Multiple Agent Modeling Applied to Agro-Ecological Development

Bonn University, Center for Development Research

Contact: Dr. Thomas Berger
Address: ZEF-Bonn, Walter-Flex-Str. 3, D-53113 Bonn, Germany
Phone: (++49) 228 73-4964
Fax: (++49) 228 73-1869
E-Mail: t.berger@uni-bonn.de

Summary:

The application of adaptive agents methods has a long history in agricultural and resource economics. Beginning in the mid 1960s, a series of empirical computer models was developed and directly applied to policy-related research questions. While the early results were highly encouraging, the further refinement of the adaptive economics approach was hampered by the very limited computation power. Equipped with inexpensive computers, object-orientated programming languages and conceptual advances in complexity theory, new efforts are now being made to revive the tradition of applied agent-based modeling in agricultural and natural resource issues. The Center for Development Research (ZEF) has gained experience with the multiple-agent modeling approach in studying technology diffusion and resource use change in the farm sector in Chile. The applicability to other areas of research and the use of multi-agent modeling for methodological integration of different disciplinary approaches and data sets is currently being tested.

Mathematical programming, i.e. the maximization of objective functions constrained by inequalities or equalities, has been used in agricultural and resource economics for almost half a century. Organizing data and processes in input and output vectors has proven to be the appropriate format for merging rather multidisciplinary information from farmers, agronomists and agricultural engineers. In combination with a properly defined objective function, mathematical programming provides a way of integrating/including human decision-making into agricultural production and resource use models.

However, if the portrayed real-world situations are characterized by spatial and behavioral heterogeneity together with economic-ecological instability, such models are often poor predictors of human behavior and might therefore fail to provide reliable information for policy analysis. Since they largely neglect the complexity of human interactions, spatial relations and feedback effects with biophysical processes, they are especially weak in analyzing the role of technological change and human organization.

A recent attempt to overcome these weaknesses was made in Berger (2001) by applying an integrated multiple-agent approach. The spatially explicit, interacting farm-household model was successfully tested in Chile and used for empirical policy analysis. Mathematical programming models for each actor represent the individual choice of a farm-household among available land and water use, consumption, investment and marketing alternatives.

Key behavioral responses and constraints of the heterogeneous farm-households are explicitly considered, as are their social and spatial interactions. These inter-household linkages include communication concerning the adoption of technical innovations, allocation of water return-flows and land/water markets. The model's economic and hydrologic components are tightly connected into a spatial grid-based framework. Each cell or pixel has several attributes associated with it: soil quality, water supply, land cover/land use, and financial returns to land. The model agents, i.e. the farm-households and non-farm owners, largely determine these attributes over time. For example, water supply depends on the amount of individual water user rights traded on markets. Land cover/land use is derived from the farm's land-use decision problem taking into account the price expectations, the technical and financial constraints.

Further testing of this model class and the incorporation of integrated ecological and economic modeling approaches is called for. ZEF's research portfolio on multiple agents modeling includes the following research activities:

Technical and structural change in agriculture
(University of Göttingen and Talca, completed in 1999)

- Study area: Melado River Catchment (Chile) of about 670 km^2 and 5,400 farm-households
- Temporal period: 19 years sectoral adjustment in agriculture (starting in 1997)
- Spatial and temporal resolution: 158 * 158 m (size of one grid cell is 2.5 ha), monthly time interval
- Types of land use and/or land cover modifications: very disaggregated land use types in agriculture and forestry (5 soil types, 3 technological levels, 160 cropping and livestock systems), investment in water-saving irrigation methods
- Specific agents: farm-household agents and non-farm land owners who engage in land and water markets and whose plots belong to different hydrological units
- Factors included for agent decision-making: agents seek to maximize expected family incomes without exhausting their land and water assets. Adoption of innovations is conceptualized as a farm investment problem under uncertainty. Several types of interactions such as contagion of information, exchange of land and water resources, return-flows of irrigation water.
- Research questions: diffusion of water-saving irrigation methods in a watershed; structural effects of a 'treadmill' innovation process in agriculture; impact assessment of government intervention.

Policies for improved land management
(jointly with IFPRI, Washington)

- Study area: 2 selected landscapes in Eastern Highlands of Uganda
- Temporal period: 15 – 20 years
- Spatial and temporal resolution: (see above)
- Types of land use and/or land cover modifications: very disaggregated land use types in agriculture and forestry, investment in soil conservation methods
- Specific agents: farm-household agents and non-farm land owners who engage in land and water markets and whose plots belong to different nutrient response units
- Factors included for agent decision making: (see above)
- Research questions: introduction of sustainable land-use practices as a farm investment decision; identification of suitable policy incentives to enhance the adoption of such practices

Interrelated water and land use changes in the context of global change (LUCC endorsed project)
• Study area: Volta River Basin (mainly Ghana and Burkina Faso), about 400,000 km^2 • Temporal period: 20 years • Spatial and temporal resolution: meteorological and hydrological modeling will take place at a very coarse and socio-economic modeling at a very fine resolution. Multiscale results will be down- and up-scaled to a basin wide 9km^2 multi-agent land use grid. • Types of land use and/or land cover modifications: aggregated and disaggregated land use types including "natural" vegetation, depending on specific research question • Factors included for agent decision making: (see above) • Research questions: human responses to policy and environmental changes

Community-based management of natural resources (Robert-Bosch-Foundation)
• Study area: selected communities in Ghana • Temporal period: several years • Spatial and temporal resolution: (still not defined) • Types of land use and/or land cover modifications: (still not defined) • Factors included for agent decision making: (see above) • Research questions: collective action and environmental externalities; dynamic evolution of property rights institutions

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Research Group at ZEF:

• Dr. Thomas Berger	t.berger@uni-bonn.de
• Dr. Stefanie Kirchhoff	st.kirchhoff@uni-bonn.de
• Dr. Soojin Park	spark@uni-bonn.de
• Johannes Woelcke	j.woelcke@uni-bonn.de

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Website featuring all these projects: http://www.zef.de/zef_englisch/f_mas.htm

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Reference: Berger, T., 2001. Agent-based Spatial Models Applied to Agriculture:
A Simulation Tool for Technology Diffusion, Resource Use Changes and Policy Analysis.
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