EXPLORING GAME THEORY AS A TOOL FOR MAPPING STRATEGIC INTERACTIONS IN COMMON POOL RESOURCE SCENARIOS

Review on Common Pool Resource Management in Tanzania

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DRAFT

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1. INTRODUCTION

The objective of this paper is to introduce game theory as an analytical tool for understanding and mapping strategic interactions amongst individuals and institutions in the management of common pool resources.

The section on the Economics of Common Property Resources explores the relation between poverty and property rights in natural resource management and emphasises the role of transaction costs in the governance structure of common property systems and how these costs shape the outcome of these systems. The section on the Economic Valuation of the different forms of land-use in Tanzania emphasises the importance of identifying and incorporating non-marketed/non-priced values of environmental goods and services and how such valuations can be undertaken so that optimal levels of land-use are identified. A question that remains open is if and how these optimal solutions can be reached. This section intends to contribute towards this broad question by introducing game theory as a useful analytical tool that helps us understand how decision-making processes are made in the management of common pool resources. The review explains how strategic decision making processes can be mapped in a game theoretic fashion so that variables that are key for arriving at socially optimal solutions can be identified.

The first part of the report will give an introduction to game theory as a method for the construction of game theoretic models, introducing the reader to game theoretic language and representation forms. The second part of the report will review the most frequently used games for depicting problems encountered in CPR settings and illustrate the use of game theory in analysing binding agreements as institutional solutions to CPR dilemmas. The last section will aim to illustrate how game theory can be applied to understanding decision making processes and assessing the desirability and viability of policy options in the context of semi-arid Tanzania.

1.1 Game Theory; language and representation forms

As a branch of mathematics, game theory started to be used as a framework for analysis after the publication of Von Neumann and Morgenstern's (1944) "Theory of games and economic behaviour'. As such, the main use of game theory was in economics through the early 1970s, when its use started to spread to other social sciences.

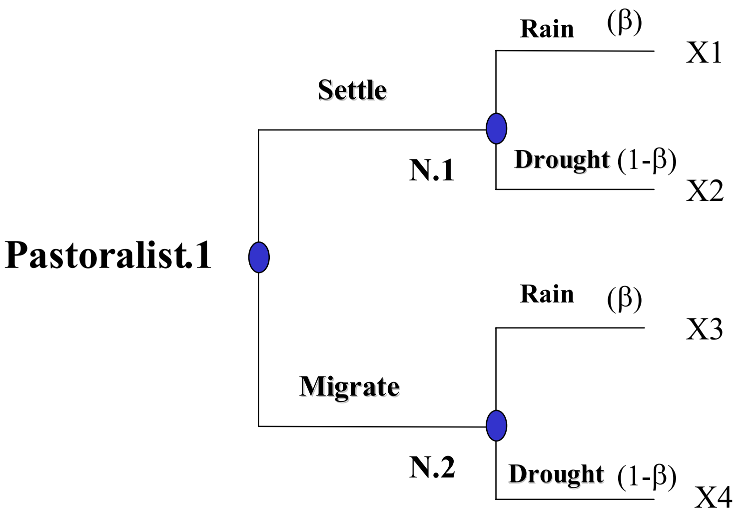
There are two major strands within game theory: cooperative and non-cooperative game theory. Cooperative game theory deals with situations in which the players can negotiate before the game is played on what to do in the game. It is assumed that these negotiations result in signing a binding agreement (Binmore, 1994). For this type of game, what is important are not so much the strategies available to the players, but the preference structure of the game itself, since this is what determines which contracts are feasible. Non-cooperative game theory is based on a different set of principles. Non-cooperative game theory calls for a complete description of the rules of a game so that the strategies available to the players can be studied in detail. The objective is to find a pair of equilibrium strategies to be designated as the solution of the game and this solution might or might not be cooperative (Binmore, 1994). This strand of game theory gives space to agreements. However, these are not conceived as necessarily binding. Agreements can be made after or before a game is played and, depending on how the payoffs and strategies available change, agreements can or cannot be sustained. At this stage, it is important to point out that game theory is not the same as game models (Snidal, 1985). Game theory sets out an analytical framework for the construction of game models, not for their design. The results of the game will change depending on the way the model is conceived. This means that one could construct a model and give it different features e.g. increase the number of players, and the result would be different. Game theory thus can be conceived as a 'metalanguage for [the construction of] game-theoretic models' (Ostrom *et al.*, 1994: 24).

As most of the games used for depicting CPR problems emanate from non-cooperative game theory, the next section intends to outline some of the key concepts used in non-cooperative game theory to familiarize the reader with game theoretic language and forms of representation.

1.2 Non-cooperative extensive form games

Non-cooperative games can be depicted in two forms: extensive and strategic forms. In the extensive form, the rules of the game are laid in full detail by drawing a tree (see Fig. 1). To illustrate the way in which extensive games are constructed, consider a simplified decision problem faced by an agro-pastoralist. He or she can decide whether to settle in an area of land, or to migrate. Her or his decision will depend on, among other things, the rainfall patterns she or he expects to encounter in different places. Consider then the following **game tree** (extensive form game) with two **players** (player 1 and player 2). Player 1 will represent the agro-pastoralist (**P**) and, player 2 will represent nature (**N**).

Figure 1. Example of an extensive form game



Pastoralist.1 represents the **node** at the **root** of the **tree** from which the first available **strategies** follow. The **strategies** are named branch lines in this **representation form**, and depart from the small circles called **nodes**. In this game, the two **available strategies** for the agro-pastoralist are to settle in the current land or to migrate and move to another place. The next nodes of the game **N.1** and **N.2** represent two different nodes for nature. When two nodes are connected with a dotted line, which is not the case in this example, it is said that both nodes are in the same **information set**. That is, there is incomplete information about the actions of the last player. Otherwise, as we move forward in the tree from left to right, information about the last player's moves is gained along the way.

In this game, the two available strategies for nature are rain or drought. In reality the level of rainfall could fall at different levels along a continuum ranging from no rain at all to very much rain but to keep this game simple, consider these two extremes. The two nodes for nature (N.1 and N.2) are **chance decision nodes** as there is uncertainty on what nature will do. In chance decision nodes, all branches deriving from them have a **probability distribution** equal to 1 (e.g. $\beta + 1 - \beta = 1$). The agro-pastoralist can have some information on these probabilities, such as what the rainfall was last year. However, there is still uncertainty on what in fact will happen.

The letters or numbers, in this case Xs at the **terminal nodes**, represent the **payoffs**[2] of each **decision path**. These payoffs will depend on the utility functions of the players in the game. In this case only the actions of nature will have an effect on the payoffs for the agro-pastoralist and not vice versa. Therefore, only one payoff is sketched. In the case that two or more players have a payoff contingent on the final scenario, these payoffs will be written at the end of the terminal nodes separated by a comma, being the first letter or number of the payoff for player one, the second letter or number the payoff for player two and so forth. In the game considered here, if the agro-pastoralist settles and it rains, she or he will receive X1, if he or she settles and there is drought, she will receive X2 and so on…

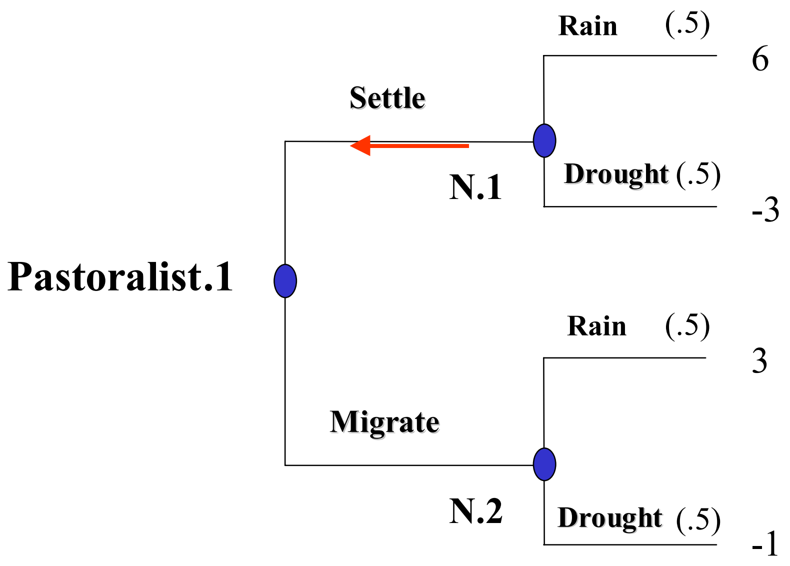
In order to find a solution for this game, we have to compute the expected payoffs at each node, starting from the right and moving to the left. This commonly used method is called solving by **backward induction**. In this

[2] In economic jargon, the payoffs represent utilities that comply with the Von Neuman Morgestern axiom.

game we thus have to compute the expected payoffs at N.1 and N.2, that is, the expected payoffs from settling and moving respectively. To compute the **expected payoffs** of a decision under uncertainty, one has to multiply the payoff by the probability of each payoff and sum them[3]. For example, the expected payoff from settling in this game would be: $Ep(S) = \beta(X1) + (1 - \beta)(X2)$. The same would have to be done for the other available strategy for player 1. These two payoffs would have to be computed and compared in order to derive a **preferred strategy**[4]. To identify the preferred strategy an arrow in the branch that represents the preferred strategy can be drawn. To make this clearer, the numerical payoffs to the example are given below.

Consider the hypothetical payoffs for the agro-pastoralist from each of her or his available strategies as those depicted in Figure 2. These payoffs would have to include all benefits and costs (e.g. monetary costs from moving, opportunity costs, etc) derived from each of her or his strategies given the actions of nature. That is, the payoffs reflect the net benefits of all contingent scenarios.

Figure 2. The "Migration Game" with numerical payoffs



Given the payoffs from Figure 2, the expected payoff for the agro-pastoralist from settling would be:

$$\mathbf{Ep(S)} = 6(0.5) - 3(0.5) = 3 - 1.5 = \mathbf{1.5}$$

Conversely, the expected payoff from migrating would be:

$$\mathbf{Ep(M)} = 2(0.5) - 1(0.5) = 1 - 0.5 = \mathbf{0.5}$$

Given these payoffs and probabilities, the best strategy for the agro-pastoralist would be to settle since the expected payoff from settling will be higher than the expected payoff from moving ($Ep(S) > Ep(M)$). An arrow on the "settle" branch denotes this.

Now, let us consider another approach to this game. What if the agro-pastoralist is not sure about the probabilities of drought or rain? How much would the expected probability have to fall or rise in order for the chosen strategy to still be preferred?. To find a solution, we need to compute the same expected payoffs and solve for β:

[3] If there are subsequent nodes involving probabilities, starting with the payoffs at the terminal nodes, we would move from right to left computing the conditional or independent probabilities, following the rules for independent or conditional probabilities respectively.
[4] In some cases knowing that one outcome is preferred over another is enough to derive a preferred strategy.

$$\mathbf{Ep(S)} = 6\beta - 3(1-\beta) = \mathbf{9\beta - 3}$$

And, $$\mathbf{Ep(M)} = 2\beta - 1(1-\beta) = \mathbf{3\beta - 1}$$

For settling to be a preferred strategy, Ep(S) > Ep(M), thus:

$$\mathbf{9\beta - 3 > 3\beta - 1}$$

Solving for the past inequality, β would have to be higher than 2/6 for settling to be the preferred strategy for the agro-pastoralist. This means that for all probabilities of rain higher than 0.33 it will always be best for the agro-pastoralist to settle.

Clearly this is a simplified view of the available decisions to the agro-pastoralist and of the variables that will shape his or her payoffs. However, once familiar with the way games can be constructed and solved, and the interactions amongst several players, then different strategies can be mapped in a game theoretic fashion. The next section will introduce the other form of game, the non-cooperative game.

1.3 Non-cooperative strategic form games

The other form in which non-cooperative games are depicted is the normal or strategic form (Fig.3). This form is useful to depict interactions amongst two or more players in which their payoffs are shaped on what the other player does and for illustrating simultaneous decision-making.

Consider two agro-pastoralists or two groups of agro-pastoralist: agro-pastoralist 1 (player 1) and agro-pastoralist 2 (player 2). In **normal/strategic form games**, the payoffs for each of the players are depicted within the boxes of the matrix (Fig.3). In some normal form representations, the payoffs are written in a parenthesis with the first number being the player 1 payoff and the second number or letter in the parenthesis, the player 2 payoff. In other normal form representations, for example the game in Figure 3, the payoffs are depicted at the corners of each box within the matrix. The payoff to the left top corner of the box being the payoff for player 1 (agro-pastoralist 1) and the one located at the right bottom of the box, being the payoff for player 2 (agro-pastoralist 2). One of the players plays the columns and the other player plays the rows. The names of the players and available strategies are written at the top of the columns and at the side of the rows, respectively.

Figure 3. A normal 2x2 form of the revisted "Migration Game"

		Past. 2	
		Settle	**Migrate**
Past. 1	**Settle**	.75 * .75	1.5 .5
	Migrate	.5 1.5	-1 -1

Drawing on the example presented in the past section, suppose that the payoffs for the agro-pastoralists are not only dependent on what she or he thinks nature will do, but on what other agro-pastoralists do. Suppose then that the payoffs from settling for the agro-pastoralist will be shaped by what other agro-pastoralists do and vice versa. For example, if land is scarce then if both agro-pastoralists settle in the same area the benefits for each agro-pastoralist will be reduced. If both agro-pastoralists decide to settle in the area (settle, settle), the payoff for each agro-pastoralist will no longer be 1.5 as derived in the past example. If both agro-pastoralists decide to stay, each will only receive 0.75. If only one of them decides to migrate, the one who settles will receive 1.5 while the one who migrates will receive 0.5. If, on the other hand both players decide to migrate, each of them will receive –1. That is, both players would carry the costs and risks of migrating and the fact that both will graze in the same area imposes a burden on one another.

In order to derive the **contingent or best response strategies** for each player given the payoffs for the game and what the other player does, let us start with player 1. What would the best response for agro-pastoralist 1 be if she or he thinks agro-pastoralist 2 will settle (left column)? Given that strategy by player 2, the best response strategy for player 1 is to settle since 0.75 > 0.5 (the two payoffs at the left top corner of the two boxes in the left column). If, on the other hand, agro-pastoralist 2 migrates (right column), the best response for agro-pastoralist 1 would be to settle since 1.5 > -1. These best response strategies are illustrated by arrows at the sides of the matrix. The vertical arrows illustrate agro-pastoralist 1's best response strategies for this game. In this game, player 1 (agro-pastoralist 1) has a **dominant strategy**. A dominant strategy is a strategy that given the rules and payoffs of the game, in any specific node, is preferred by a player no matter what the other player does.

The procedure followed with player 1 now needs to be done with player 2. What would the preferred strategy for player 2 be, given the actions of the other player? If player 1 decides to settle (top row), player 2's best response strategy would be to settle given that 0.75 > 0.5 (bottom right payoffs from boxes in the top row). If, on the other hand, player 1 decides to migrate (bottom row), the best response strategy for player 2 will still be to settle, since 1.5 > -1 (bottom right payoffs from boxes in the bottom row). Thus, the dominant strategy for player 2 will also be to settle. The horizontal arrows represent the best response strategies for player 2.

When a game has at least one of a player's arrows pointing to a box and at least an arrow of the other player pointing to the same box, then the pair of strategies is said to be in a **Nash Equilibrium**[5]. A **Nash Equilibrium** is thus defined as any pair of strategies with the property that each player maximizes her or his payoff given the actions of the other player. In this case, the Nash Equilibrium for this game is Settle/Settle.

There are additional names for specific strategies and equilibria. A **pure strategy** is one which does not involve chance (probabilities). And a **pure Nash Equilibrium** is the equilibrium reached when each player plays a pure strategy. In the game illustrated in Figure 3, there is only one Nash Equilibrium (S,S) and this is a pure Nash Equilibrium, since it does not involve probabilities. Another type of strategy, not present in this game, are **mixed strategies**. A mixed strategy requires a player to randomise her or his pure strategies in order to keep the opponent guessing. Consequently, a **mixed equilibrium** is the equilibrium reached when each of the players is playing a mixed strategy.

Two further equilibrium notations are used for specific purposes in game theory. **Symmetric equilibrium**, in which every player chooses the same strategy and an **asymmetric equilibrium** in which at least two players choose different strategies. When there is only one equilibrium in the game, this is called the **unique Nash Equilibrium** and when there are more than one equilibria, it is said that the game has **multiple Nash Equilibria**. In the game presented in Figure 3, there is a **unique pure symmetric Nash Equilibrium**. This equilibrium is represented with a star in the middle (note the star in the middle of the box settle/settle), though there are many other identifiable forms for illustrating where the Nash Equilibria are.

Having presented a brief review of game theoretic language and representation forms, next section will review the game theoretic approach to CPRs.

[5] A pair of strategies with these properties is called a *Nash Equilibrium*, after J. Nash (1953) who showed that all games with a finite number of strategies have at least one equilibrium, provided that mixed strategies are allowed. Mixed strategies will be explained later.

2. GAME THEORY, COMMON POOL RESOURCES (CPR) AND, COMMON POOL INSTITUTIONS (CPI)[6]

Game theory has been extensively used as a framework for analysis of CPR problems (see Ostrom *et al.*, 1994; Baland and Platteau, 1996). Before presenting the game theoretic approach to Common Pool Resources (CPR), it is important to review the way CPR have been conceived and the problems arising in the management of these resources.

Common pool resources have been mainly explained in terms of the physical attributes of the goods or resources. CPR are considered to share two characteristics: (a) the difficulty of excluding individuals from benefiting from the resource and (b) the subtractability of the benefits consumed by one individual from those available to others (Ostrom *et al.*, 1994). These characteristics have been considered to generate two broad problems: that of appropriation and that of provision. The first relates to extracting more than the socially optimal level[7]. The difficulty of excluding others from the use of a CPR creates the problem of effectively limiting use (Ostrom *et al.*, 1994). In the case of renewable resources for example, the concern is that the flow extracted will not exceed its regeneration rate. The second problem refers to the difficulty of investing for the "adequate" provision of the CPR or in activities related to its improvement or maintenance. Both these problems can be considered to generate negative consequences for other appropriators/users.

2.1 Commonly used games for depicting CPR problems

Three main games have been used for depicting CPR problems. These games are: (a) the prisoner's dilemma game (b) the chicken game and (c) the assurance game. The prisoner's dilemma game has been widely used to represent the appropriation problems encountered in CPRs. When limits for resource use cannot be established, all users of the CPR will want to use as much as possible so as to maximize their own profit, resulting in over-appropriation of the resource. In the case of natural resources this over-appropriation can lead to over-exploitation.

The prisoner's dilemma game is probably the most well known game with two players each having two strategies (Fig.4). The two available strategies for each player are to cooperate or to defect. The payoffs considered for this game are such that c > a, d > c and a > d. Thus, given the payoffs for this game, the best response strategy for each player is to defect. This game has a unique Nash Equilibrium that is: defect, defect. Here is where the dilemma lies, since the players could both be better off if both chose to cooperate (C) simultaneously since a > d.

Figure 4 The Prisoner's dilemma game (c > a, d > c and a > d)

		Player 2	
		C	D
Player 1	C	a a	c c
	D	c b	d * d

Source: Adapted from Ostrom *et al* (1994 :53)

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[6] This section is adaptively drawn from Ostrom *et al.* (1994)

[7] There are some problems in determining the socially optimal point. In addition to its praxis it will depend on which and how many involved or affected agents are introduced to the equation. In this case, social optimality is considered the result of equating marginal social benefits to marginal social costs of appropriators, taking appropriators to be the individuals sharing the use of the CPR (Ostrom *et al.*, 1994).

In the case of resource provision, the problem arises with free riders benefiting from the resource (as a public good) provided without having contributed to its provision. For example, in terms of investment for the maintenance or improvement of the CPR. This problem has been modelled, depending on the provision technology, with the prisoner's dilemma or with the assurance game. The former having no-one contributing to the resource provision (Fig. 4) and the latter having players contributing if, and only if, the others are to contribute (Fig. 5). The assurance game for which the payoffs are such that a > c and d > b (Fig. 5) thus depicts situations in which one person's contribution is not enough to gain a collective benefit, but the contribution of both players will result in a joint benefit. That is, both players would be willing to cooperate if, and only if, the other player cooperates. As can be seen in Figure 5, this game has multiple equilibria.

Lastly, the chicken game has been used to illustrate assignment problems when there are different resource locations with different richness. This game has multiple equilibria, as does the assurance game. If one of the locations is much better than another, both players will want to use the same location (D,D) and this might not be optimal for the group as a whole. If both locations are as good (Fig. 6), players will be indifferent and will play a mixed strategy leading either to one (C,D) or the other equilibrium (D,C).

Figure 5. The Assurance Game (a > c, c > d and d > b)

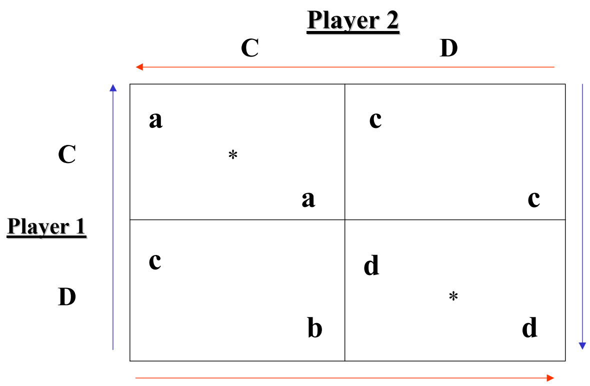
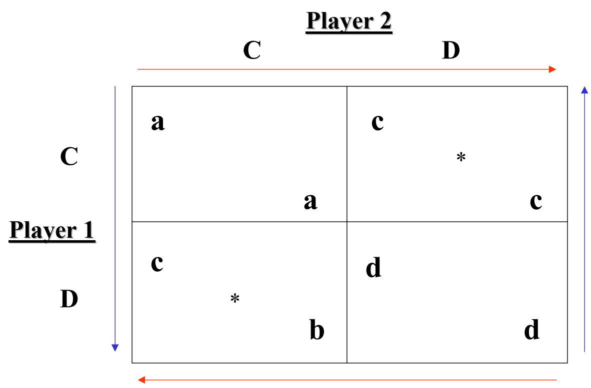


Figure 6. The Chicken Game (c > a, c > d and b > d)



Source: Adapted from Ostrom *et al.*, 1994

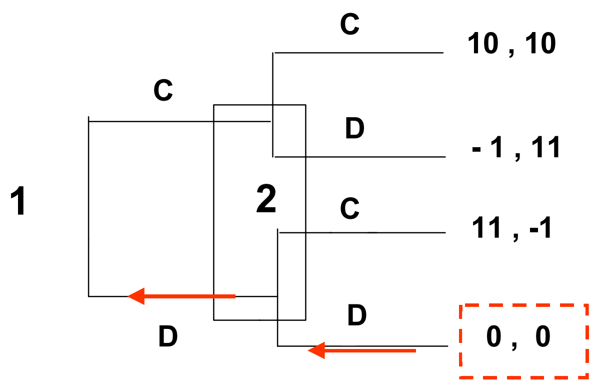
Due to the attributes of CPRs, individuals jointly using CPRs are thus stuck in a dilemma. When pursuing their own interests they will engage in non-rational collective outcomes that result in resource degradation. Institutional choice theorists have focused on identifying viable institutional alternatives by which appropriators can choose (a) how much, when, where, and with what technology to withdraw units and (b) how much, when and where to invest in the maintenance of the CPR (Ostrom *et al.*, 1994). The next section outlines the game theoretic logic for such viable institutional solutions.

2.2 Institutional solutions to CPR problems

As mentioned in the previous section, the prisoner's dilemma can be used for illustrating appropriation and provision problems within CPR, however its use has been broader than this, having been applied by many researchers to CPR issues. The use of the prisoner's dilemma game for representing CPR situations has been criticised by several authors (Ostrom, 1990; Ostrom *et al.*, 1994), whilst accepting its validity for representing sub-problems present in CPRs.

Consider the prisoner's dilemma game again, now in the extensive form, with the payoffs thought-out by Dawes (1973). As we have seen, the prisoner's dilemma structure games have a unique Nash Equilibium which is (D,D). The game in Figure 7 depicts this equilibrium in a square with the resulting payoffs of 0,0 respectively.

Figure 7. The prisoner's dilemma game in extensive form and numerical payoffs

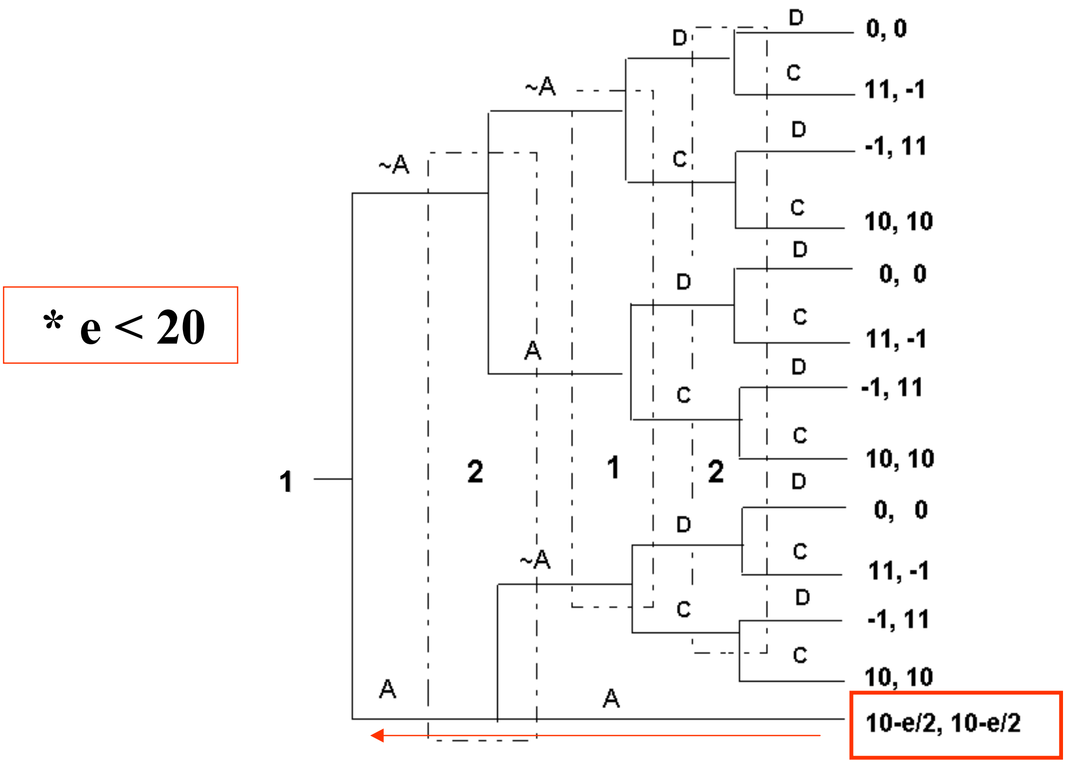


Now, consider that this game is not finite. That is there is not only one round to the game, but that the game is played over and over again. This leads to the alternative game set by Ostrom (1990) following the structure of the prisoner's dilemma game but adding two branches for each player at the beginning of the game. These branches are termed: agree (A) or do not agree (~A). That is, players can get together and arrange a contract in order to arrive at a joint payoff (Fig. 8).

In this game the issues are: 1) if the contracts can be binding i.e. there is unfailing enforcement and 2) if the payoffs are such that the transaction costs of enforcing the contract are lower than the expected gains from the contract. A binding contract is interpreted in non-cooperative game theory as one that is unfailingly enforced by an external actor. The cost of enforcing the agreement is denoted in Figure 8 by *e*.

Given the payoffs and structure of the game, the dominant equilibrium is having both parties agreeing to cooperate. The equilibrium is shown in the rectangle at the bottom of the tree. If these strategies are followed players will receive the joint benefit from cooperation minus the shared enforcement costs (10–*e*/20, 10-*e*/20). Note that this equilibrium will hold only if joint enforcement costs (*e*) are lower than 20.

Figure 8. Self-financed contract enforcement game



Source: Ostrom, 1990 :15

Encouraged by this and other parallel work, in the past decade theorists have explored the relationships between rules, institutions, property rights and resource user characteristics for arriving at cooperative outcomes that can enhance collective benefits. The next section will illustrate the use of game theory for identifying key variables and levels of variables that can enhance cooperation and for assessing the viability and desirability of policy options in the context of common pool resource management in semi-arid Tanzania.

3. WORKED EXAMPLES FROM SEMI-ARID TANZANIA

As stated elsewhere in the report, much of the Tanzanian land area is still under open access or some form of common property arrangement. This section intends to illustrate some uses of game theory in the management of common pool resources in the context of semi-arid Tanzania.

Two different problems will be taken as examples to illustrate the use of game theory for understanding decision making processes and assessing the viability and desirability of policy options in the management of common pool resources. The first will be the problems encountered by villages that face soil erosion on communally managed land. The second will be the problems faced by communities living next to wildlife conservation reserves and who are prevented from using resources within the reserve.

3.1 Erosion prevention/restoration and cooperation in common pool scenarios

Semi-arid ecosystems are characterized by highly variable rainfall patterns, such as short intense storms, and high evapo-transpiration rates. In several areas there are serious problems of land degradation and soil erosion affecting the already low living standards of people living in those areas.

Consider an area with a high degree of land erosion. Erosion can depend on natural factors such as rain fall patterns, wind and topography present on the area, but can also result from human activities such as deforestation, clearing for cultivation, overgrazing, extensive fuel wood cutting, etc. Erosion in turn affects the productivity of the natural resource base. The negative impacts of erosion can be ameliorated by investments in the common property land such as afforestation, the construction of diversion ditches, ridge banking, destocking, etc. The implementation of these activities would provide joint benefits for all users; however problems of provision can arise with free riders benefiting from the resource without having contributed to investment in its provision.

Recall that provision problems in CPR can be modelled, depending on provision technology, with the prisoner's dilemma or with the assurance game. The former having no-one contributing to resource provision and the latter having players contributing if, and only if, the others are to contribute. These two games are illustrated in Figures 9 and 10.

Figure 9. A prisoner's dilemma structure game for erosion restoration/prevention investments in common pool scenarios

		Player 2	
		I	**~I**
Player 1	**I**	**10** / **10**	**-1** / **11**
	~I	**11** / **-1**	**0** * **0**

The individual profits from realizing the investments are the individual benefits derived from the investment, minus the costs incurred in the investment, including the opportunity costs of time devoted to the activity. Realization of these investments will depend on having the flow of money or resources required for realizing the investment, but will as well depend on what an individual thinks other members of the village will do.

Consider the payoffs and strategies available in Figure 9. Two different members of the community are represented as Player 1 and Player 2 respectively, each having two possible strategies: to invest (I) or not to invest (~I) in restoration/ prevention practices. If both players invested in improvement of the CPR, there will be a joint benefit of 20. However, when maximizing individual payoffs, the resulting equilibrium is no-one contributing to the investment (~I, ~I), thereby deriving a joint benefit of zero.

Consider now that the technology is such that it is convenient to contribute only if the other player is to contribute. As seen in the past section, these situations can be modelled by an assurance structure game for which there are two possible equilibria. That is, when a player takes the initiative to invest (I), the best the other player can do is go and help him (I), since by doing so her or his payoffs will increase. However, if nobody takes the initiative, there will be no investment (~I). The result thus is, either investment by both parties (I,I) or non investment by both parties (~I,~I) as illustrated in Figure 10.

Figure 10. An assurance structure game for erosion restoration/prevention investments in common pool scenarios

		Player 2	
Player 1		**I**	**~I**
	I	**10** * **10**	**-2** **9**
	~I	**9** **-2**	**0** * **0**

As seen in the previous section, there are institutional alternatives by which resource users can organize and arrange for the collective gain to be achieved, transaction costs permitting. The issue that remains is effectiveness of village governance. If communal institutions are weak, should there be a role for third parties, such as the government or NGO's entering into co-management arrangements for the fostering of such agreements? Among the ways in which the fostering of agreements could be effected are providing the initial money for realizing investments, improving information to stakeholders on the benefits that can be derived from agreements and/or reducing the transaction costs from enforcing agreements. Analysis of the viability and desirability of the possible options for improving cooperation is not part of the present review.

The next section covers the second example on the use of game theory in the context of semi-arid Tanzania.

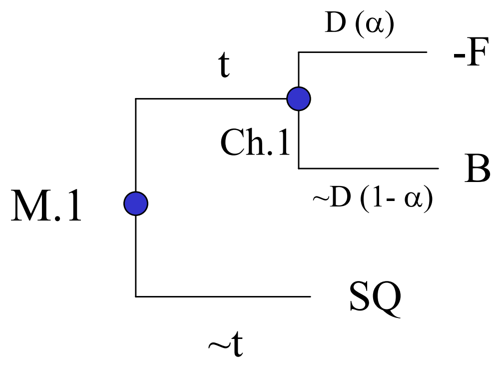
3.2 Protected areas, eviction and encroachment. Game theory as an analytical tool for assessing the viability of policy options

A central policy in Tanzania has been the creation of Protected Areas as part of a broader strategy aiming to promote biodiversity conservation and the meeting of local and national development needs. The viability of these policies cannot be isolated from strategic interactions and decisions made by different individuals and institutions at the local level. As will be illustrated in this section, game theory can also be useful in assessing the viability and desirability of policy options in common pool resource contexts.

Until now, we have considered games made under the assumption that players are symmetric, facing the same decision alternatives and being in the same position. For example, both players being appropriators and facing cooperate or defect strategies. These symmetries however can be relaxed to construct games in which the strategies do not need to be the same, nor the players be assigned to the same positions.

Let us first try to map a decision problem faced by communities living adjacent to a reserve, who are completely prevented from the use of resources within the reserve.

Figure 11. The Trespassing Game



Consider first a hypothetical scenario illustrated by Figure 11, where M.1 represents the first node for a member or members of the reserve adjacent communities and Ch.1 represents a chance decision node with a probability distribution equal to 1. M.1. has two available strategies: to trespass (t) and use the resources within the area or not to trespass (~t). If the user trespasses and is not detected (~D) he or she will receive a benefit (B) from the additional resources within the reserve (e.g. grazing land, water, wood, bushmeat, medicines, etc) with a probability of (1-α). B will be shaped by the availability, quality and dependence of resources inside the reserve relative to those outside the reserve. If, on the other hand, the member is detected (D) she or he will carry the cost of the fine (-F) with probability α. If the member does not trespass she or he will remain under status quo conditions.

Let us derive the expected probabilities for the unique decision node for the members of the reserve adjacent community:

$Ep(t) = \alpha\ (-F) + (1-\alpha)\ B = -\ \alpha\ F + B-\alpha B = -\ \alpha\ (F + B) + B$

$Ep(\sim t) = 0$

Thus for not trespassing to be a preferred strategy either:

i) $\alpha > B / (F + B)$ or

ii) $F > B\ (1- \alpha) / \alpha$ or

iii) $B < \alpha F / (1- \alpha)$

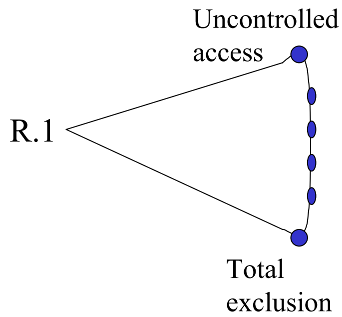
From the previous set of equations, there are four ways of making not trespassing to be a preferred strategy. These are either to:

1. Increase the probability of getting caught to the level shown in the equation, or
2. Increase the level of the fine to the level shown in the equation, or
3. Decrease the level of benefits to the level shown in the equation, or
4. A combination

The use of game theory is not a substitute for assessing side effects from each of the available strategies. These can be built up in other rounds of the game or subsequent games. Possible side effects from each of these policy options are, for example, increasing the probability of getting caught would mean having to invest more resources in monitoring activities, increasing the level of the fine might foster corruption and so on. The usefulness of this example is identification of key variables and the level of them that can shape a decision.

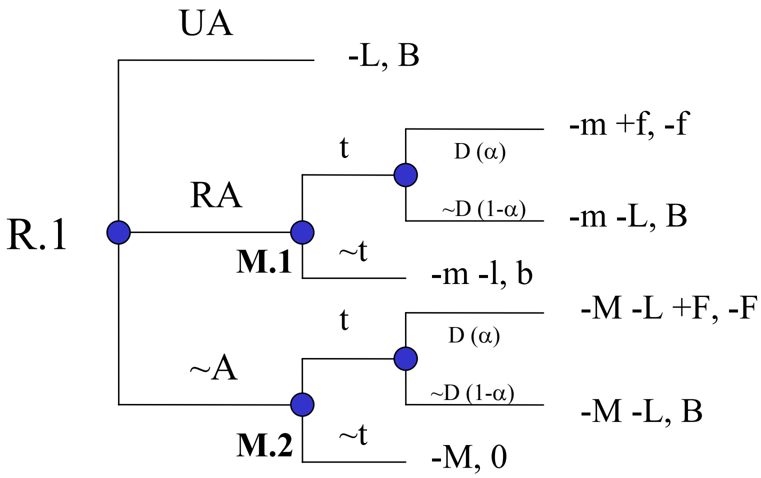
Let us now consider that complete exclusion is not the only scenario in which reserve adjacent communities can be immersed. The state, or the managers of the reserve, could have a continuum of possibilities ranging from uncontrolled access to total exclusion (Fig. 12).

Figure 12. Reserves and the continuum of resource use allowances



Merging Figure 11 and 12, we could construct a game with two players: the state (or managers of the reserve) and reserve adjacent communities (Figure 13). R.1 is the first and only decision node for the reserve managers (or the state) in this game and M.1 and M.2 are two different nodes for the members of the resource adjacent communities. For simplicity consider the three available strategies for the managers of the reserve to be 1) uncontrolled access denoted by UA, 2) regulated access denoted by RA and, 3) total exclusion denoted by ~A (no access). For the adjacent communities, consider the same available strategies at each decision node as those in Figure 11.

Figure 13. The Trespassing Game with two players



If the state decides to impose a policy of unregulated access, the reserve will bear a cost from the loss of resources (-L) and the adjacent communities will receive a benefit (B) from unregulated access to additional resources within the reserve[8]. If the state decides to regulate access, allowing uses that do not threaten the ecological stability of the reserve, the adjacent communities have two options, to trespass and carry out activities that are not allowed (t) or not to trespass (~t). If they trespass (t), and are detected (D), the reserve will bear the costs of monitoring illegal activities (-m) and will receive the level of the fine (f), whilst the adjacent communities will bear the cost of the fine (-f). If community members are not detected (~D), the reserve will bear the costs of monitoring (-m) anyway and the total losses from activities (L). In this case, the members of the adjacent communities will receive the benefits from the additional resources (B). If the communities do not trespass (~t), the reserve will bear the cost of monitoring (-m) plus a smaller loss (-l) due to allowed activities. The communities in this case will receive a smaller benefit due to the allowed activities (b). In the third strategy, if no access is allowed (~A), the reserve will carry the costs of monitoring for all types of activities (-M). The adjacent communities, if trespassing and detected, will receive the level of the fine (-F), minus the loss from additional resources (-L). If members are not detected (~D), the reserve will bear the no access monitoring costs

[8] Non-priced/non-marketed values could be incorporated to the payoffs of each alternative.

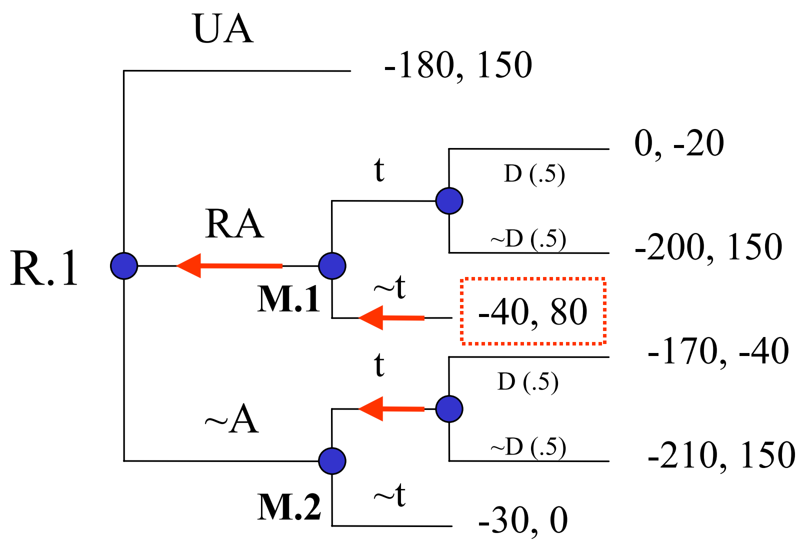
(-M) minus the loss from resources (-L). Communities in this case will receive the additional benefits (B). If adjacent communities do not trespass, the reserve will bear the monitoring costs of no access (-M) and the adjacent communities will remain under status quo conditions (SQ).

Let us give hypothetical numerical payoffs to solve for this game. Suppose that:

L = 180 B = 150 m = 20 f = 20 l = 20 b = 80

M = 30 F = 40 α = 0.5

Figure 14. The Trespassing Game with two players and numerical values



Solving by backward induction, in M.1 the best the member can do is not to trespass since her or his expected payoff from not trespassing is higher that that of trespassing:

Ep (~t) = **80** > Ep(t) = -20(0.5) + 150 (0.5) = -10 + 75 = **65**

If the member were in M.2, the best she or he can do is to trespass since the expected payoff from trespassing is higher than that of not trespassing:

Ep(t) = -40(0.5) + 150(0.5) = -20 + 75 = **55** > Ep(~t) = **0**

Given this preferred strategy for the community member, the best the reserve can do is to regulate access (RA) since the expected payoffs from regulating access are higher than those of unregulated access (UA) and higher than those of no access (~A):

Ep(RA/~t) = **-40** > Ep(UA) = **-180** > Ep(~A/t) = -170(0.5) –210(0.5) =
-85 –105 = **-190**

Note that if the state decided to completely restrict access (~A) the best response strategy for the community would be to trespass (t), the payoffs for these strategies being (-190, 55), yielding a negative joint payoff of –135.

Given the rules, available strategies and values for this game, the result will be to regulate access and not trespassing (RA, ~t) illustrated by a square. Note that the way in which the payoffs were given, the resulting pair of strategies is also the one that yields the higher social profits, since the joint profits of regulating access and not trespassing (RA,~t) are equal to 40, being the highest joint profit that can be achieved in this game.

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