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GUEST EDITORIAL

Welcome to the new issue of the journal for the Interdisciplinary Description of Complex Systems. With this edition INDECS joins 235 scientific journals world-wide in publishing a Theme Issue on Poverty and Human Development. The initiative for this campaign came from the Council of Science Editors and is intended to raise awareness, stimulate interest, and stimulate research into poverty and human development.

Some of the difficulties faced by research in this particular topic are inherent in complex systems research in general. The research problems are interdependent and multifaceted. Research based on direct evidence can only concentrate on a small and tightly-delimited part of this field. The scientific modelling methods utilized in complex systems research cannot really circumvent this. But they do offer the possibility of testing and extending our understanding of the factors believed to contribute to both poverty and development in new ways. With simulations and other analysis we can come to understand types of interactions that occur in a dynamic environment. We can then look for patterns and consequences of these interactions, and then return to real-world data to test the accuracy of our new understanding.

The contributions in this issue exemplify these possibilities. By aggregating variables as diverse as global market prices and (village) local production technologies, and modelling villages as agents, van den Broek, Koning, Hofwegen and Becx simulate the complex situation in Sub-Saharan Africa. The contribution by Hoekstra, van Arkel and Leurs is another example of modelling the situation in poor rural areas, this time focusing on monetary flow. A third related contribution by Smajgl describes the effects of rule-adaptation when multiple agents have to share common resources.

We have two contributions on modelling as a technique, applied specifically to the questions of poverty and development. Johnston, Kim and Ayyangar show how the process of building agent-based models can result in valuable knowledge. Smith discusses the relationship between economic theories and development, linking a current approach to fighting poverty to research in complex systems. A further contribution by Neumann compares the models of two different social phenomena, ethnic mobilisation and hierarchy decline, using as historical background the breakup of Yugoslavia.

Often the value of understanding how some complex system works is just that -- understanding. In this issue of INDECS we present research for which the real value comes from approaching an understanding of how the complex of factors that leads to a disadvantageous situation might best be changed to lead to something better. We hope that such research will not only bring more insight into poverty and human development, but might ultimately contribute to the alleviation of poverty worldwide.

20 October 2007

Ivana Čače and Joanna Bryson

LIST OF REFEREES

The following scholars, listed in alphabetic order, refereed manuscripts for the journal INDECS in 2007:

Serghey A. Amelkin	András Margitay Becht
Virginia Dignum	Neli Maria Mengalli
Ksenija Dumičić	Damir Pajić
Viktor Eszterhai	Mirjana Pejić Bach
Robert Fabac	Gabrijela Sabol
Zsolt Gilányi	Armano Srbljinović
Zdenka Gogale	Ivan Strugar
Erik Johnston	Vanja Šimičević
Boško Kuzmanović	Klaus G. Toritzsch
Branko Lesjak	Andrej Ule

their contribution to the quality of the Journal's content is acknowledged.

Zagreb, 20 October 2007

Josip Stepanić

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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

JEL: C61, O13, Q19

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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.

This paper is an updated version of a paper presented at the Tenth Conference of the International Association for the Study of Common Property (held in Oaxaca - Mexico, August 9-13, 2004).

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 $\hat{E}$.

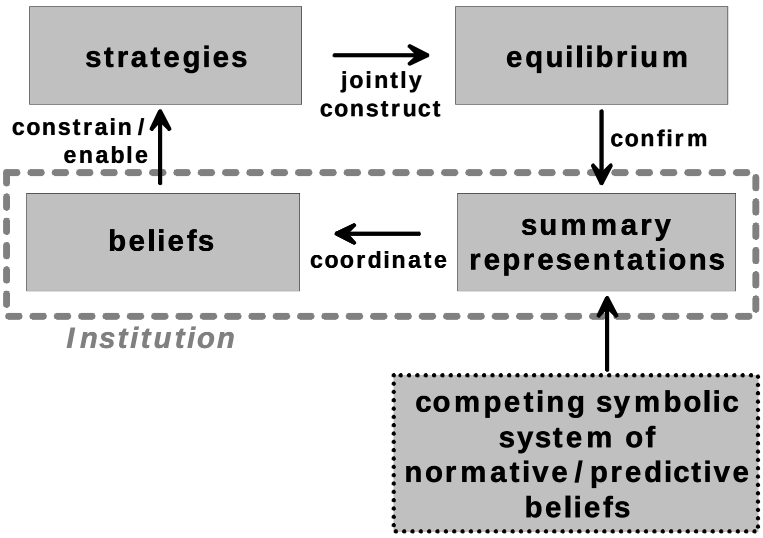


Figure 1. Game-theoretical approach to systemise institutions, see [3].

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:

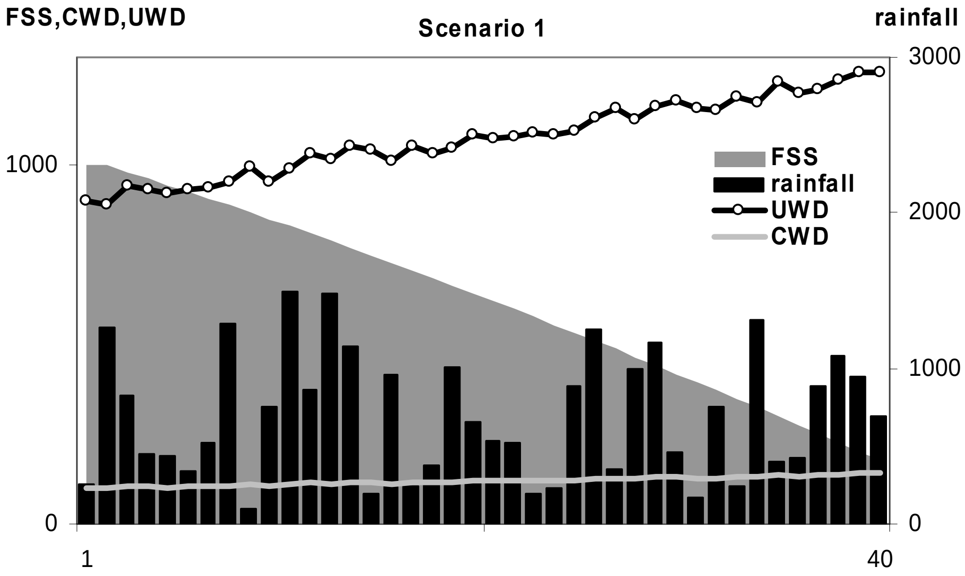
$$\Theta^{t+1} = \Theta^t - UWD^{t+1}/400 \qquad \text{with} \qquad \Theta^1 = 1000\,.$$

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.



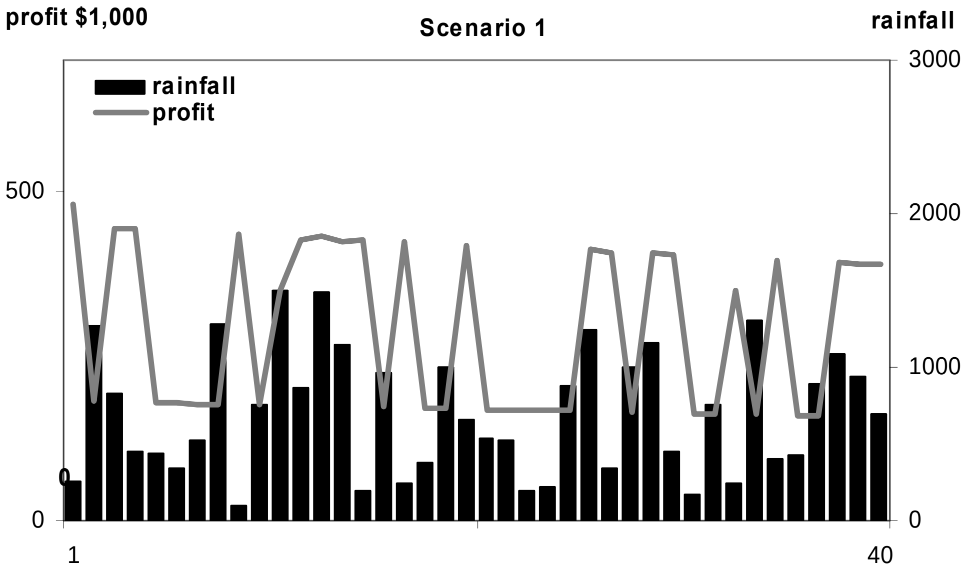


Figure 2. Results for scenario 1. a) Indices for condition of fossil site (*FSS*), controlled four-wheel driving (*CWD*), and uncontrolled four-wheel driving (*UWD*) and rainfall, b) profit for rancher in $ 1000 and rainfall.

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.

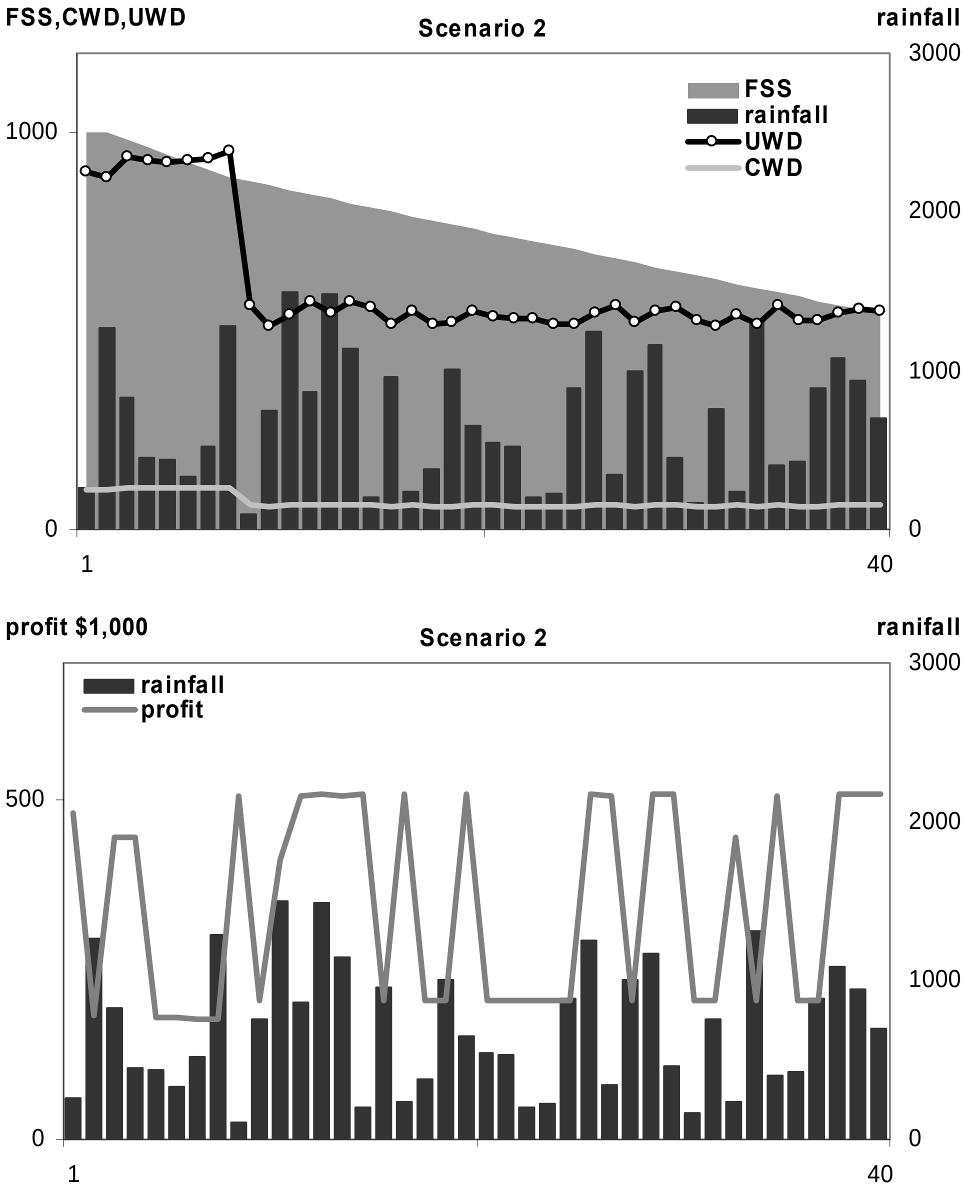


Figure 3. Results for scenario 2. a) Indices for condition of fossil site (*FSS*), controlled four-wheel driving (*CWD*), and uncontrolled four-wheel driving (*UWD*) and rainfall; b) profit for rancher in $ 1000 and rainfall.

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

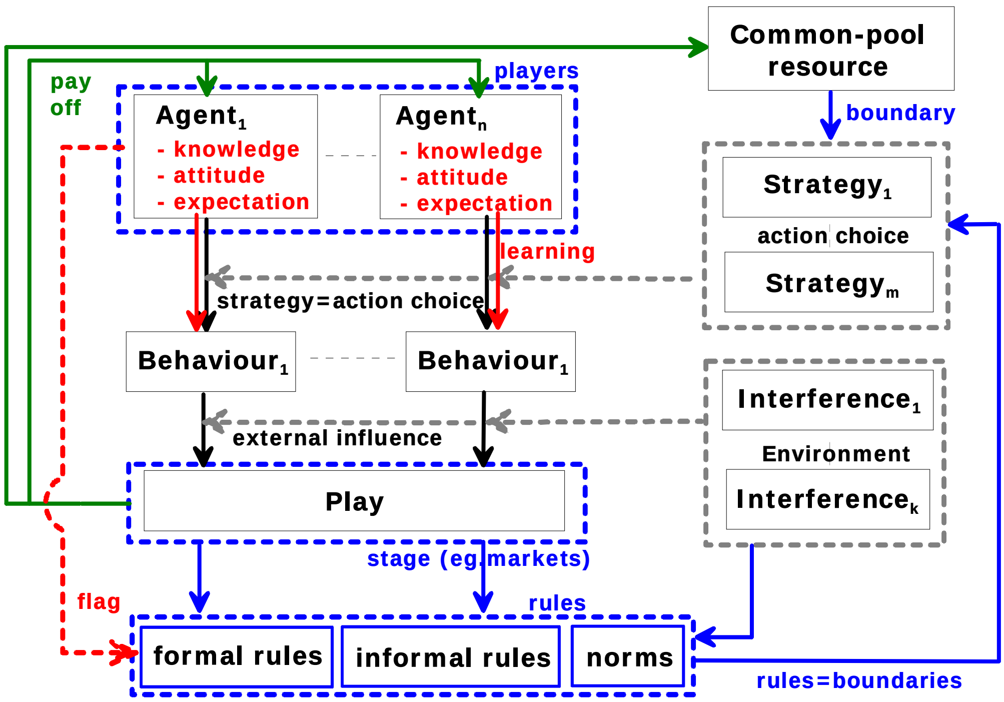


Figure 4. Agent-based conceptualisation.

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.

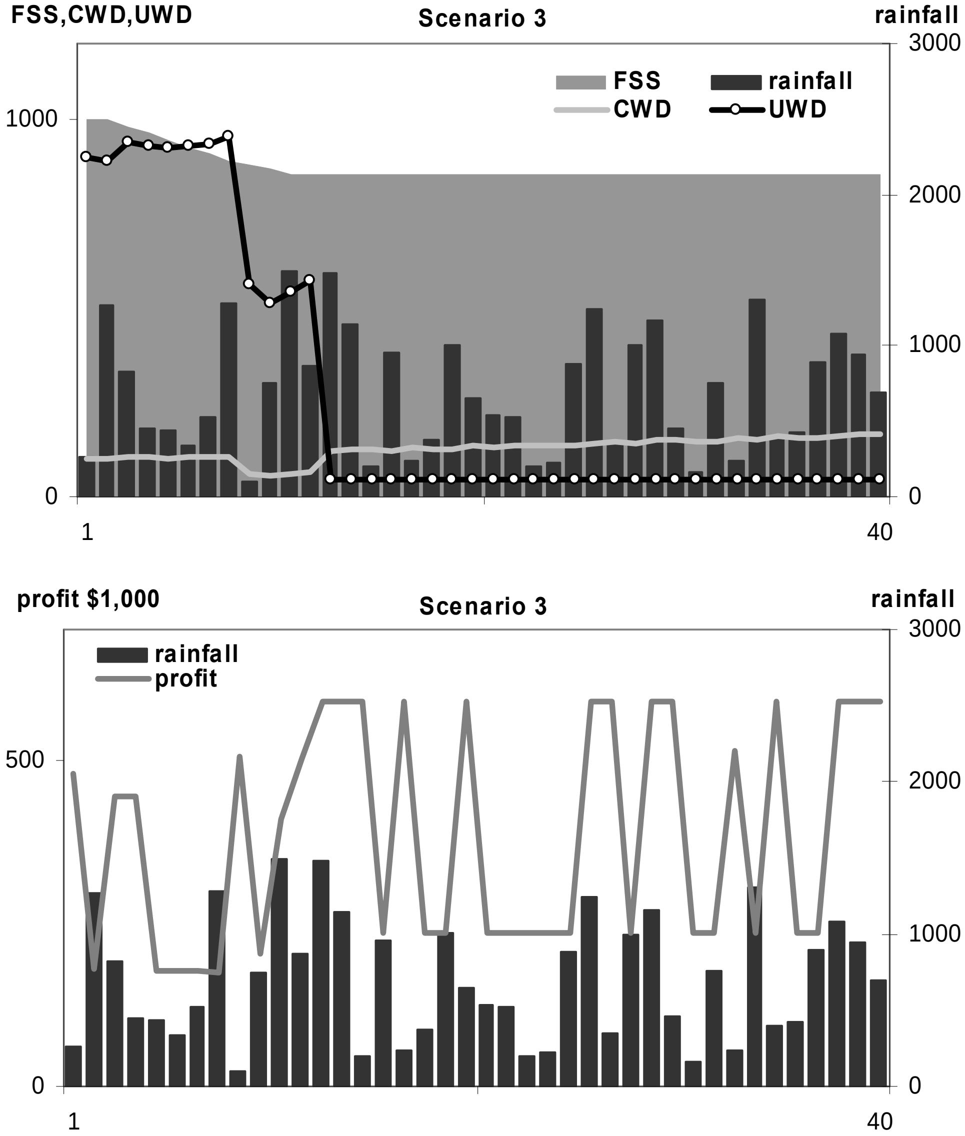


Figure 5. Results for scenario 3. a) Indices for condition of fossil site (*FSS*), controlled four-wheel driving (*CWD*), and uncontrolled four-wheel driving (*UWD*) and rainfall, b) profit for rancher in $ 1000 and rainfall.

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.

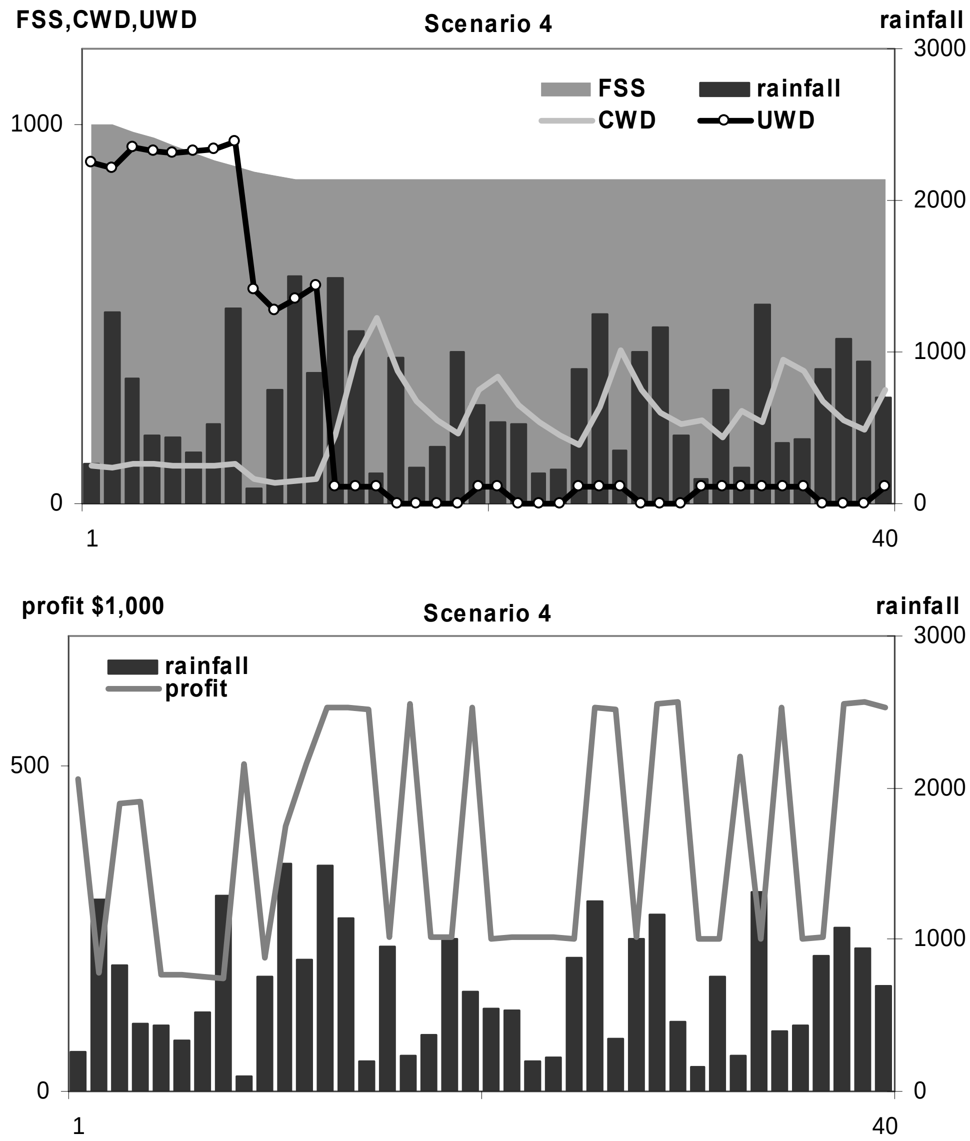


Figure 6. Results for scenario 4. a) Indices for condition of fossil site (*FSS*), controlled four-wheel driving (*CWD*), and uncontrolled four-wheel driving (*UWD*) and rainfall, b) profit for rancher in $ 1000 and rainfall.

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

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INTENDING THE UNINTENDED: THE ACT OF BUILDING AGENT-BASED MODELS AS A REGULAR SOURCE OF KNOWLEDGE GENERATION

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SUMMARY

Poverty is a complex issue that is rarely conducive to analysis in laboratory or field experiments. Effective interventions that aim to decrease or eliminate poverty require an understanding of the intricate web of associated social issues. The need for this increased comprehension necessitates the use of alternative robust means of analysis: one such being agent-based modelling. The strengths of agent-based modelling to disaggregate complex social behaviours and understand them are well known. However, while people have explored how the modelling process can prove to be fruitful, the usually unintended insight gained and the knowledge engendered during the model design process goes largely unnoticed. In this paper, we aspire to show precisely how the model building process is critical in leading to unintended knowledge generation for modellers by drawing from three US based examples where agent-based modelling was used to aid research into the effects of interventions that address poverty and human development through programs and issues facing low-income families. With these examples, we illustrate some of the means to harness new knowledge generated. In our discussion, we also highlight the advantageous nature of agent-based model design as an independent source of knowledge generation.

KEY WORDS

methods, agent-based modelling, knowledge generation, policy informatics

CLASSIFICATION

ACM: I.6.5 Model Development

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INTRODUCTION

The authors of this paper have found agent-based modelling (ABM) to be a useful tool when exploring complex social issues. This paper articulates a commonly shared, but rarely discussed aspect of agent-based modelling: unintended knowledge discovery during the model design process.

Generating new knowledge using ABM is a topic that has already been covered in various studies. *Generative Social Science* [1] is a collection of papers that demonstrates very well the benefits of using modelling to create artificial worlds that lead to new forms of understanding. Numerous articles [2 – 4], show how iterative modifications made during the modelling process are valuable sources of information. However, papers have paid less attention to the aspect of potential knowledge generation of ABM during the model design process. While some articles identify advantages of participatory and thoughtful research design or model building [5], the question of how design originated knowledge generation is achieved goes largely unaddressed. One of the common, but rarely discussed, advantages of agent-based modelling, and most modelling to one extent or another, are the unintended discoveries that occur during the creation of the model. A well-designed model will normally be developed through an iterative process with a deliberate plan for validation at the onset of the modelling process. A model will progress through stages of grounding, calibrating, and verifying. The creation of a model forces the articulation of any number of individual design decisions, and thoughtfully done, each can be a starting point for new understanding.

The increased availability of information and tools for processing information is giving rise to a new suite of methods for understanding how to address the issues surrounding poverty and other policy issues. The unique characteristics and the empirical strength of ABM make it an appropriate method by which to study various interventions in programs that target low-income families. Within an ABM, computer-simulated agents serve as experimental "subjects" whose behaviours are controlled by specific behavioural rules. Interactions among agents induce social structures, group level behaviours, and differences in performance outcomes. Individual choices can be formalized as strategic behaviours in a game-theoretic framework [6 – 12]. A model serves as an artificial collaboration environment where we can easily manipulate different parameters, visualize individual and combined effects during the growth process, and eliminate confounding influences that would be unavoidable in the real world.

Policy informatics studies how tools, models and simulations are used to aid individuals and groups make informed policy choices. Complex issues such as poverty do not lend themselves to laboratory experiments. Field experiments are costly in both time and resources and thus we look to alternative approaches to increase our understanding of various problems. One such option is agent-based modelling. In this paper we show how the process of building agent-based models can lead to unintended knowledge generations for modellers by drawing from three policy informatics examples in the US that address poverty and issues facing low-income families.

AGENT-BASED MODELLING

ABM can also be used to test competing hypotheses and generate explanations of complex group behaviour. Understanding the dynamics, history, and relations between agents in such an environment can complement field studies and may provide a more satisfying explanation of behaviour directly observed [13]. Compared with traditional social science paradigms, such as statistical estimating and differential equations, ABM has five unique characteristics. First, it takes a bottom-up approach. Rather than seeking a centralized control mechanism for orderly behaviours of a system, ABM explores whether decentralized interactions among autonomous actors can lead to system-level regularities [14 – 15]. Second, an agent-based framework assumes adaptive rather than fully rational behaviours of actors [16]. Each actor, given its assigned limited information and foresight, adopts strategies through interacting with other actors. Third, ABM allows heterogeneity among actors, whereas traditional social scientists often suppress agent heterogeneity in order to make their models tractable [17]. Fourth, ABM focuses on dynamic processes that produce or disrupt equilibrium rather than the static nature of equilibrium [17]. Last, traditional statistical or multi-equation modelling assumes linear, deterministic or predictive relationships among parameters, whereas an agent-based framework explicitly takes account of nonlinear, nondeterministic, or recursive interactions among multiple levels of actors.

Unintended discoveries made during the modelling process tie the following three examples together. The first example is a case where the designer of the model experienced metaphors of real worlds in the process of evaluating various design choices. Consequently, the designer was able to refine the understanding of the research which ultimately led to the stipulation of a new set of research questions. The second example is a case where the creator of the model found that a design decision could not be made without external assistance, particularly the program managers from the program of study. Again, the perspective from which the problem had been viewed by the modeller, and the program directors, was informed. The third example illustrates how design choices were dependent on availability of data which led to new theoretical constructs being created for the model. The constructs provided an additional benefit in aiding the communication of the research’s key findings. In each case the design process was the source of new knowledge generation.

In sum, the first and third examples are of an ABM that was built to simulate usual and unusual activities in a complex policy delivery system. The second example is of an ABM that was used to compare different implementations strategies of a program that targets health information to low-income first time mothers.

EXAMPLE 1: METAPHORS OF REAL WORLDS

Context of research: Public service delivery programs

The context of first example is the Women, Infants, and Children (WIC) program that aims to safeguard the health of low-income women, infants, and children up to age 5, who are at nutritional risk. The program provides nutritional supplementary foods, nutritional education, and referrals to health care and other social services. The WIC program originated as a direct consequence of growing concerns about malnutrition among low-income mothers and children in the 1960s [18]. The United States Department of Agriculture (USDA) is responsible for administrating the program. The main mechanism to deliver WIC services to the program participants is contracting local stores who are interested in delivering WIC foods as part of their usual business items. Therefore, this program is run by a system of heterogeneous stakeholders, such as Federal and State government, private stores, local clinics, and program recipients.

Brief description

We focused on building a model of routine activities in Ohio WIC. In terms of participation, Ohio WIC was the eighth largest program in the US as of July 2006, serving approximately 277 000 participants each month with a budget of over $150 million each year. Ohio WIC has contracts with over 200 local clinics and 1400 local stores. Each month, participants receive three or four vouchers with food benefits at local clinics. These participants are expected to redeem their benefits at WIC stores within a specified period since Ohio WIC uses the retail delivery system. Each voucher specifies what products and quantities the participant can purchase, as well as maximum prices that the state will pay for an allowable food. The state monitors the overall flow of transactions in the WIC system. The basic business mechanism of Ohio WIC provided a framework of our agent-based model [19].

The model building process of our ABM provided an opportunity to experience the common metaphors of real worlds that were possible within the structure of object-oriented programming. It has been conceptually well discussed that public policy systems such as WIC and their stakeholders are interdependent and dynamically interact [20] and that a holistic approach is needed to manage complexity in such policy systems [21]. While this view has been persistent among several policy scholars, in classroom settings these concepts are not easily experienced by students who have not been exposed to real decision-making situations. These concepts have remained as just metaphors of real worlds rather than constructs that can be modelled or examined using analytical tools and techniques. Therefore, while the policy system such as WIC needs to be considered as a whole to understand the dynamic of the system, the components had been usually and quickly reified as separate independent entities.

Experiencing the metaphors of real worlds

In ABM, agents are intrinsically interdependent within the simulation model, representative of the complex policy system. The interdependency among program recipients, local stores, and public agency can be specified in the model and experienced by the modeller. Local decisions made by an agent or trivial revisions done by the modeller have subsequent influence on other agents or to the system. Often, the complexity of the model leads modellers not to pay attention on the interdependency that they previously built. As in simulation models, it is not unusual to see such an effort to correct local issues without considering larger impacts to the whole system in real worlds. What the modeller experienced is the need to be aware of hidden interdependencies built in any social systems that aim to address such an issue of poverty, and the potential consequence of not paying attention to such.

EXAMPLE 2: STAKEHOLDER PARTICIPATION

Context of research: Civic collaborations

Civic collaborations, also known as collaborative partnerships, are alliances among community stakeholders and organizations from multiple sectors that work together to improve conditions with the aim of promoting and sustaining community health; as a strategy, such civic collaborations are increasing in frequency [22]. Federal and State health agencies routinely support, and often mandate, the formation of collaborative partnerships to design and implement community health initiatives [23]. The Institute of Medicine defines “mobilizing community partnerships” as an essential public health service.

A highly effective example of such a collaborative program is the Nurse Family Partnership (NFP) [24]. Conceived by Dr. David Olds, the Partnership sends specially trained nurses on weekly or bi-weekly visits to low-income, first-time mothers, beginning as early as possible in the pregnancy – typically between 16 and 28 weeks – and continuing until the child’s second birthday. The nurses help mothers improve their health and nutrition during pregnancy, learn effective early parenting skills, develop healthy family support systems, and reach program goals like completing school and finding employment.

Brief description

To fully leverage the value of civic collaborations, we aimed at identifying and formalizing best practices of such collaborations [25]. Specifically, Hicks et al. [23] found a correlation between program outcomes and the process quality of the early phases of civic collaboration development in Colorado. It was during this early phase that the collaboration grew from just a few participants to a functional group. By evaluating implementations of these programs, and particularly by understanding the successes and struggles during the growth process when employing civic partnerships used to implement uniquely successful programs, we can derive insights into best practices.

During the early stages of designing the ABM used to find best practices of implementation of civic collaborations, the model was intended to explore how the rate of growth was related to the ability to coordinate the actions of groups of participants. Overall the modelling process for this project spanned two years and over twenty versions of the model. During the grounding process of the model, one of the biggest design decisions was how to add new participants to the existing group. Instead of making an independent choice of how new participants joined the group, we asked the directors that were part of the implementation process in the real-world programs. When asked how new people were included in the civic collaborations communities, the Executive Director of the program responded:

> **Executive Director:** There are a lot of stories about how we have engaged additional people. We just did an orientation last week and we walked through a history of the program and it was a really thoughtful orientation. Other places were like – hi, I am so and so and I am replacing so and so.
>
> **Modeller:** Did you notice a difference in performance between those different styles of including new participants?
>
> **Executive Director:** Oh sure – one of the key things that we have seen was if the implementing agencies continue successfully the agency engaged in substantive discussion. When it is only information sharing with just updates then it is hit or miss if people are choosing to attend. If there is thoughtful and productive discussion, I think that at the end of the day is where there are the ones that are the most successful.

Recognizing that the manner in which people joined a civic collaboration differed in nature between the programs, and suggested outcome differences, our understanding of the role that including new people played in the program development changed. For the thoughtful inclusion of new people, we found that in the more successful communities, time was taken not simply to slowly include new members, but to gradually involve them into the activities of the group. In the less successful groups, new members were frequently thrust into participating in the group without knowing the history of the group. To model slowly joining the existing group, new members started interacting with only a subset of the existing population. As they continue to form part of the group, the number of participants they interact with gradually increases.

Stakeholder participation

A reasonable choice of how to include new agents could have been made independently by the model designer. However, including people with knowledge of the context of interest can be a source of knowledge generation during the design process and grounds the model. We claim that grounding establishes the reasonableness of the model, showing that simplifications made from the real world do not trivialize the model and that other researches have successfully made similar assumptions to capture the key elements of the theory. The conversation that occurred during the modelling design process led to a valuable, yet unintended discovery. At the beginning of the design process the main focus was on rate of growth, as the first version of the model was completed, the design focused on the nature of including new participants, a change in focus emerging through conversations during the design process.

EXAMPLE 3: ADAPTING TO DATA

Context of research: Same as first example

The third example is also extracted from the context that first example was illustrated, but focuses on unauthorized activities in the public service delivery program. In this example, the modeller focused on designing a construct to model agents' fraudulent behaviour informed by empirical data.

Fraud is a crime that violates social norms, uses secretive processes, injures victims, and benefits perpetrators unfairly [26 – 27]. In the public sector, fraud in welfare, health care, and child care programs have been well-documented by government agencies such as Government Accountability Office and USDA. These unauthorized activities ultimately damage the integrity and endeavour of the public program that aims to alleviate social issues such as poverty and health. Unfortunately, fraud has been a persistent and difficult issue to address especially due to its non-stationary nature. Once a fraud detection method is put into place, it begins to lose effectiveness because the pattern of fraudulent behaviours changes as a response to the method [28]. Nevertheless, traditional fraud prevention or detection methods have been developed based on the static assumption of human behaviour. To understand the adaptive nature of fraud in a public service delivery program, a construct called “risk propensity” was designed by the modeller [29].

Brief description

The goal of this simulation model was to replicate the spatial and statistical patterns of fraud found in empirical data. One of the difficulties was how to model agents' changing propensity toward risky behaviour which is influenced by, and will influence, their decision on their level of involvement in fraudulent activities. Two separate simulation models were built. One was solely based on a hypothetical construct and its functions. The construct ranged from 0 (extremely low propensity toward risky behaviour) to 1 (extremely high propensity toward risky behaviour). We tested several scenarios of risk propensity distribution in the simulation to replicate the patterns observed from empirical data. The other model was built using the construct informed by empirical data. In Ohio WIC, local stores contracted with State government are categorized with four different risk levels based on the state's routine monitoring activities. In this simulation, we converted the distribution of risk levels of local stores in the empirical data for the hypothetical construct.

The modeller could also conduct a survey to examine the prevalence of fraud among local stores in order to design the construct. However, the validity of survey data on unauthorized behaviour (e.g. fraud and crime) is often questioned because respondents may not reveal true story. Existing data from routine monitoring activities which already revealed actual behaviour can have relative advantages. This process led us two separate questions: how to model a construct working with existing data and which source might provide better information of human behaviour.

Designing a construct working with existing data

These two activities ended up as reciprocal processes to improve the construct. The modeller realized that this construct can be designed to absorb personal or socio-economic characteristics of agents into a fundamental hypothetical construct in modelling agents' decision-making for fraudulent activities. Modelling a propensity toward certain behaviours is a certainly challenging task. This is not a finished work. We are at the beginning of this endeavour. If properly done, this effort can yield valuable insights to improve the model building of adaptive behaviours in complex policy systems based on empirical evidence.

DISCUSSION

A popular example in modelling courses is to have people create a model to simulate the standing ovation phenomenon. In doing so most people struggle to think of a system wide rules and orders and the exercise reveals a bias for top-down thinking. Through the design of a bottom-up system that helps to shape a new understanding of how individual choices can aggregate to group level behaviours [30]. Similarly, when used for research it is the design process itself that changes perceptions as demonstrated by the three previous examples. We will now suggest a basic framework for understanding the nature underpinning this source of knowledge discovery.

VIRTUE OF THE MESSY PROCESS

In the current paradigm, knowledge is generated from findings or results of research. Analytical procedures of certain tools are mostly preset. The question is asked to whether the research finding adds values to the existing body of knowledge, often assuming that the researcher followed the standard procedure. It is assumed that knowledge is generated mainly by sharing the findings rather than exploring the messy process of analysis. The model building process of ABMs leads researchers to examine the messy process and forces them to make critical design decisions. Depending upon the complexity of the system, there are almost unlimited numbers of decision points that create equally unlimited logical consequences to the system at different levels. Therefore, ABM exposes researchers to and learn from the unintended discoveries – not only from the findings, but also from the process itself. This messy process of model building becomes a regular source of knowledge generation because of two crucial components of model building: decision points and contextual knowledge.

ROLE OF DECISION POINTS

Models are created to describe, understand, explain, or predict certain aspects of contexts. Modellers make assumptions on whether the context is static or dynamic. They can build static or dynamic models corresponding to these assumptions. Depending upon the assumptions made, the frequency of decision-making in the model building process also changes. In other words, there are not many decision points when the modeller assumes a static context and builds a static model; whereas the modeller will confront various decision points when building dynamic models for dynamic contexts. In a simplistic form, the area covered by linking both axes of context and model is a potential knowledge generation space which requires decision-making in the model building process (Fig. 1).

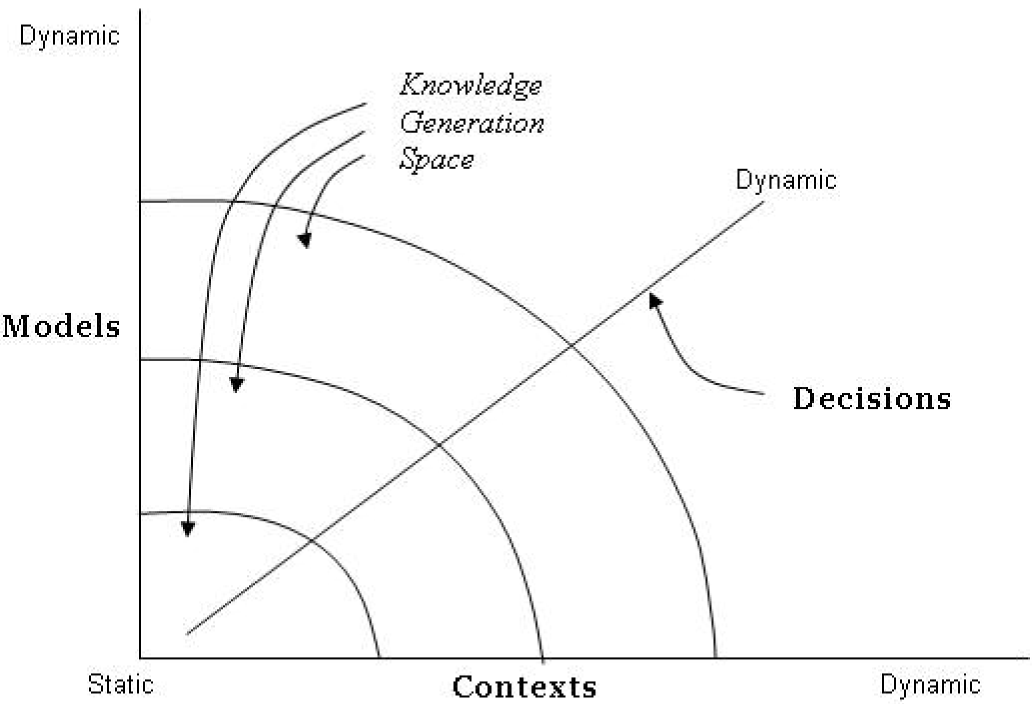

Figure 1. Constructing Knowledge Generation Space.

Knowledge can mean very different things depending upon whom we talk to. Knowledge is not something that exists independently from the person who uses it or something that can simply be stored as substance [31]. Personal knowledge is presented when a person must make a decision in a given context. Decision points force a person to use or show this knowledge and to improve their understanding. We saw that the model building process leads people to make decisions at several decision points. Providing the safe environment of trials and errors, the model building process helps researchers improve their research by experiencing the metaphors of real worlds, creating negotiated meaning, and developing crucial constructs for modelling.

POWER OF CONTEXTUAL KNOWLEDGE

It is useful to distinguish contextual knowledge from general knowledge. Imagine building a constructed world using simulation tools. You may have to have both programming skills and the context (or the system) that you are building. Programming rules are the kind of general knowledge that modellers can learn and share; whereas what the components of the constructed world imply is solely based on contextual knowledge of the specific system. Often modellers have advanced modelling skills, but lack contextual knowledge they need to have in order to build a model of social systems. Therefore, there can be at least two stages where the model building process becomes a regular source of knowledge generation for modellers at different levels. First, contextual knowledge can be elicited by the modeller while working with those who have experience in or of the system. Second, modellers must convert contextual knowledge to general knowledge by exploring such knowledge in different contexts. When one makes a decision in a certain situation, the motivation behind that decision is mainly contextual knowledge. Contextual knowledge influences us to make relevant and appropriate decisions; whereas general knowledge guides us with a broad boundary of actions. Model building process allows modellers to make relevant decisions eliciting contextual knowledge and to increase a stock of useful knowledge in the form of general knowledge.

In sum, this leads us to believe that there will not be a specified way of building ABMs as there is no single most effective solution of poverty. First, the contexts within which ABM can be based are very different. It is difficult to imagine any two social contexts that are identical over time and space. Social contexts are fundamentally defined and redefined over time and space. All contexts are unique at the moment so that general knowledge will not be able to fully capture the uniqueness. In that sense, contextual knowledge is an untapped source of regular knowledge generation. Understanding that many novel discoveries occur during the design process encourage model designers to be aware of the choices they make. In addition, including members of the models target audience in the construction of the model and be as powerful a research and learning tool as is the presentation of the final model.

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NAMJERAVATI NENAMJERAVANO: IZGRADNJA MODELA TEMELJENIH NA AGENTIMA KAO REGULARNI NAČIN GENERIRANJA ZNANJA

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SAŽETAK

Siromaštvo je kompleksna pojava koju je rijetko moguće analizirati u laboratorijskim uvjetima ili eksperimentima na terenu. Učinkovite mjere smanjivanja ili suzbijanja siromaštva zahtijevaju razumijevanja složene mreže povezanih socijalnih pojava. Potreba za povećanim razumijevanjem vodi na uporabu alternativne, robusne analize, u što ulazi modeliranje pomoću agenata. Snaga modeliranja pomoću agenata u raščlanjivanju kompleksnog socijalnog ponašanja i njegovom razumijevanju dobro je poznata. Međutim, tijekom istraživanjā kako iskoristiti modeliranje uvid, stečen često nenamjeravano, kao i pripadno znanje stečeno tijekom modeliranja većinom su nezapaženi. U ovom radu, nastojimo pokazati kako je proces izgradnje modela kritičan za stručnjake u uočavanju nenamjeravanog generiranja znanja. Kao primjere koristimo tri situacije iz Sjedinjenih Američkih Država u kojima su modeliranjem pomoću agenata potpomagana istraživanja učinaka intervencija u području siromaštva i ljudskog razvoja, provođena za obitelji s malim prihodima. Navedenim primjerima ilustriramo neka o sredstava za prikupljanje generiranog znanja. U diskusiji također ističemo prednosti modeliranja pomoću agenata kao neovisnog sredstva za generiranje znanja.

KLJUČNE RIJEČI

metode, modeliranje pomoću agenata, generiranje znanja, informatika javnih mjera

COMPLEXITY OF SOCIAL STABILITY: A MODEL-TO-MODEL ANALYSIS OF YUGOSLAVIA'S DECLINE

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SUMMARY

In this paper a model-to-model analysis is described which compares a model of ethnic mobilisation with a model of hierarchy decline. Even though the two models are not concerned with the same or at least a similar target, they are related by empirical findings: e.g. the decline of the Federal Republic of Yugoslavia was predominantly driven by processes of ethnic mobilisation. This appears to be a more general pattern, not restricted to this specific example. Hence, both models can be regarded as describing two related aspects of one and the same social process. However, since neither models describe a concrete target system, but rely on the notion of stylised facts, the models cannot be directly compared with reference to an empirical relative. Instead, in this paper a theoretical framework is elaborated which works as a rule for a comparison: relying on a differentiation between mass phenomena and decisions centres, the process of ethnic mobilisation can be identified as a mass-phenomenon, while the process of hierarchy decline concerns social decision centres. While mass-phenomena gain their effectiveness by enforcing social institutions, the working condition for decision centres is the establishment of social positions. It will be argued that the relation between these two phenomena can be described by the analogy of a lock and key. This makes possible conclusions with regard to both social theory and empirical explanations.

KEY WORDS

model-to-model analysis, political sociology, comparative sociology

CLASSIFICATION

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INTRODUCTION: NEW LINES OF MODEL-TO-MODEL ANALYSIS

In a paper describing an agent-based model of ethnic mobilisation [1] the authors expressed the hope that their model was "a small step towards the creation of a larger number of models that would eventually enable better understanding of the recent events in former Yugoslavia". The following considerations are intended as one small step in this direction. In a model-to-model analysis their model of ethnic mobilisation will be compared with a model of hierarchy decline as a consequence of internal hierarchical operational mechanisms. Comparable models of a causal analysis of ethnic mobilisation have been developed by Mimkes [2, 3] or Lim et al. [4]. The objective of this approach is comparable to these models.

Methodologically, the motivation for model-to-model analysis is to overcome a situation of researchers working in isolation without anyone else reproducing their results. It would enhance the transferability of knowledge drawn from simulation models to overcome this situation, i.e. progress should be made possible [5]. Since the research process of simulation is closer to experimental science than to deductive logic [6], only a progressive inspection of models may enfold their potential bearings. Yet, there are several modes of model-to-model analysis suggested by Hales et al. [5].

The most straightforward way of undertaking a model-to-model analysis is to replicate a model. Related to this approach is the use of models with different structures but the same target to confirm their results or to compare different models that announce the same type of results and to check their fitness with respect to particular data. What these and related techniques have in common, is that the models under investigation are concerned with the same or a related target system.

However, Hales et al. also suggest composing models of different scales in a larger model. Moreover, Cioffi-Revilla and Gotts [7] even related two seemingly unrelated models from distinct domains to draw out their structural similarities and differences. The comparative analysis undertaken here will follow this line of research: to use findings from each domain to illuminate the other. However, while the work of Cioffo-Revilla and Gotts is more methodologically oriented, the purpose of this approach is more theoretically oriented: to utilise the methodology of model-to-model analysis for a conceptual integration of different domains of social theory. Namely, to relate models of different aspects of the topic of political stability into a common framework [8-10]. Hence, if not to compose models of different scales into a larger one, as suggested by Hales et al., then at least it would be desirable to identify how they are interrelated. This could enhance the ability to transfer knowledge from one model to another. Hence, the models will be used to integrate different sociological theories. As a first step in this direction, a framework to compare at least two models will be introduced in this article.

The paper proceeds as follows: Firstly, the historical background will be outlined. The war 1991-1995 in former Yugoslavia can be regarded as a stylised target of the models. Some attempts at an explanation of the war are considered. However, this cannot be done in a comprehensive manner. The main purpose of this section is to develop an empirical framework to relate the models to different explanatory modes.

Secondly, the main conceptual ideas and the target system of the models will be introduced. However, it has to be taken into account that the models describe stylised facts that can only loosely be related to the empirical relative.

Finally, a theoretical framework will be outlined into which both models can be integrated. Since the models cannot be directly validated against data taken from processes in former Yugoslavia (because they describe stylised facts), this framework enables a comparison of the models insofar as it provides a common rule. Hence, this theoretical framework can be regarded as complementary to the empirical one. This will lead to conclusions relevant for the foundations of sociological theory and empirical analysis.

EMPIRICAL BACKGROUND

It is a phenomenon of modern European societies that in the so-called Eastern-European [11] or, more specifically, nation-to-state [12] mode of state formation, national movements emerge from larger political entities. Examples include the decline of the Austria-Hungarian Monarchy and the Ottoman Empire into nation states. This process is still underway: most recently a number of Eastern European states have declined along ethnic borderlines. Perhaps one of the most severe structural ruptures happened in former Yugoslavia: the Federal Republic of Yugoslavia ended in inter- and intra-state wars between ethnic movements, including genocide and ethnic cleaning. Hence, an understanding of the dynamics of the decline mechanisms would be crucial for political sociology [13]: ethnic identity seems to be a central driving force for the stability and instability of political power. In the following, a very brief outline of the recent conflicts in former Yugoslavia will be introduced.

BRIEF OUTLINE OF THE WAR IN YUGOSLAVIA

According to the constitution of 1974, the Federal Republic of Yugoslavia described itself as a multi-national state, consisting of six republics. Each republic comprised one of Yugoslavia's constituent nations. Moreover, the territories of the republics were drawn along historically established borderlines. Thus, ethnic movements could rely on cultural traditions. Nevertheless, for a long time until the 1980s the degree of ethnic mobilisation was considerably low. For example, marriages across different ethnic groups were not an exception. Opinion polls of 1990 in Bosnia indicate that more than 90 % of the population regarded the ethnic relationships in their local neighbourhood as good [14]. Thus, although there was an awareness of it, ethnicity was not an important feature of identity formation.

After the death of Josip Broz Tito (1892-1980), the long term prime minister of Yugoslavia (until his death) and founder of the socialist regime, ethnic movements emerged on the territory of Yugoslavia. The escalation of violence took on various forms: punch-ups between hooligans as well as rationally calculated speeches by political entrepreneurs [15]. Beginning with Slovenia's declaration to leave the Federal Republic, the process of disintegration finally resulted in a series of intra- and inter-state wars [16, 17]. Thus, for the first time after more than forty years, the phenomenon of war appeared in Europe. It is well known that the collapse of Yugoslavia went alongside massacres and genocide which was a challenge for international law [18, 19]. The intensity of the war, however, was highly different within various regions: while officially only 19 war victims were counted in Slovenia, the official number for Bosnia was 242 330.

Numerous explanations can be found in the literature, each stressing the importance of different explanatory factors:

1) Perhaps the most prominent and most widely accepted explanation is simply the reference to *wilful political actions* of Slobodan Milosevic (1941-2006), since 1989 head of the communist party and president of Serbia, and other members of the political élite. There can be no doubt that in the 1980s and early 1990s actors from the centre of the political élite consciously escalated the crisis of the Federal Republic to reinforce their personal

political power. Thus, a considerable part of the political élite gained personal advantage from the political collapse of the Federal Republic [20]. However, the questions remain, firstly, why the more aggressive politicians were more successful than the political 'doves' and, secondly, why they were successful at this particular time and not at other times [1]. This question can be traced back to two factors:

2) One factor can be identified in the *international situation* [21]: at the end of the Cold War, international relations were in a phase of destabilisation. The 'new world order' still had to be found. For example, some authors stress that the early acceptance of Slovenia and Croatia by the European Union, particularly enforced by Germany, yet, without possessing regulatory power when the war escalated, was in part responsible for the escalation. The unclear and too weak mandate of UN soldiers is another example. Yet these factors can explain the possibility of the escalation but not why it took place in the first place.
3) One therefore has to enquire about the internal conditions of the Federal Republic of Yugoslavia. Classical political economy would call for an investigation of the *economic situation*. In fact, Yugoslavia underwent a serious economic crisis in the 1980s [22]. From the mid 1980s, Yugoslavia was confronted with a decreasing production volume. Also, the republic had to face a dramatic increase in the inflation rate. In 1989, there was even a hyperinflation of 2700 %. Together with wages remaining at a constant level, this led to a dramatic decrease in the standard of living. Moreover, the combination of these factors resulted in a dramatic increase in state debts. Thus, political collapse went hand in hand with economic collapse.
4) Nevertheless, the economic situation itself cannot explain why nationalist political leaders took advantage of this particular situation. A prominent explanation for this phenomenon is the recourse to *history*. Particularly, history was stressed by the ideologies of the nationalist leaders [23-26]. Wars in the very early history of the region, such as the battle of Kosovo Polje [27] served as a demonstration of the impossibility of Yugoslavia as a nation state. Even though these 'explanations' are clearly ideological, the question has to be answered why these ideologies were successful. In fact, one can argue that the founders of Yugoslavia had to rely on pre-existing nations with a rather long history for the constitution of the Federal Republic. Thus, societal conditions determining cultural modes of identity formation have to be taken into account for the understanding of the borderlines of the conflicts [28]. In particular, conflicts may crystallise at the borderlines of the different religions [29] and different languages [30] within the one Federal Republic.

BRIEF OUTLINE OF THE MODELS

Without a doubt, all these factors contribute to an explanation of the phenomenon. Hence, a conceptual integration of these different aspects would be desirable. To contribute to an understanding of the mechanisms of the interaction of the explanatory factors, in this paper a comparison of two models concerned with two of these topics shall be undertaken. Both models highlight very different aspects of social disintegration. As the title of their paper, 'An Agent-Based Model of Ethnic Mobilisation' [1] indicates, the model developed by Srbljinovic et al. is concerned with the process of ethnic mobilisation. The MUE & HIER model [31], however, deals with the macrosocial decline of hierarchy levels.

AN AGENT-BASED MODEL OF ETHNIC MOBILISATION

The Model

The target of this model is described by its title: to study ethnic mobilisation. This is inspired by already existing theories of mobilisation [32, 33] and methodically implemented by extending modelling constructs which have already been in use so far [34, 35]. Developed in co-operation with the Croatian MoD's Institute for Defence Studies, Research and Development, the background of the model is factual ethnic mobilisation in the course of the war 1991-1995 in former Yugoslavia. However, in the model this can only be described as stylised facts. Hence, the model is not an instrument for prognostic purposes but intends to investigate possible social mechanisms that can generate patterns such as ethnic mobilisation.

The question analysed by the model is how successful political entrepreneurs are in mobilising ethnical identities and in identifying the conditions for the escalation of ethnic conflicts. In particular, the model was inspired by the observation that in former Yugoslavia regions with very little differences in their socio-economic characteristics exhibited great differences in their degree of ethnic mobilisation. The question therefore remains as to what factors are responsible for the success of mobilising activities by political actors.

The model is an agent-based model written in SWARM. It consists of 200 agents with a fixed ethnic identity: They can be blue or red, which cannot be changed. The dependent variable in the model is the *degree of ethnic mobilisation*, m^i, of each actor i. The degree to which they identify themselves with their given ethnicity can vary between 0 and 1. The difference between the maximum of 1 and the actual value is interpreted as the importance that an agent attaches to this ethnic identity in comparison to other possible identities. The actual degree of ethnic mobilisation is dependent on several social conditions:

- Firstly, it depends on the satisfaction of the agents with their life conditions, expressed by a grievance degree gr^i. It is a variable which can also vary between 0 and 1. This captures the satisfaction with economic, political and other aspects of social life.
- Secondly, it depends on the agents' social network: the agents are able to observe the identity and the agents' degree of mobilisation in their social network, which influences their degree of mobilisation m^i. This is formalised as:

$$m^i_{\mathrm{socnet}} = k\cdot(imp_{\mathrm{same}} + imp_{\mathrm{other}}) / netsize \tag{1}$$

  The term m^i_{socnet} denotes the influence of the social network on the mobilisation of agent *i*. k is simply a coefficient, to control the magnitude of this influence. The number of agents in the social network of agent *i* is denoted by netsize, and imp_{same} and imp_{other} denote the impact of members of the network whit the same and the other colour on the mobilisation of agent *i*.
- In particular, during the simulation the agents receive *appeals*, which may be red, blue or grey, i.e. neutral. However, in the absence of appeals the degree of mobilisation gradually decreases to 0 and the strength of the susceptibility of agents to ethnic appeals is smoothed by the grievance coefficient:

$$m^i_{\mathrm{app}} = \begin{cases} k\cdot k_{\mathrm{same}}\cdot gr^i\cdot m^i(t), & \text{for appeals of same colour,} \\ k\cdot k_{\mathrm{other}}\cdot gr^i\cdot m^i(\mathrm{t}), & \text{for appeals of other colour,} \\ k\cdot k_{\mathrm{neutral}}\cdot gr^i\cdot[1 - m^i(\mathrm{t})], & \text{for neutral appeals.} \end{cases} \tag{2}$$

The quantity m^i_{app} is the impact of appeals on the degree of mobilisation of agent *i*, *k* is a constant to control the magnitude of this influence. The same holds for k_{same}, k_{other} and k_{neutral}: they are constants to control the strength of the respective appeals. This is multiplied with the satisfaction with life conditions and the already existing degree of mobilisation of agent *i*. Thus, the effect of appeals is stronger, if the agent has already a high degree of mobilisation and the more dissatisfied the agents are. The inverse relation holds for neutral appeals.

The appeals are public in the sense that they are observable for every agent. Hence, the agents can react to stimuli of their own colour as well as to stimuli of other colours. Their initial degree of identification is uniformly distributed between 0 and 1 and they have a constant value of satisfaction with their life condition of 0,5. Finally, their network size is chosen randomly.

This structure can be summarised as follows: with m^{i}_{app} and m^{i}_{socnet} as defined above, and m^{i}_{cool} as the cooling effect, the dynamics of ethnic mobilisation reads as:

$$m^{i}(t+1) = m^{i}(t) + (m^{i}_{app} + m^{i}_{socnet} + m^{i}_{cool})\cdot\Delta t \quad (3)$$

which can be graphically displayed as in Fig. 1.

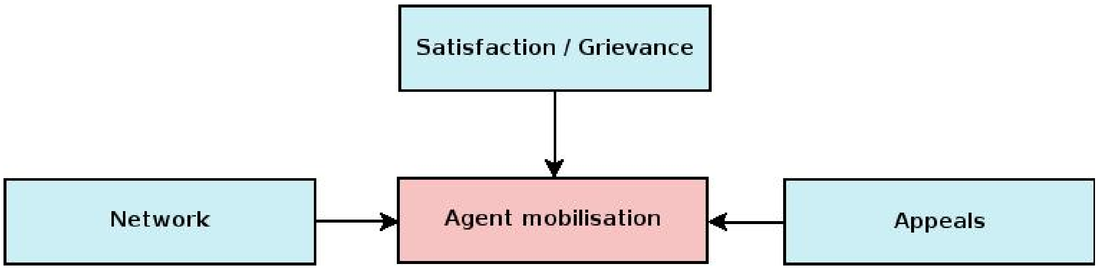

Figure 1. Structure of agent mobilisation.

Simulation results

This model was used to undertake a series of experiments to investigate the behaviour of the dependent variable – the degree of ethnic mobilisation – in cases of varying constellations of the independent variables. 100 agents are red and 100 agents are blue. Initially, they receive only appeals of the colours red and grey. These appeals are given at constant intervals. In an initial experiment it was checked whether the model behaviour was as expected: for example, an increase in coloured appeals increases the speed of mobilisation. Moreover, simulation runs resulted in a degree of ethnic mobilisation of either 1 or 0, dependent on whether the mobilising or cooling effect was stronger. This seemed to be a plausible result. Furthermore, mobilisation was faster when the agents possessed a social network.

The objective of this simulation runs was to enhance trust in the model. However, even in the initial setting it could be observed that in some simulation runs the average mobilisation intensity remained approximately constant for quite long simulation periods. This was mainly dependent on the appeal frequency. This was the focus of interest for further experiments.

Hence, in the next step a closer examination of this more complex behaviour was undertaken. Therefore the simulation runs were repeated with a randomly chosen appeal frequency. Approximately 60 % of the simulation runs showed the following result: either both populations reached a degree of mobilisation of 0 or the reds converged to 1 and the blues to 0. However, a long period of oscillation could be observed. Some simulation runs even remained in the oscillatory mode.

The next experimental setting was to investigate the influence of the agent's network composition. Hence, the experiments were repeated with a varying probability of having a friend of the same colour. In the case of relatively homogeneous networks, the result was that only the outcome documented above appeared: either both populations reach degrees of mobilisation of 0, or the reds converges to 1 and the blues to 0. However, an increase in the network's diversity also increased the diversity of the outcomes.

A further experiment was to vary the degree of satisfaction with the life conditions. Instead of a constant degree of satisfaction of 0,5, a uniform distribution with the mean value 0,5 was chosen. Moreover, the variance of the distribution was varied. While some new patterns arose, diversity of the results diminished with increasing variance of the satisfaction. The most frequent outcome was a mobilising intensity value of 0,9 for red and 0,5 for blue.

Finally, experiments were undertaken with appeals of both red and blue colour. A red appeal was given every 3rd simulation period, and a neutral one was given every 4th period. Then blue appeals were introduced with varying frequency. With the other parameters as in the initial setting, surprisingly, blue appeals seem to strengthen the mobilisation of the red agents.

Empirical evidence

The main result of these simulation experiments was that *differences* in the degree of mobilisation appeared *across similar populations*. This result captures the observation that differences in the degree of ethnic mobilisation cannot be tracked back to socio-economic factors. Srbljinovic et al. [1] mention ethnic conflicts in the Croatian region of Lika with a mixed Croatian and Serbian population, while other areas with very similar socio-demographic characteristics remained stable. This finding can be explained by the model. According to the model, this is merely due to random effects in the initialisation of the primary ethnic mobilisation as well as their network composition. Yet this limits the predictability of the simulation runs. The conclusion drawn from this result is that processes such as ethnic mobilisation, once they are initialised, are only controllable to a very limited degree.

A MODEL OF HIERARCHY DECLINE

On the other hand, the model of hierarchy decline is an equation-based model to evaluate the range of a theory of social power. While the agent-based model of ethnic mobilisation is explicitly motivated by the escalation of ethnic conflicts in former Yugoslavia, the MUE & HIER model was not intentionally developed to model a (however stylised) concrete target system. The objective of the model was to formalise a general theory of hierarchical operational mechanisms. Therefore, the relationship of this model to processes in former Yugoslavia has to be denoted explicitly.

The main theoretical term of this theory is the notion of a power territory (PT), governed by a so-called power territory ruler (PTR). The theory aims at formulating idealised structural conditions for the behaviour of PTs, namely three existence conditions and one operation condition [36]:

- Existence condition 1 (competence)
  At least one competence field has to be defined for each PT.
- Existence condition 2 (scope and effect)
  Let individuals or social units in the competence field of a PT be called clients of the PT; then the relation between the number of clients and the number of PT members may not fall below a certain minimum. It is obvious that this minimum number is greater than or equal to 1, i.e. that there has to be at least one client allocated to each PT member .
- Existence condition 3 (budget)
  The PT has to dispose of sufficient financial assets.
- Operation condition
  If a PT exists, one central condition for its undisturbed operation is that PT strategies are effective.

This theory can be graphically displayed, Fig. 2. The square indicates the society (large social unit). The PTs are indicated by the cones which serve clients in their competence field.

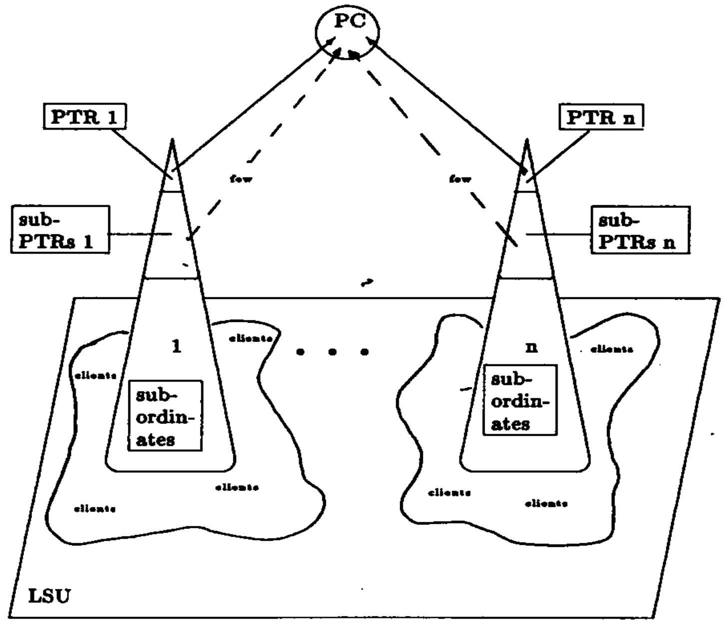

Figure 2. Structure of PT System - the wiggly lines represent the competence fields.

The Model

The MUE & HIER model described in [31] is an equation-based model written in DYNAMO. It relies on the theoretical framework as outlined above. The central variable is the number of positions in a so-called Power Territory (PT) system. The focus of the model is how hierarchical operational mechanisms are shaped by person-position relations. Hence, it is a model of élite exchange. Three types of élite exchange are implemented in the model:

- A continuous flux of ordinary replacement, for example, after retirement.
- Medium size structural ruptures, for example governmental change after elections.
- Serious structural ruptures like civil wars or the collapse of hierarchy levels.

The model consists of 8 sectors at all. However, they will not be outlined completely in this paper; to concentrate on the purpose of comparison, only the central operational mechanisms will be highlighted in more detail: the positions in the PT system, the personnel in the PT system, the hierarchical operational mechanisms, and the ruling demand and budget of the PT system.

Ad 1) The Positions in the PT System. The positions in the PT system are calculated according to the hypothesis of a strict hierarchy, i.e. it is assumed that there is a constant relation between the number of positions along the hierarchy levels. For example the relation between the positions on the top level and the underlying one is 1 : 10. Hence, the positional dynamics is predominantly driven by the top level in the hierarchy, articulating the demand for positions of sub-PTRs. It is possible, however, that one person can hold multiple positions. The growth of oligarchic positions is driven by three mechanisms:

- Ordinary growth
- PT partition
- Downward mobility; i.e. the creation of new positions on lower hierarchy levels.

The decline of oligarchic positions on level i is calculated by a specific *alarm function*, dependent on overdebt in i, and a so-called career aspirants crowding alarm (explained in the paragraph on hierarchical operational mechanisms). However, it is smoothed by a passing over of financial restrictions in i to lower hierarchy levels. The most important growth mechanism is PT partition: if ordinary growth of PT positions is low compared with the number of additional positions desired by career aspirants, then the PT partition quota grows.

Ad 2) The personnel in the PT system. The personnel dynamics is predominantly driven by career aspirants on lower hierarchy levels, waiting for higher positions in the hierarchy. However, since the model is an equation based model, the career aspirants are not modelled individually. It is simply a quota from the number of persons inhabiting positions at hierarchy level $i-1$, which are assumed to have the desire to gain positions on higher levels.

In particular, this section contains a *waiting chain* for career aspirants, which determines the above mentioned crowding alarm. At the beginning of every time step the waiting chain is occupied with career aspirants on the one hand and persons that formerly have lost their PT positions in structural ruptures on the other. This is realised as a flow model in the system dynamics style. After this process PT positions are created and occupied with persons from the waiting chain.

Ad 3) Hierarchical operational mechanisms. This section defines the *crowding alarm*. When the waiting chain is filled, the crowding alarm is activated. It will be shown below (in the section: the dynamics of the model) that this function is of central importance for the model behaviour. It is important to note that career aspirants have to follow the hierarchy: hence, first they gain positions on the lowest hierarchy level. If they have achieved a position on this level they can wait for a position on the next higher level, and so on. Again note, that their career is not modelled individually, but only as a quota of the persons occupying a position at each hierarchy level.

At this point the interaction between the positional and the personnel dynamics come into play: Positions are created by the top level. However, because a growth of top positions in the PT system leads to an even greater increase in the number of positions on the lower hierarchy levels this leads to a greater number of persons inhabiting positions which qualify them for positions on a higher hierarchy level – i.e. this leads to an increase of career aspirants. Note, that the *quota* remains constant. Thus, a greater *number* of positions leads to a greater number of career aspirants.

In particular through the mechanism of PT partition, this mechanism leads to a growth of the PT system. Hence, an autocatalytic dynamic is the consequence: growth of the PT system yields growth of the waiting chain, which yields growth of the PT system. The unsatisfied career aspirants, however, are the driving force for the crowding alarm function, since they are assumed as enhancing the revolutionary potential: they have the know-how of how PTs are running as well as the ambition to rule a PT.

Ad 4) Ruling demand and budget of the PT system. The budget of the PT is particularly dependent on the ruling demand, however limited by a ceiling, when a threshold of maximum overdebt is reached.

The ruling demand of a PT is specified by the number of involvement in activities. These are specified by the number of contacts within the PT system. The demand per activity is calculated by a linear combination of a minimum and a maximum demand per interaction. While the minimum demand is simply a constant, the maximum demand is to denote *conflict* interactions. It is assumed that a certain quota of interactions is of such a kind and that conflict interactions are more costly. If conflicts become more numerous, the so-called hectic state intensity is increasing. It is assumed that in turn conflict interactions are even more frequently when this stress is increasing, what recursively intensifies the hectic state. it follows that an increasing amount of money and personnel is needed to deal with these conflicts. Thus, again there is an autocatalytic process: increasing number of PT positions yield an increasing hectic state which yields to an increasing demand of PT positions.

Summary. Hence, in principle the model is a *waiting chain model*: In the centre of the model is a waiting chain of career aspirants, which is mostly responsible for the dynamics of the model. However, each sector of the model consists of many interdependent equations, which does not permit to display them in a fashion sufficient for replication within this article (comp. [28, pp. 274-307]). Therefore a simplified graphical illustration might help to identify its main causal structure, Fig. 3.

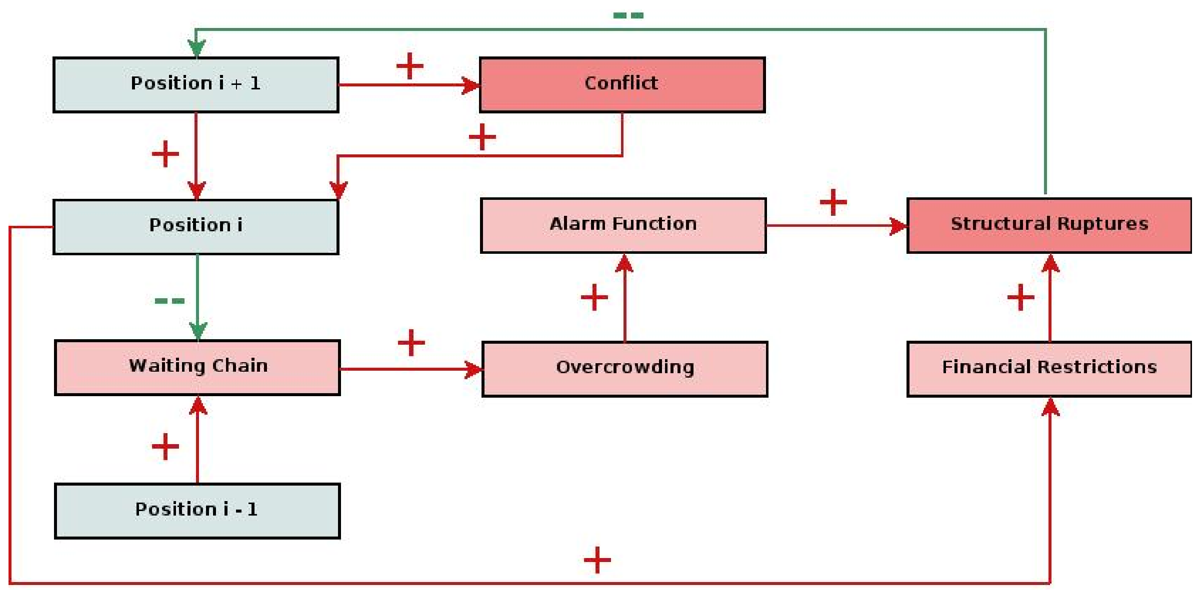

Figure 3. Causal structure of the model.

Hierarchical positions at the hierarchy level i are generated at the above level i + 1. The process of generating positions is amplified by conflicts on the hierarchy level i + 1. The positions at level i are occupied with persons from the waiting chain. Thereby the number of persons in the waiting chain is reduced. The waiting chain is filled with career aspirants from the lower hierarchy level i – 1. If the maximum capacity of the waiting chain is reached, the overcrowding of the waiting chain activates an alarm function. This alarm function enhances the value of a structural rupture register function. A further input for this register function comes from financial restrictions. The financial demand is caused by the positions at level i: the more positions exist the greater is the financial demand. If a certain threshold of the structural rupture register function is reached, the function is activated which destroys the top hierarchy level i + 1.

Simulation results

The dynamics of the model is mainly driven by the two autocatalytic processes which result in a strongly growing PT system: These are processes implemented in the sector of the personnel of PTs and in the hierarchical operational mechanisms:

- PT growth → waiting chain growth → PT growth
- PT growth → increase conflict interactions → PT growth

The growth of the PT system leads to a strongly growing financial demand. This can be financed by two means: through growth of GNP and through debt. Since in the long run the growth of GNP has to be extreme high to fulfil the demand of the PT system, after a while the

PT system turns into a mode of debt financed growth. Then the structural rupture register function is activated. After a structural rupture the register function relaxes to zero.

As a result of the decline, however, the positions on the top level are destroyed and, consequently, the persons inhabiting these positions are thrown into the waiting chain and again the process starts from the beginning.

Empirical evidence

Obviously, the decline of former Yugoslavia can be described as a decline of a hierarchy level. The Federal Republic of Yugoslavia collapsed into its pre-existing constituting parts. This process was enforced by political leaders with a high revolutionary potential: for example, during Tito's regime, Franjo Tudjman (1922-1999), from 1992 until his death the first president of Croatia, had already been in prison in the 1970s and the 1980s due to so-called nationalist agitation [12]. However, the qualitative analogies go even further: the constitution of 1974 can be regarded as a PT partition, as described by the model. This constitution describes the republics as states and even gives regions like Kosovo and Vojvodina more autonomy [37]. Therefore political aspirants can be satisfied with PT positions in these regions. Also two phases of PT growth can be distinguished in former Yugoslavia: The successful 1960s which was a phase financed by GNP growth can be distinguished from the time of the 1980s which was characterised by growing debts. Thus, even though the model was not intentionally developed to cover the events in former Yugoslavia, the theoretical assumptions underlying the model are in fact confirmed by them.

OUTLINE OF A THEORETICAL FRAMEWORK

Both aspects of ethnic mobilisation and hierarchy decline can be observed in the history of former Yugoslavia: On the one hand, there was a decline of the Federal Republic into smaller units along pre-existing borderlines of a lower hierarchy level. On the other hand, one of the central driving forces behind this process was the mobilisation of ethnic identities. Hence, empirical evidence suggests, that these models capture some relevant aspects of the processes which had to be observed in the former Yugoslavia. But how are these aspects related to one another?

In the model of ethnic mobilisation the ethnic appeals are given as external facts. No analysis is made regarding where these appeals come from. Hence, obviously the question cannot be posed why they are given at all. On the other hand, the model of hierarchy decline is blind to the borderlines of the decline. This is due to the fact that the competence fields are not specified in the model. Thus, no conditions of success or failure can be identified. Hence, it appears to be reasonable to regard both models as complementary in 'some way'.

However, both models are concerned with stylised facts; they do not represent a concrete target system [38]. Firstly, this is due to the overwhelming complexity of social reality, which cannot be represented by a simulation model. In contrast to models based on first principles (at least rhetorically) the actual state of the social sciences does not allow for reliance on some simple laws representing the complexity of their target system [38, 39]. Hence, it has to be questioned in what respect, i.e. in what 'way' they can be compared: Since the empirical facts cannot serve as a rule to compare models of stylised facts, there is no measure available to judge the validity of these models in a straightforward manner. Yet, the notion of stylised facts implies what can be called a proto-theory: in principle, a stylised fact is a shorthand for a theory taken from everyday knowledge. Thus, it is plausible to identify the theoretical framework behind the stylised facts. A theoretical structure will therefore be developed which is able to relate both models in a common theoretical framework. Within such a framework it is possible to identify which questions are posed and answered by the models and which are left open by them. Hence, such a theoretical framework is a precondition to relate isolated models of stylised facts to one another insofar as this theoretical framework can serve as a rule: instead of comparing the models directly, firstly the theoretical topic with which the models are concerned will be identified and then these theoretical topics can be compared to relate the modelled stylised facts to one another. It thus becomes possible to identify the extend to which the models' behaviour factually intersects.

DECISION CENTRES AND MASS PHENOMENA

In fact, the targets of the models can be distinguished by the way they are generated as well as by their functional relevance within social processes.

In a first step, a more formally oriented differentiation will be introduced of how some output data Y is generated to reflect the difference between the models [40]: it may result from a sequence of processes which, in principle, can be divided into two categories. It may result as a consequence of a process in a social decision centre or it may result as an aggregate of a sum of individual processes, thus, it may be a social mass phenomenon. Decision centres are social units whose reactions constitute instances of concentrated influences [41]. The concentration can be identified by the relationship between the number of specific reactions and the number of actors producing these reactions. Examples may be war between nation states or the building of motorways [40]. For instance, if the president of the United States declares war, this is a decision of an individual person. Yet it can affect – in principle – the whole human race. If no such influence concentration can be observed, the socially generated data has to be regarded as mass phenomena. Examples of mass phenomena are income distributions, language or a traffic jam. Every statistical aggregate is a mass phenomenon. Hence, in principle, socially generated data Y is the set union of the set of mass phenomena and phenomena caused by decision centers:

$$Y = \{Y_{\mathrm{DC}}\} \cup \{Y_{\mathrm{MASS}}\} \tag{4}$$

With regard to the models, this distinction leads to the following formal classification of the models:

- In the model of ethnic mobilisation no influence concentration is implemented. Of course, the agents are highly determined by the ethnic appeals they receive. However, these appeals are not ascribed to an individual actor. Thus, the model describes a mass phenomenon, since ethnic mobilisation is a social phenomena only insofar as it appears as a mass phenomenon.
- On the contrary, the existence or the decline, respectively, of hierarchies is not a mass phenomenon. Hierarchies can be regarded as mechanisms for collective decisions, i.e. as a decision centre. Hence, the model of hierarchy decline is concerned with operational mechanisms of decision centres.

Thus, as a first result, the models can be identified as models of mass phenomena and decision centres, respectively. This distinction leads to a first more formally oriented conclusion of how the processes described by the models can be differentiated.

However, the next sociological question is under what circumstances mass phenomena and processes within decision centres are related to one another. Obviously, many operations of decision centres do not cause mass mobilisation. On the other hand, not every mass phenomenon concerns competence fields of PTs and will in turn enhance the probability of conflict interactions. For instance, the mass phenomenon of smoking has caused operations within decision centres only in the last decade. Hence, the question remains: when do both levels affect each other? This leads to the question of what are the material social conditions at work behind these two phenomena. What is the causal mechanism to connect decision centres and mass phenomena? Hence, the question of their functional relevance has to be addressed.

INSTITUTIONS AND POSITIONS

On the one hand, the mass phenomenon of ethnic identity is a predisposition for social orientation, directing social action. This refers to the notion of the homo sociologicus [42]. Hence, ethnic mobilisation can be regarded as an example of the enforcement of a social institution [43, 44]. Although a detailed examination of the sociology of institutions cannot be undertaken [45, 46], some key elements can be highlighted: these are elements of sociality within the individuals, which can be regarded as the non-contractual elements in the social contract [47]. They can be regarded as an element of sociality in the brains of the individuals. It is claimed that institutions are necessary to regulate social interaction in a way that people are able to interpret and enable them to react to other actors' behaviour. Hence, institutions create stable behaviour patterns. Ethnicity provides a means for the formation of such forms of stable behaviour patterns. People can create a personal identity by relying on their ethnicity: ethnicity provides a social role for individuals [48]. Moreover, it enables people to structure their world view insofar as it provides a means for the inclusion and exclusion of other people in a commonly shared way. Hence, ethnicity is an institution to regulate social interaction.

Now, let us ask what kind of phenomena decision centres are: hierarchically organised decision centres can be regarded as formal organisations. Yet, a comprehensive review of the sociology of organisations cannot be the task of this article (compare e.g. [49, 50]). However, a central feature of formal organisations is that the legitimisation of social relations is organised by a membership relation [51]. Following Peter Blau [52], it will be proposed to conceptualise the difference between membership and non-membership in a decision centre as the distribution of a population among social positions. This is because social structure "nearly always includes the concepts that there are differences in social positions, and that there are social relations among these positions" [52, p. 27]. Undoubtedly, social positions influence people's social relations, but they have to be distinguished from mere interaction. At different times the same position can be inhabited by different people. By the establishment of social positions, society faces the individuals. Inhabiting positions in formal organisations enables individuals to distinguish between official duties and private life [51]. Note, that the creation of position and the struggle of individuals to gain positions are the core process of the model of hierarchy decline. Thus, it is a model of the dynamics inherent in organisational positions. To sum up:

a) Hierarchies, on the one hand, are operational mechanisms of decision centres, constituted by social positions.
b) Ethnicity, on the other hand, as a mass phenomenon is a social institution, directing individual actions as their precondition.

Yet the question remains, as to how they are related: empirically, the phenomena of hierarchy decline went alongside ethnic mobilisation. However, the extend to which the behaviour of the models intersects must be theoretically deduced. It will therefore be theoretically demonstrated that, in fact, institutions and organisations have a causal power on each other.

THE THEORETICAL LINK

Thus, the stylised target systems of the two models can be distinguished by the way they are generated as well as by their functional relevance. However, the question remains of how they are linked together: when do mass phenomena and decision centres affect each other. Such a link would enable to integrate sociological theories of institutions and organisations.

1) *The input of the model of hierarchy decline for the model of ethnic mobilisation*

On the one hand, it is a plausible assumption, that the appeals that the agents receive in the model of ethnic mobilisation are caused by decision centres. Obviously, this was the case in former Yugoslavia. Their analysis is left open in the model of ethnic mobilisation. Note, however, that the degree of mobilisation drops to zero in the absence of ethnic appeals. Therefore appeals and, in turn, the existence of decision centres is of central relevance for the reinforcement of the social institution of ethnic identity. The absence of ethnic appeals can explain the long period of peace in former Yugoslavia. The MUE & HIER model provides an explanation for their appearance. The frequency of ethnic appeals can be explained by the length of the waiting chain of career aspirants. The frequency of appeals should increase with the length of the waiting chain, because career aspirants (the persons in the waiting chain) might gain advantages if they can be identified as a representative of a social institution like ethnic identity. This might help explain the rise of the number of political entrepreneurs in the specific situation of Yugoslavia in the late 1980s and early 1990s. Namely, the precarious economic situation of the 1980s did not allow for the creation of a sufficient number of positions to satisfy career aspirants, i.e. an overcrowding of the waiting chain has to be expected.

2) *The input of the model of ethnic mobilisation for the model of hierarchy decline*

On the other hand, according to the model of hierarchy decline, a precondition for the operation of decision centres is the existence of a competence field. The specification of competence fields, however, is left open by the model. This is what the model of ethnic mobilisation is about. To be regarded as competent, a decision centre has to possess defining power over a specific topic. However, the topic cannot be arbitrary. For instance, people would not ascribe any competence to a political leader appealing to condemn, e.g. red-haired people (at least nowadays). The propensity, to be regarded as important, increases if a competence field refers to a social institution. Ethnicity provides such an institution. Thus, the notion of a competence field links decision centres to mass phenomena of social institutions like ethnicity. This might help explain the concrete nature of the appeals of the political entrepreneurs. Insofar as they have to find a competence field, it might be an advantage for them to appeal to institutionally deep-seated patterns of social orientation like ethnic identity. The degree of mobilisation can be regarded as a measure of their success. Note, for instance, that the parents of Slobodan Milosevic were Montenegrins and that his brother Bora made a political career as a Montenegrin.

In conclusion, the relation between institutions and organisations can be described by the analogy of a *lock and key*: a social institution like ethnic identity provides a possible competence field for decision centres. Since the existence of a competence field is a necessary precondition for the operation of decision centres, institutions may be regarded as a lock for the success of a decision centre; namely insofar as appeals from decision centres have to match a social institution like a key has to match a lock. The metaphor of a lock is used to denote that institutions play a 'passive role': obviously, they are not a social actor.

Conversely, decision centres possess the power to reinforce a social institution like ethnicity (for instance, by sending ethnic appeals). In fact, this is reflected in the model of ethnic mobilisation by the assumption that ethnic mobilisation drops to zero in the absence of ethnic appeals. Thus, decision centres are the key to call into being the social institution of ethnic identity, and, in turn, processes of ethnic mobilisation. The metaphor of a key is used to denote that organisations are a social actor, they play the 'active role'.

Hence, this theoretical framework allows us to show where the behaviour of the models intersects: Namely, the appeals in the model of ethnic mobilisation may be generated by the model of the decision centres while the competence fields in the model of hierarchy decline may be defined by the model of the mass-phenomenon of mobilisation. The success in establishing a competence field can be measured by the degree of mobilisation. The formal structure of a model docking can be described as in Figure 4.

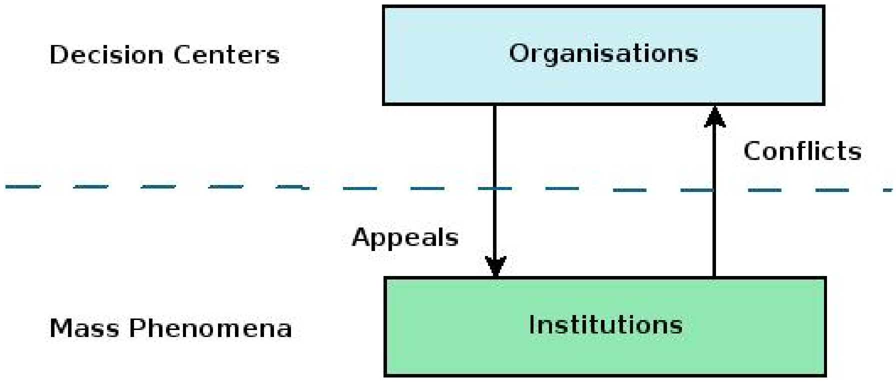

Figure 4. Causal interaction of the models.

Decision centres have to be regarded as possessing a competence field. This is a precondition for their succesfull operation: it is the legitimisation for the positions in the PT. To be regarded as competent, they can send appeals. These may be successful if they address social institutions. Note, that a competence field may not necessarily be ethnicity. The frequency of ethnic appeals may be determined by the length of the waiting chain. In particular, waiting chain overcrowding might increase the number of appeals. Thus, career aspriants are the main driving force. This in turn leads to a reinforcement of an institution. Yet, the competition between decision centres to be regarded as representing an institution may cause conflict interactions between the decision centres. Note, that the degree of conflict interactions already serves as an input for the structural rupture register function, which determines the stability of the organisational system. However, in the model it not specified what the conflicts are about. This can be specified by a model of the mass-phenomenon of mobilisation. Thus, the degree of ethnic mobilisation may be used as an input for the calculation of conflict interactions.

EPISTEMOLOGICAL FRAMEWORK

Finally, this investigation shall be brought to an end with some remarks on the epistemological perspective opened up by these considerations: Theoretically, the model-to-model analysis opens a perspective on theories of the relation between culture and politics and the related question of social constructivism: following Cederman [53], 3 theories of the relationship between culture and politics can be distinguished. An essentialist, an instrumental-constructivist, and a limited-constructivist approach. The essentialist approach stresses the role of the cultural ‘raw material’. Hence, ethnicity is assumed as given and ”each ethnic core produces a political identity more or less straightforwardly” [53]. The constructivist approaches, on the contrary, emphasize the active role of politics in the formation of ethnic identities by manipulating cultural symbols. According to the instrumentalist-constructivism the causal chain goes from politics to culture, which is seen more or less as an epiphenomenon. The limited-constructivist approach, however, sees the relation between culture and politics as a complex feedback structure: political actors do shape the cultural material, but they are limited in their freedom of choice.

The two models under consideration implement a mechanism [54, 55] of such a feedback loop: On the one hand ethnicity is a pre-given fact in the model of ethnic mobilisation. Thus, this assumption is in contrast to an instrumentalist-constructivist approach. Nevertheless, the degree of mobilisation is open for political manipulation by the means of ethnic appeals. These appeals can be analysed by the means of the model of hierarchical operational mechanisms: PTs are successful if they can find a competence field. This means that they have to send some forms of appeals to prove their competence. This is a constructivist perspective since they have the ability to manipulate cultural symbols. However, they can be more or less successful. In particular, their chance to be successful enhances if they can point to social institutions. These institutions can be regarded as the cultural 'raw material', which limit the freedom of manipulating cultural symbols. Thus, the integration of the two models, i.e. the methodological approach of a model-to-model analysis, turns out to be relevant for the epistemological foundations of social theory: namely, it suggests a limited-constructivism by demonstrating possible mechanisms of a feedback loop between voluntary political action and cultural conditions.

CONCLUSION AND PERSPECTIVE

The considerations developed in this paper can only be regarded as a brief outline and are by no means a comprehensive investigation of either the empirical or the theoretical background of a political sociology. Moreover, no direct political advice could be expected from this more fundamental research. However, it enables a methodological and a theoretical clarification as well as it helps for a conceptual integration of the different explanations of the inter- and intra state wars in former Yugoslavia:

1) Firstly, due to the fact that Artificial Societies describe stylised facts, this model-to-model analysis is only possible by explicitly enfolding the theoretical dimensions behind the everyday theories of stylised facts. Theoretical considerations provide a tool for relating models concerned with seemingly diverse phenomena. Thus, at this point the theoretical considerations developed in this paper serve as an input for methodology.
2) On the other hand, also social theory profits from this methodological research. Insofar as simulation models allow for a formal docking of models, they should also allow for a theoretical discourse: commonly, theories concerned with cultural phenomena on the one hand and political theories on the other hand, or more general theories of social micro- or macro phenomena, respectively, employ a highly different language. It is therefore no trivial task to undertake a comparative theory analysis. However, by using simulation models, a common language can be elaborated within which it seems possible that the theories from both levels could benefit from findings on the other level. In principle, it should be possible that both models could import and export data to a common software frame: On the one hand, the model of hierarchy decline could export data about the length of the waiting chain. This data could be utilised to calculate the appeal frequency that could be imported by the model of ethnic mobilisation. Note that appeals are given externally in this model anyway. On the other hand, the model of ethnic mobilisation could export data about the average degree of mobilisation. This data could be imported by the model of hierarchy decline to calculate the degree of conflict interactions. Note that these are given as a simple quota and are not calculated internally in the original model. Along these lines, the model-to-model analysis could allow for the conceptual integration of social theory. In particular, a sensitivity analysis might allow for an investigation of the recursive impact of the two levels of social theory (which are at the backdrop of the stylised facts of the models) on each other.
3) Moreover, it has been pointed out, that the different explanations of the empirical phenomenon of the series of intra- and inter-state wars all contribute to an understanding of different aspects of the phenomenon. The model-to-model analysis allows for a conceptual integration of those explanations highlighting internal conditions: The *first*

explanation outlined in the section about the empirical background was that the decline of Yugoslavia was driven by wilful political action. This can be explained by the model of hierarchy decline: namely, an overcrowding of the waiting chain with career aspirants suggests a high probability of aggressive political action. However, the possibility of PTs to generate positions, which could prevent such an overcrowding is dependent on financial restrictions. This refers to the *third* explanation: precarious economic circumstances. Thus, the model of hierarchy decline might help to integrate these two explanations: why aggressive political actors emerge at a given time. By the model of ethnic mobilisation the cultural borderlines of the conflict can be taken into account. This was the *forth* explanatory mode. This model explains why aggressive political actors where successful with propagating a nationalist ideology. Hence, except for the international situation the two models provide a framework to integrate the internal conditions that where proposed to explain Yugoslavia's disaster.

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KOMPLEKSNOST SOCIJALNE STABILNOSTI: ANALIZA RASPADA JUGOSLAVIJE POMOĆU MODELĀ

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SAŽETAK

U radu je opisana analiza modelā u kojoj se uspoređuju model etničke mobilizacije s modelom raspada hijerarhije. Ti modeli nisu postavljena za jednaku, ili sličnu svrhu, ali su empirijski povezani: raspad federativne republike Jugoslavije većinom je uzrokovan etničkom moblizacijom. Ovo je općenitija situacija i nije vezana samo uz ovaj posebni slučaj. Zbog toga oba modela mogu biti razmatrana kao povezani aspekti jednog društvenog procesa. Međutim, budući da ni jedan model ne opisuje konkretni nego stilizirani sustav, ne možemo ih izravno uspoređivati s podacima. Umjesto toga, u ovom je radu postavljen teorijski okvir: na temelju razlikovanja masovnih pojava i središta odlučivanja, etničku mobilizaciju može se promatrati kao masovnu pojavu, dok je raspad hijerarhije vezan uz društvena središta odlučivanja. Dok masovne pojave postaju djelotvorne uključivanjem institucija, radni uvjeti za središta odlučivanja je uspostava društvenih pozicija. Relacija navedenih pojava slikovito je opisana na način koji omogućava zaključivanje vezano uz društvene pojave i emprijska objašnjenja.

KLJUČNE RIJEČI

analiza modelā, politička sociologija, komparativna sociologija

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UNRAVELING THE UNSUSTAINABLITY SPIRAL IN SUBSAHARAN AFRICA: AN AGENT BASED MODELLING APPROACH

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SUMMARY

Sub-Saharan Africa is trapped in a complex unsustainability spiral with demographic, biophysical, technical and socio-political dimensions. Unravelling the spiral is vital to perceive which policy actions are needed to reverse it and initiate sustainable pro-poor growth. The article presents an evolutionary, multi-agent modelling framework that marries a socio-ecological approach to a world system perspective and takes agriculture as the engine for sustainable development in Sub-Saharan Africa. A number of possibilities for empirical validation are proposed.

KEY WORDS

multi-agent systems, development, poverty trap, degradation, social capital, sub-Saharan Africa

CLASSIFICATION

JEL: O13, O33, O55, Q20

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INTRODUCTION

For three decades, Sub-Saharan Africa has been trapped in economic stagnation, coupled to pathologies like widespread poverty, child malnutrition, violent conflict and the HIV-Aids epidemic. That a new boom of the world economy now entails somewhat higher growth rates does not alter the fact that per capita GDPs have hardly increased since the 1980s in Africa below the Sahara.

Today, it is once more recognized that this stagnation is rooted in agricultural crisis. Both the World Bank and scientists [1, 2] already stressed that modern growth requires agricultural development as a starter, but many believed that “globalization” would allow export demand for manufactures or services to assume this role. The absence of cases of successful development without agricultural growth has belied this view (cf. [3]). In Sub-Saharan Africa, agricultural crisis caused a flight from the land, but no incentives for non-farm development, so that urbanization entailed a proliferation of marginal activities and fights over public sector jobs.

Why is agriculture stagnating? For a long time, experts forwarded mono-causal explanations. They pointed to adverse natural conditions (e.g. [4]), high population growth (e.g. [5]), overtaxation of farmers [6], and so on. When donor prescriptions to redress some of these conditions failed, a new mono-causal bogey was looked for. The blame was put on “bad governance” and “social capital problems” that would stem from Africa’s particular culture and history [7-9].

Gradually, some experts came to realize that Africa’s problems had multiple and mutually reinforcing drivers rather than single causes. Various vicious cycles or ‘poverty traps’ were identified: of poverty, population growth and soil degradation [10]; of poverty and low public investment [11]; of thin markets and low private investment in agro-industrial chains [12]; of dependence on traditional commodities and low export earnings [13], and so on and so forth. All these explanations are right, but each lifts only one corner of the veil. In fact, Sub-Saharan Africa is trapped in a complex unsustainability spiral with demographic, biophysical, technical and socio-political dimensions. Unravelling it is vital to perceive which social actions could reverse this spiral and initiate a positive dynamic of sustainable pro-poor growth.

In our opinion, such unravelling requires an evolutionary framework that marries a socio-ecological approach to a world system perspective. Sub-Saharan Africa is a region that has retained certain pre-industrial traits, with consequences for its internal dynamics, but that is integrated in an industrialized world economy which makes its dynamics deviate from pre-Industrial Revolution societies. This paper sketches a broad vision that is based on this premise, and proposes a computer model that can serve to elaborate it, test its consistency, and explore ramifications. At the end we discuss possibilities for empirical validation.

VISION

In pre-industrial societies, centuries of demo-economic growth alternated with Malthusian crises [14, 15] (for theoretical interpretation [16]). Central to it was Ricardo’s classical “law” that farm production could only be raised by reclaiming less fertile lands or labour-demanding intensification, so that population upswings raised agricultural prices [17]. It made food dear for the poor, but as Malthus [18, pp.29-31] already observed, it lowered real wages and prompted investment and innovation in larger farms (also [19]). This fuelled the phases of agricultural intensification that historians have called ‘agricultural revolutions’. The resulting increases in food supply moderated the rise in food prices. More mouths could be fed, rural markets for commerce and industry expanded, and no severe distress precluded co-operation and the maintaining of soil fertility. In these phases the farm economy was more or less robust; harvest failures caused suffering but no collapse. However, risk aversion and time-consuming communication made innovation a slow process [20]. Sooner or later, agricultural growth ran up against diminishing returns. For some time, a precarious stability could be maintained by elaborate safety nets, intricate social hierarchies, and small technical improvements (cf. [21]), but in the end, strong increases in scarcity could not be avoided. Food prices skyrocketed, squeezing the demand for non-farm products; artisans lost their livelihoods swelling the ranks of the rural poor and small farmers over-exploited their plots in an effort to minimise their dependence on food markets (cf. [22]). Harvest failures or other shocks pushed society into a spiral of interlocking vicious cycles of soil degradation, food insecurity, rising conflict and disruption, which ended in demographic crisis. This "Malthusian correction" released the pressure of population on the food supply. Wages rose and farm prices fell, causing a decline in large farms and halting or reversing the process of intensification. It initiated a low tide in economic development, which lasted until a new population upswing prompted a new cycle.

In the late 19th century, a new phase of the Industrial Revolution broke the Ricardian constraints [23]. Modern transport enabled the tapping of land reserves in temperate zones outside Europe; industrial fertiliser accelerated the increase in yields; and fossil substitutes freed farm production capacity that had been used for non-foods. For the first time in history, international agricultural prices went through a series of price falls without this being caused by a crisis in population. It ended the age-old problem of scarcity, but at the same time it brought a new challenge. Low prices squeezed farm profits which entailed a decline of large farms and threatened to slow agricultural growth. Western countries responded through government support and co-operatives that bolstered knowledge infrastructures, moderated the diseconomies of small farms, and ensured that frugal household producers kept margins for investment [24]. Rather than leaving a sector with low earnings, farm families seized upon the new technical and market opportunities to defend their incomes. It started a treadmill of production growth, low prices and new innovations [25] that became the engine of a new agricultural revolution of agri-chemicals, high-yielding varieties and mechanization.

The regime change that emanated from the 'western' world deeply affected other countries too. The impacts varied depending on local conditions. East and South Asia had gone through a long history of population growth, state formation, class differentiation and market development. Farmers tended to organize on class basis, and a political class had emerged with some feeling for long-term national interests. It stimulated 'developmental states' (cf. [26]) that followed the western response at some distance. The Japanese Empire invested in irrigation and rural infrastructure and protected its farmers at the outer border. It enabled significant agricultural growth, which after WWII got a new impulse by redistributive land reform and US aid [27]. Rural incomes became an important demand factor for industries that produced simple goods for domestic consumption. It facilitated the cross-subsidization of industrial exports by which these countries established themselves as industrial powers.

Meanwhile in Asian colonies of European countries farmers were not supported. Population increased, but low world market prices discouraged the farmer investment in land management that was needed for sustainable intensification. Rural societies were pushed in vicious spirals of poverty, population growth and resource degradation that suffocated economic development [21, 28]. It reminded of pre-industrial Malthusian crises, but these occurred because an agricultural revolution was exhausted, while here an agricultural revolution was nipped in the bud. However, independence was a historical watershed. Several new governments introduced supportive farm policies [29-32]. Together with the high-yielding seeds from international research institutions it led to the Green Revolution, which became an engine of industrialization.

In the Americas, pre-Columbian Stone Age societies had been overrun by European invaders with superior weapons and diseases for which they had no immunity [33, 34]. In the (sub)tropical parts, where profitable export crops could be grown for the European market, large plantations evolved that employed coercive labour systems to prevent workers from using the abundance of land and setting themselves up as independent peasants. It created a social divide between planter elites and rightless masses of rural workers, which encouraged 'oligarchic' political structures, hampered the development of simple consumer goods industries, and reinforced the export orientation of the plantations [35, 36]. When international agricultural prices fell, agrarian elites kept to open trade policies. Rather than calling for protection, they used their dominance to shift the burden to the rural poor. In the end, they evicted large numbers of rural workers to pave the way for cost-cutting mechanization. It allowed a development of a kind, but one that involved more inequality, slower growth and more socio-political tensions than in the West or the industrializing Asian countries [37, 38].

In Sub-Saharan Africa, endemic diseases and iron-armed warriors postponed the colonial scramble until the time that international agricultural prices declined. It limited the establishment of European-owned farms and plantations, as well as the evolution of larger indigenous farms. Africa's agriculture became even more a smallholder agriculture than it already was. Like in Asia, colonial governments failed to protect indigenous smallholder farmers, and signs of Malthusian crisis appeared where land had been confiscated for white settlers [39-41]. Elsewhere, however, relative abundance of land provided an outlet for population growth. In the 1960s, per capita incomes in Sub-Sahara Africa were still higher than in Southern Asia. However, national independence brought no real breach with colonial farm policies. Sub-Saharan African societies were little differentiated, had property rights in people rather than material assets, and had more fluid and personalist socio-political relations [42, 43]. People tended to organize in clientelist factions rather than in class-based movements. Politicians saw themselves obliged to remunerate large numbers of supporters with public sector jobs, while farmers were too weakly organized to prevent footing the bill [6, 44]. Meanwhile, population growth was closing the safety valve that abundant land had provided. The effect was felt when oil shocks and a new fall of international agricultural prices deteriorated the input-output price ratios for farmers. On-farm investment in land management remained too small to make the increase in population pressure sustainable [45]. The resulting poverty pushed individual discount rates up. It reduced the value that people attached to the future benefits of soil conservation or cooperative solutions for social dilemmas. Intra- and inter-household conflicts increased [46], and civil society in the countryside degenerated into counter-democratic networking [47]. The malaise drove many young people from the land, but squeezed the demand for domestic industries and services, so that the rural exodus fuelled political markets that were based on the doling out of public sector jobs. Civic organizations became vehicles of competing migrant networks [48]. The burden of civil servants' salaries was shifted to farmers and squeezed investment in rural infrastructure, which only deepened the agricultural crisis [49]. Donor-imposed reform sought to roll back the bureaucracies, but the dominance of free market ideas obscured the underlying dynamics that made supportive policies (including price policies) a sine qua non for development. Failing to redress the root cause of the agrarian crisis, the reforms went not further than the liberalization of macro-policies, and foundered on the resistance to public sector retrenchment.

APPROACH: MODELLING

To elaborate this vision, test its consistency, and explore ramifications, we need a model that can handle the co-evolution of population, natural resources, techniques and social strategizing at local, regional and global scales. Although computer modelling is praised an important tool in understanding complex, long term phenomena and assessing policy instruments [50], traditional economic or ecological models are ill-suited for our study. However, we think that a spatial specific multi-agent model can be used for this purpose. Such a model provides a flexible structure [51] that can represent interactions between phenomena that belong to different layers and scales of reality [52], and that are at the focus of different disciplines [53, 54]. It also allows for the internal representation and goal-seeking behaviour that characterizes human actors, without falling in assumptions of perfect information and rationality of orthodox economic models [53].

There is a current tendency towards spatially explicit, highly sophisticated models that try make concrete a one to one simulation of reality (examples PALM [55]), but our model is abstract and theoretical like the FEARLUS model [56] and the early contributions to agent based modelling (e.g. [57]). We use CORMAS software for building our multi-agent model.

There are important challenges in agent based modelling: the first is they demand much computer power. Second, agent based models are difficult to test and validate [58]. A later section of this paper, therefore, is dedicated to new methods for testing and validating the model assumptions. A third drawback is that the details of agent based models are difficult to describe and communicate [59]. To tackle this point we will use a widely tested protocol for describing our model [59].

THE MODEL: DESCRIPTION

The model description follows the ODD (Overviews, Design Concepts and Details) protocol for describing individual and agent based models [59] and consists of seven elements. The first three elements provide an overview, the fourth element explains general concepts underlying the model's design, and the remaining three elements provide details. The last element, containing an overview of the calculations and procedures in the models' sub-modules, is provided in the appendix.

PURPOSE

The main purpose of the model is to gain insight in the long-term agricultural and environmental changes of Sub-Saharan Africa, based on the hypothesis that Africa operates as a pre-industrial society in an industrialized world economy. This insight is needed to unravel the current unsustainability spiral in order to provide policy recommendations. The unsustainability spiral has many dimensions and multiple scales. The model will serve as a discussion support tool for the Dutch Directorate General for Development Cooperation (DGIS) of the Ministry of Foreign Affairs.

STATE VARIABLES AND SCALES

Grimm [59] defines state variables as low-level variables that characterize the low-level entities of the model. State variables are variables that characterize a level and cannot be derived from other variables. However defining which variables are state variables is not unambiguous in a system containing many feedbacks. Our model comprises the following 5 levels or entities without a clear hierarchy: 1) brain, 2) teams, 3) villages, 4) area, and 5) the world market. The relations between the levels are described further on.

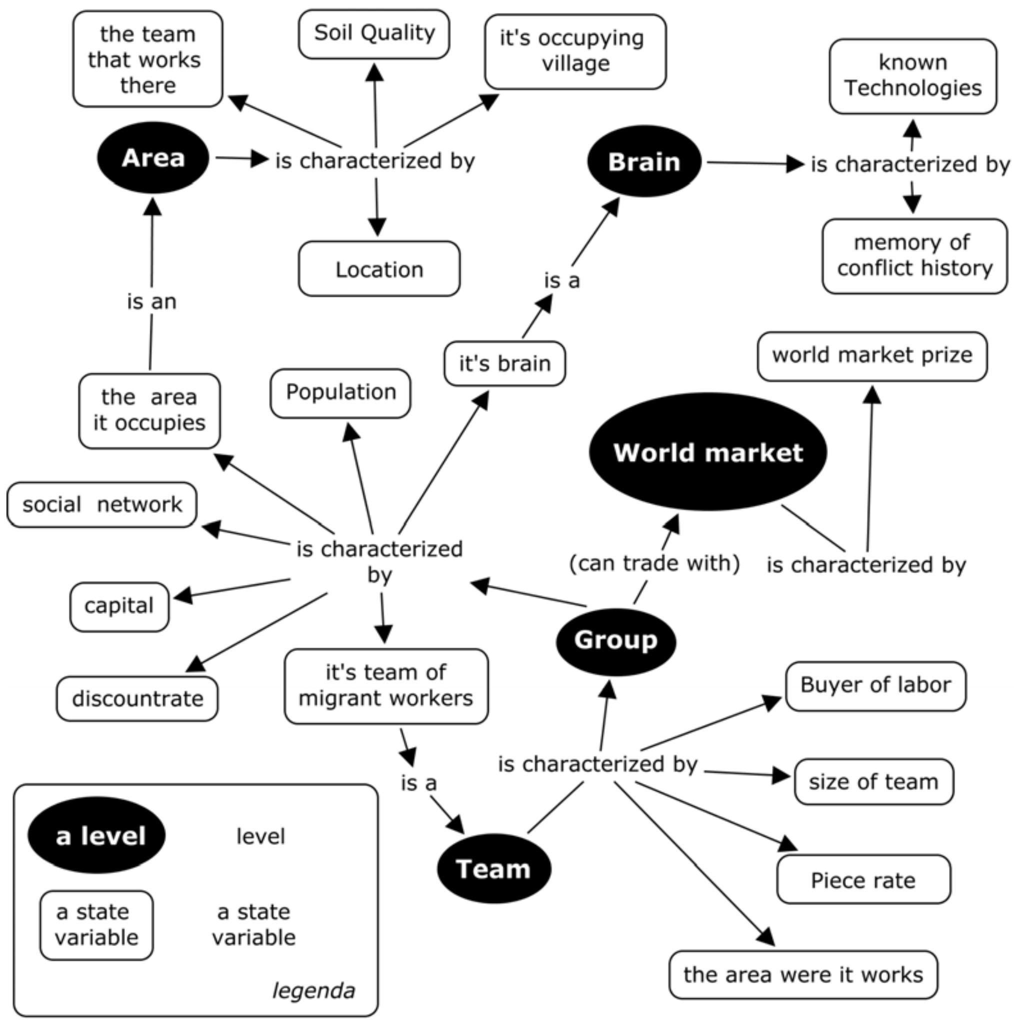

Figure 1. Overview of levels and subsequent state variables.

The first entity of the model is the brain which is characterized by the village that holds it. The brain contains a list of technologies that are available to the holder, and a list of its conflict history. A brain can invent, imitate and forget production technologies. The technologies a brain knows are an element of a big list of technologies, which is an input variable.

Villages (groups) form the second entity. They are the Sub-Saharan farmer villages which are characterized by the state variables: population, the characteristics of the area they occupy, the list of other villages they know (their social network), their brains, teams, capital, and discount rate. Instead of discount rate, nutrition status can also be used as a state variable, because the one is derived from the other. One of the villages is set to be the 'port'. By trading with the port the villages can trade with the world market. In the remainder of the article villages are sometimes called individuals or agents.

The third entity, teams, consists of migrant workers sent by one village to another village to work. The teams are characterised by their village of origin, the buyers of their labour, their size and piece rate.

Areas are the fourth entity of the model. Areas are characterized by the village which occupies it: the location on the grid, the migrant workers sent to work on it and the land quality. The latter is a lump variable representing all aspects of land quality, like a.o.: organic matter and nutrient content, texture and water availability. An area is always occupied by a village. For modelling purposes villages are not allowed to starve entirely.

The fifth hierarchical level is the world market which can be accessed by thE villages via the port. The characteristic state variable of the world market is the world market price which is the price per unit of labour (piece rate) sold by the villages to the port.

Spatial scale is abstract but can be considered an area of 400 by 400 kilometres. This will be occupied by around 10 000 villages or villages with an average population of 100 people corresponding with an average population pressure of 6,25 per square kilometre. This is a normal density in rural Sub-Sahara Africa (mostly between 5 and 10 per km, although it is much higher in urban and ore densely populated areas. The average population density of Sub-Sahara Africa, including the cities, is about 30 [60].

Table 1. Overview of parameters of the unsustainability spiral model.

Overview of parameters per module	Value* (Unit)
Initialization	
Number of areas	10000 (#)
Number of villages	10000(#)
Neighbours of each cell	8 (#)
Initial land Quality	(food)
Initial local list of technologies represented by Cobb Douglas Coefficients	
Population Dynamics	
Minimum mortality	(people/people)
Food intake per caput at which mortality does not further decrease	(food/people)
Food intake per caput at which fertility is zero	(food/people)
Food intake per caput at which fertility does not further increase	(food/people)
Evolution of knowledge	
Time after which a technology becomes forgotten	(time steps)
Threshold to experimenting	(food)
Global list of technologies represented by Cobb Douglas coefficients	
Evolution of cooperation strategy	
Time that a conflict is remembered	(years)
Plan production, trade and robberies	
World market price	(food)
Labour intensity	1 (labour/people)
Amount of food that is robbed during robbery	equals wage (food)
Transaction costs after robbery	(food/labour)
Distance to transaction costs coefficient	(food/meter)
Risk aversion threshold when accepting trade	(change)
Evolve agro-ecology	
Value at which land regenerates each time step	(food)
Rate at which land degradation takes place (food production minus conservation investment)	(food/food)
Conservation efficiency	(food/food)
Minimum land quality	(food)
Maximum land quality	(food)
Regeneration per time step	(food)
Spend harvest	
Capital Access coefficient	(food/food)

*if values are not yet determined, units are provided

PROCESS OVERVIEW AND SCHEDULING

Each time step is a cropping season, which can be considered a year. Each time step five modules are processed in the following order: evolve demography, evolve knowledge, plan production and evolve cooperation, evolve agro-ecology and spend production. Details about the procedures and calculations within these modules are provided in the appendix.

The ‘Evolve demography’ module consists of the submodules birth and death. The ‘Evolve knowledge’ module consists of the submodules: forget production technology, imitate from villages and experiment, which are processed in the given order. Subsequently, villages make their decisions on production and trade in the ‘Plan production and evolve cooperation’ module which consists of three submodules which are processed in the following order: consider agricultural production, consider trading with other villages, and allocate the inputs. Once the decisions on production have been made the module ‘Evolve agro-ecology’ calculates the crop-growth in the submodule ‘Grow crop’ and changes ‘Land quality’ in the submodule ‘Evolve land quality’. When the crop production is realised, the ‘Spend production’ module is run, which consists of a submodule that determines the capital input for the next year and a module that calculates next year’s discount rate. Finally, the village evolves its cooperation strategy, based on the conflicts in its social environment and its relative wellbeing.

Within each submodule the villages or areas are processed in a fixed order except when trade is considered. During the ‘Consider trading’ phase, the trade possibilities of a village and its partner are assessed at the same time.

DESIGN CONCEPTS

The design concepts section describes the general concepts underlying the design of the model along with concepts that are common in the field of Complex Adaptive Systems [61, 62] and facilitate the integration of this study into others.

Emergence

A certain system property or behaviour is emergent if it is not directly specified by individual traits. Here we will explain which properties of the model system really emerge from the interaction of the adaptive behaviour of the agents, and which are merely imposed. Here we differ between rather linear dependence between factors and the emergence of macro level phenomena that not linearly follow from the procedures at micro scale. First, we will deal with the first category and then describe the expected emergence of macro scale properties.

Population, capital, land quality, technology, conflict history and the discount rate are the main driving variables of the model. None of these variables, however, are imposed but are derived from each other.

Births and deaths and the subsequent population dynamics depend on a village’s nutritional status. The nutritional status emerges from all main driving forces listed above. Capital emerges from the current and expected income status and the discount rate. The discount rate is derived from the previous nutritional status, while the income status emerges from the main driving variables. Land quality depends on degradation, regeneration, and conservation investments. Degradation occurs in a fixed relation with yield (again emerging from the main variables). Regeneration is imposed and conservation investments depend on the main driving variables. Known technology is a product of imitating, experimenting and forgetting. All those are dependent on other changes in the environment. However the global list of technologies is imposed, limiting freedom in technological innovation. Conflicts are also dependent on changes in the main variables.

What is imposed is the way in which the villages make their decisions, which is based on household economics (see also fitness section). Furthermore, the social networks of the villages are imposed; the position of a village is also imposed and cannot change during the model. Other imposed parameters are shown in Table.

We expect the following emerging patterns at macro scale. In case the model is run without a port to the world market and hence a pre-industrial society is simulated we expect a sinus like wave pattern in which the up-going phase, or the Boserup phase is characterized by synergetic interaction of land quality improvement, technological progress and cooperation driven by a relative abundance of food and a consequent favourable discount rate.

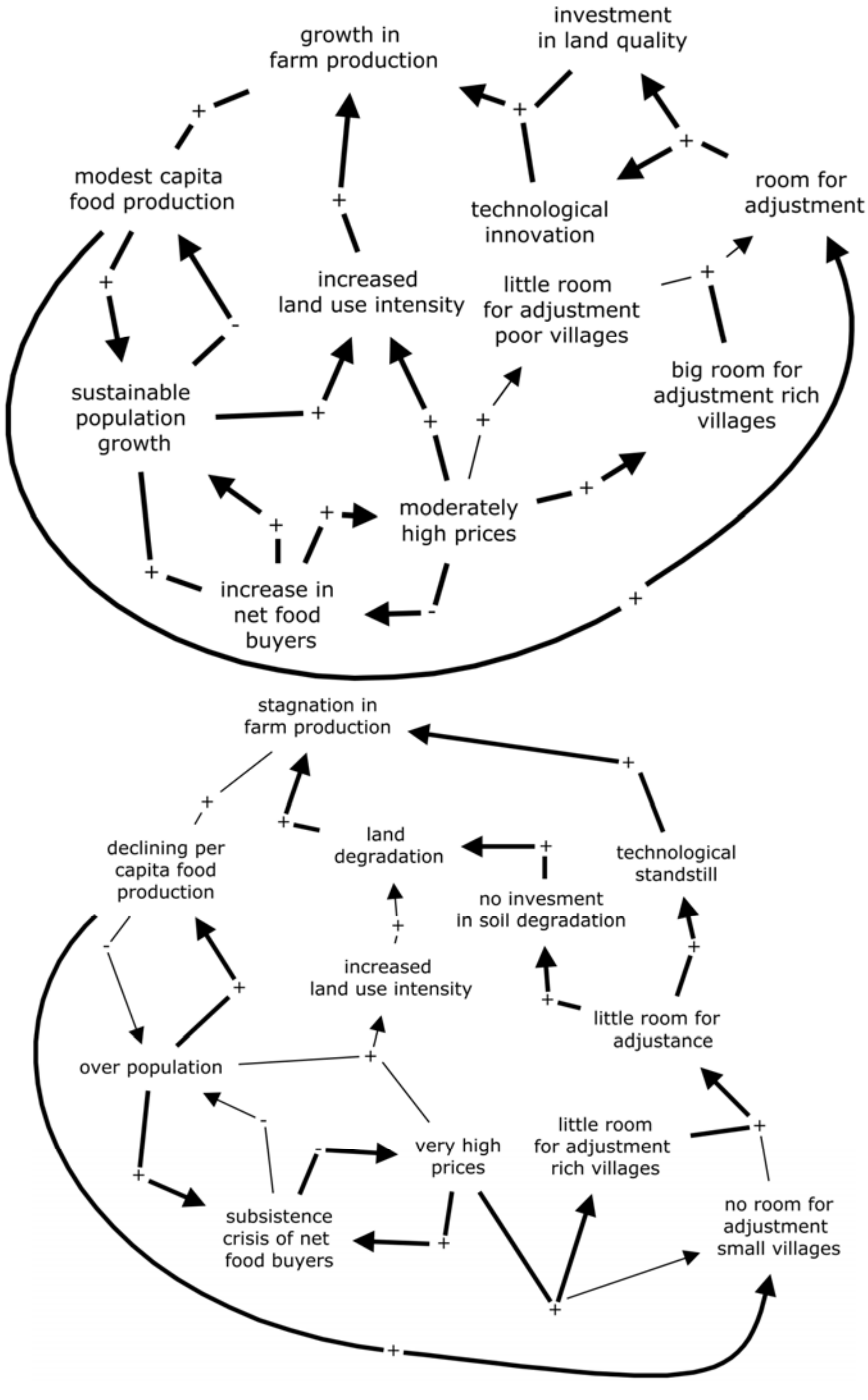

Figure 2. Overview of feedbacks that trigger growth of an agrarian market economy (left) and feedbacks that trigger a crisis in an agrarian market economy [63].

The downward or Malthusian phase is characterized by resource depletion, a technological standstill and conflicts that are triggered by a high discount rate which is caused by overpopulation. In case this pre-industrial society is connected to the world market with low food prices, poor villages send their labourers to the port, because the food to labour ratio is favourable. Rich villages, consequently, will run out of labour and this labour stress will reduce technological innovations and investments in soil quality. As a result land degradation and a technological standstill will cause stagnation in farm production, without an increase in agricultural prices. Therefore the system will find itself in a loop of impoverishment and the unsustainability spiral emerges [63].

The first sociological multi-agent models focussed on describing the emergence and dynamics of norms and values in society is found in [57]. Some of these notions are planned to be included in the model in a later stage.

Welfare maximizing behaviour

In our model the goal of the villages is to maximise welfare, which we operationalize as utility. Utility is maximized using a farm household economics utility optimising procedure based on Cobb Douglas production functions for current and future income and leisure time. Villages try to increase their long and short-term utility by making choices on investment in land quality and allocation of food and labour for on-farm production, hiring or hiring out labour and robbing.

We model goal seeking at village level and use conventional theories from household economics. In agricultural households, decisions about the management of the farm are closely linked with household decisions on what to eat or how to allocate time between farm work and other activities [64]. The farm household operates within a socio-economic and an ecological environment. It may have access to natural resources and (functioning) markets and within this context the household produces, invests and consumes. Different farm household models have been developed over the last century. The theory of Chayanov [65] has been the base of many farm household theories [66, 67]. The latter have all altered some of the conditions for specific applications, e.g. leaving out market imperfections and trade of labour.

Ellis [68] describes different farm household models based on objectives, market assumptions, predictions and practical effects. One of the special features of the household model is the integration of production and consumption decisions of the household. We will consider the farm household model of Barnum and Squire [69] as the basis for this study, although we make some minor alterations. This household model specifically provides a framework for generating predictions on the response of the farm household to a change in domestic and market variables. An important reason to use this model is that it, other than the Chayanov model, recognises the labour market and thus enables trade of labour between different villages. It considers the quantity of land available as fixed and it ignores the uncertainties that are part of the production process. These features are comparable to the assumptions in our study.

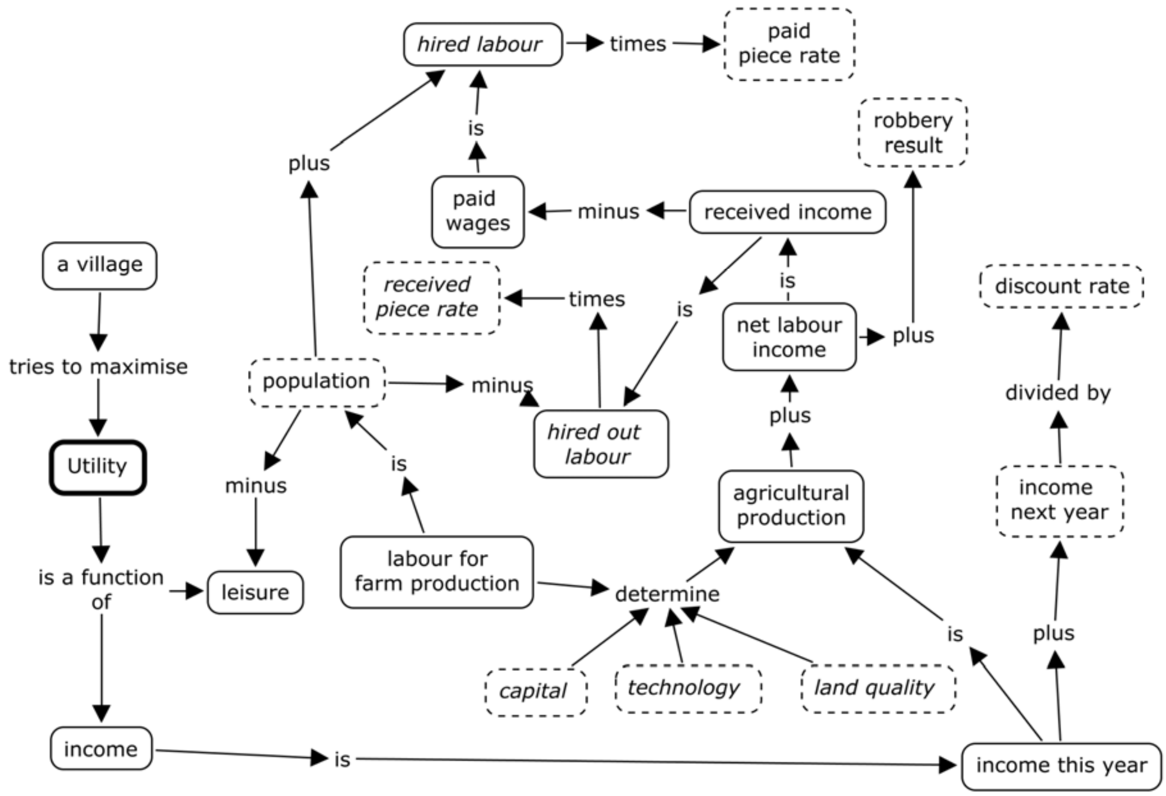

Figure 3. Conceptual map of welfare (utility) maximization of the villages. Dashed box indicates that the origin of the variable is not shown. Cursive indicates that the variable is altered by the village in order to maximise welfare.

The Barnum and Squire [69] household model also introduces a new product village: the Manufacturers. We will not use these in our model. Here, only one type of good will be produced which, considering perfect markets, can be traded for other goods. Secondly, the model introduces an alternative calculation of utility; which can be considered the driving force behind the household model. Barnum and Squire [69] do not only determine the utility by the amount of leisure time and consumption, but also by home production. We will not include this alteration but consider utility as the amount of leisure time and consumption available.

An important law when optimizing utility between different sets of products is the law of diminishing returns. This leads to a bias towards a leisure seeking behaviour of farmers with a high income and an income seeking behaviour of poor farmers. This law will form the basis for the choices made when maximum utility.

Another adaptation we make to the Barnum & Squire [69] model is the inclusion of land quality to the production function and writing it into a Cobb-Douglas production function with the elements: effective labour, total capital input and current land quality.

Adaptation & innovation

Here, we describe what adaptive traits villages have to improve their welfare in response to endogenous or exogenous changes. As explained above, we see utility as a measure for welfare.

In the long-run villages can adapt to a changing social and natural environment by changing their knowledge and investments in land quality. They can gain knowledge by investing in food or labour by experimenting, imitating and forgetting. Experimenting can yield new technologies that can result in higher utility in a specific situation. In the short-run villages can adapt to the changing demand or supply of labour and food; by trading with other villages or the world market; robbing; allocating more or less food for capital inputs. Till now, the cooperation strategy is directly related to the conflict history (a village will not trade for X years with a village that robbed another, known village last year) and the expected utility of robbing someone.

Till now we have not included any kind of game theoretical behaviour, because we assume technological learning more important because it directly affects agricultural production. However, we plan to introduce more sophisticated game theoretical strategies and game theoretical learning during further modelling efforts. Using game theoretical learning agents improve their cooperation strategies by repeatedly grappling with interaction processes over time [70].

Foresight

Foresight refers to the way a model represents how agents foresee the future outcomes of their decisions. The model uses so-called overt foresight, which means that agents explicitly forecast the consequences of each alternative decision.

The effects of selecting a known technology, doing a conservation investment and robbing a trading partner are calculated for two years in advance. Agents assume that their trading partner, their own labour input and technology will be the same during two years, but land quality, capital and transaction costs change. The latter increase when a village robs its trading partner. When assessing trade, agents take into account the conflict history of their known villages. The increased risk of conflict is represented by increased transaction costs.

Agents foresee the effects of technological innovation based on a ceteris paribus increase in utility. The foresight of the amount of capital needed for next year is done after harvest and with a ceteris paribus assumption of other factors. The effect of the prediction of the second year is altered by a discount rate which increases when the nutritional status of a village decreases.

Sensing

Sensing is the way an agent based model represents how agents obtain information about their (internal and external) environment and neighbouring agents. In line with classic economical theory, villages have complete information and awareness of their own characteristics and they know the following characteristics of their known villages: location, practiced technology, possible trade arrangements and the potential outcome, the piece rate when hiring out labour, the conflict history of the villages with other known villages. Furthermore they have full information about the characteristics of the area they live on.

Interaction

Interactions are mechanisms by which model agents communicate with each other or otherwise affect each other. In this model, agents (villages) can trade with each other, steal from each other and imitate each other's technologies. Villages can only interact with villages within their social network and with the port. The entire network of agents in the model is a small world network.

A small world network is a connected network with two properties: each node is linked to a relatively well-connected set of neighbour nodes; and the presence of short-cut connections between some nodes makes the average minimum path length between nodes small. Such networks have both local connectivity and global reach. Small world networks are common and believed to be an emergent property of many socio-economical transactions [71].

As said under sensing, we consider the information to be complete, but subject to the limited memory capacity. Within the suitable conditions trade is subject to transaction costs, which are determined by the social and psychological costs of trade. Within societies and especially rural societies social norms, trust and social networks are of great importance for economical development [72-74]. Transaction costs can be seen as an economic reflection of the state of a relationship between two villages. Resulting in the punishment of a wrongdoer by an increase in the transaction cost between the wrongdoer and the members of social network to which the mistreated village belongs.

Interaction between agents and their environment

The effect of agriculture on land quality in Sub Sahara Africa is subject to a long and on-going debate (e.g. [45]). Within this debate the impact of population growth on land degradation and vice versa [75] is of great importance. In the model land degradation is proportional to crop production. Villages, however, can choose to diminish the degradation of their natural resources by investing in land quality. Agents can foresee the effect of both cropping as well as investing in land quality up to two years in advance.

In the model increased population can both cause land improvement as well as deterioration depending on the choices of the villages.

The production is considered to have impact on the quality of the land as well. We consider land degradation as a function of the crop produced, the natural regeneration and investments in land quality.

This on its turn is very much dependent on consumption. Demographical processes determine the consumption level of a farm village. It is of importance to consider that an extreme decrease of consumption will lead to a decrease of the population. Birth and death rates are related to consumption levels.

Stochasticity

Stochasticity in agent-based modelling means that pseudo-random numbers are used to represent a process or trait. We plan to limit stochastics to a minimum. We will only introduce stochastics during initialization when it appears necessary to get things running.

The selection of a technique as a result of modelling is done using a normal distribution. The social networks are created by (uniform) randomly changing connections of a regular square lattice network, using a power law distribution till the network shows the characteristics of a small world network.

Collectives

Villages can choose to cooperate (trade), rob each other or live in autarky. There is however no real formation of collectives. Villages interact within their interrelated social networks which are imposed.

Observation

Observation is the process of collecting data and information from an agent based model. Typical observations include graphical display of patterns over space and time and file outputs of summary statistics.

For model testing and calibration we will look at the network structure, which should represent a small world phenomenon (described by [76]). For analysis we will look at population dynamics, land quality dynamics, welfare development (which includes nutritional status and utility), and cooperation dynamics.

INITIALIZATION

During initialization, 10 000 villages and areas are created. Each village is linked to an area. The grid has closed boundaries and grid cells have a square shape. Each village is placed in a social network: a network of villages with which the village can trade. The networks are created in such a way that the entire network is a small world network. A small world network means that the path length or the degrees of separation between two villages is never more than six. To create a small network we will use the algorithm used by Wats & Strogatz [76].

During initialization villages calculate the distance to the other villages in their network. Furthermore, they are appointed a certain population and a certain amount of capital that is related to the size of the population. Furthermore, they are provided with a brain that holds a selection of technologies and a history of conflicts between the villages they know. We try to start with a community that is as homogenous as possible. We will only introduce diversity or stochastics during initialization when it appears necessary to get things running.

All areas are given a certain land quality which will be the same for all areas. Later on we plan to include some ecological zones using the land quality variable. The zoning will be loosely based on the comprehensive analysis on agro-ecosystems in Africa by Dixon et al [77].

One of the villages is changed into a port to the world market. By sending labour to the port villages can virtually trade with the world market. The price or the amount of food that the villages get per amount of labour will be set during the start. All villages have a direct access to the world market.

INPUT

Two categories of input variables can be distinguished. Those that we are not planning to change during model experiments and those that we want to change during model experiments. The latter are discussed in the paragraph Simulation experiments. The first category includes much of the parameters of table 1. We have not fixed the values of the first input category yet, but will do this based on best available knowledge and expert judgement.

MODEL TESTING & VALIDATION

The multi-agent model as described above needs empirical testing in the real world. Though the model has a bottom-up structure based on theoretical notions of agriculture, ecology, and household economics, our outcomes are at an integrated level. Therefore, we will test and validate our results using regional insights.

The more complex interactions will be worked out mostly qualitatively in several case studies. Janssen & Ostrom [58] suggest case studies as a suitable method to empirically link up multi-agent models with reality. Especially in interdisciplinary research, where causal relations between social and environmental variables play a role, they propose qualitative case studies.

We illustrate this here by two projected case studies that focus on two different parts of the unsustainability spiral: (i) natural resources: the land quality, population and agricultural prices nexus, and (ii) social capital: the trust, migration and agricultural prices nexus. For the two other domains of development, technology and demography, a vast amount of empirical evidence is already available [10, 78]. For the moment we do not foresee more empirical work in these fields.

Linking up multi-agent modelling with multiple empirical case studies is shown to be a powerful tool in integrating research from different fields of study (e.g. [79, 80]). However, as our model does not intend to be a simulation model of real events we will rather test on patterns than on exact events.

LAND DEGRADATION AND DEVELOPMENT

Within the multi-agent model notions are embedded in the nexus between population growth, land degradation and low agricultural prices. Recent multi-agent work on less favourable areas in Chile and Uganda shows that negative feedbacks exist between these variables [80], which have already been quantitatively been expressed in earlier works [10]; [81] on a small scale level. However, evidence at higher scale levels (regions) and longer time scales (decades) is lacking.

New research on sedimentation in coral reefs [82] offers great possibilities for extending the time and spatial horizon. Fleitmann et al found Ba/Ca records from the Sabaki river, Kenya, in coral reefs, that reflect the sedimentation, and hence erosion, history of the past 300 years of an aggregate area of more than 60 000 km2. The records show that especially in the last 100 years, after colonisation, erosion was most severe and erosion peaks are visible in the periods between 1930 and 1960, and again from 1975 onwards. These results are irrespective of the precipitation variability in these periods and therefore are a result of human interference. The results of this study can be linked up with the historical economic and demographic development in the Sabaki catchment and, hence, test hypotheses on the population, land quality and agricultural prices nexus.

TRUST AND DEVELOPMENT

Feedbacks exist between agricultural development, migration and trust. Networks of cooperation subsist within villages and between villages. High trust in the agricultural sector, in addition, can have positive spill over effect on the non-farm sector. However, positive effects of cooperation (e.g. knowledge sharing, cooperatives) can easily dissolve at times of resource scarcity or economic hardship. It is hypothesized that problems of social capital hamper economic development in Africa [83]. The background of these social capital problems needs a better understanding.

The interactions between trust, agricultural development and migration are hardly researched and we project a study on these linkages. Qualitative cultural-historical case studies are proposed to find out differences in trust relations between villages and find out the underlying causal relationships. We intend to interview farmers on social capital indicators that are a result of positive and negative experiences. This involves questions on a.o.: stealing, cheating and conflicts; and on: work agreements, economic cooperation and more in general people that can be trusted. These images will be linked up with the historical background of the villages with its agricultural, economical and demographic developments. Subsequently, conclusions can be drawn on the causes of trust as related to independent variables as agricultural prices, soil suitability, population density and market vicinity.

SIMULATION EXPERIMENTS

As described in the introduction, the model will be used to test hypotheses on the causes of the unsustainability spiral in Sub-Saharan Africa (see Figure 4 for some examples).

By taking into account the feedbacks, the model provides an integrative setting to study the influence of the drivers.

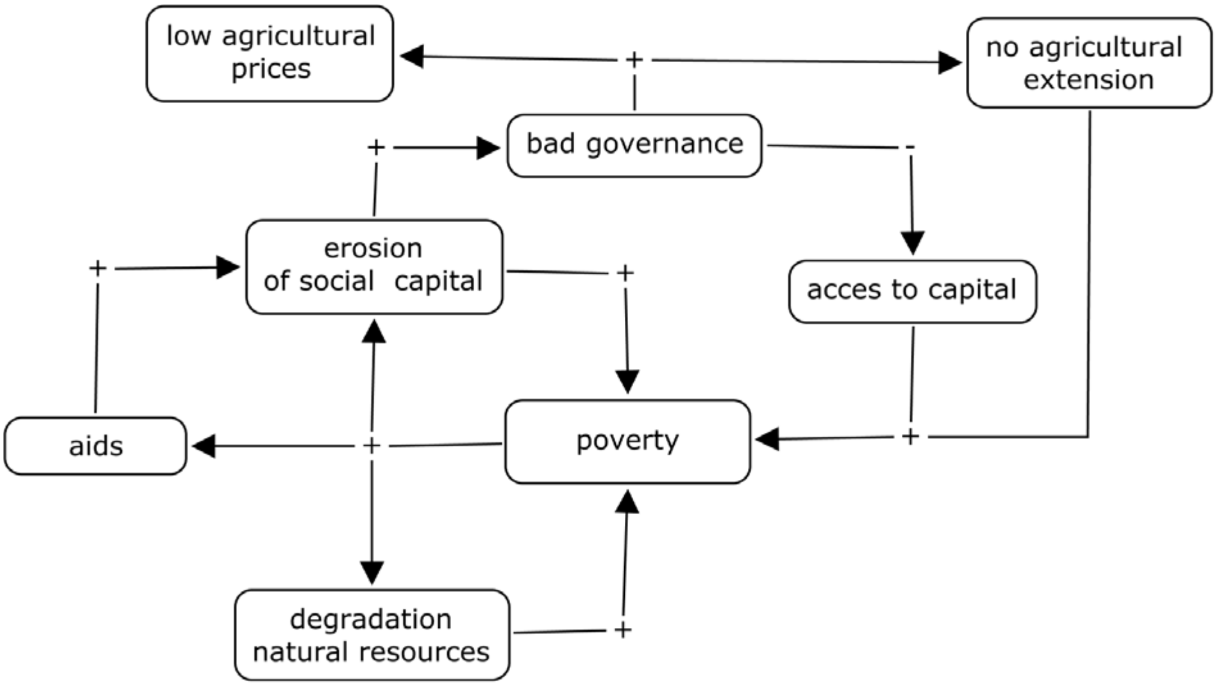

Figure 4. Some examples of factors and feedbacks that drive the unsustainability spiral in Sub-Saharan Africa. See Figure 2 and design concepts for an overview of the impact of low agricultural prices.

First of all we will test the hypothesized emergence of the unsustainability spiral (see emergence) by simulating a society isolated from the world market, where after we introduce a port to the world market with several price regimes. Besides that we will simulate the effect of governance by introducing an extra level which represents governmental bodies that can build roads (and other infrastructure), supply inputs and facilitate access to capital and spread new technologies (agricultural extension). The effect of infrastructure will be simulated by altering the transaction cost conversion coefficient. The effects of fertiliser subsidies will be simulated by increasing the soil investment coefficient. The effects of policies related to improved access to capital (loans, subsidies etc) can be simulated by increasing the capital access coefficient. Efforts of agricultural extension can be simulated by providing groups (either all or those within a certain distance from the capital) with technologies.

Furthermore, it is possible to simulate the effect of nepotism by introducing a sort of kinship, and provide villages that belong to the clique of the leader preferential access to markets in the port city. Subsequently, the effects of land degradation on poverty dynamics will be studied by simulating land improvement programmes. This will be done by increasing land quality. Additionally, the influence of access to capital will be simulated by changing the coefficient that determines access to capital. Finally, the effects of diseases like AIDS will be simulated by decreasing the labour intensity coefficient.

Large scale catastrophic events like the massive slave trade, droughts, floods, form not a central part of our vision of the unsustainability spiral. This does not imply, however, that these events are unimportant. We will simulate some catastrophes in order to see how robust the emerging properties of our model are. In other words: we will use simulated catastrophes as a way to test the sensitivity of our model outcomes.

DISCUSSION

Models are always wrong and models do not directly improve the yield of the African rural population. However, modelling can shine a new light on one of the most serious lock-in situations that our world faces today. Policy makers and scientists often focus too much on individual drivers at short time scales, whereas we hypothesise the need for integrated research and a long-term view. A multi-scale, multi-driver phenomenon as Sub-Saharan Africa's unsustainability spiral needs a multi-faceted policy approach. We believe that our research will offer valuable material to policy makers to make informed decisions on development cooperation and trade policy.

Rather than offering a blue-print like decision support model, that gives the welfare response for every change in variable *X*, we aim at offering a discussion support model that provides insights to the scientific and policy making communities on the complex interactions that cause the poverty spiral.

In the model we deliberately used rather conventional economics for describing the choices agents can make. We believe the use of conventional economics eases the communication with policy makers from governments and international bodies. Conventional methods at micro level can create easier acceptance of possible unconventional outcomes at macro scale. These outcomes at macro level will also give us a possibility to validate the patterns as found in empirical data.

A major shortcoming of working with theoretical agents is that the decision making procedure cannot be validated. However, even when using conventional theories we have to note that our model is limited. Firstly, some of our assumptions are hard to test or validate. First of all in our model we assume full information. This approach is especially questioned within the economic multi-agent modeller society [53].

Secondly, in the model we assume that land quality is a linear function of land quality investment and production. This appears not to be in line with recent findings of Giller [84] and Antle & Stoorvogel [85] who found strong hysteresis in land degradation and regeneration, while Giller found great heterogeneity in land characteristics in the fields around villages. However, we define land quality as all the characteristics of the area that is occupied by a village that influences the marginal capital and labour productivity. Although non-linear behaviour in land quality change definitely deserves attention, Antle & Stoorvogel's and Giller's findings do not provide any evidence that change in land quality shows non-linear behaviour as well.

Thirdly, an important issue is the starting point of the scale level. Although, we use a bottom-up approach with the lowest scale level being a village of farmers, behaviour of individual people is not included in the model. As a consequence individuals' decision making and diversity is not taken into account.

Finally, it might well be that non-farm production and products, which are currently ignored, play a far more important role than expected. Besides that, the use and impact of fertiliser use and application can only limitedly be simulated. Furthermore, we excluded many institutional factors (although they can be simulated indirectly) like for example property rights and legal equity.

The model description and proposed simulations and validations are all work in progress. The past efforts and planned activities will further promising and novel insights into the unravelling of Sub-Saharan Africa's sustainability spiral and the use of multi-agent methodology.

APPENDIX

Here, we describe in some detail the submodels, including the parameterization of the model.

EVOLVE DEMOGRAPHY

Calculate Births

Births are calculated using the following formula:

$$Births = x \cdot population \cdot maximum\_birth\_ratio, \qquad (1)$$

in which x is calculated by:

$$x = min\ (\ (nutrionStatus - zeroFertilityNutrition)/\ maximum\ fertility\ nutrition,\ 1), \qquad (2)$$

in which the *nutritionStatus* is the amount of food per capita (*income* $\cdot$ *population*-1, further on for the calculation of income), *zeroFertilityNutrition* the amount food intake per capita when fertility is zero and *maximumFertilityNutrition* is the level of nutrition after which the birth rate does not increase further.

Deaths

$$Deaths = \max\left(1 - \frac{(1 - minimumMortality \cdot nutritionStatus}{criticalNutritionStatus}, minimumMortality\right) \cdot population\ , \quad (3)$$

in which *criticalNutritionStatus* is the nutrition level from whereon the mortality rate does not further decrease, at this nutrition level the mortality will be the *minimumMortality*.

EVOLVE KNOWLEDGE

This consists of the submodules: forget production technology, imitate and experiment. Villages can also imitate technology from the villages they know.

Forget production technology

First, a village looks whether an experiment has been undertaken in the last year. If so, the resulting production technology is stored. After assessing the experiments the stored technologies are used. All technologies possess a counter that counts the years that a technology was not used. After a number of subsequent years of non-usage a technology is forgotten.

Imitate production technology

Villages copy the production technologies used by the villages they know to their list of technologies.

Experiment

A farmer will experiment if the expected, discounted increase in utility of the found technology is higher than a certain threshold:

$$(Discountrate + 1)^{-1 \cdot}\ U_1 > U_0 + threshold, \qquad (4)$$

in which the U_1 is the utility when the old technology is used and U_0 the utility when the yet to be found technology is used.

$$U_1 = U(I_1, F)\ and\ U_0 = U(I_0\ , F), \qquad (5)$$

in which F is leisure and I income which is agricultural production and other income (O), which is here constant. Then:

$$I_1 = Y_1 + O\ and\ I_0 = Y_0 + O \qquad (6)$$

$$Y_0 = A_0[a_0 \cdot max(0, L - T_{L0})]^{\alpha_0} \cdot [b_0 \cdot max(0, K - T_{K0})]^{\beta_0} \cdot [c_0 \cdot max(0, P - T_{P0})]^{\gamma_0} \qquad (7)$$

$$Y_1 = A_0[a_1 \cdot max(1, L - T_{L1})]^{\alpha_1} \cdot [b_1 \cdot max(1, K - T_{K1})]^{\beta_1} \cdot [c_1 \cdot max(1, P - T_{P1})]^{\gamma_1} \qquad (8)$$

In which A_1, α_1, β_1, γ_1, TR_{L1}, TR_{K1}, TR_{P1} are the coefficients that represent the new technology, while A_0, α_0, β_0, γ_0, T_{L0}, T_{K0}, T_{P0} is the set of coefficients that represent the previous technology. The set of coefficients that forms the new technology is randomly selected using a uniform distribution from a pre-composed list of n technologies. The selection is done within a certain range to, literally speaking, prevent that an Iron Age community suddenly invents a tractor. The threshold is a parameter that is the same for each village. For experimenting no additional food or labour is required. The found technology will be available to the village the year after the experimenting has been done.

PLAN PRODUCTION AND EVOLVE COOPERATION STRATEGY

In the plan production and evolve cooperation strategy module, the village will try to invest its resources (food and labour) as effective as possible. This is done by maximizing the expected utility (U) which is the sum of this year's utility (U_t) and the estimated and discounted Utility of the following year (U_{t+1})

$$U = U_t + U_{t+1} \cdot (discountRate + 1)^{-1},$$

$$U_x = U_x(I, F)$$

$$I = Y + tradeResult + robResult - conservationInvestment,$$

in which Y is harvest:

$$Y = A[a \cdot max\ (0, L - T_L)]^{\alpha} \cdot [b \cdot max\ (0, K - T_K)]^{\beta} \cdot [c \cdot max\ (0, P - T_P)]^{\gamma},$$

in which Y is yield or agricultural production, L is labour, K is capital and P is land quality. α, β, γ, a, b, c, T_L, T_K, T_P and A are technology dependent variables. T_x is for the threshold value of an input x. Before x reaches T_x no production is realised.

$$L = labourIntensity \cdot (population - outworkers),$$

in which *labourIntensity* is an input variable with a default value of 1. *outworkers* is the number of people from the village who work at another village. Below is explained how this number is determined.

The trade result (*tradeResult*) is the food paid to the migrant workers of the village minus the transaction costs and the wages paid to other villages. Wages of normal villages equal the marginal labour productivity of the village that sends the workers. The wage of the port is a fixed parameter which represents the world market price. Transaction costs are determined by the physical distance to a village and trust. The latter is affected by robbing (see details further in the appendix).

A village can only trade with one of the villages it knows. It can either be an importer of labour or an exporter of labour. If a village trades with another village, it might also decide to rob the other village. If a village is importer, this is done by not paying the migrant workers of the other village. In case a village is an exporter, robbing is done by stealing of food that equals the wage of the workers. The *robResult* is the result of robbing and be robbed.

First a village calculates the best expected two year income in case it will be self-subsistent using the optimal combination of technology, conservation investment (using the *consider producing* submodule).

Subsequently, each village will search the best combination of send workers, technology, conservation investment and robbing for each of the known villages (in the *consider trading* submodule). The best amount of workers sent to the port to the world market (*sendWorkers*) is calculated as follows:

$$sendWorkers = population - L \cdot labourIntensity^{-1},$$

in which L is the labour needed on farm, which is calculated as follows:

$$L = \left(\frac{opportunityCost}{\alpha \cdot A \cdot K^{\beta} \cdot P^{\gamma}} \right),$$

in which the *opportunityCost* is the price of labour at the world market minus transaction costs. In this way a village will self-employ workers till the marginal productivity equals opportunity costs. From that point onwards, workers are sent to the world market.

The best possible combination of technology and the amount of conservation investment is simply searched by assessing all possible combinations. When trading with a village (which is not the world market) the best amount of workers is searched by checking all possibilities until the best combination is found. To limit the amount of calculations, conservation investment is considered a discrete value.

Using these best combinations a list is compiled (see Table 2). This list is used to select the best trading partner. This best trading partner is invited to trade with the village (the *allocate inputs* submodule). If the trading partner is the world market, the answer will be positive. In case the partner is a normal village it will asses its preferential trading partners, which are villages that can offer a better trade deal than the deal that is currently on the table. Subsequently, it counts for each preferential partner the amount of worse options they have than dealing with the village (the village that is offered the deal). The village that is offered the deal uses this information to calculate the probability that the village can realise a better trade deal, than the one that is offered now. If this change exceeds a certain risk aversion threshold the trade offer will be rejected.

When estimating the income of the second year, the amount of capital and the land quality are updated (see the outline of the *spend harvest* module for more details). So the village can take into account the effect of investments in conservation (*conservationInvestment*). In estimating the trade part of the income of the second year the village assumes that it keeps the same trading partner. If a village decides to rob from its trading partner, an extra transaction cost will be added when trading with any village from the known village list of the robbed village.

If a partner cannot find a trading partner it will be self sufficient.

Table 2. Example of a trade outcome list of a village that contains the expected income of trading with all known villages at optimal combinations of technique, amount of hired out workers, conservation investment and robbing. In this example a village will first try to realize trade with village 2.

Trade with	Expected income (food)	Hired out workers (#)	Technique	Conservation investment (food)	Rob? (Y/N)
self (autarky)	200	0	T1	10	NO
known village 1	300	3	T3	10	YES
known village 2	400	4	T6	20	NO
known village 3	200	2	T2	10	NO

EVOLVE AGRO-ECOLOGY

GrowCrop

Crop production is calculated per area using a Cobb Douglas production function:

$$Y = A \cdot \max(0, L - T_L)^{\alpha} \cdot \max(0, K - T_K)^{\beta} \cdot \max(0, P - T_P)^{\gamma}$$

In which Y is yield or agricultural production, L is labour, K is capital and P is land quality. α, β, γ, T_L, T_K, T_P and A are technology dependent variables. T stands for the threshold value of a certain input before it has any effect.

Evolve LandQuality

In this submodule the area updates the land quality. *Land quality* is the sum of the previous land quality, regeneration and degeneration with a minimum value and maximum value.

Regeneration is a constant value. *Degeneration* is calculated as:

$$\textit{Degeneration} = \textit{crop production} - \textit{conservation investment} \cdot \textit{conservation efficiency}.$$

SPEND PRODUCTION

The villages spend production module consists of a submodule that stores the capital (including seed) for next year and a module that sets the discount rate. The amount of capital available to the village is chosen in such a way that the sum of the current year's utility and next year's discounted utility is maximized assuming ceteris paribus of other factors.

Once the seed is stored a new discount rate is calculated using the following formula:

$$discountRate = \frac{discountParameter}{nutritionstatus},$$

in which the discount parameter has a default value of 100, and the nutrition status is food consumption per capita with a minimum of 1,106. The discount rate cannot be higher than 100.

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RAZVEZIVANJE SPIRALE NEODRŽIVOSTI U PODSAHARSKOJ AFRICI: PRISTUP MODELIRANJEM POMOĆU AGENATA

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SAŽETAK

Podsaharska Afrika zarobljena je u kompleksnu spiralu neodrživosti demografskih, biofizičkih, tehničkih i socio-političkih dimenzija. Razvezivanje te spirale nužno je za spoznavanje akcija koje su potrebne za njeno invertiranje i podsticanje održivog razvoja. Članak prezentira evolucijski višeagentski okvir koji povezuje socioekonomski pristup i svjetsku perspektivu te uzima poljoprivredu kao motor pokretač održivog razvoja u podsaharskoj Africi. Razmotreno je više mogćnosti empirijske validacije.

KLJUČNE RIJEČI

višeagentski sustavi, razvoj, zamka siromaštva, degradacija, socijalni kapital, podsaharska Afrika

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MODELING LOCAL MONETARY FLOWS IN POOR REGIONS: A RESEARCH SETUP TO SIMULATE THE MULTIPLIER EFFECT IN LOCAL ECONOMIES

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SUMMARY

In poor regions, lack of local monetary circulation is one of the key elements causing underdevelopment. The more incoming money is passed from hand to hand, the more the local economy will be stimulated. However, in most poor areas money is spent outside the community before circulating locally, reducing the effectiveness of money inflow dramatically.

Development programs would increase their effectiveness if knowledge was available on how spending money could lead to optimized and prolonged local circulation. To gain this knowledge a simulation tool will be created, which is able to analyze financial flows, to evaluate the potency of specific actions aimed on local development, and to monitor a development scheme during the execution phase.

The basic model will be developed through a multi-agent approach, where each agent represents one (or more) family/households belonging to one of several socio-economic groups. A Social Accounting Matrix (SAM) of the local economy will be used as a basis to set up a spendings matrix for each agent, defining its spending priorities. Artificial Intelligence techniques will be used to give the agent the possibility to make decisions on how to satisfy these spending priorities. Also, social dynamics, the simulation of strategic planning behavior, learning, and exchange in limited networks will be addressed.

The simulation application will consist of a common user interface allowing the user to "play" the simulation. This user interface layer will be "pluggable" with the underlying programming layer responsible for the calculations on the simulation, so that different plug-ins may be used for different simulation techniques.

KEY WORDS

multiplier effect, simulation, multi-agent based simulation, social accounting matrix, artificial intelligence techniques

CLASSIFICATION

ACM: J4
JEL: E51, O18, R15

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INTRODUCTION

PROBLEM IDENTIFICATION

Lack of circulation

This project is based on the assumption that – next to many other reasons – one of the main causes of poverty is that poor regions are too often caught in something that can only be described as a permanent economic depression in the traditional meaning of the word, characterized by underemployment and under-use of productive capacities. Development of such regions is hindered by a whole set of economic circumstances, such as the lack of credit, weak market demand, low levels of education, weak supply chains and an overall lack of attractiveness for investors, to name only a few. A general result is that the concentration of any incoming money to be used for outside purchases and a lack of circulation of money in the local economy, with a subsequent lack of exchange, even of otherwise viable supply and demand. All other policies to improve the regional economy might fail if there is hardly any purchasing power provoking entrepreneurial qualities locally.

Commonly used strategies to improve a depression in a country (like stimulating exports, allowing more credit, and stimulating governmental debt-spending) generally focus on creating a stronger inflow of money into the domestic economy. Less studied and practiced are strategies not focusing on higher inflow, but on optimizing the local circulation of existing or new monetary resources in the local market, which is a field that can be opened once one has a sufficient overview of the expenditure and circulation patterns.

Limited multiplier effect due to fast outflow

Fishers' equation of exchange "$MV = PT$" (Fisher, [5]) can be used to explain that when the velocity of circulation of money (V) increases and the amount of money remains (M) stable, the income (PT) will increase. For a local economy this means the more inflowing money goes from hand to hand, the more it supplies the productive chain with income and liquidity and the more it leads to an overall stimulation of the local economy. This is called the multiplier effect of expenditures, a concept that receives little or no attention in the Local Economic Development debate.

Of course there is no multiplier effect if the first or second actor in the chain does not spend the money with the next but spends it outside the region. This is too often typical for what happens in poor regions: these regions are characterized by the fact that incoming money leaves the region before being properly used to perform the above mentioned tasks. Hence the (lack of) circulation of money is one of the essential aspects of the vicious circle of (under)development. This is an under-estimated aspect and it is the central focus of this research effort – which is still in a preliminary phase.

If donor or governmental project support wants to optimize the effectiveness of its financial inputs there is a need to know the actual flows of money and how these will be influenced by the potential strategies of spending. In other words: it is important to look beyond the immediate impact of these strategies, and be able to predict the multiplier effects in the longer term. Gathering knowledge about these flows and identifying the parameters which have effects on the duration and velocity of internal monetary circulation is essential in this process.

Government programs, (micro-)credit and investment programs and other local economic initiatives might increase effectiveness if activities and programs could be realized in such a way that also subsequent impacts following from the multiplier effect can be optimized

(Strohalm, [10]). To be able to do this policy makers are in need of a cheap and effective evaluation tool capable of monitoring and simulating all the flows of money in the local or regional economy – specifically where it concerns the poorer areas.

PROJECT FOCUS

This research project will focus on the realization of a computer simulation program specifically applicable for analysis of the monetary flows in poor regions and which allows simulating the multiplier effects of expenditures in the economies of poor regions. This would:

- help to increase the general understanding of all monetary flows in a particular poor local economy, and their significance for development. Even if this project would only contribute to the awareness of this issue it would present a significant achievement,
- strengthen the planning process with ex ante tests and projections of the potential effects of the policies,
- make it possible to identify and determine the parameters which have a positive effect on the duration and velocity of internal money flows,
- support innovative approaches to optimize the multiplier effects,
- in general: get more understanding about how to optimize development strategies.

LITERATURE REVIEW

SIMULATING VILLAGE ECONOMIES

To simulate the effect of a money injection that results in development efforts on a relatively small local economy, we should model the transfers between economic units in that economy. There are several ways to do that.

Literature of modeling these local economies is abundant. Taylor and Adelman [10] give an overview of different techniques for modeling these economies, described in the following sections.

Social Accounting Matrix (SAM)

In a Social Accounting Matrix (SAM) (Adelman, Taylor and Vogel [1]) the population is divided into several actors (including “Rest of the World” as an actor). A table defining all transfers between these actors is used as basis for identifying money flows in the community. The method is used to calculate how increasing or decreasing incomes work their way through the economy. Apart from defining the matrix itself, the method is relatively easy.

SAM has several shortcomings, of which the (unrealistic) assumption of fixed prices is one of the most important.

Computable General Equilibrium (CGE)

Where SAM considers the village to be a price taker for all products, Computable General Equilibrium (CGE) (Singh, Squire and Strauss [9]) acknowledges that prices for some goods are determined at village level. The method is based on maximization of the utility-function: the overall sum of the product of price and demand is assumed to be maximized for all products.

CGE is generally more complicated, and is more of an overall technique, which fails to address distributional aspects within defined groups. For this reason, we will not use it as a basic technique in the first versions of our simulation (the null version). Some CGE aspects might be used on a detailed level later on in the development of the simulation, especially where it concerns the simulation of the existence of an additional currency besides the national currency. However, as this is only in the extension of our project, it is left outside the scope of this article.

Multi-Agent Based Simulation (MABS)

Multi-agent Based Simulation (MABS) is a rather new scientific discipline, in which an environment is created where "agents" define the behavior of the system on an individual level in order to monitor the output of this behavior on a macro-level. The interactions between the individuals create effects on the macro level.

MABS is a technique which can be made as complicated as one would want to. In general, it is the best tool when one is especially interested in distributional aspects, as the tool allows for monitoring on an individual agent level, thus respecting heterogeneity in the underlying population. See http://www.econ.iastate.edu/tesfatsi/ace.htm for an overview of "agent based computational economics".

Combining techniques

Davies [4] summarizes how several of these techniques can be combined in one simulation, depending on its geographic scope and the focus and objectives of the study. A combination of techniques usually provides significantly more realistic results than using only one technique. In economic simulations it is not uncommon that different simulation techniques lead to different results.

Also, one of the basic shortcomings of customary economic simulation is the very poor concept of agent decision making that lies behind calculations in customary simulations: the basic assumption that each agent is only concerned in "optimizing" its utility function, and that this is the only driving concept behind an agent's behavior – where each economist knows this is not a realistic assumption, as social processes play a role which is at least as important. This is where the concept of Artificial Intelligence comes in.

ARTIFICIAL INTELLIGENCE

The art of creating intelligent agents

Artificial Intelligence (AI) is a branch of computer science that studies the computational requirements for tasks such as perception, reasoning, and learning, and develops systems to perform those tasks. Artificial Intelligence (AI) is the study of how computer systems can simulate intelligent processes such as learning and reasoning.

Computational Intelligence is the study of the design of intelligent agents. Computational intelligence combines elements of learning, adaptation, evolution and Fuzzy Logic (http://en.wikipedia.org/wiki/Fuzzy_logic) to create an artificial form of agent intelligence in order to simulate natural behavior as realistic as possible.

A multi-agent approach based on intelligent agents has many advantages over customary simulation techniques. First of all, not only "utility maximization" is the only driving concept behind agent behavior, but a whole set of motivations can be assigned to the "rule interpreter" which is defining an agents behavior. In this way, several complicating factors influencing economic behavior may be simulated, such as:

- social dynamics (such as copying behavior, "fashion", etc),
- strategic behavior and planning of agents – which is of course an integral part of doing investments,
- learning and experiences with certain products, producers or even networks of producers,

- the role of social conventions in exchange,
- behavioral dispositions,
- asymmetrically available information, etc.

Where classic simulation methods fail to address most or all of these issues, Computational Economics offers instruments to implement these in a simulation, resulting in more realistic results and a program that can be adapted when knowledge accumulates.

Local Networks

A special role can be given to modeling economic behavior in local networks [12]. Naturally, a large portion of economic interactions involves a very small portion of the population, as consumers seem to prefer familiar venues. This factor is typically omitted in customary simulation of markets – where agents seem to interact impersonally and efficiently with an infinite number of faceless other agents. Applying Artificial Intelligence and social network techniques can define networks where agents are assumed to occupy nodes from which they have a strong preference to interact only with agents directly linked. Applying such network structures in simulation has proven to be able to change the outcomes of the simulation drastically.

OBJECTIVES & RESEARCH QUESTIONS

PURPOSE

The **purpose** of the project is to contribute to the increase of the (understanding of) efficiency and real impact of development interventions in poor local and regional economies.

OBJECTIVE

The **objective of the research is** to develop a software for the simulation of local development policies and projects, including second-degree effects on non- direct beneficiaries, in a feasible and affordable way, including the option to test less common ways to optimize the effects.

Specific Objectives

The specific objectives of the project are:

- To develop a simulation of economies in poor regions, which can be used to evaluate and predict the effect of injections of money into the region, such as local welfare subsidies (for example the Brazilian Programa Bolsa Familia, an income-transfer policy for poor families), credit programs, infrastructural and other investments, etc.
- To create a simulation that is able to address secondary and deeper levels of impact which take place as a result of the multiplier effect.
- To add extensions to this simulation so that it is capable to simulate also the impact of actions to reinforce the multiplier effect at the local level. The following options to simulate development policies and programs will be included: specific tax policies, micro-credit programs and programs to stimulate regional trade circuits based on internal accounting structures.
- To publish results in appropriate scientific magazines and disseminate the results within several organizations, researchers and practitioners in the area of development and cooperation, with the aims of influencing policies of regional and local development, generating more dialogue and action on the issue.

- To create a gaming software extension introducing the players to the specific problems of poor regions, and the policies to tackle these problems. This will be done by making the simulation software adaptable towards a game, or by the simulation software being pluggable into specific gaming software, so that its results may be used by the gaming software. Different versions of this game might be produced that aim at different groups, like politicians, general public, community workers, etc.

UNDERLYING HYPOTHESIS

Focusing a simulation on multiplier effects suggests that increasing the local circulation of money inside a community is a possible strategy for improving local economy. This is the hypothesis underlying the research effort. The idea is that money will be more effectively organizing a region before it leaves. In the longer run all will profit if regions are more specialized and have less unused capacities.

RESEARCH QUESTIONS

The following questions will be central to the research:

- What are the general parameters that determine the flows of money in poor regions? Amongst parameters considered will be inflow of money, outflow of money, interest rates, local taxes, investment opportunities, etc.
- Which are the optimum values for the sets of these parameters resulting in optimization of economic activities, local circulation, and effective use of money?
- What is the relation between the level of local development and the patterns of flow and outflow of money in the community?
- Can temporary actions to prolong the local circulation and/or postpone outflow of money indeed benefit the long term economic development of a poor region? And is this practical as a strategy to boost local economic development?
- Is it possible to forecast the impact of various development policies and methodologies with the created simulation? If it is, what is the outcome of these forecasts?

METHODOLOGY

MODEL

Simulation techniques

As pointed out in the literature section, there are shortcomings on both SAM (with its assumption of fixed prices) and CGE (failing to address distributional effects). Our analysis has led to the conclusion that a multi-agent simulation would represent an important added-value to the research – offering optimal flexibility in general, enough possibilities to monitor distributional effects on the household level, and the opportunity to introduce intelligent decision-making on an individual level. The latter is specifically needed when applying the software for the simulation of more complex elements like the introduction of the effects of informal economy and regional exchange circuits if these would facilitate a significant part of the regional trade.

Basic model

The basic model will be a multi-agent setup. An agent represents one (or more) basic economic units being the family household, where each household belongs to one of several pre-defined socio-economic groups. Membership of a socio-economic group determines a family's main income raising activity (e.g. farmers, civil servants, merchants, pensioners, etc.).

Each socio-economic group has a set of pre-defined features, such as "household size in number of persons", "debt level", etc. This does not mean that every member of this group is exactly copying the group level features; by bringing in variation over the agents within a group, the features of members in one group fall inside a reasonable range, where the mean of all members of the group is the predefined value of the feature.

One of the features of each agent is the amount of incoming money per month – where "incoming" means coming in not from other members of the community, but from the outside world. Again this number is not exactly the same for each member of a socio-economic group, though the group membership determines the range in which this amount falls.

The basis of the model implies the application of SAM data upon a multi agent population. According to the SAM data, for each group of agents a sum of money comes in from the outside world, and we will follow all these sums of entering money on its journey through this community, passing from hand to hand by the different agents in the model, until the money is spent outside the community by any agent.

For being able to follow this money, we must know how every agent spends its monthly income: how much is given to which other agent belong to what other socio-economic group. For each agent we will have a matrix of expenditures which is a derivation of the matrix of expenditures of the group as it is defined by the SAM – again within certain bounds of variety. The matrix of expenditures of each group is determined by the global Social Accounting Matrix which serves as the basis for this model.

So, one agent is the entry point for this community of a certain amount of money; this money is spent via this agent's personal matrix of expenditures. Part of the money will be spent immediately outside; another part will be spent to another agent, which, in turn, will spend it again according to his personal matrix of expenditures, etc.

The example above sketches the starting situation of the simulation – where the general assumption is that the community is in a "steady state": as well on a global level, as on a group level, as on an individual level:

- incoming money = outgoing money,
- no growth, no shrinking,
- debts are also in steady state, neither growing, nor shrinking. (Debts will of course be paid back, but then new debts will come in place).

The goal of the simulation is not, however, to model this initial "steady state" but to gain knowledge of what would happen if an extra amount of money would be injected at certain entry points in the simulation. Therefore, it is important to realize that this "steady state" assumption only holds for the initial state as a starting point of the simulation.

When simulating the injection of money in this community, it is essential to know how households will react on this. It is not very likely that when receiving 20 % extra income a month, a household will immediately pay every recipient of its money a 20 % extra – one does not pay 20 % extra rent when having a lucky month with 20 % extra income. For each agent, a "matrix of priority in expenditures" will be set up. This is an extra dimension to the personal SAM, indicating which spending has priority at which moment. When raising income, a poor family would first want to buy more food, then more luxury, then probably think about investments – this kind of decisions are reflected in this "matrix of expenditures".

Artificial Intelligence techniques come in where it comes to an agent's decision on how to satisfy its “priority matrix of expenditures”. Within certain boundaries, an agent has the ability to weight its priorities in expenditures, depending on the availability, kind and prices of the commodities purchased. Also the agent may, within certain boundaries, actively search for “best offers” inside the community. “Best offers” can of course only be modeled when not only the consumption side of the model is flexible, but also the production side of the model allows for a dynamic approach. This will also be modeled via artificial intelligence techniques, with respect to the fact that people have a tendency to be much less flexible in changing their jobs than in changing their consumption.

SETUP

Data

Data collection is often very expensive in terms of time, efforts, and money. An associated problem is that one has to be very careful not to lose oneself in data collection, as data are never perfect, and there are always more data to be retrieved.

Also, the scope for this study is not trying to create a simulation which tries to describe as realistic as reasonable a specific real life situation. The focus is not developing a case study; the focus is developing a model to be used in various cases. Also, this model should work with most (reasonable) data.

This research effort will not spend much time on data collection in general. The first stages in the research we use data of an imaginary poor economic region. We will use existing cheap and easy available data to base our artificial population upon, and we will use various methods described by Schreinemachers [8] in order to bring diversity in our artificial population.

In various stages we will fine tune and verify the artificial data by tests with data gathered in one area, presumably the north of Uruguay.

Application setup and instruments

Axelrod [2] emphasizes the importance of replicating simulations of other researchers in order to retrieve more reliable results, and gives various suggestions for making simulations easier to be replicated. Use of the Java programming language (with the REPAST simulation library) is explicitly recommended by Axelrod. In order to improve the reliability of simulated results, the simulation application will be built as a separate user interface in Java, which can be plugged into different base-applications which handle the actual simulation, and pass the results of it to the user-interface. Various base-applications will be produced, each of them using a different (combination of) simulation methodology. With this approach, we are able to combine different simulation techniques, which may hopefully lead to more reliable results.

The Java language with its strong support for interfaces is the most appropriate tool for this approach. Java is typically supporting a setup as described above, where different, pluggable application layers communicate via strictly defined interfaces, and need no more “awareness” of each other than the interface contract. In this way, the choice for Java facilitates working on independent simulation layer plug-ins while still being able to use a single common user interface. The choice for REPAST in this application model is merely practical and based on personal experience; the choice of another Java simulation library would of course not violate this application setup.

Project setup

It is important to realize that the project is still in preliminary phase. We hope to realize the project through a joint- effort of several universities and research institutions throughout the world. At this moment there are prospects in Brazil, China, the Netherlands, Spain, and Uruguay.

Several project teams may be formed, each of which will be working on a specific model or module of the simulation. Project teams might adapt a (different) simulation methodology, and apply that to provide one of the base-applications which can be plugged into the user interface application.

The duration of the complete project is estimated for 4 years. The complete project will include several subprojects and the following corresponding phases:

1. **A null simulation** (36 months), which is able to model monetary flows inside local economies. This part of the research is of interest to any organization or project which aims to examine primary **and** secondary effects of policies or projects. This would involve:
    - 1.1. **Gathering (existing) data:** the emphasis in this first phase lies more on methodology than on validity of the data. Existing basic data will be used, completed where necessary with artificial data. See the section on data collection in the Methodology chapter.
    - 1.2. **Creating the Graphic User Interface Application:** At first, a team of programmers will create the Graphic User Interface Layer of the Application. All necessary user actions will already be programmed into the application wherever possible. The User Interface Layer will communicate via Java interfaces with the simulation layers of the application, which can be plugged in to it. These interfaces will be defined for all project groups in an early stage of the project. The first plug-in simulation layer will be a mock simulation producing mock data to feed the user interface layer, so that initial testing of the user interface can begin.
    - 1.3. The main simulation team will work out the first **simulation plug-in**. This program will be plugged in to the user interface layer. This first simulation will be based on MAS, combined with SAM for identifying the basic money flows in the community, and with CGE for determining price mechanisms related to complementary currency issues. Special attention will be given to create a population of agents which is as realistic as possible, by using various techniques to maintain variability inside the population of agents (after Schreinemachers [8]). The latter includes the implementation of local subnetworks inside the population of agents.
    - 1.4. Optionally, other teams could work on plug-ins using different simulation techniques, for example:
        - 1.4.1. a simulation where the emphasis is more on “intelligent agents” with “rule interpreters”. The focus is here more on quality of decision making agents, rather than on a large quantity of relatively simple agents.
        - 1.4.2. a simulation combining CGE with micro simulation, after Robilliard, Bourguignon and Robinson [7] or Cogneau and Robilliard [3].
        - 1.4.3. a macro/microsimulation combined with SAM, after Lattarulo, Paniccia and Seielone [6].
    - 1.5. A first game based on the simulation will be produced.
2. **The “actions” simulation (24 months, partly overlapping)**, focusing on **modeling supportive actions.** Software is developed that allows testing different ways of reinforcing the economic impact of monetary injections. What if these expenditures are done in a specific context? For example: Does it help to spend under limiting conditions

like binding the purchasing power inside a regional trade circuit? What difference would it make to induce it as a credit? What kind of credit has what kind of effects, etc?

The software not only allows introduction of purchasing power in different points of the economy, but specifically models several actions which are performed in order to stimulate the effectiveness of this injection.

RESULTS

Measurements of results

The results of the simulation are defined in the following ways for the case of different kinds of projects and methodologies of development interventions:

- Evolution/impact on gross product for the complete population, and for each of the defined groups of families.
- Development of multiplier effects: how long (in time and in the amount of transaction steps) does it take before the value of 1 national currency unit leaves the community?
- Evaluation of efforts that target on reinforcing the multiplier effect.
- Evolution of distribution of income in the local society, in particular the reduction of number of poor families.

Validation of the simulation

In the final stage of the project, the simulation must be validated. This will be done in several ways:

- Feeding existing studies of other economic models into the simulation and compare our results with the results of those studies. This will be done with several studies based on various different simulation techniques.
- Feeding data of a real world situation in the simulation, and verify if the simulation reasonably describes the development of that specific region. In order to validate the results, there should be data available for two different points in time (which define a reasonable time span, preferably 3 to 5 years). If applicable data are available from literature, these will be used.

RELEVANCE OF THE FORTHCOMING STUDY

VALUE OF THE PROJECT

Modeling of local economies has been done numerous times before. We believe this project to represent an added value to previous research because of the following features:

- Focus on the practical application of a software tool that facilitates measuring and predicting the effectiveness of development projects.
- Approaching the subject from a monetary point of view, by taking the multiplier effect as a basis of the simulation. Through this approach, also secondary and longer term effects of money injections can be included.
- Applying state of the art technology in favor of the poorest.
- Use of multi-agent simulation as the basic simulation technique, combined with “artificial intelligence” techniques to make decisions of agents as realistic as possible. Each agent is representing (a group of) economic units, and gets a “rule interpreter” allowing him to take reasonably intelligent decisions.

- Additional to multi-agent simulation as the base technique, several combinations of other simulation techniques will be applied and compared.
- The end application will be able to compare large sets of several simulation runs under varying circumstances, and to apply sound statistical analysis to them.
- Ability to present the outcomes of the research as a playable "game".

Application of the tool

Basically, the overall application of the tool will be focused on evaluation and improvement of development projects and strategies. The tool will be used as:

- **A policy tool**, contributing to refinement and higher effectiveness of development tools and policies.
- **A research tool** that will provide the model and instrument to:
    - Represent and understand more completely the monetary dynamics at the level of local economy.
    - To make comparative studies of the (*ex ante*) simulation of the potential effects of (combinations of) different development approaches.
- **A monitoring and evaluation tool** usable during the execution of development programs, allowing to evaluate, in a more accurate manner, their progress and impact.
- **A training tool** for existing and new employees working on projects with a monetary development approach: as the subject of these projects is very complex, a training tool that simulates the operation and impact of the activities would be very helpful to train employees and staff in how to set up a program and even offer the opportunity to learn by "trial and error".
- **A tool to create awareness** and interest of third parties, policymakers, local actors and the public in general, especially when the program is applied as a "game". From this point of view, people must be able to use and handle the application without intensive training and should be able to apply growing complexity of the simulation in a step-by-step process.

Relevance of monetary focus

Though at present several simulations are available for testing the effectiveness of development projects, generally there is very few attention to monetary aspects. For example: too often, evaluations on micro credit programs only focus on the direct receivers of credits, but fail to determine how the money flows through a community after this first step – thus ignoring indirect effects. In that case evaluations could create wrong impressions. For example a credit to finance a bakery may be considered as successful, while it might not especially contribute to the economic development of the region. This could be the case if five other bakeries nearby go into bankruptcy and no additional exports towards outside the region are realized, only a swift within the internal market. Therefore, we believe economic simulations and evaluations should also include secondary effects and monetary flows, and should also be able to visualize effects on a detailed level.

Relevance of implementing Artificial Intelligence techniques

The fact that Computational Economics is a relatively new technique which offers various extremely interesting features to cover many shortcomings of classical simulation techniques has unfortunately not yet been realized enough in the world of econometrists and modelers of economies. In practice, Computational Economics techniques are not often being used in economic simulations. Computational Economics provides the opportunity to closer simulate the reality. This is of special importance for our simulation, as it is not merely meant to simulate a static reality, but is also meant to test whether investments in different places or different ways might create better results.

Especially the objective to simulate the multiplier effects of innovative policies towards financial injections is in need of advanced simulation techniques which are able to simulate planning behavior and strategy building by agents. As this part of the simulation is specifically aimed at actions which are focusing on, or at least resulting in (stimulation of) increased investments, there is a definite need for simulation techniques able to handle planning and strategy building behavior at an agent level.

Also the options offered by Computational Economics to simulate the existence of subpopulations and networks of agents is a very important addition, as in reality most trade in a community is taking place inside informal networks of people knowing each other, and only a small part of money is spent outside the small circle of "people we know". This feature is also of major importance when it comes to simulating the effect of networks such as existing in micro credit programs or semi open circuits of local businesses.

With the application of Artificial Intelligence techniques, the simulation program we hope to produce will be a learning program which is capable to integrate the understanding of its users and grow step by step in usability to implement investment policies in poor regions.

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MODELIRANE LOKALNOG TOKA NOVCA U SIROMAŠNIM PODRUČJIMA: ISTRAŽIVAČKI POSTAV ZA SIMULACIJU UMNAŽAJUĆEG UČINKA U LOKALNIM EKONOMIJAMA

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SAŽETAK

U siromašnim područjima, smanjeni opticaj novca jedan je od ključnih uzroka nerazvijenosti. Što se više novca uključi u opticaj, više će lokalna ekonomija biti stimulirana. Međutim, u većini siromašnih područja novac se troši izvan zajednice prije lokalnog opticaja čime se dramatično smanjuje učinkovitost uključivanja novca.

Razvojni programi bi povećali svoju učinkovitost kad bi bilo poznato kako trošenje novca može dovesti do optimiranog i produženog lokalnog opticaja. Za saznavanje navedenog bit će razvijen simulacijski alat kojim se može analizirati financijske tokove, radi izvrijednjavanja utjecaja specifičnih akcija na lokalni razvoj i radi praćenja sheme razvoja tijekom faze izvršavanja.

Osnovni model bit će razvijen u multiagentskom pristupu pri čemu svaki agent predstavlja jedno (ili više) kućanstava iz nekoliko socio-ekonomskih grupa. Na temelju matrice socijalnog računanja za lokalnu ekonomiju bit će postavljene matrice potrošnje za svakog agenta, definirajući njihove prioritete. Pomoću tehnika umjetne inteligencije agentima će biti dane mogućnosti odlučivanja kako zadovoljavati prioritete potrošnje. Također će biti razmotrene socijalna dinamika, simulacija strateškog planiranja, učenje i izmjena u omeđenim mrežama.

Primjena simulacije sastojat će se od sučelja pomoću kojeg će korisnici postavljati parametre za simulaciju. Korisničko sučelje će biti nadogradivo dodatnim programskim modulom odgovornim za proračune, tako da će biti moguće upotrijebljavati različite module za različite simulacijske tehnike.

KLJUČNE RIJEČI

učinak umnažanja, simulacija, višeagentna simulacija, matrica socijalnog računanja, tehnike umjetne inteligencije

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COMPLEXITY MEETS DEVELOPMENT – A FELICITOUS ENCOUNTER ON THE ROAD OF LIFE

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SUMMARY

Since before Adam Smith, economists have been concerned with development. However, they have seldom understood it or paid it enough mind. For example, the "sequence" economists, such as Marx in the 19th Century and Rostow in the 20th sought to force development everywhere into a rigid pattern. Since 1874, the marginalists and their Neoliberal descendents have emphasised comparative statics and steady-state equilibriums, not growth.

Although many new ideas popped up after WW II, none proved satisfactory. These included alleged "silver bullets" such as "free" trade, foreign direct investment, import substitution, industrialization and investment in human capital, as well as varied sets of "multiple drivers", whose individual effects proved hard to sort out.

Meanwhile, Neoliberal economics gradually took over the non-Marxist world. But it lost its credibility by spawning a mindless globalisation and long series of economic, human and social disasters. So today development economics is undergoing a "rebirth", with "the Barcelona Consensus", custom design, multiple objectives and sustainability among its guiding stars.

By happy coincidence, a new discipline called complexity began to emerge in the mid 1980's. Out of it has come a new kind of economics which is not only congruent with current thinking about development but also provides useful advice in the design and management of development programs, including those related to poverty.

Meanwhile the Commonwealth of Puerto Rico (USA) is trying a new approach to the eradication of this evil. Poor communities have been identified, organised and then made responsible for taking the lead in coordinating their own development. This coordination covers not only projects managed by the community but those sponsored by outside private- and public-sector organisations.

The "jury is still out" but the odds are that this approach will provide much more civic, economic and social development for the poor than previous attempts. And a major factor improving these odds, is that this approach is the one most compatible with a vision of Puerto Rican society as a complex system.

KEY WORDS

complexity, development, international economics, poverty

CLASSIFICATION

JEL: B59, D31, F43, I38, O10. O20

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A VERY BRIEF HISTORY OF DEVELOPMENT

Since before Adam Smith, economists have been concerned with development. However, they have seldom understood it or paid it enough mind. For example, the "sequence" economists, such as Marx in the 19th Century and Rostow in the 20th sought to force development everywhere into a rigid pattern. Since 1874, the marginalists and their Neoliberal descendents have emphasised comparative statics and steady-state equilibriums, not growth. And in the 1920's, J.W. Mitchell not only considered business cycles to be the dominant feature of economies but saw each one a unique event.

Nevertheless, after WW II, renewed efforts to understand and model economic growth spawned many alternatives, but none of them turned out to be satisfactory. Some people sought alleged "silver bullets" in "free" trade, foreign direct investment, import substitution, industrialization or investment in human capital, for example. Others identified sets of "drivers" for development but then had great difficulty in sorting out their individual effects. And almost nobody, except for Piana, has faced up to the serious deficiencies in international trade statistics and their implications for the many theories based on the latter [1-10].

Meanwhile, Neoliberal economics gradually took over the non-Marxist world. But out of arrogance and an obtuse infatuation with self-righting market equilibriums, it spawned both a mindless globalisation and long series of economic, human and social disasters, many under the banner of "the Washington Consensus", and so it lost its credibility. These disasters began in 1983 with defaults of developing countries which had borrowed "petrodollars" and continued on through yet another Argentine crisis in 2002. As a result, development economics is today undergoing a "rebirth", with "the Barcelona Consensus", custom design, multiple objectives and sustainability among its guiding stars. This rebirth coincides with a renewed effort to reduce poverty worldwide and hopefully will lead to a better coordination of the two than has occurred in the past [11-18].

In the West in fact, many different approaches to poverty have already been tried — ignore it, punish it, leave it to municipal charity, leave it to private charity, leave it to "trickle down" policies, militarise society, undertake general measures of economic development, undertake specific measures to benefit the poor as a class and/or undertake measures to benefit specific groups of poor people, such as the malnourished, poor farmers or the unemployed. So the typical national "anti-poverty program" [if one exists at all] is usually a hodgepodge of historical accidents, with performance and support varying greatly by approach. Last but not least, the relation between demography and poverty is usually ignored or given only lip service. So everywhere, for these reasons and others, poverty is still with us, and it is hard to distinguish business cycle effects from program impacts [19-21].

Meanwhile and by happy coincidence, a new interdisciplinary discipline called "complexity" began to emerge in the mid 1980's. Out of it has come a new kind of economics which is not only congruent with current thinking about development but also provides useful advice in the design and management of development programs, including those related to poverty.

And by another happy coincidence, the Commonwealth of Puerto Rico (USA), is trying a new approach to the eradication of poverty. Poor communities have been identified, organised and then made responsible for taking the lead in coordinating their own development. This coordination covers not only projects managed by the community but those sponsored by outside private- and public-sector organisations.

Despite a successful "field test" in 53 communities in San Juan, "the jury is still out" as to the eventual success of this approach. But the odds are that it will provide more civic, economic and social development for the poor than any other approach tried to date. And a significant factor in improving these odds, is that this approach is the one most compatible with a vision of Puerto Rican society as a complex system.

COMPLEX SYSTEMS

A "system" may be defined as a set of components which interact much more with each other than with their "neighbors", whether by human design or natural happenstance. A system also includes boundaries [fuzzy to sharp] and one or more processes by which the components [a] interact with each other, [b] interact with neighbors and [c] transform inputs into outputs. Each process typically leaves one or more "tracks in the sands of time" (orbits, time series, trajectories.) [22].

Most common are the ubiquitous dynamical systems, systems whose state space and position in that space change with time. These range from nanosystems to the Universe itself. Unfortunately there is no agreement on taxonomy or definitions, so following is a revised version of a taxonomy which we developed for the convenience of business economists [23].

Non-engineered dynamical systems come in three basic "flavors": the sporadic [avalanches, earthquake faults, volcanoes] the unimodal [pendulum clocks, toy trains] and the multimodal. The latter are legion, but three "families" – the chaotic (erratic deterministic) the random and the complex account for most ecologies, economies, human societies, large communications systems, living things and suchlike.

To confuse matters further, all three are "chameleon" systems. That is, within the time horizon of interest to the typical analyst and for line segments of significant length, the track of one may imitate at least one of the behavior patterns generated by another. A classic example is the price index of that complex system known as the New York Stock Exchange, which trended, fluctuated randomly, crashed chaotically and then trended again, all within the 30 months centered on October 17, 1987.

Chaotic systems are largely or entirely deterministic, yet their behavior is unpredictable beyond the short run, mainly because their processes are nonlinear and the evolution of their tracks is extremely sensitive to initial conditions. They are also prone to "crashes" whose "triggers" turn out to be inconsequential. [The "butterfly effect"]. Surprisingly their processes are often simple, such as the logistic function, frequently used in biology and marketing. By way of contrast, the processes of random systems are always generate a sequence of completely independent events, but their tracks, especially those of cumulative realisations, may exhibit spurious trends and/or cycles.

Unfortunately with no agreement on definitions, how do we know a complex system when we meet one? The answer is, sometimes we don't! Indeed most of the 30 or so definitions of "complexity" and "complex systems" already "on the table" consist of a set of criteria in the form of dicta by eminent researchers. Although nearly all of these definitions "sound right", few of the criteria are quantifiable and many use undefined terms, such as "emergent properties" [24, 25].

The foregoing is not purely an academic matter. Failure to identify a system's pattern of behavior correctly or to anticipate changes in this pattern may not only cost one money. In the healing arts and sciences, the inability to "read" a track correctly can be a matter of life or death.

Given the foregoing, we provisionally define a complex system as one which has at least one nonlinear process which generates at least one output which exhibits at least four modes of behavior, within the time horizon of interest to the analyst. One mode should be chaotic, another random and another trending. The other(s) may be biotic or periodic, for example, but not an exact Hamiltonion. Complexity is the study of complex systems so defined. (Biotic modes can be described by functions with at least one trigonometric argument.)

By comparison, other chameleon systems typically exhibit fewer modes. A weather system in the Aleutian Islands of Alaska will spend most of its time in a chaotic mode. A North Atlantic hurricane will spend most its time in a random or trending mode and the rest in a chaotic one [26-33].

The most interesting complex systems are also adaptive, evolutionary and have people as their participants [26-32]. Those CAE systems which meet our provisional criteria usually meet as well most or all of the criteria of popular dicta:

1) At a minimum, all that is required for a CAE system's "birth" is a critical mass of moderately rational participants with some characteristics in common, access to local information, a set of rules for their interaction and some positive feedback from their "decisions". This feedback may come from increasing returns to scale, networks, positive externalities or other factors.
2) Regardless of intelligence, participants often have limited information and/or face high incremental costs of information acquisition and processing. So for decision making, most of them rely on heuristics rather than fancy mathematical models. Their world is a far cry from that of the Walrasian auctioneer or that of the Neoliberal utility maximiser.
3) When the number of participants reaches a critical mass, they self-organise without any command structure or templates. The resulting CAE system may exhibit various levels of hierarchy, each with its own "emergent properties". These are properties which cannot be deduced from the characteristics of the participants, those of the adjacent levels or any combination thereof. Adam Smith's "invisible hand" is a classic example of an emergent property, including those frequent cases where a market does not meet Neoliberal standards for equilibrium and Pareto optimality [33-38].
4) A CAE system is likely to spend more time out of equilibrium than in it or near it. And being in equilibrium even may be dangerous to one's financial health! (Recall the US auto manufacturers on the eve of the first Japanese assault on their market share.) [23, 39]
5) The evolution of a CAE system reflects the complicated interplay of many different factors such as – chance events; co-evolution with its environment and/or neighboring systems; decreasing and increasing returns to scale; externalities; "lock ins" of infrastructure, institutions and/or technologies; nonlinear dynamics; path dependence; and "branch jumps" on the possibility tree, as when an economy based on herding discovers several large oil reservoirs on its premises.
6) As a result, multiple equilibria or none at all are possible, and the future of CAE system in the medium and long runs is more likely to be dominated more by events in the domains of uncertainty or by those which come "off the wall", than by those in the domains of certainty and risk.
7) As a result of the above, "best estimate" forecasting and the traditional planning based on it are "out". Scenario planning and periodic reoptimisation of capital improvement programs are "in". The most important people in the organization are not top managers but "antenna people", those who detect which scenario is unfolding, mutating or being replaced, especially if the replacement does not appear on the organisation's current menu of planning scenarios!
8) Strategically management must try to maintain its organization "in the zone of fruitful turbulence", wherein lie the greatest number of opportunities as well as threats. (An alternate metaphor "the edge of chaos" is used frequently in the literature, but we believe it is misleading, in part because it was derived from the study of chaotic, not complex systems.)

9) Organizational effectiveness will depend more on interaction between participants and on "bottom up" innovations than on the quality of the orders handed down from "above" by a management accustomed to command and control. In fact, a lot of knowledge will emerge out of interaction between the system's participants, rather than from specific participants or groups within the organization who claim to have certain "proprietary" knowledge. So leadership must be more indirect than direct. It must understand how the organization's functions in network terms and foster the right degree of and variation in "connectivity", between formal groups, informal groups and individuals within the organizational structure.

COMPLEXITY, DEVELOPMENT AND POVERTY

Very clearly complexity supports the current trends in development theorising and planning. The perception of murky futures and emergent properties unique to each CAE system, the stress on connectivity and bottom-up innovation, all clearly favor "custom made" development plans, flexibility in their implementation and a broad participation of the populace in both planning and execution.

The foregoing does not mean, however, that one should abandon all macro and intermediate-level attempts to help the poor. No development program can ever be the "rising tide which lifts all boats" but the right kind will certainly lift a lot of them. Minimum wages set by industry and judiciously jacked up from time to time, will certainly help many who are poor or close to it, maybe even more than the right to organize labor unions. And so on.

However, in a CEA-type economies, priority should be given to measures to eradicate poverty which are carefully targeted and which galvanize the beneficiaries into a fruitful interaction with each other and with the organizations providing assistance. The Puerto Rican program for Special Communities describe ahead is a good example of what we mean.

PUERTO RICO

The USA is a semi-federal, semi-national entity composed of 50 states, four jurisdictions under the direct control of the Federal legislature, two self-governing commonwealths and two associated republics. The Commonwealth of Puerto Rico lies between the Caribbean Sea and the Atlantic Ocean in the string of islands known as the Greater Antilles. The Island is 156 km long and 56 wide, with an irregular topography, 156 soil series and a subtropical climate. The great majority of its almost four million inhabitants of diverse ethnicities are US citizens, speak Spanish as their mother tongue, drive Japanese cars and travel frequently to the States, where several million of their descendents live. It also has 2,8 million vehicles, 40 000 retail stores, 2000 wholesale business and 1500 factories, more or less. Puerto Rico is a world leader in the manufacture of biological and pharmaceutical products. But it also makes a wide range of other products and has a large dairy industry and produces some of the best coffee in the world.

Personal income per capita for 2006 was estimated at $ 13 000, but the true number is probably closer to $ 17 000, due to underreporting. At 70 % of the latter, the median is $ 11 900, so given the cost of living, an estimate of 45 % or 1 776 000 for the number of people in poverty is probably close to the mark [40].

THE SPECIAL COMMUNITIES PROGRAM

Daughter of a self-made businessman, doña Sila María Calderón scaled heights of power and wealth seemingly beyond the reach of a woman of her generation, but never lost her conscience. Now retired, she not only was successful in business and public service but became the first woman in the history to be elected first mayor of the capital, San Juan, and then governor of the Commonwealth 2001-2005. Starting as a private citizen with one poor “barrio”, she developed the concept of special communities, extended it to 53 as mayor and then, as governor went Island wide with Law 1 of March 2001. Today there are 737 special communities in Puerto Rico with an estimated population of 488 000.

The basic ideas of this program are to [a] help people as members of their communities, not as atomistic individuals or families, and [b] simultaneously encourage them to take a leading role in the development of these same communities. This may be elaborated in terms of four principals: (1) the people of the communities should be empowered and learn to demonstrate self initiative; (2) they should be the axes of the planning and execution of their own development; (3) this development should be based on an alliance between the community, the enterprise sector and the various public sectors; (4) all of the foregoing activities should be thoroughly integrated.

To these four, the writer would add a fifth – the channeling into the special communities of public of private and public funds which would otherwise be expended for other purposes in the same municipality or for the same kind of purpose in another municipality. Needless to say, the fulfillment of this prinicipal depends heavily on the priority which the Governor gives to the program.

Community operations are the responsibility of an Office of Special Communities, reporting directly to the Governor. To date, the need to construct or rehabilitate 11 850 housing units has been identified, as has the need for 2005 civil works. As of May 2007, 9458 housing units had been completed, at a cost of $ 689 million, as had some 1600 civil works. The rest should be finished by December 2008. In addition, over 2000 community leaders had received a 30-day course, and some 4000 meetings of community councils had been held. This latter may not seem an achievement for readers who regard meetings as a wasteful, unpleasant duties, but it is quite a different matter for people who for generations have never had a say in their own destinies or any hope for the future.

Initial financing has been provided the by the income from a perpetual trust fund, created by a $ 500 million special dividend by the long-profitable Government Development Bank and by a $ 500 million loan from the Bank to be paid off by legislative appropriations [41].

This program has been subject to the usual problems caused by the complex coordination involved and by individuals and organization who don’t do what they promise, don’t do it on time or “all of the above”. But there are also special problems such as those caused by jealous agencies or some of Puerto Rico’s 78 mayors. Some have even tried to have the program abolished and the trust fund income transferred to the mayors or put to some other use. And some mayors want to expropriate community land without community agreement. So the success of this program very much depends on strong support by the Governor.

Reacting to criticisms of the program in the media, Carmen Villanueva, leader of the “Hill Brothers” Community in the municipality of Trujillo Alto, very much expresses its spirit: “Who among us has suffered from government bureaucracy? All of us. Who has not suffered from the problems caused by people without scruples? All of us. In this regard, nothing has changed – that contractors do not do what they are supposed to do, that public-sector employees steal money, that managers do not coordinate with others or do not pay attention to the requirements of the job. So what shows up in the newspapers is nothing new, but this may nevertheless hurt all who believe in social justice, by implying that the problem is the program, when it is not the program.

“The Office of Special Communities prepares a budget for each community and tells them: ‘I have the money. You decide how to use it.’ It is an ambitious work plan which seeks to remedy [for example] 150 years of neglect in a community such as Tocones which never had asphalt on the streets and whose houses lacked storm drains, sewage pipes and electricity.

“If we talk about all that [the question naturally arises] – How much time do we need? I believe we are being dishonest, if we believe that this is a four-year job. It will take [most of] the time we left these communities abandoned, maybe 50 to 100 years [because] it is a project to create a new Puerto Rico. This is not about infrastructure. This is about creating a consciousness of belonging and [instilling in people] the power [of the belief] that you can do things yourself.” [42].

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KOMPLEKSNOST SUSREĆE RAZVOJ – SRETNI SUSRET NA STAZI ŽIVOTA

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Ured guvernera Portorika
Portoriko, SAD

SAŽETAK

Još iz vremena prije Adama Smitha ekonomiste zanima razvoj. Međutim, rijetko su ga razumjeli ili mu psovetili dovoljno pozornosti. Na primjer, "linijski" ekonomisti poput Marxa u XIX. stoljeću i Rostowa u XX. stoljeću nastojali su razvoj uključiti uvijek u zadani obrazac. Od 1874. marginalisti i njihovi neoliberalni nasljednici naglašavaju komparativnu statičnost i stacionarnost, a ne razvoj.

Iako je nakon Drugog svjetskog rata nastalo mnogo ideja, nijedna se nije dokazala zadovoljavajućom. Neke od njih su smatrane univerzalnim rješenjem, poput slobodne trgovine, izravnih stranih ulaganja, uvozne zamjene, industrijalizacije i ulaganja u ljudske resurse, kao i različitih „višestrukih pokretača" čiji su neovisni učinci teško izdvojivi.

U međuvremenu, neoliberalna ekonomija polako je preuzela vodeću ulogu u nemarksističkom svijetu. Ali ona je izgubila svoju vjerodostojnost potičući besmislenu globalizaciju i niz ekonomskih, ljudskih i društvenih katastrofa. Zato danas razvojna ekonomija prolazi ponovno rađanje s konsenzusom u Barceloni, što uključuje uobičajeni pristup, višestruke ciljeve i održivost među vodećim postavkama.

Sretnom slučajnošću, nova disciplina nazvana kompleksnost počela se razvijati sredinom osamdesetih godina prošćog stoljeća. Iz nje je nastao i novi pristup ekonomiji koji nije samo sukladan sadašnjem promišljanju razvoja nego također pruža korisne savjete u dizajniranju i menadžmentu razvojnih programa, uključujući i one vezane uz siromaštvo.

U međuvremenu, Portoriko primjenjuje novi pristup za iskorijenjivanje tog zla. Siromašne zajednice su identificirane, organizirane i učinjene odgovornima za preuzimanje vodeće uloge u koordiniranju vlastitog razvoja. Ta koordinacija pokriva ne samo projekte koje vodi zajednice nego i one sponzorirane vanjskim privatnim organizacijama i organizacijama javnog sektora.

Još se čeka na prosudbu takvog pristupa, ali začuđuje kako on vodi na više civilnog, ekonomskog i društvenog razvoja siromašnih nego raniji pristupi. A kao glavni čimbenik unaprijeđivanja, aktualni pristup je najusklađeniji s vizijom portorikanskog društva kao kompleksnog sustava.

KLJUČNE RIJEČI

kompleksnost, razvoj, međunarodna ekonomija, siromaštvo

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