens" and the farmers are generic "players". This AP is more consistent with classical protocols used in Experimental Economics than the CE protocol; it allows a complete control of the parameters. Therefore, the hypotheses formulated on the basis of the RPG observations can be tested in a strict experimental way.

The comparison of the AP results with the CE ones should provide a first lesson about the influence of the context on players' behaviour. However, only the influence of the context elements as a whole is evaluated. The impact of each context element (that is "water" on a one hand, "farmers" on another hand, etc.) remains to be evaluated separately. The protocol building process therefore could be made in a "bottom-up" approach. It consists in starting from the AP, and adding and ordering each contextual element (considered as an elementary "brick") to obtain new contextualized protocols, each one being designed to test the impact of a particular contextual "brick". By a "top-down" approach, the simplification of the initial situation (RPG) in order to isolate specific elements and to test hypotheses based from the RPG observations, reaches to a first block of experimental protocols. By a "bottom-up" approach, the context re-building process made in order to test the influence of contextual "bricks" on players' behaviour provides a second cycle of experiments. Many experiments could be obtained from a first experience (a RPG developed in the field) by following these two protocol building ways, each experiment being designed to test specific hypotheses.

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Let *N* be a finite set of *n* players, *S* a subset of *N* composed by *s* players, and *v* a real-valued function defined over all the subsets of *N*. Commonly, *v* is the payoff obtained, such as the payoff obtained by farmer i as singleton is noted v(i) and the payoffs for the coalitions *S* and *N* are *v(S)* and *v(N)* respectively.

Shapley proposed that there exists a unique value φ that satisfies the conditions of efficiency, dummy player property, anonymity and additivity (cf. Parrachino et al., 2006a). For all *i Є N*:

$$\varphi_i(v) = \Sigma\ [s!\ (n\text{-}s\text{-}1)!]^* \ [\ v(S \cup \{i\}) - v(S)\ ] / n!$$

The Shapley value could be interpreted as follows:
Considering any permutation *π* of the set *N* and any player *i Є N*. If P(i, *π*) is the set of players that precede *i* in the permutation *π*, M(i, *π*) = v(P(i, *π*)∪{i}) − v(P(i, *π*)) is the marginal contribution of i to the coalition P(i, *π*). The Shapley value will be:

$$\varphi_i(v) = 1/n!\ \ \Sigma\ M(i, \pi)$$

Considering a situation with *n* players agreeing to meet in a certain room, imagine the *n* players entering one at a time into that room in a random order (specified by the permutation *π*) and that each player, as soon as he enters and reaches the coalition S created by the players arrived before him, receives a reward equal to v(S∪{i})-v(S), that is his marginal contribution.

The Shapley value is the mean marginal contribution, averaged on all of the n! permutations π.