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MODELLING EVOLVING RULES FOR THE USE OF COMMON-POOL RESOURCES IN AN AGENT-BASED MODEL

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SUMMARY

Institutional arrangements are key drivers of the use of common-pool resources (CPR). The analysis of existing arrangements requires a framework that allows research to describe a case study systematically and diagnose the institutional setting. Based on a sound understanding of current institutions the question of what effects alternate arrangements would have becomes evident. This step requires a predictive model, which can either be qualitative or, preferably, analyses an empirical case quantitatively. A major conceptual challenge of a quantitative model is the evolution of rules, which define the boundaries for the agents to choose strategies. This paper develops the conceptual foundations for such a modelling approach and an agent-based model for the analysis of institutional arrangements in a CPR setting.

KEY WORDS

multi-agent simulation, agent-based modelling, institutional arrangements, common-pool resources

CLASSIFICATION

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INTRODUCTION

Land-use includes different interests, especially, if common-pool resources are involved. 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 [52, p.19] evolve from and depend on several drivers such as environmental conditions. The context of multiple-use can have a significant impact on the use of common-pool resources as a diversity of interests is linked with the common-pool resources, partly preserving and partly exploiting them.

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, as 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.

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

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MULTIPLE USE IN THE CONTEXT OF COMMON-POOL RESOURCES

This paper is focused on land use in the outback of Australia. Land can be used in 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 [52, p.7]. Common-pool resources are of special interest because excluding others is difficult and subtractibility is high.

The case of multiple use and CPR is not in the focus of current literature although the pressure on a CPR, described in the ‘Tragedy of the Commons’ [27] or in ‘Governing the Commons’ [51], can include very different dynamics considering multiple use options. This paper will analyse the connection of multiple use opportunities and CPR in section 7 with the example of privately owned land that is used for grazing. On this block of land is a gorge that contains an archaeologically important fossil site but which is also water source for cattle and a popular site for four-wheel driving. The fossil site can be identified as a CPR. Additionally, as tourists increase income in the community, a pool of interested tourists becomes a CPR. Businesses in the community can use this CPR to generate income and the rancher can use this pool by keeping them away, as four-wheel drivers reduce the productivity of his cattle by scaring them away from the gorge. Therefore, this paper includes a renewable resource (potential tourists) and a non-renewable resource (fossils) as CPRs and combines this with multiple-use of privately owned land. The land owner, the community businesses, and the tourism operators act as individuals. All agents form together with the resource and the institutional arrangement the system.

In order to analyse institutional arrangements in the context of multiple use I first develop the theoretical background of institutional arrangements. After that I will focus on individuals and learning as their dynamic dimension, followed by the system in an evolutionary game-theoretical approach.

INSTITUTIONAL ARRANGEMENTS IN THE CONTEXT OF ECONOMIC THEORY

Institutional issues were for a long time not part of economic research as the main problems allowed 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 [67] puts the focus of neoclassical theory in a way that "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 [11] where the idea of transaction costs was introduced. Coase [12] and Hayek [30] 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 [11] 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 [65] structures Coase work in a very useful way: In his paper 'The Nature of the Firm' [11] Coase focuses on institutions of governance, which can be called the play of the game, while his paper 'The Problem of Social Cost' [12] analyses the institutional environment, the rules of the game.

Williamson [64] 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." [64, p.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 [65]. North [47] 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” [48]. Institutions exist because of the need to reduce transaction costs. This means the lower transaction costs are the more efficient institutions work [48]. The institutional framework defines the constraints for the maximisation of an organisation’s economic performance.

Institutional change can be a result of changes in formal rules or informal constraints. North [46] 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 [47], 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.” [47, p.6]. The concept of learning will play a critical role in a later stage of this paper. In addition, North [45, 49] 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.” [49, p.3].

Williamson [64] 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 [66]. 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. Other authors [1, 2, 16] founded the basis for property rights theory.

Demsetz [16] 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 him[16] 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 overuse the connected resources and 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 [2]), and undermining negotiations about the optimal use.

At the same time however, private property can cause various investments to not 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." [16, p.358]. These aspects are considered in [2] from another perspective, whereby the value of an organisational structure is equated with the transaction costs it saves. This approach corresponds with Coase's [11] initial theory about the fact that for the existence of transaction costs (different) organisations exist.

The theoretical discussion provides the understanding of institutions. An applied analysis of a real-world case 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 [59]. This simulative dimension is covered by different quantitative approaches. For instance, Johnson, Kaufman and Zoido-Lobatón [38], Hellman and Kaufmann [33] or Beck et al. [4] 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.

MICRO-LEVEL: INDIVIDUALS ADAPT BY LEARNING

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?" [8]. Rawls [54] 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 that 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." [55, p.XLIV].

This approach has to be seen in a 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 Luhman, who founded the system theory, and Adorno and Habermas. This German scholar emphasises the difference between action as individual behaviour and rules or, as Homann [36] defines it, between the constitutive and the operational level. Economic incentives only determine rules directly and not the action of an individual which underlies in this approach strictly the rules. 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 [36].

This approach implements the same mechanism 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 in [49], mentioned above. As Homann states [36], the normative validity of a rule depends on sufficient implementation and it is the implementation, which provides the validity.

The question is how rules can 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 as it is defined, for instance, in the Brundtland Report [6], 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 [57] gives a systematic view on 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 [63] concludes that there is not much 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.” [63, p.19]. This does not mean that only existing institutional arrangements can be compared but also 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 [7] state that every individual will try to minimise his or her 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.” [7, p.70]. This approach shows a clear emphasis of 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 [8] 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.” [8]. This dynamic perspective gives a significant meaning to constituting the institutional arrangement from the individual perspective. An alternative approach is presented by Hayek [31, 32], who defines rules pertaining to institutions as a 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 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 [61, p.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 because individual's behaviour is a main driver for a change of the system. Young [67] 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 different learning mechanisms, which defines point (1).

Brenner [5] gives a comprehensive overview of learning in agent-based models. Young [67, pp.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 is modelled in so-called replicator dynamics. Imitation means that agents copy successful strategies of other agents and focuses obviously more on the agent's decision making process 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 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.

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

Fudenberg and Levine [25] 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 expectation held by other agents. Additionally, reputation can describe a situation where one agent behaves myopic and the other agent has a competent understanding of the effects the strategies of both agents have on the system.

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 [25, pp.264-266] demonstrated that this outcome depends highly on the difference between the payoffs of A and B and 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 myopic.

The existence of a rational player simplifies the game and its learning mechanism. Kreps and Wilson [40] 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 highly depends highly on beliefs and Kreps and Wilson [40] show that solutions like the chain-store paradox[1] [58] only appear when the reaction of the monopolist is defined as common knowledge. Under imperfect information other equilibria result. While Fudenberg and Levine [25] give a broad overview on existing learning mechanisms Chen and Khoroshilov [10] focus on learning under imperfect information. Their simulations show that the implementation of beliefs, like in experience-weighted attraction learning in Camerer and Ho [9], leads to less stability than in reinforcement models because the agents keep all strategies over all stages active. Camerer and Ho [9] 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 the own strategy and the strategies chosen by the other agents, and (2) the agent's belief. This belief depends on the strategies, which the agent perceives other agents choose.

Oechssler and Schipper [50, p.137] point out what Harsanyi [28, footnote 2] stated much earlier; there is far 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 [19] develop a reinforcement mechanism and combine it with *forgetting and experimenting* to explain changes in the strategy choice of agents. Sarin and Vahid [56] work on the same data as Erev and Roth [19] and develop a simple repeated game to explain the learning process. Oechssler and Schipper [50] collect their own data in experimental situations, focussing on the approach of Kalai and Lehrer [39] 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 [3] a rule is established in form of equilibrium. Oechssler and Schipper [50] compare the reinforcement learning in Erev and Roth [19, pp.859-862] with that of Sarin and Vahid [56] 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 [15] 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.

RULES EVOLVE AND CONSTRAIN INDIVIDUAL STRATEGIES

In this section game theory is used to analyse institutional changes and to 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 that contains the different strategies the agent can choose from.

Harsanyi [28] 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 [28] use of rules is on a different level to that of strategies and his rules correspond with those of other [12, 47].

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 [13] define in their *Grammar for institutions* a general structure of rules for institutional statements. These are build out of the elements *attributes*, *deontic*, *aim*, *conditions* and *or else*. Their examples is (see [13, p.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 [44, p.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 [8] "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 [53] 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 [18] sees for individual behaviour. Harsanyi [29] 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 [20] 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 [21] and Leitzel [41] point out that formal rules can be perceived as bad rules. This maintains an essential dynamic because, as Aoki [3] 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, how the group level is transformed by the level of individuals.

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 4. 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 this 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.

MACRO LEVEL: SYSTEMS ADAPT BY EVOLVING RULES

Games based on common-pool resources focus primarily on the users' behaviour. Changes in behaviour are treated differently in game-theoretic literature. 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 [22, p.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 [23, p.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 [26, p.211] sees the difference in 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 [24, p.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 4. 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).

Other authors [42, 43] 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 evolutionary stable if the mutant cannot invade the species. Taylor and Jonker [60] proved that an ESS is sufficient for stability in dynamic games. Young [67, pp.44-65] discusses dynamic and stochastic stability of such equilibria and Gintis [26, p.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 [23] 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 in [3, 67].

Hurwicz [37] 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 [44] 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 institution 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 [3, p.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 [37]) which dominates the theory of New Institutional Economics described above.

Aoki [3] 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 $\hat{E}$, with $\varepsilon \in \hat{E}$, 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 $\hat{E}$.

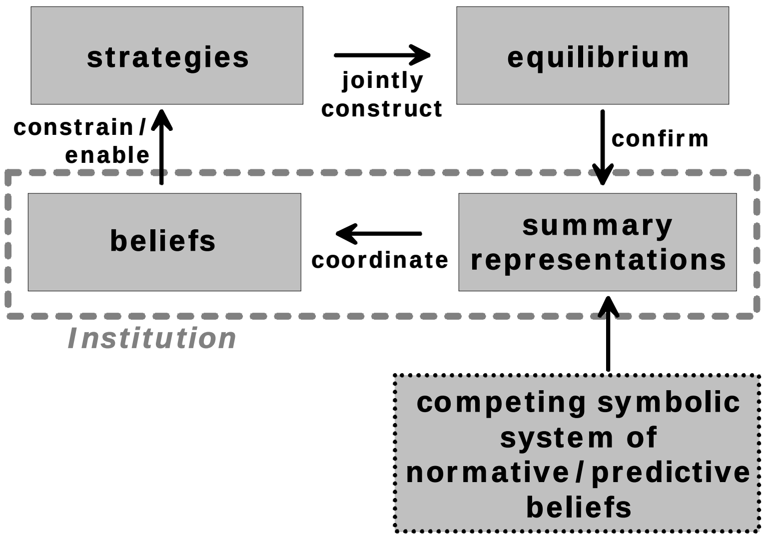

Figure 1. Game-theoretical approach to systemise institutions, see [3].

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 contradictory to the shared beliefs and through this learning process, new institutions are developed based on subjective game models.

SPECIFICATION AND SCENARIOS OF THE AGENT-BASED MODEL

Based on the evolutionary game-theoretical approach, in this section I develop a model for the context of CPR and multiple use issues. In order to develop simulative capacity for a real-world situation I do not describe the decision making process by differential equations – see for this area of game-theory Fudenberg and Tirole [24, p.521] or Gintis [26, pp.164-187] but as 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" [61, p.281]. As Deadman [14, pp.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." [61, p.1]. In-depth descriptions of ABM can be found in, for instance, [34, 35].

In this approach I will apply an agent-based model to mimic the evolution of rules as institutions and include the context of multiple use. Crucial for the problem are the mechanisms that drive the dynamics of the system, which includes the common-pool resource. Tesfatsion [61, p.292] raises in this context an important question: "How should agent adaptation, learning, and evolution be constructively represented in these artificial economic worlds?" The previous sections were focused on these three elements placed on two levels. The following part defines an agent-based model for an applied common-pool problem.

As I focus the modelling exercise on multiple-use issues in combination with a common-pool dilemma I have to include diverging interests in the use of one resource. In this case I assume one rancher in Australia's outback who leases his land and makes his decision on how much cattle he puts on the paddock, a decision that depends on expected rainfall. Additionally, I assume that on the land he leases there is a gorge with an important fossil site, which several national and international archaeologists try to preserve.

The multiple-use issue is extended by another dimension by considering tourists approaching the land for four-wheel-driving, a famous activity in outback Australia. Several groups of tourists access the land without the permission of the rancher. As the tourists are perceived as creating additional income in the local community a very vocal part of the community has an interest in an increasing number of tourists visiting the area. The problem is that uncontrolled four-wheel driving is likely to cause significant damage to the fossil sites. Additionally, four-wheel driving happens mostly in the mud regions around the gorge, which scares the cattle away and reduces the productivity and, therefore, the income of the rancher. It is obvious that (uncontrolled) four-wheel driving is not in the interest of the rancher.

The question is how the community of interest organises its individual interests on a community level and how the rules organising the system evolve on the background of multiple use opportunities. In the case described above two main CPR can be identified. First, the archaeological site that is used by different groups, archaeologists for research, the public just by knowing it exists, and the four-wheel drivers as part of the ideal driving area. Secondly, is the pool of potential tourists a CPR, in order to allow the community to increase its income and to allow the rancher to protect his land from decreasing productivity.

The i agents with $i = 1, \ldots, n$ have a strategy choice Σ_i^t with $s_{ij}^t \in \Sigma_i^t$ and $j = 1, \ldots, m$. In a multi-stage game the agents move simultaneously (normal form game). The two main control variables in the action choice of the agent *rancher* is 'fencing' FC^t and 'number of cattle' NOC^t. The rancher starts with 'no fencing' as fencing and the emplacement of locked gates is linked with significant annual costs of \$ 2000. The rancher has to decide before the start of the wet season on the number of cattle. The decision is based on last year's rainfall. I assume an indicator ψ^t for rainfall, which goes from 0 (no rain) to 1500 (heavy rainfalls). It is common knowledge that the block of land of this rancher can carry a livestock of 600 cattle at an average rainfall. The rancher needs a minimum livestock of 200 cattle to secure a minimal income. Therefore the rancher will put a livestock of 200 on the paddock even expecting a very dry year. Additionally, I assume that even in very wet years the paddocks cannot carry more than 1000 cattle.

A significant influence for the condition of cattle is their access to the gorge. I assume that NOC not only represents the number of cattle but includes also an average weight, which is important for the profit function later on. Four-wheel drivers that drive along the gorge without caring about cattle scare the cattle away. Therefore, the weather-dependent term is multiplied by a ratio that represents the impact of uncontrolled four-wheel driving UWD^t. This multiplier assumes that the higher the level of UWD^t is the more of the maximal impact β decreases NOC^t. I assume for these simulations a maximal impact of $\beta = 0{,}5$. This means that even if UWD^t doubles over time it can reduce the condition of livestock by 50 %. On the other extreme, if UWD^t is zero, the cattle is not impacted at all.

Therefore, the function for the weighted number of cattle is defined as follows:

$$NOC^t = \begin{cases} \left(1+\frac{\beta}{2}\frac{UWD^t}{UWD^1}\right)\cdot\left(600+200\cdot\frac{1500}{\psi^t-750}\right), & if \quad \psi^t \neq 750, \\ \left(1+\frac{\beta}{2}\frac{UWD^t}{UWD^1}\right)\cdot 600, & if \quad \psi^t = 750. \end{cases}$$

The fossil site is the common-pool resource Θ^t. Its condition depends highly on the amount of four-wheel drivers frequenting the gorge. One type of driver has higher priorities in preserving the site and drives responsibly, the other type values the driving much higher and does not care or does not know about the damage of driving. Lets assume there are 1000 drivers and 90 % of them belonging to the group of irresponsible drivers that do not control where they drive, UWD^t. Ten percent of the tourists control their driving to preserve the fossil site in the gorge, CWD^t. I assume that both types of drivers are part of a potential pool of tourists. This pool is increasing as there is a rising interest in four-wheel driving and as that site becomes more and more famous for good four-wheel driving. The following discrete function shows how the number of potential tourists grows in time.

$$NTO^{t+1} = NTO^1 + 10t \qquad \text{with} \quad NTO^1 = 1000.$$

As four-wheel driving is more exciting with higher rainfall ψ^t the actual number of drivers on the paddock varies with rainfall and follows, additionally, the main path of the potential tourists.

$$UWD^{t+1} = UWD^1 \cdot NTO^{t+1} / NTO^1 + 0{,}9 \cdot q \cdot \left(\Psi^{t+1} - 750\right),$$
$$CWD^{t+1} = CWD^1 \cdot NTO^{t+1} / NTO^1 + 0{,}1 \cdot q \cdot \left(\Psi^{t+1} - 750\right).$$

The difference between dry and wet years is important but to smoothen the amplitude of these reaction functions I assume $q = 0{,}5$.

The condition is that the fossil site decreases as the more uncontrolled four-wheel driving UWD^t happens. As this condition is not reversible the site has to be modelled as a non-renewable resource. I assume the following linear function:

$$\Theta^{t+1} = \Theta^t - UWD^{t+1} / 400 \qquad \text{with} \quad \Theta^1 = 1000.$$

The rancher's profit is defined by the following function:

$$\pi^t = NOC^t \cdot 600.$$

This means that the rancher can get an average price of $ 600 per cattle.

It is obvious that UWD^t has an impact on NOC^t and therefore on π^t. First scenario assumes the rancher does not realise this impact, which means that no learning takes place. In such a scenario 80 % of the fossil site would be destroyed after 40 years. Figure 2 (a) shows the decline in the grey area. The columns present the stochastic influence ψ^t, the light grey line on the bottom the number of CWD^t and the white spotted black line on the top UWD^t. After 40 year CWD^t and UWD^t have each increased by 40 %. Figure 2b shows the periodical pay-off of the rancher (grey line) and the rainfall (columns). The range in which the weather dependent profit varies decreases for rising UWD^t.

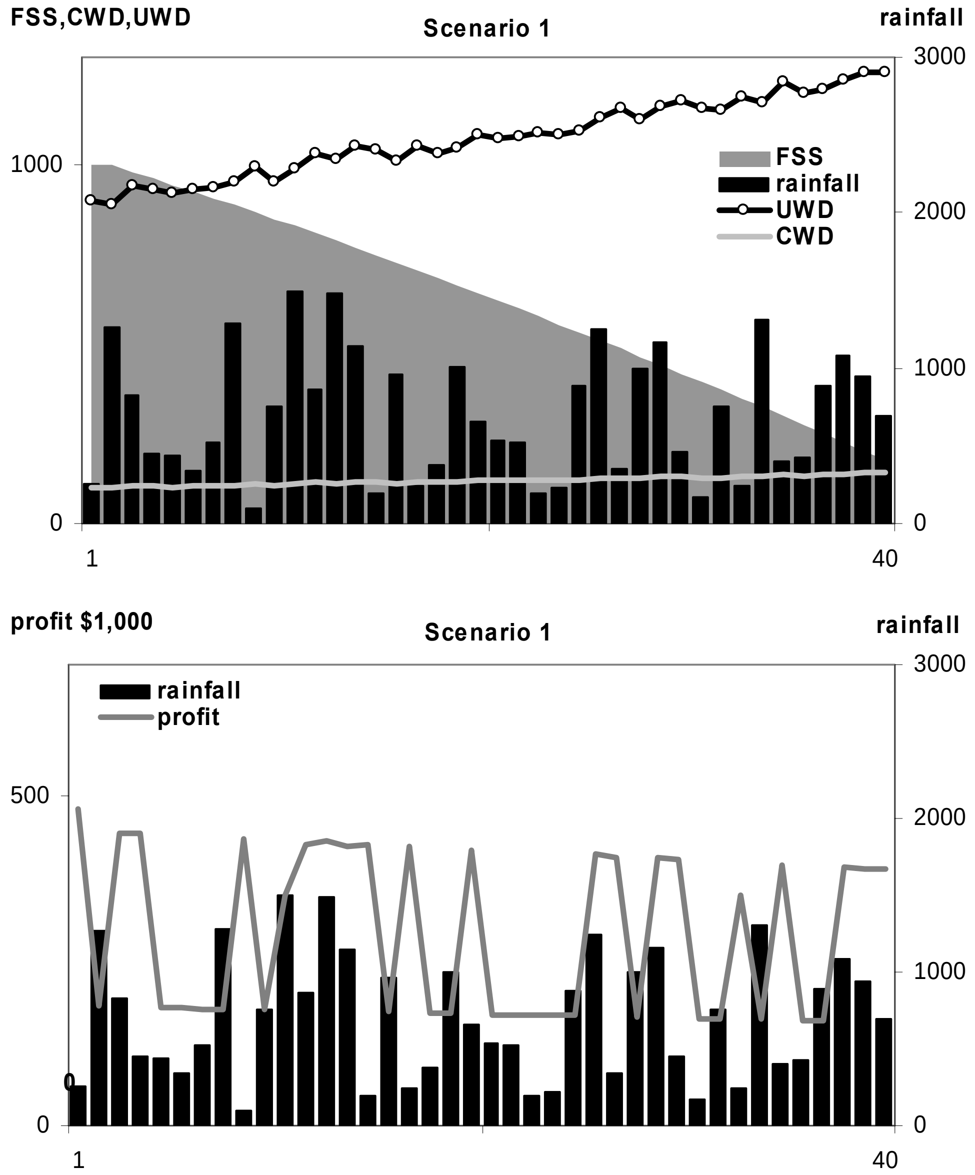

Figure 2. Results for scenario 1. a) Indices for condition of fossil site (*FSS*), controlled four-wheel driving (*CWD*), and uncontrolled four-wheel driving (*UWD*) and rainfall, b) profit for rancher in $ 1000 and rainfall.

One of the main interests of this paper is the effect of knowledge on the evolution of rules. Therefore, in the next step knowledge is implemented. At the beginning of every period the rancher observes the payoff of the last move π^t and Nature's move ψ^{t-1}. Additionally, the rancher perceives tourists driving on his paddock mostly around the gorge that scares the cattle away. His attitude towards four-wheel driving starts as being neutral. But he learns as he identifies the pattern

- Unprotected gorge means
- more four-wheel drivers means
- less productive cattle means
- less profit

The implementation of *reinforcement dynamics* shows the rancher that his strategy choice 'no locked gates' has a negative impact on his pay-off. In other words, the rancher realises that today's fencing decision has an impact on tomorrow's pay-off. I assume that the rancher has to identify this pattern three times to become active. The moment the rancher realises the reduced productivity is caused by the four-wheel drivers, he starts installing locked gates, which takes him one period. Another reason for a decrease in production can also be the difference between expected rain and actual rainfall. Technically, the rancher accumulates knowledge points for each identified pattern. Costs for additional fencing, gates and locks for the rancher are $ 2000 per period. We assume that even this fencing strategy can just reduce UWD^t by 40 % but as the rancher does not distinguish between UWD^t and CWD^t both parties decrease by 40 %.

This reinforcement learning takes part on the individual level of the rancher and it helps increasing the profit over 40 years by another $ 2089.

Assuming that the strategy locked gates is able to reduce the overall driving by 40 %, for the community this means that 40 % less tourists visit the area and spend their money in local shops and restaurants. In the third scenario we assume that also this agent (a vocal part of the community) learns about this link and identifies the pattern:

- Fenced property of the rancher means
- less tourists means
- less community income.

At the same time a third agent represents the local interest in preserving the fossils and they learn about the pattern:

- Fenced property of the rancher means
- less tourists means
- better protected fossils.

In this third scenario all three agents start learning based on their patterns. In the moment they accumulated their knowledge (again three identified cases to realise the pattern) the agents communicate their interests on the community level. According to Aoki [3], the agents signal disequilibrium. In terms of institutional arrangements a bottom-up process is initiated that leads to a formulation of a new rule, in this case an informal rule.

To explain the general approach of this paper this essential step from individual learning to evolving rules has to be developed: As a result of (best reply) learning, agent *i* may want to influence other agents' behaviour whose strategy choice has a negative externalities on *i*'s future payoff, like the rancher's strategy reduces the communities income. One option is to influence the other agent in the form of reputation (see above). Let us assume that there are three agents. Essential for their strategy choice are their expectations, attitude and knowledge.

Expectations are implemented as a set of beliefs Ω_i^t, which are subjective and can change in time. Beliefs exist for Nature's move, the future condition of the common-pool resources FSS^t and NTO^t and the other agents' strategy choice, $\Omega_i^t = \Omega_i^t(\psi^t, NTO^t, FSS^t, s_j^t)$.

Attitude Φ_i is a long-term element with important meaning for the dynamics and we assume that it will not change in time (and therefore has to be treated as a parameter). This assumption implements *path dependency* – see [45, 49] – in such ways that knowledge does not change the behaviour immediately, but includes attitudes as slow moving (in this case constant) variables, that work like a filter for perceived information.

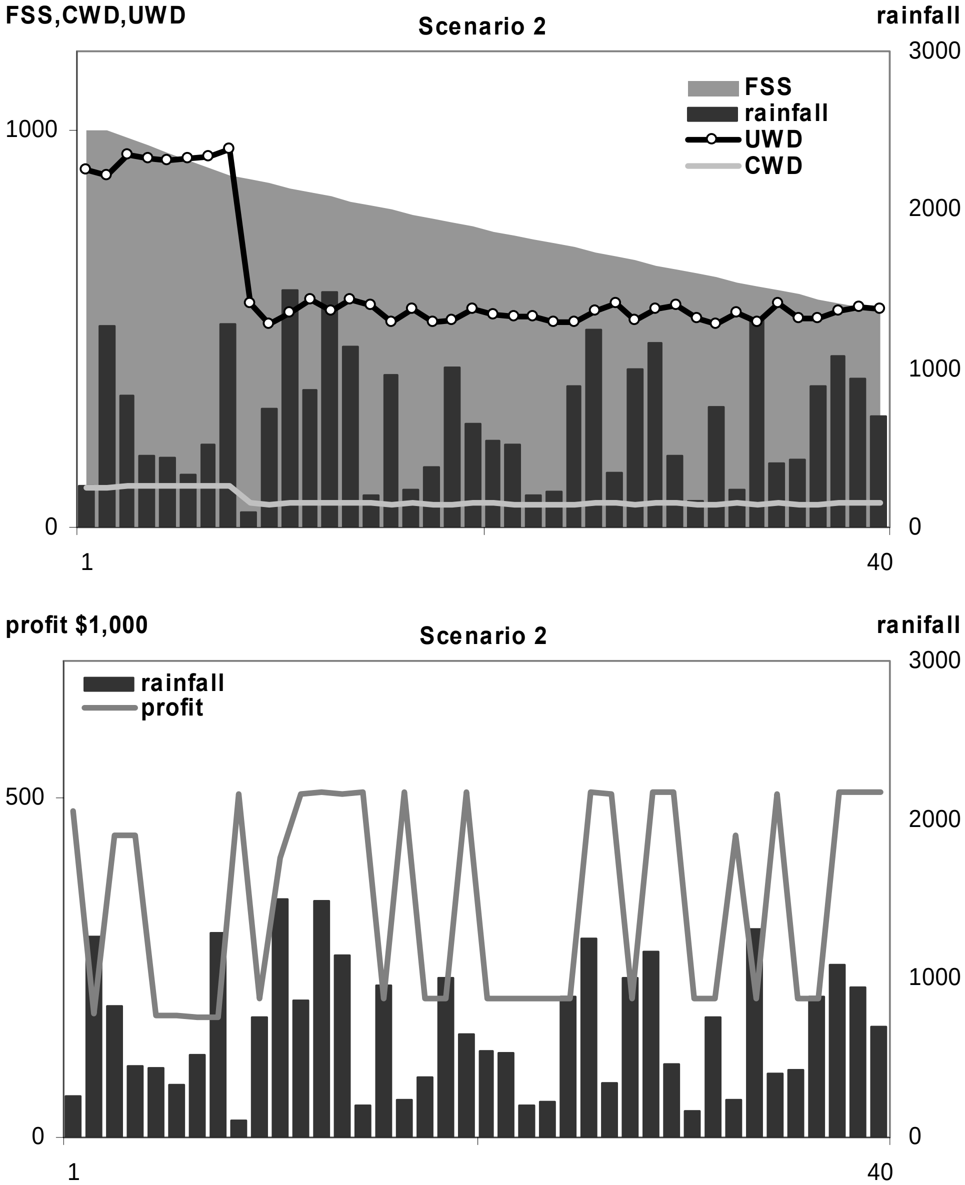

Figure 3. Results for scenario 2. a) Indices for condition of fossil site (*FSS*), controlled four-wheel driving (*CWD*), and uncontrolled four-wheel driving (*UWD*) and rainfall; b) profit for rancher in $ 1000 and rainfall.

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 hit-and-run strategy, any information about long-term effects might be ignored if the agent's utility function contains only profit. Section 4 discusses the importance of economic indicators for individual behaviour. Another way to distinguish the agents for 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, as described above, defined as $\Gamma_i^t = \Gamma_i^t(\Phi_i, \psi^t, NTO^t, FSS^t, s_j^t)$. From this point on we can define the individual's beliefs also as a function of knowledge $\Omega_i^t = \Omega_i^t(\psi^t, NTO^t, FSS^t, s_j^t, \Gamma_i^t)$. Figure 4 shows the general approach of this paper.

In this approach every agent is described by its' *knowledge*, *attitude* and *expectation*. Agents can choose from a set of strategies (action choice) and behave in a certain way. This behaviour is interfered 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) or a norm. 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. fossil site) can restrict strategy choices (e.g. attract fossil interested tourists) and this restriction can lead to a long-term degradation of payoffs (e.g. fossils destroyed). 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 6. If the common-pool resource was a fossil site the agents should, for instance, think about changing rules in terms of allowing access to this site. For such an approach the agents would have to negotiate the costs of such a rule as the rule itself has externalities on other agents pay-off function by

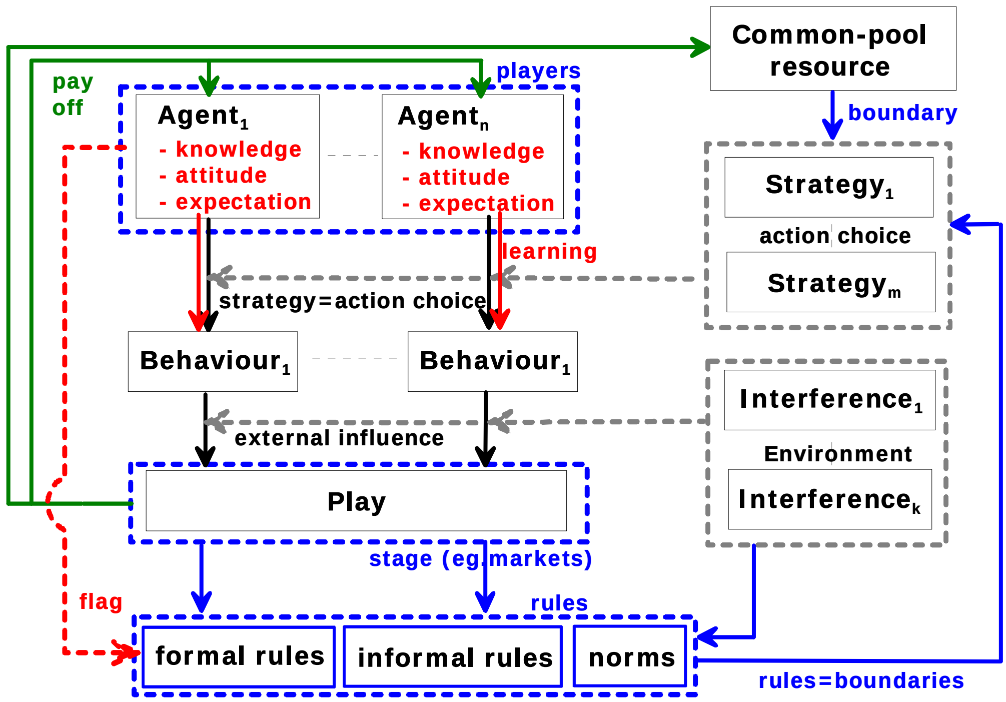

Figure 4. Agent-based conceptualisation.

changing their strategy choice. Such an approach is unlikely to occur if there are no predefined elements of choice in order to build rules. This leads to the second option, which defines different sleeping elements agents can activate and deactivate. In a more sophisticated manner, sleeping elements can approximate the eligible definition. Agents can experiment with different techniques such as bringing new agents into the game or using methods to regulate the use of the common-pool resource. This means that the learning process will include the application of different rule-specifying decisions in a *best reply* manner on the level of evolving rules.

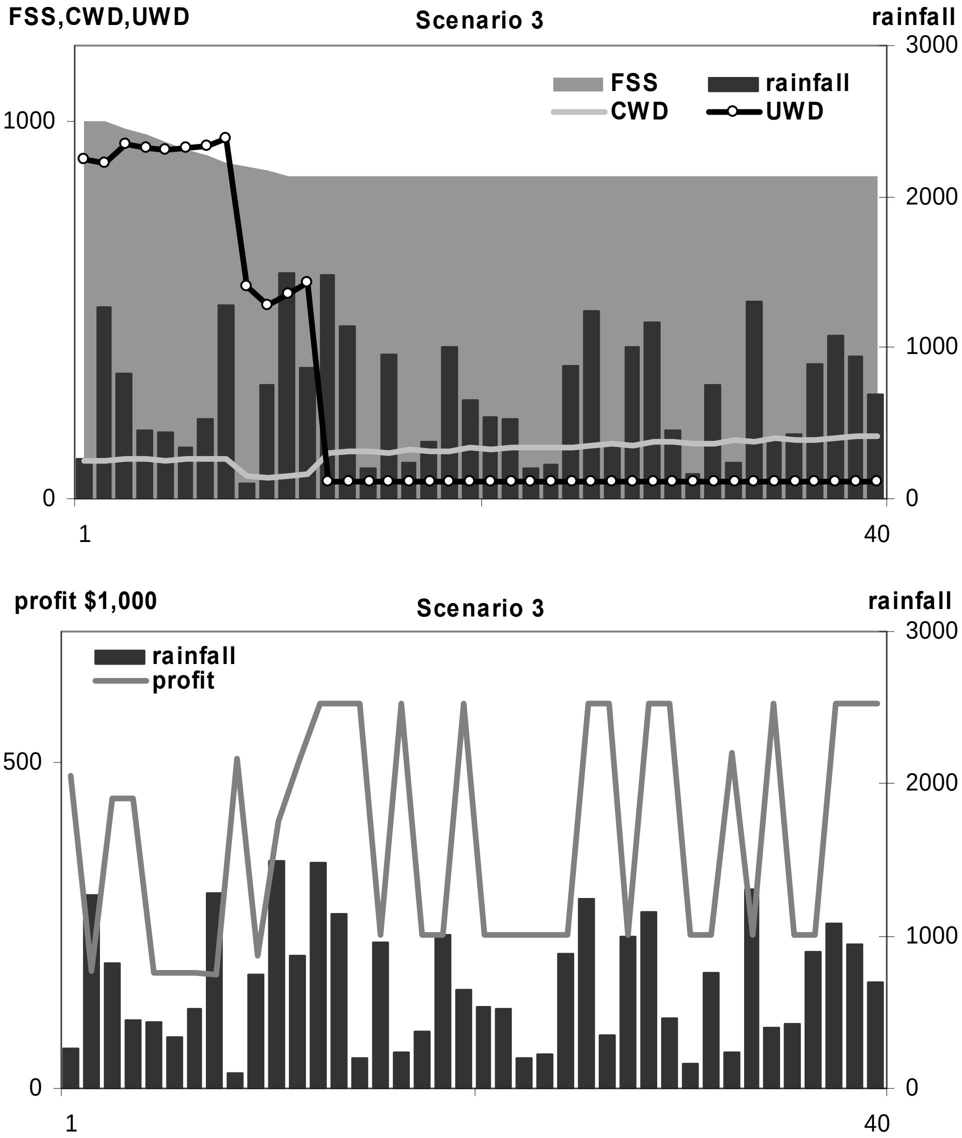

Figure 5. Results for scenario 3. a) Indices for condition of fossil site (*FSS*), controlled four-wheel driving (*CWD*), and uncontrolled four-wheel driving (*UWD*) and rainfall, b) profit for rancher in $ 1000 and rainfall.

Applying this conceptual model in the agent-based simulation means that the three agents flag if they are happy with the rancher's strategy choice on the community level. Making the realistic assumption that the rancher wants to avoid any social isolation in the small community he is open for the enquiries. As the fossil loving part of the community backs the *locked gates* strategy the business part of the community tries to find a compromise. They realise that there is a difference between *UWD* and *CWD*. They convince the rancher and the fossil loving part of the community that *CWD* should not be kept off the property because they care about cattle and the fossils. The three parties realise the need for monitoring. The business part of the community organises a permit system with information material and posts them at the entries of the property. The effect is that the rancher can reduce *UWD* to 45 drivers, which reduces the negative impact on the cattle productivity.

Figure 5 (a) shows the first drop in UWD^t occurs in period 8. Five years in a row rainfall decreases, which distracts the learning process of the rancher. In period 8 the rancher starts putting locked gates in place that causes a reduction in tourists by 40 %. He does not distinguish between CWD^t and UWD^t. Between year 9 and 11 the community learns about the effects and starts negotiating. In year 13 the permit system starts and CWD^t increases instantly while UWD^t drops to 45 drivers. At the end of the 40 years CWD^t varies around 250 drivers. FSS^t remains at a level of 85,5 %. In comparison with scenario 2 the rancher's profit increases by $ 1621 as UWD^t is further reduced.

In scenario 4, a further dimension of institutional change is introduced. The number of potential tourists NTO^t for this area is constantly increasing and as the community creates a scarcity of accessible area, entrepreneurs are likely to identify this created scarcity, they learn about it on an individual level. This new agent offers the rancher to manage the permit system and to reduce UWD^t to maximal one driver. The tourism operator plans also to advertise the possibility of four-wheel driving to increase CWD^t, an argument for the negotiation with the community. The tourism operator expects to attract at least 250 tourists. As this is also for the benefit of the community the tourism operator wants the community to cover 40 % of the total costs of $ 10 000. As UWD^t will be reduced to maximal one driver the rancher shall cover another $ 1000. The tourism operator who charges a driving fee of $ 30 shall cover the remaining $ 5000.

Realistically, such a fee will make CWD^t more volatile, $q = 1$. On the other side, I assume that advertisement can attract up to 60 % more CWD^t . This scenario is focused on the effect of *Nature's move* on the evolution of rules.

Figure 6 shows that in comparison with scenario 3 the first 15 years remain unchanged: The rancher learns first and locks the gates, which has an impact on the benefit of the community (positive in terms of preservation and negative in terms of income), the community offers another solution and the community follows a new rule. This restriction – and the high difference between demand and supply of drive sites – initiates a learning process of a new entrepreneur, starting in year 13. Negotiations start in year 15 and in the following year the new arrangement becomes active. In this period   climbs up to nearly 500. But for a row of dry years the tourism operator pulls out as he starts making losses. In year 20 the old regime returns and the community manages the access for four-wheel drivers without charging. In the following two years a new entrepreneur gets attracted and negotiations start again. This management holds for another three years before it breaks down again for six years.

Such a change in management of four-wheel driving is very common in outback Australia and is, as modelled, weather dependent. This flexible change in rules leads just to a marginal increase of profit for the rancher. But at the same time the number of CWD^t increases for the whole 40 years by 70 %. FSS^t decreases, like in scenario 3, in the first 11 years to 85,5 % and remains afterwards at this level.

CONCLUSIONS

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 from the basis of institutional economics and game theory, a concept to model the evolution of institutions endogenously in an agent-based model.

Firstly, the paper shows that agent-based models can be applied to real-world cases of common-pool resources. Secondly, multiple-use issues are modelled against the background of common-pool resources and it is shown that different uses can help protecting common-pool resources, given institutions are able to adapt.

This paper provides the methodological foundation for the endogenous simulation of evolving institutions like the introduction of new arrangements or the formation of new agents.

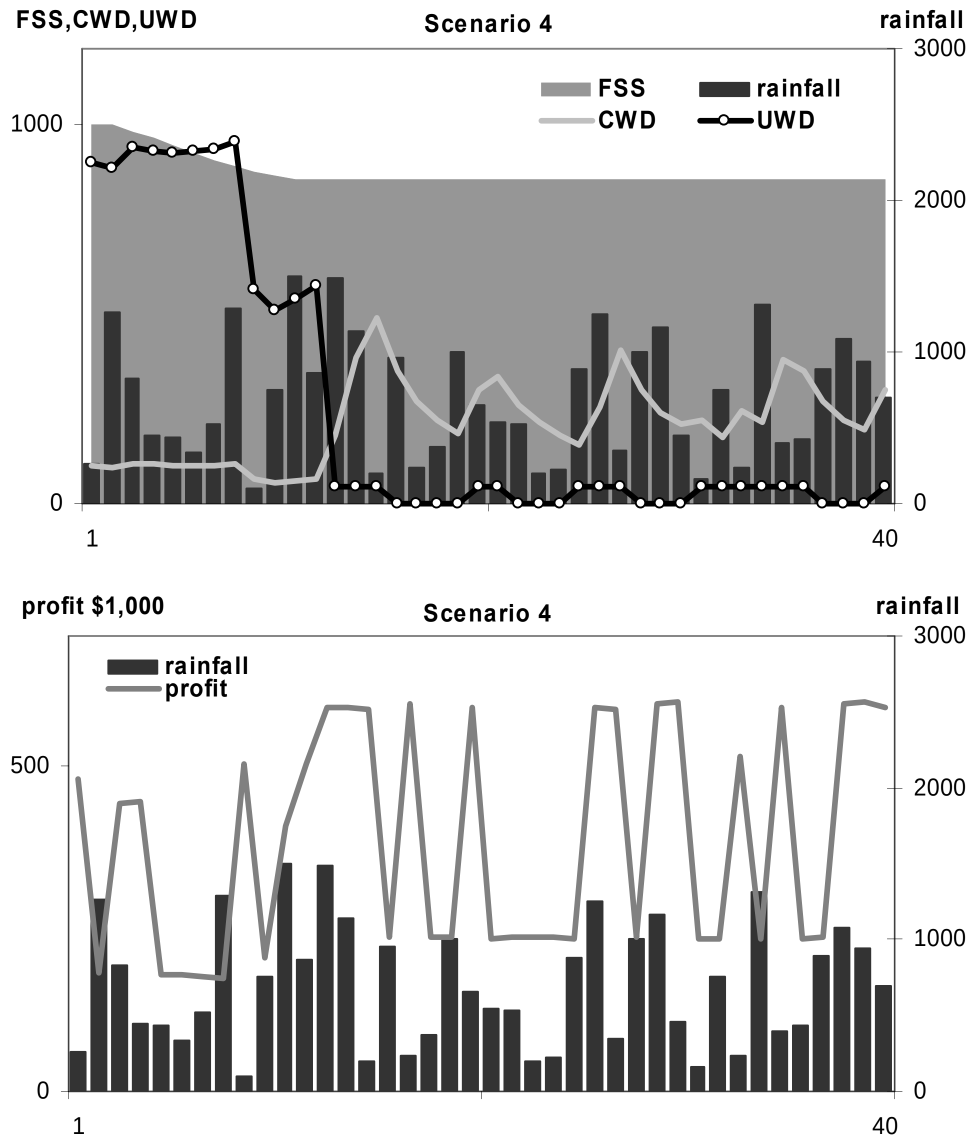

Figure 6. Results for scenario 4. a) Indices for condition of fossil site (*FSS*), controlled four-wheel driving (*CWD*), and uncontrolled four-wheel driving (*UWD*) and rainfall, b) profit for rancher in $ 1000 and rainfall.

REMARKS

[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 will not 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 does not fight the entrant and the entrant enters [58].

[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)." [28, FN2].

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Modeliranje evoluiranja pravila uporabe zajedničkih resursa u modelu temeljenom na agentima

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SAŽETAK

Institucionalni postav ključni je pokretač uporabe zajedničkih resursa. Analiza postojećeg postava zahtijeva okvir koji u istraživanju omogućava sustavni opis slučajeva i dijagnosticiranje institucionalnog sklopa. Na temelju razumijevanja postojećih institucija pitanje koji su učinci alternativnog postava postaje jasno. Odgovarajući korak traži prediktivni model, bilo kvalitativni bilo – što se i preporuča – onaj koji analizira emprijske podatke kvantitativno. Suštinski konceptualni izazov kvantitativnog modela je evolucija pravila koja određuju granice unutar kojih agenti određuju strategije. Ovaj članak razvija temelje koncepta odgovarajućeg pristupa modeliranju i model temeljen na agentima za analizu institucionalnog postava zejdničkih resursa.

KLJUČNE RIJEČI

višeagentska simulacija, modeliranje pomoću agenata, institucionalni postav, zajednički resursi