Multiple-Agent Modeling Applied to Agro-Ecological Development

Overview of Research Activities at ZEF - Bonn University
Agent-based Spatial Model Class

Balmann's Farm Cellular Automata
+ Behavioral heterogeneity
+ Interaction, communication
+ Integration of natural resources
+ Empirical parameterization and validation

= Agent-based spatial model class
  → Diffusion of innovations
  → Resource use changes
  → Dynamic policy analysis
Outline

1. Combination of MAS and CA
2. Empirical parameterization
3. Validation of model outcomes
4. Wrapping up
5. Multiple Agent Modeling at ZEF
Dynamic Spatial Modeling of LUC

Statements:

◆ Spatial patterns of land use change can be modeled in terms of individuals' economic decisions

◆ Data requirements can be met by applying a “common sampling frame”

◆ Ex ante impact assessment of technological alternatives and policy options provides useful insights for policy makers
Steps for Model Building

(1) Define the basic entities or agents of an agricultural region (e.g. farm-households, landscape units, hydrologic units)

(2) Establish the rules for their dynamics and interactions

(3) Set up the starting situation and calibrate the spatial MAS on micro and macro level

(4) Run the simulation model and observe "self-organizing" processes at aggregate level
Bandwagon Process

Adopter categories

Network thresholds

S-shaped diffusion curve
Adoption Decision Rule

(1) Monitor the present adoption level and compare it with the individual threshold
(2) If threshold is reached, calculate the farm's net benefits from adoption
(3) If the net benefits are positive, adopt the technology

Adding a few more assumptions allows predicting the time path of adoption for several technologies simultaneously
Spatial Data Representation

Layer 1
Human actors/Communication networks

Layer 2
Land and water markets

Layer 3
Land use/cover

Layer 4
Farmsteads

Layer 5
Ownership

Layer 6
Soil quality

Layer 7
Water flow
### Variables and Parameters

<table>
<thead>
<tr>
<th><strong>Exogenously Determined Variables</strong></th>
<th><strong>Endogenous Variables</strong></th>
<th><strong>Parameters</strong></th>
</tr>
</thead>
<tbody>
<tr>
<td>market prices for &quot;tradeables&quot;</td>
<td>prices for &quot;non-tradeables&quot;</td>
<td>input-output coefficients</td>
</tr>
<tr>
<td>interest rates</td>
<td>acreages of crops</td>
<td>depreciation rates</td>
</tr>
<tr>
<td>wages</td>
<td>yields</td>
<td>sunk costs for fixed assets</td>
</tr>
<tr>
<td>taxes and contributions</td>
<td>investment levels</td>
<td>unit transport cost</td>
</tr>
<tr>
<td>minimum consumption level</td>
<td>working capital expenditures</td>
<td>adoption constraints</td>
</tr>
<tr>
<td>supply of land</td>
<td>borrowing and saving levels</td>
<td>expectation coefficients</td>
</tr>
<tr>
<td>supply of freshwater</td>
<td>labor utilization</td>
<td></td>
</tr>
<tr>
<td>supply of innovations</td>
<td>return flows in irrigation</td>
<td></td>
</tr>
<tr>
<td>initial location of farms</td>
<td>ownership of plots/water</td>
<td></td>
</tr>
</tbody>
</table>
Estimation of Model Parameters

1. Farm-Household Survey (round 1)
2. Identification of household groups
3. Selection of representative households
4. Farm-Household Survey (round 2)
5. Estimation of parameters for LP-Matrix
6. Generation of a complete household data set (random-generated "synthetic" data)
Study Area (Chile)

study area (670 km²)
Policy-related Research Questions

(1) Can we expect substantial changes in the use of land and water as a result of water-saving irrigation methods?
(2) Will these innovations create sufficient incomes and reach the traditional farmers?
(3) Will out-migration increase or decrease?
(4) What will be the structural effects of a "treadmill" innovation process?
Model Validation

◆ "Goodness of fit" at micro and macro-level
  0.977 (standard error = 0.01, $R^2 = 0.991$)
  0.704 (standard error = 0.107, $R^2 = 0.657$)

◆ Robustness experiments and supportive statistical tests
  identical and changing starting conditions
  (average income; on-farm labor allocation)

◆ Expert opinion and "peer" review
Simulation Results: Land Use

mercruor

"baseline"

withoout
cereals
vine
fruits
vegetables
legumes
forest
greenhouses
root crops
forage plants

years [1 = 1997]
## Simulation Results: Irrigation

<table>
<thead>
<tr>
<th>&quot;ideal&quot; technical change</th>
<th>market solution</th>
<th>without technical change</th>
</tr>
</thead>
</table>

inner ring = year 1; ring in between = year 10; outer ring = year 19

Frequency of irrigation methods (% of total irrigated area)

- Traditional
- Sprinkler
- Improved furrow
- Drip
Simulation Results: Incomes

<table>
<thead>
<tr>
<th>Agricultural Incomes (absolute regional values)</th>
<th>Agricultural Incomes (relative regional values)</th>
<th>Legend</th>
</tr>
</thead>
</table>

- **y-axis**: Billions Chilean $  
- **x-axis**: years [1 = 1997]

Legend:
- "ideal" technical change
- policy intervention (with bandwagon)
- market solution (with bandwagon)
- without technical change
Simulation Results: Farm Exits

<table>
<thead>
<tr>
<th>Rate of Annual Change in Farm Number</th>
<th>Legend</th>
</tr>
</thead>
<tbody>
<tr>
<td>Commercial farms</td>
<td></td>
</tr>
<tr>
<td>Family farms</td>
<td></td>
</tr>
</tbody>
</table>

- **Type of bandwagon:**
  - "ideal" technical change: blue line
  - slow bandwagon: red line

Legend:
- "innovators"
- "early majority"
- "late majority"
- "innovators"
- "early adaptors"
- "late majority"
- "innovators"
- "early adaptors"
- "laggards"
## Simulation Results: On-Farm Labor

<table>
<thead>
<tr>
<th>On-farm labor allocation</th>
<th>Legend</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Persons employed in agriculture</strong></td>
<td><strong>Legend</strong></td>
</tr>
<tr>
<td><img src="graph.png" alt="Graph showing on-farm labor allocation over years" /></td>
<td>&quot;ideal&quot; technical change</td>
</tr>
<tr>
<td></td>
<td>market solution (with bandwagon)</td>
</tr>
<tr>
<td></td>
<td>without technical change</td>
</tr>
<tr>
<td></td>
<td>labor capacity of all farm households</td>
</tr>
</tbody>
</table>

| Years [1 = 1997] |
Conclusions

- Heterogeneous economic behavior and policy responses from the farm-households' viewpoint
- Introduction of improved land use practices and migration as a farm investment decision
- Inclusion of inter-household linkages permits modeling of "bottom-up" phenomena
- Further integration of biophysical and socioeconomic processes at multiple spatial scales is called for
ZEF’s Research Portfolio

**Project 1**
Technical and structural change in agriculture - Chile (completed in 1999)
- Diffusion of water-saving irrigation methods in a watershed
- Structural effects of a 'treadmill' innovation process in agriculture

**Project 2**
Policies for improved land management - Uganda (with IFPRI)
- Introduction of sustainable land-use practices as a farm investment decision
- Identification of suitable policy incentives to enhance the adoption of such practices

**Project 3**
Interrelated water and land use changes in the context of global change – Volta Basin (LUCC endorsed)
- Spatially explicit representation of decision-making processes
- Human responses to policy and environmental changes

**Project 4**
Community-based management of natural resources - Ghana (Robert-Bosch-Foundation)
- Collective action and environmental externalities
- Dynamic evolution of property rights institutions