Modelling the effect of learning and evolving rules on the use of common-pool resources

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Abstract: Whether common-pool resources are used and managed in a sustainable manner depends highly on incentives. Incentives influence the behaviour of individuals with respect to natural resource management and are determined by institutional arrangements including formal and informal rules and markets. Changes in institutional arrangements will affect individual incentives and will therefore have an impact on resource use.

To model the connections between institutional arrangements and the sustainable use of common-pool resources requires the consideration of individual behaviour. Some game-theoretical models appear to be an adequate modelling technique with which to assess the behaviour of individuals as well as the development of institutions in common-pool resource regimes. The implementation of a game-theoretical framework in the form of an agent-based model seems to be a particularly appropriate tool with which to assess common-pool resource use regimes as such models enable the behaviour of different agents to be modelled as strategies (eg: self-interest, collective-interest).

Traditionally with agent-based models, the strategies that agents pursue are given, determined by the set of rules, which govern their behaviour. In this paper we focus on the implementation of mechanisms that also allow for rules to adapt endogenously. Such an approach will be applied to common-pool resources use in order to analyse the effect of rule changes.

Keywords: Agent-based modelling, institutional arrangements, common-pool resources

1. Introduction

Common-pool resources are often confronted with the threat of being overused because they are defined by a low excludability of users and high subtractability of use. In situations where multiple users have access to the resource, individual behaviour determines if a resource is used in a viable way. Incentives for individual behaviour are defined by so-called institutional arrangements, including markets as sources for incentives, as well as boundaries for individual decisions. These *behavioural regularities* (Ostrom, Gardner and Walker 1994, 19) evolve from and depend on several drivers such as environmental conditions.

In the context of multiple-use, different interests come together and impact the common-pool resource considerably. These interests are based on different ways of resource use, which can have a preserving or an exploiting influence on the common-pool resource.

The elements of an institutional arrangement are linked by a complex system. Perturbations like environmental shocks or exogenous changes in statutory law affect these arrangements and the system must adapt to the new conditions. The aim of this paper is to describe how a predictive tool can be developed in order to evaluate the impact of such changes in institutional arrangements. This tool aims to simulate the use of common-pool resources in the context of multiple-use.

In section 2 the research project, in which this work is embedded, is explained. Section 3 discussed common-pool resources in the context of multiples-use. Section 4 gives an overview of the theoretical work on institutional arrangements, followed by section 5, where the individual dimension of agents and their adaptation process is discussed. Section 6 analyses the impact of links between individual, while section 7 brings the individual agents and their links together in a systems perspective and analyses the adapting dynamics of the structure. In section 8 agent-based models are specified for four games and the results of the scenarios are discussed. Section 9 draws conclusions from this work.

2. Case-study context

The project *Opportunities for the Australia Outback – Researching institutional arrangements in the North* (Greiner 2003 and Smajgl, Vella and Greiner 2003) analyses the existing institutional arrangements in the Outback of Australia using different case studies and develops a predictive capacity to evaluate the effect of possible changes. The analysis is conceptualised as a holistic approach in order to evaluate environmental and socio-economic impacts. Environmental impacts focus on multiple-use and multiple-user issues and include common-pool resources. Therefore, the concept of this project has a qualitative dimension in which a framework has to be developed with which to analyse institutional arrangements and structure the information gained from different case studies.

The problem of common-pool resources can only be analysed in a contextual way; every situation has different rules and incentives to govern the use of the resource. In an applied approach it means, for instance, that the users and the rules these users follow have to be identified, the common-pool resource and its biophysical dynamics

have to be understood, and the incentives driven by institutions like markets, categorised. For such a qualitative analysis, different approaches were developed, such as the Institutional Analysis and Development (IAD) Framework (Ostrom 1990, Ostrom 2003) and the Multiple Use Commons Framework (Edwards and Steins 1998).
The case studies will be located in small areas in pairs and they will have different institutional arrangements but similar environmental conditions (like rainfall) and *vice versa*. The quantitative dimension develops a predictive tool with which to process the data delivered by the case studies and structured by the qualitative framework. This predictive tool has to mimic these outback areas as systems considering environmental and socio-economic elements. In this paper we will develop a preliminary step for the development of this predictive capacity. For this purpose I will give an overview on research in institutional economics and develop from that point on a quantitative modelling approach.

3. Multiple users and multiple use

As described in section 2 our analysis is focused on land use in the outback of Australia. Land can be used in a variety of different ways, from planting crops, over grazing cattle, to pure transportation purposes. If a resource, in this case land, is used for different purposes (at the same time) we have a multiple use context. A multiple user context is defined if more than one person uses the resource for the same purpose. Multiple user scenarios are widely discussed and common-pool resources (CPR) are defined for multiple user situations. Generally, goods and resources can be categorised for subtractability and possibilities to exclude others, see Ostrom, Gardner and Walker (1994, 7). Common-pool resources are of special interest because the exclusion of others is difficult and subtractibility is high.
The case of multiple use *and* CPR is not the focus of current literature although the pressure on a CPR, described in the 'Tragedy of the Commons' (Hardin 1968) or in 'Governing the Commons' (Ostrom 1990), can include very different dynamics considering multiple use options. We will analyse the connection of multiple use opportunities and CPR in section 8 with the example of privately owned land that is used for grazing. All blocks of land are at a river and its riparian zone is crucial for the biodiversity in the whole region. It is obvious that biodiversity is a CPR. Additionally, we will consider tourism operators that try to locate areas for tours, which depend highly on the biodiversity of the region. Tourism as an income option becomes in this context a second CPR. The link between the two CPRs and the privately owned land is multiple use. The land owners act as *individuals*. All owners form together with the resource and the institutional arrangement the *system*.
In order to analyse institutional arrangements in the context of multiple use we first develop the theoretical background of institutional arrangements. After that we will focus on individuals and learning as their dynamic dimension, followed by the system in an evolutionary game-theoretical approach.

4. Institutional arrangements in a theoretical context

Institutional issues were for a long time not included in economic research as the main problem allowing a broad aggregation of economic entities and activities. Neo-classical approaches focused on the understanding of the fundamental context of market mechanisms and market results. For this reason these scholars were able to make restrictive assumptions about human behaviour. The rationally acting *homo oeconomicus* with perfect information dominated economic research. Young (1998) puts the focus of neoclassical theory in this way, “Neoclassical economics describes the way the world looks once the dust has settled; we are interested in how the dust goes about settling.” In other words, the world does not switch from one general equilibrium to the next; transitions exist, dust exists. These evolving interests changed the focus from this principle of general equilibria as an attractor, towards institutional aspects. Nowadays institutional theories provide some of the most important approaches used to explain economic issues.

This development commenced with Coase (1937) where the idea of transaction costs was introduced. Coase (1960) and Hayek (1960) improved the conceptual foundation to consider institutions in economic research. Since then several disciplines have had an important impact on the direction of institutional economics, namely philosophy, political science, and social science. While the New Institutional Economics provided a solid theoretical framework for the understanding of institutions and transaction costs, the focus shifted towards possibilities of applying this work. This shift paved the way particularly towards (evolutionary) game-theoretic approaches.

Coase (1937) begins with the organisation of market processes and addresses the question as to why companies organise some of their activities inside (‘make’ position) and others outside (‘buy’ position) of their organisational structure. Coase uses the existence and importance of transaction costs and institutions to explain the real world and stimulating economic research in a significant way. Williamson (1998) structures Coase work in a very useful way: In his paper ‘The Nature of the Firm’ (1937) Coase focuses on *institutions of governance*, which can be called the *play of the game*, while his paper ‘The Problem of Social Cost’ (1960) analyses the *institutional environment*, the *rules of the game*.

Williamson (1985) focuses on transaction costs and distinguishes between *Institutional Economics* (eg. Commons, 1931) and *New Institutional Economics*. He comes to the conclusion that “any relation, economic or otherwise, that takes the form of or can be described as a contracting problem, can be evaluated to advantage in transaction cost economic terms.” (Williamson 1985, 387) Therefore, according to Williamson all actions between different parties can be seen as transactions and these transactions result in costs.

Transaction costs have to be seen in connection with the *rules* those transaction follow, see Williamson (1998). North (1993b) defines institutions as “rules of a game of a society or formally [institutions] are the human-devised constraints that structure human interaction.” These rules can be formal, like statute law, common law and regulations, informal, like conventions, norms of behaviour or codes of conduct, or they can incorporate “the enforcement characteristics of both” (North, 1993c). Institutions exist because of the need to reduce transaction costs. This means that lower transaction costs are, the more efficient institutions work (North 1993c). The institutional framework defines the constraints for the maximisation of an organisation’s economic performance.

Institutional change may be a result of changes in formal rules or informal constraints. North (1993a) defines five propositions about institutional change:

- The key for institutional change is the interaction between institutions and organisations in a competitive setting.

- To survive in this competitive setting organisations have to invest in skills and knowledge.
- The institutional setting provides incentives that dictate the kinds of skills and knowledge perceived to have the maximum pay-off.
- Perceptions are derived from the mental constructs of the players.
- Economics of scope, complementarities, and network externalities of an institutional matrix make institutional change overwhelming incremental and path dependent.

In this approach organisations are groups of individuals, see North (1993b), and can be political bodies, economic bodies, social bodies, or educational bodies. As mentioned previously, competition is a crucial aspect for the development of institutions. "While learning is a result of curiosity, the rate of learning will reflect the intensity of competition amongst organisations"(North 1993b, 6). The concept of learning will play a critical role in a later stage of this paper. In addition, North (1991 and 1997) emphasises the importance of *path dependency*: Whereby the cultural heritage and the specific historical experience of the economy determines institutional change. "Changing merely the formal rules will produce the desired results only when the informal norms are complementary to that rule change, and enforcement is either perfect or at least consistent with the expectations of those altering the rules " (North 1997, 3).

Williamson (1985) identifies three variables as the main drivers for transaction costs: asset-specificity, uncertainty, and frequency. These variables provide two essential drivers for another research field within the area of institutional economics: the focus on property rights and contracts. The fact that asset-specific investment decisions have to be made under uncertainty leads to the possibility of investment protection. These drivers are highly relevant because in most cases information is unequally distributed; one party has more information than the other one. This leads to a closer view on contracts, see, for instance, Williamson (2000). In order for it to be feasible to have different possibilities to securing investment we must assume that there are visible differences in owning property and the kind of rights, which are connected to this ownership. Demsetz (1967) and Aichian and Demsetz (1972 and 1973) founded the basis for property rights theory.

Demsetz (1967) states that "property rights specify how persons may be benefited and harmed, and, therefore, who must pay whom to modify the actions taken by persons." With this definition he develops the concept of distinguishing the need for property rights from that of the existence of externalities. This allowed Demsetz (1967) to develop a dynamic definition of property rights as they change in order to minimise externalities in a dynamic environment. These externalities can be seen in an inter- or intra-generational perspective, similar to the concept of sustainable development. If the community owns the property, it is possible that present generations may overuse the connected resources as future generations are underrepresented in decisions about the intensity of use. In addition, the presence of multiple-users can increase transaction costs in a dramatic way, especially by creating free rider problems (see Aichian and Demsetz 1973), and undermining negotiations about the optimal use.

At the same time however, private property can cause various investments not to be undertaken if they are outside the range of the perspective of an individual. The greater the numbers of private owners, the higher transaction costs are to arrange investment that increases the overall benefit. Property rights will be modified over time in such a way so that “negotiating and policing costs will be compared to costs that depend on the scale of ownership, and parcels of land will tend to be owned in sizes which minimize the sum of these costs.” (Demsetz 1967, 358) These aspects are considered in Aichian and Demsetz (1973) from another perspective, whereby the value of an organisational structure is equated with the transaction costs it saves. This approach corresponds with Coase’s (1937) initial theory that as a result of the existence of transaction costs, (different) organisations exist.

The theoretical discussion provides the understanding of institutions. An applied analysis of a real-world case illustrated in the project described in section 2 requires not only the ability to analyse a situation qualitatively but also a base for a simulative capacity with which to evaluate effects of changes. This simulative dimension is covered by different quantitative approaches. For instance, Johnson, Kaufman and Zoido-Lobatón (1999), Hellman and Kaufmann (2003) or Beck et al. (2000) use econometric instruments to work on different elements of institutional arrangements in order to measure the quality of institutions. Another approach is the modification of game-theoretic approaches for institutional issues. In this paper we will focus on agent-based models. Before we develop the game-theoretical framework for our model, we discuss in the following section, the question about how to model individuals and their behaviour as defining agents in a game is a crucial step.

5. Micro-level: Learning and adapting individuals

The field of constitutional economics is related to political economics, public choice theory or public law and implements the normative perspective on market behaviour and results. A core question is, as cited above, “Why do persons choose rules that seem to constrain or limit their choices?” (Buchanan and Yoon 1999, 1). Rawls (1971) developed the theory of justice as fairness, used in the first framework of this research field, by analysing the normative perspective of action choice. Normative means that there is a perception about ethically right and wrong behaviour, which is mainly defined by Rawls’ criterion of reciprocity:

> “Citizens are reasonable when, viewing one another as free and equal in a system of cooperation over generations, they are prepared to offer one another fair terms of social cooperation... and they agree to act on those terms, even at the cost of their own interests in particular situations, provided that others also accept those terms. For those terms to be fair terms, citizens offering them must reasonably think that those citizens to whom they are offered might also reasonably accept them.” (Rawls 1996, XLIV)

This approach has to be seen in the tradition of Kant who founded the theory regarding the deduction of ethical principles from rationality. On this theoretical basis stands also the Frankfurt School of thought, with popular representatives like Adorno and Habermas, and Luhman, who founded the system theory. This German scholar emphasises the difference between action as individual behaviour and rules or, as Homann (1997) defines it, between the constitutive and the operational level. Economic incentives only determine rules directly and not the action of an individual that underlies the rules in this approach, strictly. This means that individual behaviour is bound to rules and as they are complementary to economic incentives, the rules are self-enforcing. The reliability of individual behaviour is therefore not given by the moral commitment of the individuum as Kant defined, but by the definition of complementary rules, see Homann (1997).

This approach implements the same mechanism that the game theoretical approach develops and states, as Hobbes points out in Leviathan, that a rule can only be enforced if all parties accept the rule. This theory confirms the context of path dependency described by North (1997), mentioned above. As Homann (1997) states, the normative validity of a rule depends on sufficient implementation and it is the implementation that provides the validity.

The question is how can rules be influenced or created that are acceptable and at the same time allow a sustainable use of common-pool resources. Firstly, it has to be stated that the concept of sustainability was developed from the tradition of social justice, which was primarily moulded by Rawls. Secondly, the individual acceptance depends on individual goals. Most economists help themselves and simplify reality by assuming a *homo oeconomicus*. But as we have seen above, constitutional economics allows a broader view on the motivation of individual behaviour. Schramm (1997) gives a systematic view of the different approaches on the extent to which individual behaviour is dominated by economic incentives or ethical considerations and states that there is no consensus on this in normative theories.

This makes it difficult to step from a normative analysis to a positive one and it is no surprise that Voigt (1997) concludes that there has not been a great deal of research done in positive constitutional economics. However the comparison of alternative institutional arrangements requires a positive approach: “Comparing institutional analysis asks how alternative institutional arrangements effect (economic) outcomes.” (Voigt 1997, 19) This does not mean that only existing institutional arrangements can be compared but comparisons may also be made to possible arrangements with an empirical reference, as developed by laboratory settings. An essential element in such an empirical approach must be the evaluation of individual behaviour and the extent to which it is driven by economic incentives on the one hand and ethical considerations on the other. Without this knowledge the definition of complementary rules would be part of a trial-and-error process.

Buchanan and Tullock (1962) state that every individual will try to minimise its’ own costs in the choice of an institutional arrangement: “For a given activity the fully rational individualist, at the time of constitutional choice, will try to choose that decision-making rule which will minimize the present value of the expected costs that he must suffer.” (Buchanan and Tullock 1962, 70) This approach shows a clear emphasis on economic incentives in the individual’s action choice. Buchanan and Tullock limit this optimisation behaviour not only to material goods but include also immaterial effects and thereby explain institutional/constitutional aspects using economic mechanisms. The individual decision weighs up reduced possibilities and increased conditions. In later works Buchanan shifts from a position dominated by *homo oeconomicus* to a morally constrained one (bounded rationality).

Buchanan and Yoon (1999) state that there are three reasons for individuals to create rules. The first one is to reduce the temptation to behave how the individual feels they should not behave. The second reason is to reduce the complexity of the decision making process. The third reason is to “constrain collective actions that might be undertaken without the explicit consent of the individual who evaluates her role as a participant in post-constitutional politics.” (Buchanan and Yoon 1999, 211) This dynamic perspective gives a significant meaning to constituting the institutional arrangement from an individual perspective. An alternative approach is presented by Hayek (1973 and 1979), who defines rules pertaining to institutions as the result of cultural evolution. The connection between the community level of (cultural) evolution and the level of individuals is obvious. Therefore we analyse in the

following section learning mechanisms on the individual's level and interpret them as a driver for the evolution of rules at a community level.
Evolution of rules refers to the incorporation of individual incentives (long-term and short-term optimisation). On the basis of their objectives, individuals perceive their environment and changes to their environment and they *learn* to recognise particular elements, how these elements are connected and where the drivers are. Therefore, an applied model has to implement a context-specific learning mechanism. Learning can take place on an individual level or on a group level.
The three elements Tesfatsion (2001, 292) lists point out two levels and, as the core point of this analysis, the link between the two of them. The *agent adaptation* is focused on the dynamics at an individual level. *Learning* incorporates the process of delivering the feedback from the system to the individual. The *evolution* of a system requires the analysis of drivers of a change of this system, for instance, the institutional arrangement. The latter point includes the feedback coming from the individual level, as individual's behaviour is a main driver for a change in the system. Young (1998) puts his analysis of learning under the title "Individual Strategy and Social Structure" which describes the same levels.
In reality this is an ongoing process of (1) signals perceived and processed by the individual and (2) feedback given to the system which is processed on that level and produces changes. Crucial for the application of agent-based models in real-world case studies is the definition of these two dynamic mechanisms. Before we discuss the possibilities to define mechanism (2) we will discuss the different learning mechanisms, which defines point (1).
Young (1998, 27-28) summarises the variety of learning mechanisms into four main groups. *Natural selection*, describes an evolution where those agents with high payoffs have a higher population than those agents with low payoffs and this is modelled in so-called replicator dynamics. *Imitation* means that agents copy successful strategies of other agents and focuses more obviously on the agent's decision-making process rather than on natural selection. Regardless of other agents' behaviour, *reinforcement* dynamics are based on the agent's own payoff. This mechanism defines the experience link between the chosen strategy and the yielded payoff of an agent for their present strategy choice. The fourth learning mechanism is *best reply* in which the agent compares the outcome of different combinations of their own strategies with those of other agents in so-called *fictitious plays*. This mechanism implements very different approaches regarding how far the agent is able to forecast and process another's strategies.
Fudenberg and Levine (1998) give an overview of different mechanisms of so-called *sophisticated learning* mechanisms. An essential approach for our problem is the consideration of *reputation*. Reputation describes a mechanism where by past actions of an agent determine the expectations held by other agents. Additionally, reputation can describe a situation where one agent behaves in a myopic fashion and the other agent has a competent understanding of the effects the strategies that both agents have of the system.

	A	B
A	10/10	0/0
B	0/0	1/1

The sophisticated agent will try to teach the other agent to choose strategy A, which maximises the payoff of both players. In a Stackelberg game A/A would be the solution for all periods if the rational player moves first. Fudenberg and Levine (1998, 264-266) demonstrated that this outcome depends highly on the difference between the payoffs of A and B as well as on the behaviour of the myopic agent. In a noisy environment – the myopic agent tends to randomise their strategy choice – it becomes reasonable that both agents behave myopically.

The existence of a rational player simplifies the game and its learning mechanism. Kreps and Wilson (1982) analyse a game with reputation and imperfect information. In a game where a possible entrant faces a monopolist and the entrant doesn't know about the monopolist's payoff function, beliefs become a function of the monopolist's reputation. The equilibrium of the game depends highly on beliefs and Kreps and Wilson (1982) show that solutions like the chain-store paradox[1] (Selten 1978) only appear when the reaction of the monopolist is defined as common knowledge. Under imperfect information other equilibria result. While Fudenberg and Levine (1998) give a broad overview on existing learning mechanisms, Chen and Khoroshilov (2003) focus on learning under imperfect information. Their simulations show that the implementation of beliefs, like in experience-weighted attraction learning in Camerer and Ho (1999), leads to less stability than in reinforcement models because the agents keep all strategies over all stages active. Camerer and Ho (1999) formulate with their learning mechanism a bridge between fictitious games modified with weighted beliefs and reinforcement models. This approach defines the strategy choice as a function of expected payoffs. These expected payoffs depend on (1) the periodical payoff as a function of their own strategy and the strategies chosen by the other agents, and (2) the agent's belief. This belief depends on the strategies the agent perceives other agents have chosen.

Oechssler and Schipper (2003, 137) point out what Harsanyi (1967, FN2) stated much earlier; there is for more extensive research done in the field of (learning with) imperfect information than (with) incomplete information.[2] Our problem falls into the category of incomplete information.

With the goal of modelling real-world learning processes, some analyses try to find learning mechanisms for games with incomplete information and mixed strategies with the help of experiments. Such approaches look for patterns to describe dynamics in observed data. Erev and Roth (1998) develop a reinforcement mechanism and combine it with *forgetting* and *experimenting* to explain changes in the strategy choice of agents. Sarin and Vahid (2001) work on the same data as Erev and Roth (1998) and develop a simple repeated game to explain the learning process. Oechssler and Schipper (2003) collect their own data in experimental situations, focussing on the approach of Kalai and Lehrer (1995) to define subjective Nash equilibria. In such a subjective view one agent can realise a single equilibrium while another agent perceives multiple equilibria. Following this approach, the main question is whether or not agents learn to perceive a game correctly. Their experiment compared the ability of agents to guess the payoff function of the other agent over the range of different games. Although this ability often does not seem to be very high, the games are close to Nash equilibrium. This is important for our problem, as according to Aoki (2001) a rule is established in form of equilibrium. Oechssler and Schipper (2003)

[1] The chain-store paradox describes the game between a monopolist and an entrant. Assumed that fighting the entrant is combined with negative payoff, the monopolist won't fight in the last stage of a finite multi-stage game. Rolling backwards this argument is valid for every stage of the game and the monopolist doesn't fight the entrant and the entrant enters. (Selten 1978)

[2] "The distinction between games with *complete* and *incomplete* information (between C-games and I-games) must not be confused with that between games with *perfect* and *imperfect* information. By common terminology convention, the first distinction always refers to the amount of information the players have about the *rules* of the game, while the second refers to the amount of information they have about the other players' and their own previous *moves* (and about previous chance moves)."(Harsanyi 1967, FN2)

compare the reinforcement learning in Erev and Roth (1998, 859-862) with that of Sarin and Vahid (2001) and find that both describe their data reasonably well.
In addition to learning about other agents, individuals learn by perceiving and processing effects of nature. Dekel, Fudenberg and Levine (2002) focus on learning about nature's moves and on the existence of equilibria. Modelling a real-world situation means that individual learning has to implement an agent's own and others' behaviour as well as nature's moves. Before an agent-based model will be specified the following section provides a game-theoretical base.

6. Connectivity: Games, rules and strategy

In this section we will use game theory to analyse institutional changes and develop a quantitative method to formulate simulative capacity with which to evaluate policy decisions. Game theory primarily uses the expression rules according to strategies. Every agent has an action choice, which contains the different strategies the agent can choose from.
Harsanyi (1967) uses rules as a term for the model specifications, which comes close to the definitions given above. He uses rules to define the difference between games with complete and incomplete information: They differ "in the fact that some or all of the players lack full information about 'rules' of the game… For example, they may lack full information about other players' or even their own payoff functions, about physical facilities available to other players or even themselves, about the amount of information the other players have about various aspects of the game situation, etc." Harsanyi (1967) use of rules is on a different level to that of strategies and his rules correspond with those of Coase (1960) and North (1993b).
By this definition, rules and norms are seen to be on a higher level than strategies as rules and norms are defined by a group rather than on an individual level. While a strategy can be "Pump 20 l/min" and another one "Pump 100 l/min" a rule has the form "No individual is allowed to pump more than 50 l/min at all times from aquifer X or else he gets fined by local police". Formal and informal rules restrict the individual action choice.
Crawford and Ostrom (1995) define in their *Grammar for institutions* a general structure of rules for institutional statements. These are built from the elements of *attributes*, *deontic*, *aim*, *conditions* and *or else*. Their examples is (see Crawford and Ostrom 1995, 584)

attribute	deontic	Aim	conditions	or else
"All villagers	must not	let their animals trample the irrigation channels	at all times	or else the village who owns the livestock will be levied a fine."

Mittenzwei and Bullock (2001, 10) add the enforcing mechanism as a sixth element:

attribute	deontic	aim	conditions	or else	enforcing
"The landlord	must	pay a reward r^2=*ay*+*b* to the peasant	conditioned on the peasant's output y	or else the landlord has to pay a fine c	being levied by a court."

These rules restrict the individual strategy choice, which leads to the question in Buchanan and Yoon (1999, 1.) "Why do persons choose rules that seem to constrain or limit their choices?" If, for instance, the short-term optimising view of individuals has an ecological footprint, which does not conform to social preferences, institutional arrangements like rules will be formed to avoid unsustainable behaviour. Ostrom (2003) structures rules in a very useful way by stating that rules have to be seen in the

context of (1) *enforcement* and (2) *moral behaviour*. Enforcement is the essential point Eggertsson (1997) sees for individual behaviour. Harsanyi (1969) delivers another useful definition of the two core drivers for incentives: "People's behaviour can largely be explained in terms of two dominant interests: economic gain and social acceptance." Fehr and Falk (2002) point out the importance of the social approval of individual behaviour and stress the importance of feedback effects as the presence of approval motives may lead to permanent negative effects on rule compliance. Feige (1998, 8) and Leitzel (1997) point out that formal rules can be perceived as bad rules. This maintains an essential dynamic because, as Aoki (2001) states, changes in institutional arrangements are (merely) caused by disequilibria if incentives for individuals don't match with formal (or informal) rules. This may lead to a process that changes the formal (or informal) rule. The institutional arrangement defines how this disequilibrium is solved, and, how the level of individuals transforms the group level.
The three main questions are therefore:

- What preferences do individuals have?
- How are these interests organised on a group level?
- How are these rules enforced?

The first question is in the domain of constitutional economics and was discussed in section 5. The second question refers to the process of formulating informal and formal rules, while the third question is concerned with the organisation of the rules' enforcement. While we assume for our case that the enforcement of rules happens endogenously in a small system by social pressure and monitoring is not necessary, the following section focuses on the second point, the evolution of rules.

7. Macro level: Evolving rules and adapting systems

Games based on common-pool resources focus primarily on user behaviour. Game-theoretic literature covers varied implementations of behavioural change. One scholar defines it as a dynamic game with incomplete information, and they analyse questions like moral reputation, moral hazard or signalling. The second scholar follows the biological interpretation of evolutionary games. Friedman (1991, 637) defines evolutionary games as games where "each individual chooses among alternative actions or behaviours whose payoff or fitness depends on the choice of others. Over time the distribution of observed behaviour in a population evolves, as fitter strategies become more prevalent."
The dissimilarity between the two approaches is expressed quite differently by a number of authors. Friedman (1996, 1) points out that "Strategic interactions over time can be modelled as an evolutionary game if the players do not systematically attempt to influence other players' future actions and if the distribution of players' action changes gradually." However, Gintis (2000, 211) sees the difference through another perspective: While traditional game theory analyses, for instance, the fight between a predator and its prey, evolutionary game theory focuses on how predators "fight among themselves for the privilege of having their offspring occupy the predator niche in the next period and improve their chances by catching more prey." In this sense the same game can be set up in an evolutionary way. As our main focus is institutions (equilibria) as an effect of changes in behaviour, Fudenberg and Tirole (1991, 28) give a relevant statement on the application of Nash equilibria: "It can be

used to discuss the adjustment of population fractions by *evolution* as opposed to learning."

In our game with common-pool resources the rules evolve on a Meta level. As rules determine the availability of strategies, the action choice evolves according to equilibria at the level of rules. While this Meta level is modelled in an evolutionary process the individuals change their knowledge, attitude and expectation in accordance with their learning. For this reason learning was discussed as an overview in section 5. In this section we will stay at the level of *rules of the game*. If the aim is to interpret equilibrium (as the outcome) of a game as an institution, we have to acknowledge the existence of two different equilibrium concepts, the Nash equilibrium and the Evolutionary Stable Strategy (ESS).

Maynard Smith and Price (1973) and Maynard Smith (1982) combine the mathematical approach with the biological perspective and develop an evolutionary concept of equilibria in games. Species have strategies in the form of their genotypic variants and in repeated, random pairing of players an (evolving) equilibrium results. Perturbations occur by mutations. A strategy (genotype) is evolutionarily stable if the mutant cannot invade the species. Taylor and Jonker (1978) proved that an ESS is sufficient for stability in dynamic games. Young (1998, 44-65) discusses dynamic and stochastic stability of such equilibria and Gintis (2000, 150) provides the link to traditional (and modified) Nash equilibria: "A Nash equilibrium in an evolutionary game can consist of a *monomorphic* population of agents, each playing the same mixed strategy, or as a *polymorphic* population, a fraction of the population playing each of the underlying pure strategies in proportion to its contribution to the mixed Nash strategy."

Friedman (1996) analyses experimental results of equilibria in evolutionary games. He uses the Hawk-Dove game and confirms the assumed small group effect that agents will seldom try to influence the other agents' behaviour. Kantian behaviour (behave how you expect others to behave – cooperative attitude) dominates games in groups with up to 6 persons playing Prisoner's Dilemma. (At the same time this experiment shows when *large games* begin.)

The discussion of equilibria leads to the core point of institution modelling. This step analyses the possibilities of interpreting equilibrium as a rule. While most of the work on institutional patterns assumes rules to be given (exogenously), game-theoretical approaches, especially the evolutionary field, focus on dynamic aspects of institutions and assume that rules are the result of behaviour. This means that a rule can be defined technically as equilibrium of the behaviour of different agents. Excellent introductions to the game-theoretic approach of institutional economics are Aoki (2001) and Young (1998).

Hurwicz (1994) sets up a non-cooperative multi-stage game with a finite number of moves and *n* players and uses the resulting decision tree in the extensive form game to show how end nodes and branches can be used for institutional reasons. Branches can be used to analyse transaction costs, while end nodes demonstrate which moves result in a Nash equilibria.

Mittenzwei and Bullock (2001) build on this approach and set up a similar game, which they call Game with Institutions. In their approach an institution player exists and is dealt similar to *nature* as a non-player. The game is defined on three levels: The first level is called institution forming, the second institution applying, and the third, institution dependent. Players and Nature play on the first and third level, while the institution player plays (strategically) on the second level. An institution is presented as the strategy, the institutional player makes their choice on the second level which then determines the action choice on the third level and therefore also (together with Nature's move on level three) the players' outcome. The location of the driver for the institution player and the strategies this non-player can choose from remain open.

Aoki (2001, 10) characterises institutions as "a self-sustaining system of shared beliefs about a salient way in which a game is repeated." With this approach he distinguishes between the equilibrium-of-the-game view, which is based on evolutionary game scholar, from the rules-of-the-game scholar (for instance Hurwicz 1994) that dominates the theory of New Institutional Economics described above.

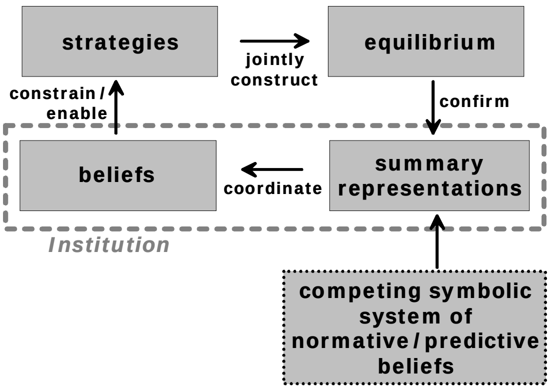


Figure 1: Game-theoretical approach to systemise institutions, see Aoki (2001)

Aoki (2001) visualises this evolutionary approach by Figure 1. Institutions are constituted by beliefs of agents and are (partially) coordinated by summary representations. Summary representations stand for compressed information which agents take as given. On the basis of these beliefs the agents chose their strategies, in other words, the strategies are constrained by the beliefs. Jointly the strategies of all agents constitute equilibrium. This equilibrium of agreed strategies confirms the summary representation (compressed information).

The sets of environments $\hat{\mathrm{E}}$, with $\varepsilon \in \hat{\mathrm{E}}$, and the environment-dependent equilibrium paths $s^*(e)$ and $s^{**}(e)$ are represented by the compressed information (summary representations) Σ^* and Σ^{**}. The equilibrium path $s^*(e)$ or $s^{**}(e)$ is generated by the summary representation Σ^* respectively Σ^{**} and 'residual private information' $I_i^*(s^*(e))$, with $I_i^*(s^*(e)) = \sum_i^* s^*(e) \sim \Sigma^*$. In this process the equilibrium paths themselves reaffirm the compressed information Σ^*, which reproduces the institution. In this dynamic the institution becomes self-sustaining on $\hat{\mathrm{E}}$. The agents have no direct control over institutions. The summary representation (compressed information) coordinates the agents' expectations and helps them to find the 'corresponding' strategy (action choice).

But what if the results of each game are not in accordance with expectations? This can occur as a result of external shifts such as technological innovations, environmental threats, by internal cumulative issues from distribution effects (eg. power, assets) or mutant strategies. Aoki uses this argument to differentiate the subject cognition (which defines the subjective stage of the game) from the general cognition. If enough expectations differ from the games' result it is possible to get a general cognitive disequilibrium. Such disequilibrium instigates the search for new strategies. These new strategies are in contradiction to the shared beliefs and through this learning process, new institutions are developed based on subjective game models.

8. Model specification and scenario results

8.1. General approach

Based on the evolutionary game-theoretical approach, we develop in this section a model for the context of CPR and multiple use issues. In order to develop simulative capacity for a real-world situation we do not describe the decision making process by differential equations (see for this area of game-theory Fudenberg and Tirole 1991, 521; or Gintis 2000, 164-187)) but using an agent-based (or rule-based) approach.
Agent-based models (ABM) or agent-based computational economics (ACE) allow analysis of “evolving systems of autonomous interacting agents” (Tesfatsion 2001, 281). As Deadman (1999, 161-162) points out, ABM defines a bottom-up approach and instead of defining the overall behaviour “this overall behaviour emerges as a result of the actions and interactions of the individual agents.” The modeller defines the initial conditions of the game, which includes, for instance, how many agents exist in the first period, and how much of a common-pool resource is available. Critical for the specification is the definition of strategies for each of the agents (action choice) as well as the if-then conditions. “The result is a complicated dynamic system of recurrent causal chains connecting agents’ behaviours, interaction networks, and social welfare outcomes” (Tesfatsion 2002, 1). In-depth descriptions of ABM can be found in, for instance, Holland and Miller (1991) and Holland (1992).
In this approach we will apply an agent-based model to mimic the evolution of rules as institutions and include the context of multiple use. Crucial for our problem is the mechanisms that drive the dynamics of the system, which includes the common-pool resource. Tesfatsion (2001, 292) raises in this context an important question: “How should agent adaptation, learning, and evolution be constructively represented in these artificial economic worlds?” We worked in the previous sections on these three elements placed on two levels. In the following part we will define an agent-based model for the project, described in section 2.

8.2. Context

As we focus our modelling exercise on multiple-use issues in combination with a common-pool dilemma, we have to include diverging interests in the use of one resource. In this case we assume the scenario of six ranchers leasing blocks of land along a river in Australia’s outback. The leases are long-term leases of twenty years and give the owners property rights regarding land use, whereby water resources are excluded. Seasonal rainfall varies and has a significant impact on the carrying capacity for cattle on the paddocks. All ranchers are part of a local community and connected by a social network. Seasonal rainfall leads with a high likelihood to river flooding which enriches the ecological system along riparian zones. Unfenced vegetation in riparian zone also attracts grazing cattle and diminishes rapidly the variety of plants, which leads to an erosion of the rivers bank and has a negative accumulative impact on biodiversity issues. Apart from this, the riparian zones biodiversity in this Outback area also depends on the vegetation in the paddocks. Overgrazed paddocks mean a direct decrease of biodiversity (flora) and may lead indirectly to a decrease in fauna such as emus and brolgas.
An increasing amount of tourists along the east coast of Australia has lead to the development of additional strategies in the tourism sector. Outback activities like wildlife spotting, embedded in longer overnight trips, appears to be a promising emerging niche. As these activities require no stationary investment and depend on

buses and tents only, the tourism operators are highly mobile and choose those areas with the best wildlife – including icon species – and areas with more cooperative land owners.

8.3. Formal description

Agents and strategies

Generally, the i agents with $i = 1,..,n$ have a strategy choice Σ_i^t with $s_{ij}^t \in \Sigma_i^t$ and $j = 1,..,m$, with m as the number of strategies. In a multi-stage game the agents move simultaneously (normal form game). The two main control variables in the action choice of the agents are 'fencing the riparian zone' FC_i^t and 'number of cattle' L_i^t. All ranchers start with 'no fencing' as fencing is linked with costs of \$1,000. The ranchers have to decide before the start of the wet season on the number of cattle. Their decision is based in this first instance on last year's rainfall. We assume a rainfall indictor Ψ^t from 0 (no rain) to 150 (heavy rainfalls). In this community it is common knowledge that each paddock can carry a livestock level of 600 cattle at an average rainfall indicator of 75. Each rancher needs a minimum livestock level of 200 cattle to secure the minimum income for their family. Even in very wet years the paddocks cannot carry more than 1,000 cattle. Therefore, the ranchers' decision (before learning takes place) follows

$$L_i^t = \begin{cases} 600 + 200 \cdot \left(150 / \left(\Psi^t - 75\right)\right) & \text{if } \Psi^t \neq 75 \\ 600 + 200 \cdot \left(\Psi^t - 75\right) & \text{if } \Psi^t = 75 \end{cases}$$

The riparian zone RZ_i^t is a function of the livestock on the paddock in the previous period L_i^{t-1} and the binary variable 'fencing' FC_i^{t-1}.

$$RZ_i^t = \begin{cases} RZ_i^{t-1} - 0.5 \cdot L_i^{t-1} + \Psi^t - RZ_i^{t-2} & \text{if } FC_i^{t-1} = 0 \\ RZ_i^{t-1} + 5 \cdot \Psi^t - RZ_i^{t-4} & \text{if } FC_i^{t-1} = 1 \end{cases}$$

Common-pool resource

The common-pool resource biodiversity at the beginning of the next period Θ^{t+1} is a function of the chosen strategies, Nature's (stochastic) move Ψ^t and the biodiversity level in the current period Θ^t; $\Theta^{t+1} = f\left(s_{ij}^t, \Psi^t, \Theta^t\right)$. As the agents' strategy choice is based on the two control variables, fencing and livestock, we can define a specified function of Θ^t: We assume biodiversity to be a function of the riparian zone RZ_i^t, the livestock on the paddock L_i^t, rainfall Ψ^t and the binary variable 'fencing' FC_i^{t-1}.

$$BD^t = \begin{cases} 0.85 \cdot BD^{t-1} + \sum_{i=1}^{n}\left(RZ_i^t - RZ_i^1\right) + \sum_{i=1}^{n}\left(100 \cdot \Psi^t - L_i^t\right) & \text{if } FC_i^t = 0 \\ BD^{t-1} + \sum_{i=1}^{n}\left(RZ_i^t - RZ_i^1\right) + \sum_{i=1}^{n}\left(100 \cdot \Psi^t - L_r^t\right) & \text{if } FC_i^t = 1 \\ 0 & \text{if } BD^t \leq 0 \end{cases}$$

In case of unfenced riparian zones, biodiversity accumulates at a lower rate of 0.85. The second term describes the influence of the riparian zone; a decrease of riparian vegetation has a negative impact in biodiversity and an increase compared to the starting value of 1,000 has a positive impact on biodiversity. As a maximal vegetation

of riparian zones we restrict the index to 5,000 and the minimum to 0. The third term includes the stochastic impact of *Nature*'s move and the density of cattle in the paddock. Therefore, we implement the block of land itself as the second part of the ecosystem apart from the riparian zone. The maximum amount of livestock on all paddocks and no rainfall, depletes the basis for other species, while the minimal livestock and maximal rain biodiversity has a positive affect. In case of fenced riparian zones we assume a higher accumulation effect of 1. The two following terms remain unchanged. Essentially, the biodiversity is based on all paddocks as we can assume an interactive ecosystem. Therefore, it becomes a common-pool resource for the ranchers in this community.
As a second CPR we consider potential tourism activities in the region. Tourism activities depend on the expected wildlife, whereby we assume that the operators get their information retrospectively for the last period. We define the reaction function in four stages:

$$TA_i^t = \begin{cases} 0 & \text{if } \quad BD^{t-1} \leq 1{,}500 \\ 26 \cdot 10 & \text{if } \; 1{,}500 < BD^{t-1} \leq 2{,}500 \\ 52 \cdot 20 & \text{if } \; 2{,}500 < BD^{t-1} \leq 4{,}500 \\ 104 \cdot 25 & \text{if } \; 4{,}500 < BD^{t-1} \end{cases}$$

Tourism activities TA_i^t are measured on a paddock scale. Operators offer tours in the regions twice a week. For the size of the paddocks in this case the operators see a maximum carrying capacity of two big busses per week. They plan an average of 25 tourists per bus for locations with excellent biodiversity and 20 for a location with good biodiversity and 10 for locations with average wildlife. The tourism operators try to access excellent locations twice a week, paddocks with good biodiversity reputation once a week and paddocks with an average biodiversity index fortnightly. As tourists stay five days the farmer can claim in average $100 per tourist and guarantees therefore help in emergency and a visit to the farm. We assume strategic behaviour for tourism operators. As they are interested in a better product they only visit paddocks with fenced riparian zones.

Learning
At the beginning of every period the agents observe their own payoff of the last move π_i^{t-1}, Nature's move Ψ^{t-1} and the condition of the common-pool resources BD^t and TA_i^t. After several moves agents realise that their payoff function is $\pi_i^t = f\left(s_{ij}^t, \Psi^t, TA_i^t, BD^t\right)$ and, as $BD^{t+1} = f\left(s_{ij}^t, \Psi^t, BD^t\right)$, that tomorrow's payoff depends on the strategies of all i agents in t.
As a result of this (best reply) learning process, agent i may want to influence other agents' behaviour whose strategy choice has a negative external effect on i's future payoff. One option is to influence the other agent in the form of reputation (see above). Let us assume that there are six agents. Two green ranchers (GR: #5-6) are willing to protect environmental issues like riparian zones as long as their income is high enough to maintain their land. The second type of rancher is money oriented (MO: #3-4) which means that if environmental protection helps increasing their profit they, for instance, fence riparian zones. The differences between GR's and MO's are (1) that Mo's have no interest in environmental issues for their own sake and (2) that MO's learn slower about environmental issues. The third type of ranchers are conservative and very risk avers (CR: #1-2).

As the attitude of the unsustainable agents do not allow a reaction on reputation as an additional learning process, the green agents flag their dissatisfaction with the rules that allow the unsustainable agents to overuse the resource. Let us emphasise this important mechanism: In the first moment, the green agents are discontent with the behaviour of MO's and CR's but the learning process shows them that it is the rules that allow the other agents to behave in an unsustainable way. The flags reduce the fitness function of the rule that is connected with this particular behaviour and (supposed that there is a majority system established as part of a democratic structure) when the majority turns the rule down it will be replaced.
At this stage we have to formalise the three main attributes, *expectation*, *attitude* and *knowledge*. Expectations are implemented as a set of beliefs Ω_i^t that are subjective and can change in time. Beliefs exist for Nature's move, the future condition of the common-pool resource and the other agents' strategy, $\Omega_i^t = f\left(\Psi^t, BD^t, TA_i^t, s_j^t\right)$. As the learning process drives the evolutionary process on the group level, and the individual attitude is a dominant element for individual behaviour, this belief definition has to be refined. Attitude Φ_i is a long-term element with important meaning for the dynamics and we assume that it won't change in time (and therefore has to be treated as a parameter). This assumption implements *path dependency* (see North 1991 and 1997) in such ways that knowledge does not change the behaviour immediately, but includes attitudes as slow moving (in this case constant) variables, which works like a filter for perceived information.

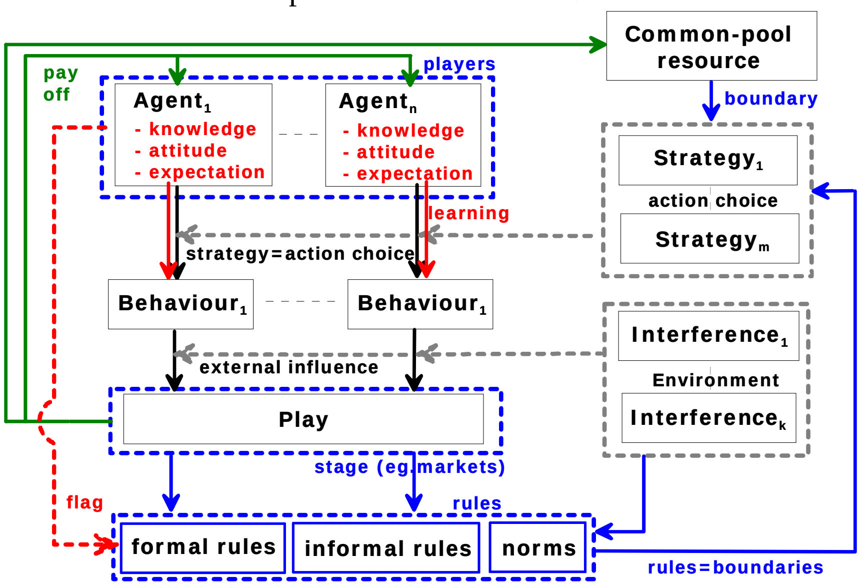


Figure 2: Agent-based conceptualisation

The essential influence of attitude is in the perception of new information. New information might be accepted as correct but if the agent's goal is, for instance, connected with a short-term optimising strategy, any information about long-term effects might be ignored if the agent's utility function contains only profit. Section 5 discusses the importance of economic indicators for individual behaviour. Another way to distinguish the agents by their attitude towards sustainable development is the implementation of different discount rates. A green agent will discount future payoff by a much lower rate than other agents. In a differential approach this leads to a higher extraction rate of an unsustainable agent. Individual knowledge is driven by the perception of new information in a learning process and is defined as

$\Gamma_i^t = f\left(\Phi_i, \Psi^t, BD^t, TA_i^t, s_j^t\right)$. From this point on we can define the individual's beliefs also as a function of knowledge $\Omega_i^t = f\left(\Psi^t, BD^t, TA_i^t, s_j^t, \Gamma_i^t\right)$. Figure 2 shows the general approach we use.

In this approach every agent is described by its' *knowledge*, *attitude* and *expectation*. This will allow us to cluster real-world data in order to identify similar agents. Agents can choose from a set of strategies (action choice) and behave in a certain way. This behaviour is interfered with by Nature's move. The net result of all *n* behaviours and Nature's move determines the equilibrium of the play. We interpret this equilibrium as a rule (formal or informal). The payoff leads, in connection with observed behaviour of other agents, Nature's move and the change in common-pool resource, to a particular expectation of future possibilities of strategy choices. The agents learn that the condition of the common-pool resource (e.g. groundwater aquifer) can restrict strategy choices (e.g. irrigate and use land for agriculture) and this restriction can lead to a long-term degradation of payoffs (e.g. no more groundwater available). In this instance the agent and other respective players may disagree with what is expected (depends on the attitude) resulting in a disequilibrium. Technically, this agent flags his/her discontent and if the majority is dissatisfied with their subjective expectations the rule will be changed. This means the strategy choice of all agents receives new boundaries and one or more strategies can fall out of the action choice or become modified.

The modification can be modelled in different ways. The appropriate approach would be to let the agents develop their own rules as is discussed in section 7. If the common-pool resource was an aquifer the agents should, for instance, think about changing rules in terms of the maximum amount of water that agents are permitted to pump. For such an approach the agents would have to calculate this amount. Such an approach is unlikely to occur if there are no predefined elements of choice in order to build rules. This leads us to the second option, which defines different sleeping elements agents can activate. In a more sophisticated manner, sleeping elements can approximate the eligible definition. Agents can experiment with different techniques such as using econometric approaches to calculate the optimal level of resource use. As in the real world, agents have to make a choice between different techniques to guide themselves through the unknown future. This means that the learning process will include the application of different rule-specifying techniques in a *best reply* manner on the level of evolving rules.

We assume in our model the existence of an econometric approach in addition to calculating sustainable levels of use which are based on the number of cattle on a paddock and the expected rain. This sustainable amount will be incorporated into an existing rule, which is valid for all agents independent from their behaviour and attitude. The definition and flexibility in changing rules depends on the knowledge existing in the community.

As described above, learning takes place on the individual level. Learning leads to a change in the knowledge of the agents and can thereby lead to evolving beliefs. Knowledge is defined as

$$\Gamma_i^t = f\left(\Phi_i, \Psi^t, BD^t, TA_i^t, s_j^t\right).$$

We assume that consistent cause-effect patterns are realised by the agent if the same change in strategy choice combined with a certain observed direction of Nature's move Ψ^t leads to the similar change of the common-pool resource Θ^t - we assumed Φ_i to be constant. This means if $\hat{s}_j^t < 0$ in reaction to $d\Psi^t / dt = \hat{\Psi}^t < 0$ leads to

$\hat{\Theta}^t > 0$ the agent identifies that fencing increases biodiversity along riparian zones and lower levels of livestock help in times of a drought to maintain biodiversity on the paddock. To simplify the model we define Γ_i^t as an integer variable and assume that in the case described above - $\hat{s}_j^t < 0$ (less unfenced areas and less livestock) and $\hat{\Psi}^t < 0$ and $\hat{\Theta}^t > 0$ - knowledge increases: $\hat{\Gamma}_i^t > 0$. In a discrete approach we can define learning as an accumulative process with $\Gamma_i^{t+1} = \Gamma_i^t + 1$ given $s_j^t < s_j^{t-1}$ and $\Psi^t < \Psi^{t-1}$ and $\Theta^t > \Theta^{t-1}$.

As described, the beliefs of agent *i* are defined as a function of knowledge, Nature's move, the condition of the common-pool resource and the other agents' strategy choice: $\Omega_i^t = f\left(\Psi^t, \Theta^t, s_j^t, \Gamma_i^t\right)$. Such an approach allows for definition of the dynamics of the beliefs, which are driven by the multiple aspects that the agent observes. Beliefs are context-specific. A user of the common-pool resource does not expect other agents to follow conservative strategies if there is no scarcity. In a situation where no knowledge exists about the effect of different strategies, agents would not expect other agents to choose conservative strategies, i.e., they will expect the other to put more livestock on the paddock if grass is available.

The first stage learning is modelled as *reinforcement dynamic*. The agents identify patterns between their strategy choice and the following pairs of variables

- inquiries by tourism operators to access one of the paddocks and biodiversity,
- fencing and biodiversity, and
- the number of grazing cattle and biodiversity.

This knowledge will lead to the development of an action choice on a Meta level, where agents try to influence other agents' behaviour to remain or improve their future action choice concerning the payoff. This Meta level is similar to the general cognition and summary representation in Aoki (2001) but differs in one essential way: Each agent has the option to change the rules of the game, but this cannot be done alone. Rather it is accomplished through a change on the Meta level.

Knowledge Γ_i^t is modelled as a stock that accumulates points. As mentioned, we assume two conservative ranchers (CR), two money oriented opportunists (MO) and two ecology oriented greens ranchers (GR). The learning process of these ranchers differs as the greens are assumed to be the fastest learners. They accumulate 1.5 times the points of the average, the MO's accumulate with the factor 0.5 and the CR's do not accumulate at all as their strategy is to stick exclusively to their old business.

Assuming that democratic structure provides an effective result, the evolutionary process will minimise the absolute number of disequilibria on the individual level. Similar to this is a second strategy choice, whereby agents can flag their dissatisfaction with each rule. This corresponds with the approach mentioned above where the evolutionary process takes place on the community level, that is, on the level of rules. This means that rules are connected with a fitness function, which depends on the satisfaction of the agents.

GR's attitude Φ_i is defined to be one for the others Φ_i are assumed to be zero. While an increase in knowledge and understanding of the system leads to the definition of individual rules, the agent also expects other agents to follow similar rules. Dissatisfaction caused by contrary beliefs, motivate the agent (in this case just GR can become active) to flag their opinion. MO can become active by combining tourism activities (TA) and biodiversity (BD) as their dissatisfaction is caused by the negative externalities of CR. In fact, such a flagging means that the agent wants all agents to

follow this individual rule. In a democratic system the individual rules become *socialised* if the majority flags their unhappiness with the existing rule and agrees to follow another specified rule. According to Aoki (2001) flagging signals disequilibrium, and rules (on the community scale) evolve as a result of changes on the individual scale.
By following this argument it can be seen that rules depend on the support of community members who are defined by their knowledge, attitude and beliefs. In game-theoretical terms a lower acceptance of an existing rule leads to a decrease in the fitness function of this rule. We simplify the model by defining the activity of rules as integer variables; formal or informal rules are either in place or not. The majority of community members decide if a rule is active or inactive.

Scenarios

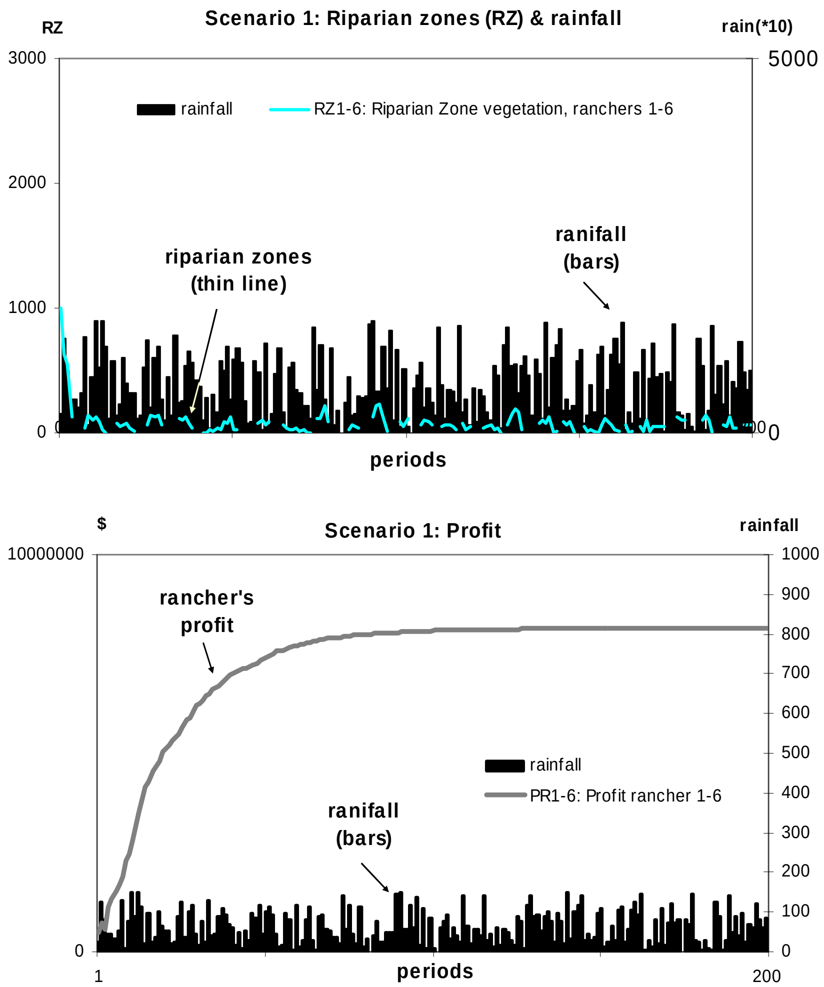
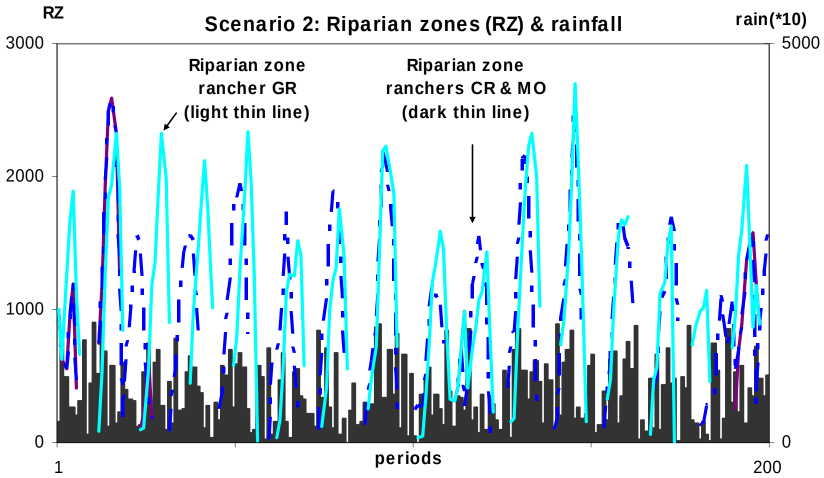
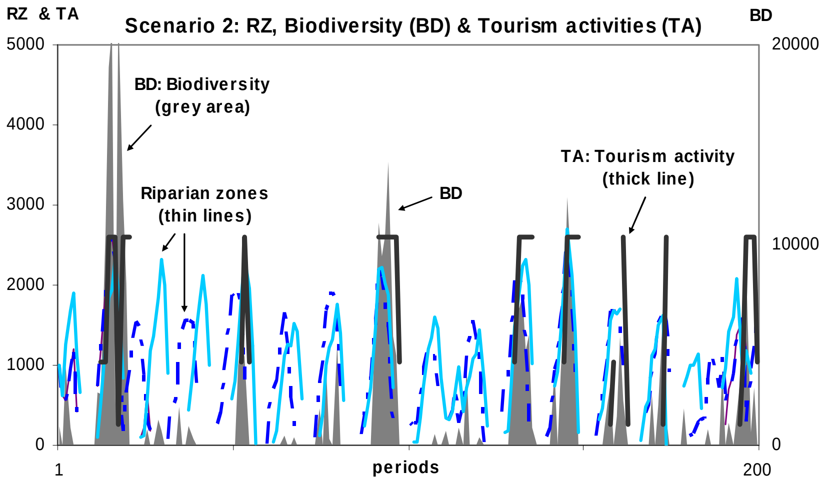


Figure 3: Results for scenario 1, (a) Indices for riparian zones (*RZ*) and rainfall;
(b) profit for each rancher and rainfall

First, we simulate a scenario without learning agents. Figure 3 (b) shows the accumulation of discounted profit π_i^t (in figures $PR_i(t)$, discount factor: 5%) as lines (primary y-axis) over 200 periods (x-axis). The stochastic impulse Ψ^t (rainfall) is shown as bars (secondary y-axis). The business reaches over time a value of $8.15 Mio. Figure 3 (a) shows the development of riparian zones RZ_r^t as lines (primary y-axis) under the same stochastic conditions (bars, for display reasons magnified by factor 10). The index for BD^t is mainly zero as RZ_r^t are unfenced and extremely sparsely vegetated. Tourism operators do not enquire for access to the paddocks.





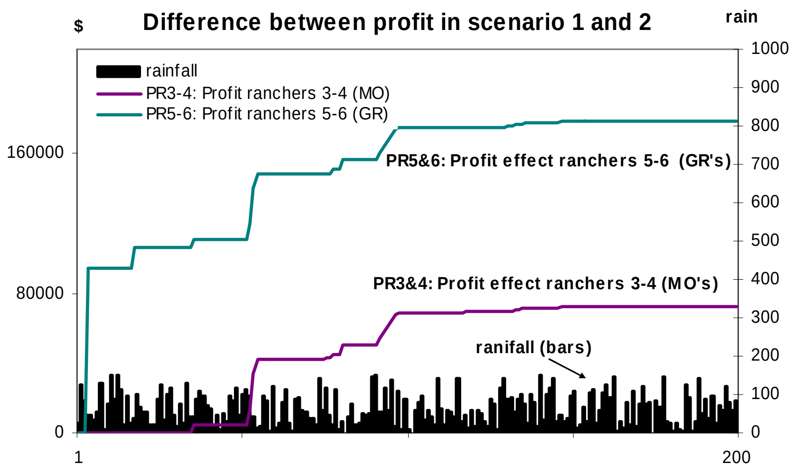
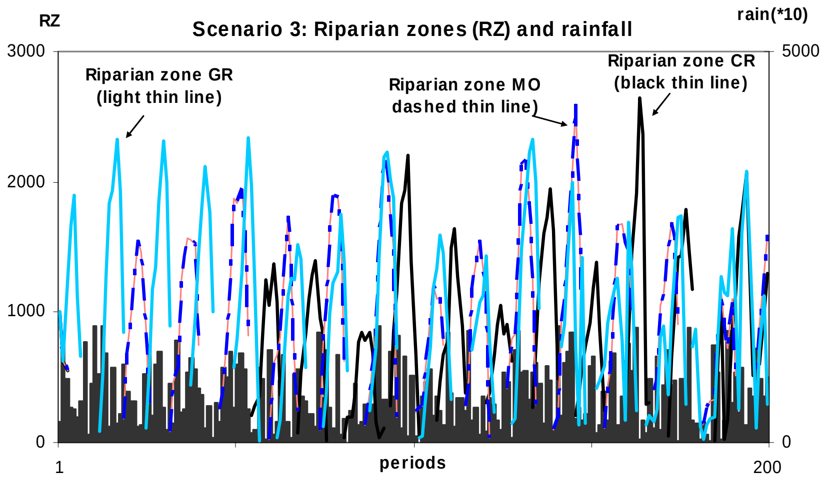


Figure 4: Results for scenario 2, (a) Indices for riparian zones (*RZ*) and rainfall;
(b) riparian zones (RZ), biodiversity (*BD*) and tourism activity (TA);
(c) rainfall and effect on profit for ranchers

In scenario 2 reinforcement learning occurs and we assume a threshold of 4 for the accumulated amount of knowledge points. This means that the agents have to identify the same pattern four times until they understand the connection and translate this pattern into their decision making process.
Figure 4 (a) shows much higher levels of vegetation in riparian zones (RZ) along four paddocks. These paddocks belong to the green ranchers (*RZ*5 & *RZ*6) and the MO's (*RZ*3 & *RZ*4). The effect of higher vegetation in riparian zones on biodiversity is very positive, as the grey area in (b) shows. With improving biodiversity tourism operators start to approach the fenced paddocks and, as (b) shows, becomes a regular activity, just interrupted by long dry periods. Both groups learn (in different extend) which leads to periodic fencing. This has a positive impact on the wildlife in the whole area as the increasing biodiversity index signals. Figure 4 (c) shows the difference between profits in scenario 1 and 2. As tourism operators only visit fenced properties the conservative ranchers do not increase their profits. The *GR*'s are able to increase their profits by up to $180,000 because they have the highest fencing rate. The *MO*'s learn much slower and fence less than the *GR*'s. Their profit increases by $73,000.



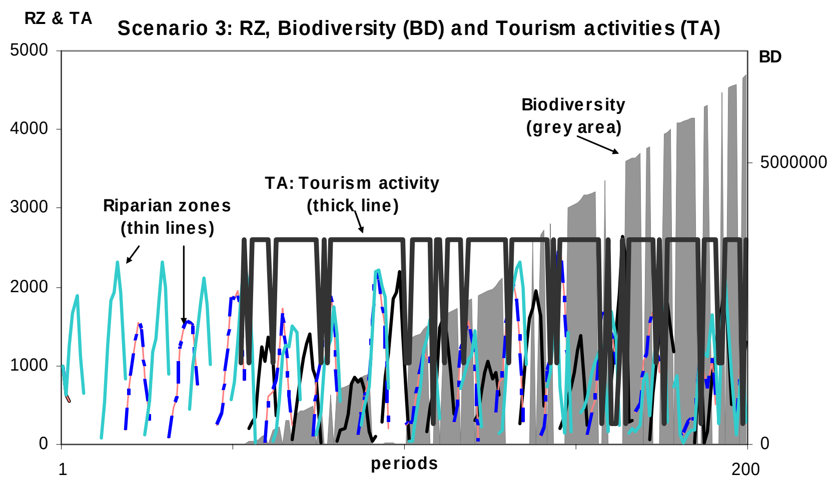


Figure 5: Results for scenario 3, (a) Indices for riparian zones (*RZ*) and rainfall;
(b) riparian zones (RZ), biodiversity (*BD*) and tourism activity (TA)

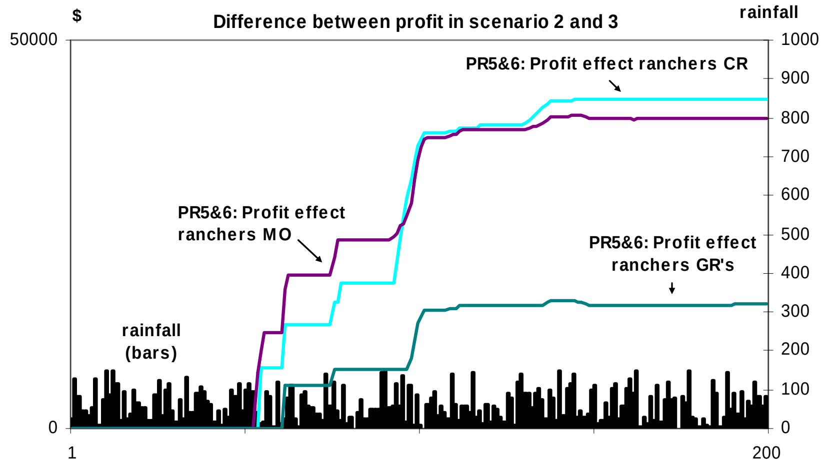


Figure 6: Results for scenario 3, (c) rainfall and effect on profit for ranchers

Figure 6 shows the results of scenario 3. In this scenario we analyse the effect of individual learning on institutional arrangements. We assume that the ranchers are part of the same social network which means that they can communicate, for instance, their discontent. The introduction of *fictitious plays* in the individual learning (*best reply* learning) means that the individuals realise that a change in the other agents' behaviour would increase their own payoff. In other words, they realise the existence of externalities. This also means that in a pure *reinforced* learning environment none of the agents would become aware of externalities. Furthermore, we assume that individual knowledge is communicated on a community level. On this macro level the individual with identified negative externalities, flag their unhappiness. In a democracy this dynamic would lead to a decrease in the fitness function of a rule. This rule can have the form of an informal or a formal rule as well as a norm. The assumptions require only that the agents follow the rule. We assume that the small size of the community is enough (social) pressure for each agent to follow a rule.

In this scenario the accumulation of knowledge leads to the ability to learn about externalities and their causalities. If the majority realises that (1) the potential income from tourism increases with the biodiversity in the region and (2) that biodiversity is higher the more paddocks are fenced, they will signal that all paddocks should be fenced. It is important to mention that the *GR*'s aim for more wildlife because of their green attitude and the *MO*'s because of the potential increase of their profit.

Figure 6 (b) shows that the biodiversity index increases constantly (changed scale of secondary y-axis to figure 3 & 4) under identical stochastic influences like previous scenarios. This leads to more tourism activities and profits of all ranchers increase in comparison to scenario 2. As the profits of the *CR*'s increase the most they have also the highest change in their knowledge because they learn from their changed behaviour although they were first unwilling to fence. It becomes obvious that this evolutionary process increases the fitness function of the rule for fencing riparian zone.

In the third scenario we implemented the possibility of an evolving rule. The agents changed an existing (informal) rule about fencing and institutionalise that riparian zones have to be fenced. In technical terms it means that the '*what kind of rule*' and the '*when to activate the rule*' is modelled endogenously as a bottom-up approach. In many real-world cases we have to consider also the '*intensity of a rule*'. By how much is a person forced to pay or by how much is the consumption of a person constrained.

The implementation of this dimension in an agent-based model is crucial for its application in real-world scenarios.

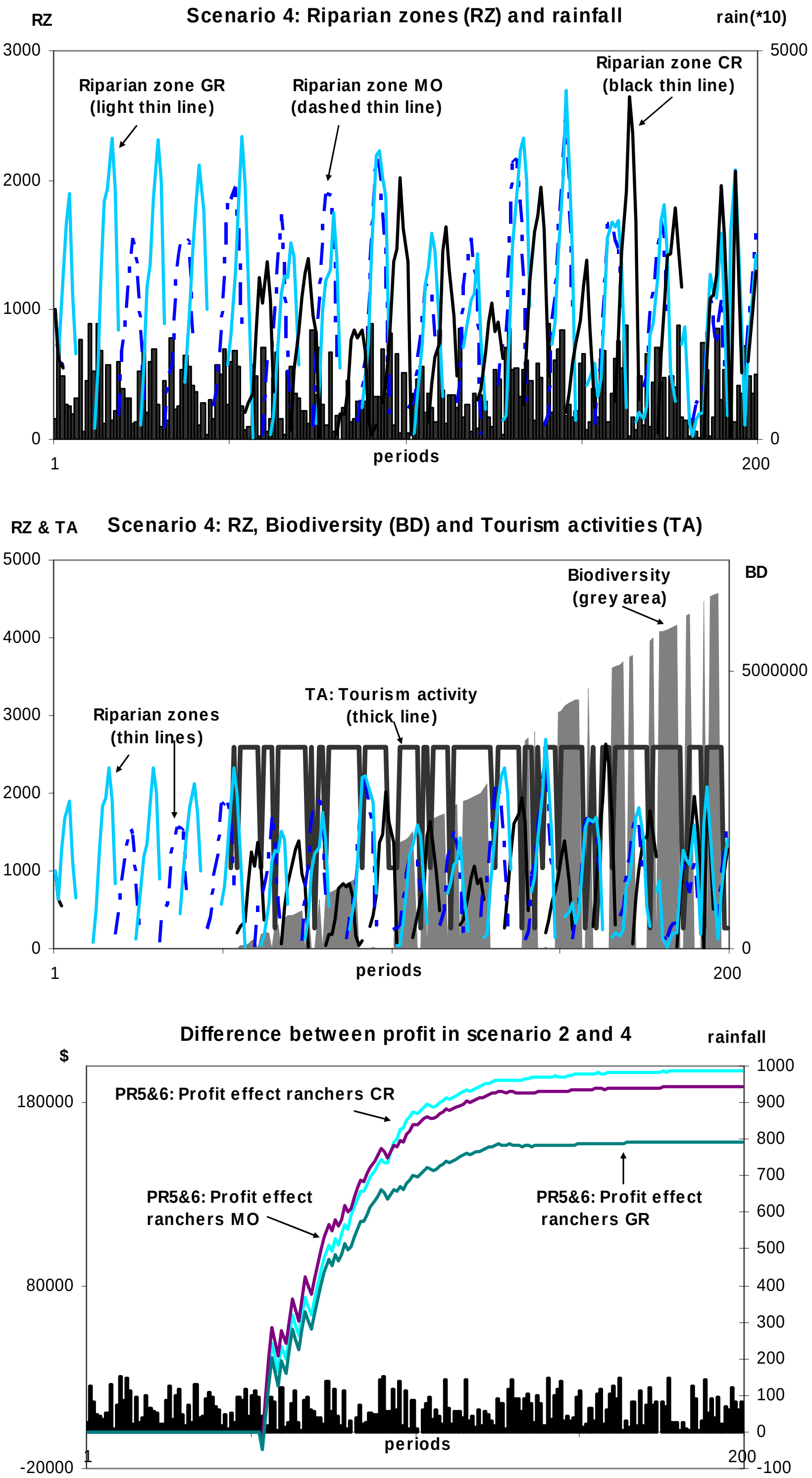


Figure 7: Results for scenario 4, (a) Indices for riparian zones (*RZ*) and rainfall
(b) riparian zones (RZ), biodiversity (*BD*) and tourism activity (TA)
(c) rainfall and effect on profit for ranchers

Therefore, we implement in the fourth scenario the possibility of agents deciding about the intensity of control variables. We assume that the others cannot convince the *CR's*, and the social pressure, which occurs by the flagging majority, leads to a negotiation instead of a direct change in the strategy choice. The CR's realise that tourism (and biodiversity) is a common-pool resource but their expectations don't see an increasing pay-off (as they are very risk avers). This means that they are willing to fence but just under compensation. To be able to model gradual changes in evolving rules we assume no direct compensation. Instead we assume the case that *CR*'s and *MO*'s were often talking about hiring a consultancy. In the moment when the majority flags their unhappiness with the unfenced property of *CR*'s and the *CR*'s offer negotiations, *MO*'s convince the *GR*'s to share the costs for the consultancy. This means that *CR*'s pays less for the consultancy but fence instead their riparian zones (indirect compensation). The consultancy delivers each period following these negotiations, the optimal amount of cattle per paddock under consideration of tourism and rainfall. Instead of last years rainfall the consultants apply a linear regression over all periods since t=1.

In period 53, knowledge has accumulated in such a way that the majority is unhappy that not all paddocks along the river are fenced. As described above, this scenario does not assume an easily installed rule for fencing. Instead the consultancy is paid as a compensation for *CR*'s fencing effort. Comparing this with scenario 2, the result is an additional cost of $7,500 for *GR*'s and *MO*'s. The consultancy defines per period the number of cattle (optimising biodiversity induced income from tourism and direct income from cattle). All six ranchers follow this advice (as an informal rule). Figure 7 (c) shows the effect on cost but at the same time there is a much higher increase of profit for all three rancher types (mind different scale of primary y-axis to figures 3-5).

9. Summary

This paper targeted the implementation of multiple-use issues in the context of common-pool resources and analysed the capability of agent-based approaches to model such scenarios. Therefore, this paper developed on the base of institutional economics and game theory a concept to model the evolution of institutions endogenously in an agent-based model.

Firstly, multiple-use issues are modelled on the background of common-pool resources and it is shown that multiple-use can help protect common-pool resources, given institutions are able to adapt. Secondly, the model simulates how more elements of institutional change become implemented endogenously, the introduction of new informal rules, the consideration of new agents and the variation of the level of benchmarks in rules.

The model developed in this paper shows that different aspects of evolving institutions modelled in an agent-based approach. The agents decide endogenously when to (de)activate which rule and on the upper limit of resource use. Additionally, the model shows the endogenous (de)activation of new agents. Those three aspects define important aspects of the evolution of institutional arrangements: (1) which rule, (2) intensity of rule and (3) which actors.

The scenarios developed in this paper emphasise the importance of learning processes and of commitment of agents: Biodiversity as a common-pool resource is just protected by tourism as the multiple-use option if tourism operators make a commitment to generate future income for ranchers. As costs for fencing riparian zones occur far before income from tourism occurs most ranchers avoid this investment. The reason is that tourism depends in this context on biodiversity which itself needs time to build up. This investment decision can be observed in reality and most institutional arrangements in communities for fencing fail because there is no long-term commitment of the tourist industry.

The case studies are developed out of real-world problems linked to the research project *Opportunities for the Australia Outback – Researching institutional arrangements in the North* (Greiner 2003 and Smajgl, Vella and Greiner 2003).

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