Jul 1st, 12:00 AM

Knowledge-Brokering with Agent-Based Models: Some Experiences from Irrigation- Related Research in Chile

Thomas Berger

Chris Schilling

Christian Troost

Evgeny Latynskiy

International Environmental Modelling and Software Society (iEMSs)
2010 International Congress on Environmental Modelling and Software
Modelling for Environment's Sake, Fifth Biennial Meeting, Ottawa, Canada
David A. Swayne, Wanhong Yang, A. A. Voinov, A. Rizzoli, T. Filatova (Eds.)
http://www.iemss.org/iemss2010/index.php?n=Main.Proceedings

Knowledge-Brokering with Agent-Based Models: Some Experiences from Irrigation-Related Research in Chile

Thomas Berger, Chris Schilling, Christian Troost, Evgeny Latynskiy
Dept. of Land Use Economics in the Tropics and Subtropics, Universität Hohenheim
(i490d@uni-hohenheim.de)

Abstract: One key advantage of agent-based modeling (ABM) is the one-to-one correspondence of real-world and computational agents, which facilitates participatory simulation and model-enhanced learning. Using ABM effectively poses a number of challenges that have not been fully resolved yet. Some of these challenges relate to organizational and institutional factors, such as finding an appropriate boundary arrangement in which scientists, policy makers and stakeholders can interact and jointly make use of the models. Other challenges relate to technical and economic factors, as the models must ensure continuous stakeholder involvement and actually provide some returns to end-users. This research tested computer-based decision tools in a knowledge broker arrangement. We applied the MP-MAS software to simulate how farmers interact with each other and react to changes in their economic and natural environment. In particular, we used the model for evaluating the willingness-to-pay for the construction of a new reservoir. A key innovation of the research was the development of the decision-support tools in close interaction with multiple stakeholders, including water user associations and members of the irrigation and agricultural administration. This interaction, which was organized in the form of individual consultations, workshops and training sessions, ensured that the simulations addressed the needs and priorities of different stakeholders and took their local knowledge into account.

***Keywords**:* Mathematical programming; multi-agent system; water shadow price, reservoir, decision support.

1. Introduction

In recent years, multi-stakeholder governance structures, such as River Basin Management Boards, have gained increasing importance for the management of water resources [Neef 2009]. By providing a platform for knowledge exchange and negotiation, such governance structures have a considerable potential for improving water resources management, because they can take the socio-economic complexities of river basins into account. To become more effective in their decision-making, such platforms benefit from access to policy-relevant information about the bio-physical parameters that determine the opportunities and challenges of water resources management [Hare et al. 2003; Letcher et al. 2006]. In particular, they benefit from information about the economic, social and environmental impacts of different development and management options [Hazell et al., 2001]. Likewise, policy-makers at the regional and national level, who make ultimate decisions on public investments in water resources development, will be able to make more informed decisions if they receive adequate information on the impact of different investment scenarios. Science-based information is, of course, only one factor that influences decision-making on river basin management. Ultimately, such decisions reflect policy beliefs as well as interests and power structures.

Yet to exploit the full potential of providing knowledge for better decision-making on river basin management, it is essential to use the best available methods to generate information, and generate and disseminate information in a form that is relevant and accessible to the stakeholders involved in decision processes. The "Integrating Governance and Modeling" project within the CGIAR Challenge Program on Water & Food (CPWF) pursued this goal by (a) developing computer-based decision tools for evaluating environmental-economic-social interactions of river basin management in a participatory setting, and (b) by testing and promoting the use of these decision tools within multi-stakeholder governance structures. The research under this project was conducted in the White Volta Basin in Ghana and the Maule Basin in Chile. During the course of the project, various decision support tools were developed in close collaboration with stakeholders in both countries. Tools included whole-farm programming models, specific user maps from GIS, water-balance models, hydrology simulation models, agent-based simulation models, and network-influence-mapping. For reasons of scope, this paper concentrates on Chile and the application of the agent-based software MP-MAS, which played a central role in this project and which combined other different models mentioned above. Only results for one use case will be presented, the construction of a water reservoir and how this might affect the farmers' willingness to pay. Other use cases involving other types of agents are reported on http://www.igm.uni-hohenheim.de/.

2 Computer-based decision tools in practice

Computer-based decision tools have been proposed as an effective means to disentangle the complexities and uncertainties related to the management of natural resources [Van Paassen et al. 2007]. Agent-based simulation in particular has been suggested as a promising approach to involve stakeholders in the definition and solution of resource use problems [Parker et al. 2003]. Because of their interactive and participatory features, agent-based simulation can integrate various sources of knowledge and help to reach consensus on the implementation of problem solutions [Becu et al., 2008].

Step 1: **First round contacts, introductions**
Inform stakeholders
Contribute to understanding of governance structures

Step 2: **Demonstrations of computer-based tools**
Elicit feedback on problems, needs and potential solutions and evaluation criteria (use-cases, scenarios), may involve another workshop

Step 3: **Organizing feed-back, especially regarding front-ends of computer models**
More workshops and evaluation of workshops, may also involve smaller working groups/interviews

Step 4: **Practical use of the computer tools by stakeholders**
Identify people who to train
Offer training courses with computer tools

Step 5: **Monitoring/evaluating the use of tools by stakeholders**
Establish the use potential of the model

Figure 1. Collaborative research and learning framework

Sterk et al. [2009] describe several ideotypical arrangements for using computer models as decision tools at the science-policy interface. *Knowledge broker* is the arrangement relevant for the decision tools developed and tested in this project. Compared to traditional arrangements with a clear distinction between the science and policy domains, knowledge broker means that scientists developing the models directly engage with interest groups (resource users) and devote much effort in merging and transferring the scientific knowledge generated by their models. The focus is on model-enhanced learning, i.e. scientists, resource users, extension workers, government officials and other stakeholders jointly increase their knowledge about the land system in question, exchange their views and may then finally negotiate possible solutions.

An important prerequisite for a useful decision support tool in a knowledge broker arrangement is to earn the trust of stakeholders in the model and its simulation results. In this project, a collaborative research and learning framework guided the joint development of the model with those interested in using it (Figure 1). The joint development had three objectives: (1) to improve the quality of information used to set up and parameterize the model, (2) to ensure that the relevant questions and criteria can be addressed with the model as well as to identify relevant and feasible policy options and (3) to provide decision makers with access to the model which ideally includes training them to use it. The work reported on here differs from the participatory modeling approaches used for common-pool resources and social learning [D'Aquino et al. 2003]. Knowledge brokering in this use case refers to market-oriented policy interventions that involve many stakeholders and in which equilibrium outcomes cannot be easily predicted. Various stakeholders such as farmers, water user associations, government agencies and other public sector organizations were engaged in this simulation experiment and shared their data and points of view.

3 Setting for using agent-based simulation tools

Chile has a history of being at the forefront of water reform. The Chilean Water Code of 1981 established fully tradable water rights, separate to land rights; non-consumptive rights for hydroelectricity generation were incorporated in the 1990s; and a number of policies to promote investment in irrigation infrastructure have been implemented over the last 25 years. During the project period, private and public stakeholders were engaged in the planning of a new reservoir to be built on the Ancoa River, about 300 km south of the country's capital Santiago de Chile. The region is characterized by a relatively high percentage of rural population in small-scale agricultural holdings that undertake farming on fertile soils but under low water security. Water security is defined here in percentage terms as the likelihood (within 95% confidence limits) that a farmer can withdraw 100% of water right entitlements in any given year. The low level of water security (between 25%-85%) has historically limited farmers' profitability and their ability to make investments in high-value crops that require a secure water supply such as apples and raspberry for exportation [Berger et al. 2007].

The Ancoa dam project aims to address this issue by the construction of a reservoir that can capture and hold water during the winter season, and distribute it through the summer irrigation season, thereby increasing water security for farmers. The construction of the dam will be largely financed by the state but it also needs to recoup a net sum from farmers over the life of the investment. Project calculations assessed this value to equate to approximately 900,000 CHP (~1,120 Euro) per water right owned by the farmer (1 water right ~= 1L/s which is sufficient to irrigate approximately 1 hectare of crop land). This value is heavily subsidized to farmers however, based on the number of water rights they own. A small-scale farmer possessing less than 5 water rights would be subsided 95% of this price; a large-scale agricultural enterprise owning over 50 water rights would receive a subsidy of 54.5%. For the dam construction to go ahead, the state required an agreement from farmers equating to a minimum of 50% of total water rights within the region, that they are willing to accept this pricing scheme (i.e. that they are willing to pay these costs for the dam in order to gain the improved water security).

At the time of commencing our research, farmers, water user associations and various government organizations were debating and negotiating the "terms of reference" for the Ancoa dam, in particular the distribution of water rights among irrigation sectors, the amounts of subsidy to be paid for small and large-scale holdings, and the timeline of handing over the infrastructure after construction. Knowledge sources and information needs differed considerably among stakeholders: farmers, for example, were keen to get a better estimate of the "shadow price" of irrigation water at farm level, while government officials were interested in reaching the 50 percent willingness to engage in the construction works. Accordingly, the timing of the planning and negotiation process provided a perfect setting for testing agent-based simulation tools within a knowledge broker arrangement.

4 Specification of the multi-agent software

MP-MAS is a freeware application developed at Hohenheim University and can be downloaded from http://mp-mas.uni-hohenheim.de. A detailed user manual is available from the same website. MP-MAS is written in C++ programming language and is available for both UNIX and Windows operating systems. It works with a set of input files that are organized in Microsoft Excel workbooks and can be manipulated through the user interface, an MS-Excel Add-In programmed in Visual Basic. The user interface offers two modes of using MP-MAS: for interactive simulation of single agents and for full simulation of all agents in the study area. In single agent mode, MP-MAS simulates one decision problem for one agent only, for example the land use plan for one particular year without interactions with other agents. In full agent mode, MP-MAS simulates the decision-making and actions of all agents, i.e. their production, investment and consumption decisions [Schreinemachers and Berger, 2006], the agent-agent interactions and all relevant biophysical processes, typically over several years.

The philosophy of agent-based modeling has always been to replicate the complexity of human behavior with relatively simple rules of action and interaction [Parker et al., 2003]. In empirical applications to the complexity of land use changes, the question arises how simple these rules need to be. Most applications have used relatively simple heuristics to represent the economic decision-making of agents. Schreinemachers and Berger [2006] argued that farm agents in such applications might have too limited heterogeneity and adaptive capacity (decision trees are rather thin and make use of fixed input-output relationships), and henceforth preferred implementing their farm agents with goal-driven behavior based on mathematical programming (MP). The MP matrix used in this research is an extension of the matrix developed by Berger [2001]. Other agents considered are land-owners and reservoir managers; their decision rules, however, are represented with heuristics and not MP. The MP matrix and all other input files of the Chile application can be downloaded from the MP-MAS website.

The objective function of the MP is to maximize the farm agent's total expected gross-margin. The matrix includes 18 specific crops, ranging from staples, pasture, vegetables, industrial crops and perennial crops. For each crop, the model requires production parameters for items such as yield, water usage, and labor requirements; however these parameters vary considerably depending on the irrigation method used, the technology level adopted and soil type that the crop is grown on. The matrix therefore includes many production activities for each single crop, based on the machinery technology used, the soil type grown on, and the irrigation method adopted (size of matrix: 943 columns, 249 rows). Additional activities allow the agent to supplement its endowment of certain resources by hiring/investing/lending. The model also includes activities that allow the farmer to create off-farm income by selling excess labor and saving excess liquidity.

Following the land suitability classification used in Chile [Uribe et al, 2009], land resources are designated to 5 soil types with different levels of crop suitability. Irrigation water requirements are a function of crop water demands and irrigation efficiency and have been adjusted by local experts following the FAO56 crop growth model [Allen et al. 2004]. The monthly water constraints limit the sum of monthly production activity water usage to less than the farmer's expected monthly endowment. As is common in single time-frame linear programming, crop rotation limits are implemented by limiting production activities to a percentage of total available hectares as a proxy for crop rotation (e.g. corn is grown in 4 years out of 5 in rotation, thus corn limit is 80%). Other constraints considered are machinery technology levels, farm labor in various time spans, and market access.

5 Calibration and validation

Good validation in the context of collaborative research and learning centers on the research questions of stakeholders and develops confidence in the ability of the model to provide insight into these questions. This research here is about water shadow prices and productivity at the farm-level, and as such the model's land-use outputs (i.e. crop hectare production levels) under different water allocation levels are essential outputs for validation. The major land use categories analyzed are staple crops, pasture, vegetables, rice, agro-industry crops, fallow and perennial crops. These different land uses have significantly different water requirements, gross margins, and input requirements.

For the model to adequately predict crop production, farm-level allocation decisions must be adequately represented, and this requires that MP-MAS (i) uses accurate parameter values and (ii) includes the key resource constraints. The first point is addressed by obtaining parameter data directly from the national statistics office, the project's household survey and Chilean experts from the study region. The second point is addressed by direct interaction with stakeholders in the field through interactive validation sessions.

5.1 Interactive validation sessions

In addition to the project's household survey, a special farm questionnaire was developed for gaining in-depth information about farmer resource endowments, crop production schedules, irrigation methods and attitude to water trading, to be used for model validation. 10 in-depth farm interviews were conducted, chosen where possible to be representative of the greater basin population. The farm resource endowment data gathered in the in-depth survey was used as input for single-agent simulations with MP-MAS, and the model results were compared to actual farm production. In a second visit to the farmers, the disparities between simulated and observed data were discussed. Important limiting constraints that were not previously included in the model were noted and subsequently used to improve the model. In this way, the model is validated interactively, and the most important constraints are sure to be included.

Incorporating the improvements and fine-tuning the model as described above, increased the accuracy of the model to observed data. For MP model validation, we use the goodness-of-fit method and compare the major land use categories that are simulated and observed. In Figure 2, simulated land use results for the 10 validation farms are regressed on the observed land uses (here: staples, rice, vegetables, fruits, and pasture). The regression line has a coefficient close to unity and a high R^2 value, indicating a high goodness of fit.

Of particular importance for this research is the ability of the model to accurately represent farmer response to changing water allocations. To gain confidence in the model for this particular task, water sensitivity analysis of the 10 validation farms is conducted, by simulating each farm with water endowments varying from 50% to 150% of default level endowments. The results are then compared to farmer verbatim captured in the in-depth farm survey. In general, results highlight that the model successfully matches farmer response to water allocation changes.

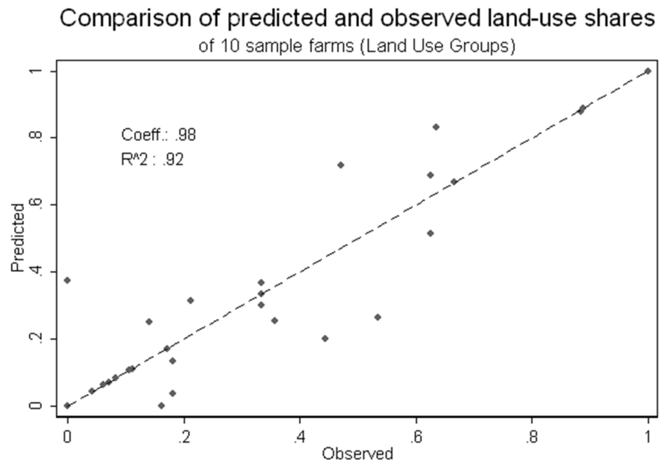

Figure 2. Model validation ("goodness of fit")

5.2 Up-scaling to the study region

Having validated the model at farm level through interactive simulation, it is then up-scaled to the study region level by means of the Monte Carlo method of Berger and Schreinemachers [2006]. The method uses statistical distributions to create farm endowments for each farm (agent) within the study region. The sample data used for this process is from the project's household survey conducted in 2005 (http://www.igm.uni-hohenheim.de/cms/index.php?id=7). More details on this method for parameterization and validation of the agent-based simulation model can be found in Berger et al. [2007] and Schreinemachers et al. [2009].

As additional input for the up-scaling, we utilized available data obtained from Geographic Information System (GIS) mapping (at a 1 Ha grid size) of the study region. Experts in Chile classified each parcel according to soil type and farm ownership, thus the basis for the population of agents is created directly from the empirical data. A total of 1,370 agents are generated, accounting for over 33,000 Hectares (~90%) of the study region. Farms that are smaller than 2 hectares are not included in the agent population. Due to lack of empirical data at the time of the interactive modeling sessions, water rights were assigned on a constant per hectare approach. This is a strong simplification as water rights per unit land vary across the study region, however as the data was not yet available, a simplifying assumption was required. It is strongly noted here, that this allocation of water rights will directly impact the resultant shadow price of the farmer. In current model versions, we employ the actual water right registries and perform extensive calibration and validation tests using census data to ensure that the MP-MAS model resembles observed values at basin level. For details on current model versions and tests, the reader is referred to the project completion report available at http://www.uni-hohenheim.de/igm.

6 Simulation results

The single agent and the full agent modes of MP-MAS were used for simulation analysis. We first present the summary of results for the single agent mode and discuss them in terms of practical relevance for stakeholders; then we present the summary of results for the full agent mode.

6.1 Single-agent simulation

As Section 3 highlighted, the Ancoa Dam Project seeks to increase irrigation security by storing surplus winter flows and using them to ensure a full satisfaction of water rights in the summer months. Farmers as well as policy makers are interested in the economic value ("shadow price") of this increased water security for farmers. We are estimating the value of fully securing one water right (i.e. 1 L/s) by comparing the total farm gross margin between the baseline and after securing one of the farmer's insecure rights (scenario "without investments"). In a second step, we run the same two scenarios allowing the farmer to adapt his asset structure by investments into machinery and perennial plantations in order to arrive at conclusions for a longer term perspective (scenario "with investments"). In a third step, additionally opportunities to invest in advanced irrigation technologies to improve on-farm irrigation efficiency are considered (scenario "advanced irrigation").

Key features of the single-agent results are:

- The shadow price of water and therefore the willingness-to-pay (WTP) for securing one water right is disparate between farms, and this is not just correlated with farm size
- In regular years, only 3 farms have increases in gross margins higher than the cost of securing one of their water rights. If one considers adaptation by investments only two farms remain.
- 4, considering investments 5, farms have a shadow price of zero, although 2 of them have no or only a minor share of insecure rights and thus cannot be affected. The availability of advanced irrigation technologies only affects two farmers in regular years. The effect is ambiguous: for one farmer the shadow price declines, while for the other one it rises.
- Contrary to what one might expect, the effect of dry year conditions on the shadow price of a secured water right is ambiguous. Although it rises for most farms, there are 2 farms where it is actually lower.

The key message from the farm-level analysis of shadow prices is clear: water shadow price levels will be higher when the farmer is not constrained by lack of other resource endowments, most importantly land and liquidity. This finding is neither new nor surprising, it does reiterate, however, the importance of other resource endowments on the shadow price of water, and the need to incorporate this effect when considering public investments to improve water allocation and farmer profitability.

6.2 Full-agent simulation

Using the same procedure as in the single agent mode, the shadow price for each agent within the study region can be assessed with MP-MAS. Figure 3 highlights the result of this analysis for water allocations varying from 100% down to 60%. Shadow prices are here expressed in Chilean Peso ($) per m^3 irrigation water.

Key features of the full-agent results are:

- At 100% water allocation, over 50% of agents have a shadow price for water less than $1 Peso/m3.
- As water allocation decreases, this percentage decreases, to about 15% at 60% water allocation.
- The distribution graphs are more skewed the higher the water allocation i.e. the level of water shadow prices is more unevenly distributed the higher the water allocation.

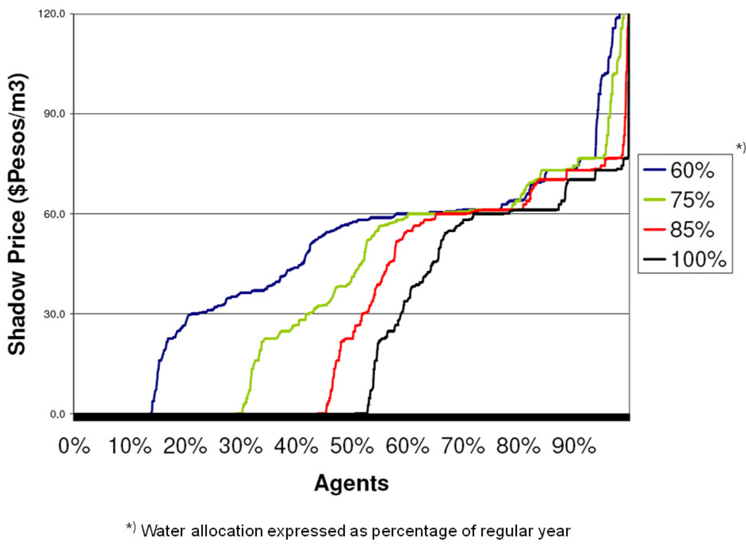

Figure 3. Distribution of water shadow prices

The comparison between the results at different water allocation levels provides insight into the benefits of the Ancoa dam. Figure 3 shows that around 40-50% of farms have a significantly higher shadow prices at 60% than at 100% water allocation, suggesting that these farms would benefit directly from increased security in water allocation that the Ancoa dam would provide. Interestingly, this result turned out to be consistent with the actual farmer response, which reached 45% approval level as of July 2007 and finally exceeded the 50% minimum approval level by a slight margin. The graphs also indicate that for water allocations closer to 100%, such as the 85% water allocation, the gap between shadow price cumulative distribution functions is significantly smaller, suggesting that farmers with already high levels of security of allocations will not benefit significantly from the Ancoa dam.

On a more general scale, the results highlight how reallocation mechanisms could improve the distribution of water. In theory, farmers with a low shadow price of water could sell their rights to a farmer with a higher willingness to pay. At higher levels of shadow price unevenness, the benefits of this type of water reallocation increase. Thus the inference is that the Ancoa dam would increase the incentive for water trading to occur. Transaction costs, physical limitations of water distribution and farmer risk aversion contribute to limiting water trading, but the results nonetheless suggest there is room for reallocation to benefit all farmers. Further investigation will investigate optimal pricing strategies for promoting allocative efficiency. A commonly cited problem with the current trading arrangements is imperfect information between farmers (Berger et al, 2007); the use of this type of analysis could assess the socio-economic implications of this type of imperfect market, and who wins and who loses.

7 Conclusions

Using agent-based land use models effectively—so that model users receive early feedback, share their system understanding and improve the outcomes of their land-use decisions [Hazell et al., 2001]—poses a number of challenges that have not been fully resolved yet. This research tested computer-based decision tools in a knowledge broker arrangement. As part of a project within the CGIAR Challenge Program for Water and Food, a multi-agent simulation model was applied for evaluating farmer water shadow prices and the overall willingness-to-pay for the construction of a new reservoir in Chile. We developed a collaborative research and learning framework, in which the computer tools were parameterized jointly with stakeholders and validated interactively.

The use of the computer-based tools, i.e. the last step of the collaborative research and learning framework, however, could not be monitored to the extent originally intended in the project proposal (funding from the CGIAR Challenge Program completed after 4 years). Although stakeholders provided extensive datasets collected at their organizations, cleaning and consolidating these datasets proved to be highly demanding in terms of time and personnel. Stakeholders received training and gained experience with the computer models during the course of the project but ready-to-use versions of the software were available only at the final training workshops. A follow-up project in Chile will attempt to monitor actual model use in terms of changes and impacts on stakeholder decision-making. Monitoring activities will cover the following model use cases: changes in (i) operation of two reservoirs in the study area and water distribution to the various irrigation sectors; (ii) investment planning of the water user organizations for building new irrigation infrastructure; (iii) implementation of irrigation subsidy programs of the National Irrigation Commission, especially regarding the selection procedure of subsidized projects.

In general, stakeholder involvement and support for this research has been strong and sustainable in Chile. Over the 4 years of the project, 3 out of 4 water user associations continued to send their technical staff to all model training sessions. This can be seen as an encouraging quality assessment, considering that water user associations in Chile are not state-run organizations, but are directed and funded by farmers who typically have a highly developed sense for opportunity costs of time and money.

ACKNOWLEDGMENTS

The financial support of the CGIAR Challenge Program on Water & Food is gratefully acknowledged. We thank the project team, in particular Diego Varas and Carlos Padilla, and the participating farmers in Chile for their inputs into this interactive modeling experiment.

REFERENCES

Allen, R.G., Pereira, L.S., Raes, D., Smith, M., Crop evapotranspiration: Guidelines for computing crop water requirements. *FAO Irrigation and Drainage Paper 56*, 2004.

Becu, N., Neef, A., Schreinemachers, P., Sangkapitux, C., Participatory computer simulation to support collective decision-making: Potential and limits of stakeholder involvement. *Land Use Policy* 25 (4), 498-509, 2008.

Berger, T., Agent-based models applied to agriculture: a simulation tool for technology diffusion, resource use changes and policy analysis. *Agricultural Economics, 25* (2/3), 245-260, 2001.

Berger, T., Birner, R., Díaz, J., McCarthy, N., Wittmer, H., Capturing the complexity of water uses and water users within a multi-agent framework. *Water Resources Management 21*, 129–148, 2007.

Berger, T., Schreinemachers, P., Creating agents and landscapes for multiagent systems from random samples. *Ecology and Society, 11(2)*, 2006. [online] http://www.ecologyandsociety.org/vol11/iss2/art19

Berger, T., Schreinemachers, P., Woelcke, J., Multi-agent simulation for development of less-favored areas. *Agricultural Systems 88*, 28-43, 2006.

D'Aquino, P., Le Page, C., Bousquet, F., Bah, A., Using self-designed role-playing games and a multi-agent system to empower a local decision-making process for land use management: The SelfCormas experiment in Senegal. *Journal of Artificial Societies and Social Simulation: 6(3)*, 2003 [online] http://jasss.soc.surrey.ac.uk/6/3/5.html

Hare, M., Letcher, R., Jakeman, A.J., Participatory modelling in natural resource management: a comparison of four case studies. *Integrated Assessment* 4(2), 62-72, 2003.

Hazell, P., Chakravorty, U., Dixon, J., Celis, R., Monitoring Systems for Managing Natural Resources: Economics, Indicators and Environmental Externalities in a Costa Rican Watershed. EPTD Discussion Paper No. 73. International Food Policy Research Institute, 2001.

Letcher, R.A., Croke, B.F.W., Jakeman, A.J., Merritt, W.S., An integrated modelling toolbox for water resources assessment and management in highland catchments: Model description. *Agricultural Systems* 89(1), 106-131, 2006.

Neef. A., Transforming rural water governance: Towards deliberative and polycentric models? *Water Alternatives 2*(1): 53-60, 2009.

Parker, D. C., Manson, S. M., Janssen, M. A., Hoffmann, M. J., Deadman, P., Multi-agent systems for the simulation of land-use and land-cover change: a review. *Annals of the Association of American Geographers 93*(2), 314-337, 2003.

Schreinemachers, P., Berger, T., Land-use decisions in developing countries and their representation in multi-agent systems. *Journal of Land Use Science 1*(1): 29-44, 2006.

Schreinemachers, P., Berger, T., Aune, J.B., Simulating soil fertility and poverty dynamics in Uganda: A bio-economic multi-agent systems approach. *Ecological Economics 64*(2), 387-401, 2007.

Schreinemachers, P., Berger, T., Sirijinda, A., Praneetvatakul, S., The diffusion of greenhouse agriculture in northern Thailand: Combining econometrics and agent-based modeling. *Canadian Journal of Agricultural Economics* (4), 513-536, 2009.

Sterk, B., Carberry, P., Leeuwis, C., van Ittersum, M.K., Howden, M., Meinke, H., van Keulen, H., Rossing, W.A.H., The interface between land use systems research and policy: Multiple arrangements and leverages. *Land Use Policy 26* (2), 434-442, 2009.

Uribe, H., T. Arnold, J. Arumí, T. Berger, Rivera, D. 2009. Modificación del modelo WaSiM-ETH para mejorar su aplicación en áreas regadas. *Ingeniería Hidraulica en México 24* (2), 23-36, 2009.

Van Paassen, A., Roetter, R.P., Van Keulen, H., Hoanh, C.T., Can computer models stimulate learning about sustainable land use? Experience with LUPAS in the humid (sub-)tropics of Asia. *Agricultural Systems 94* (3), 874-887, 2007.