An Agent Based Model of Multifunctional Agricultural Landscape Using Genetic Algorithms

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\end{itemize}

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Agricultural landscapes are potentially important producers of ecosystem services e.g., enhanced water quality, nutrient recycling, reduced sedimentation, carbon sequestration, and enhanced wildlife habitat, in addition to traditional agricultural commodities.

Multifunctionality refers to the possibility that an economic activity may have multiple outputs, both commodity and non-commodity outputs and consequently may contribute to societal welfare (OECD 2002).

Problem: Public goods
Ecosystem Services

• Changes in land use, e.g., result in changes in the flow of ecosystem services
Modeling farmers as agents

A large number of factors affect land owners willingness to change land use decisions to capture ecosystem services (Lockeretz, 1990, Napier, 1991, Kraft and Loftus, 2003)

- Personal characteristics of the farm owner
- Institutional connection
- Economic
- Financial incentives
- Legal rights.
Problem with modeling human choice

Not always maximizing/minimizing or optimizing.

Herbert Simon*: “Bounded Rationality”:
limits on knowledge and analytical ability force people
to choose the first satisfactory option.

Heterogenous individuals
Income and preferences
intelligence, experience

Thinking Spatially

- Lack of spatial information
Agents

Woolridge and Jennings, 1995:

Agent are:

- Autonomous
- Ability to sense their environment
- Ability to act upon their environment
- Rational behaviour

Could include humanistic characteristics such as beliefs, desires, intentions (Shoham, 1993) and even emotions (Maes, 1995)
Human decision making Model

- Agent model: human decision making

- Spatial (Pattern-based model): humans are located in geographic space

Interaction environments:

- Landscape (Biophysical factors, e.g. soils, crop productivity)
- Political institutions
- Social interaction
- Markets
Research Objective

1. How well the ABM predict the actual land-use

2. Analyze multiple policy scenarios using the ABM.
Cache Watershed encompasses 1,944 km² of southern Illinois near the confluence of the Mississippi and Ohio Rivers. The Watershed has diverse ecological resources and unique natural communities. At least 100 state threatened or endangered plant and animal species are known within the watershed (USFWS 1990).

**Study Area**

Endangered species: Cypress and Tupelo Swamps
The Big Creek is a tributary of the Lower Cache River with a drainage area of 33,088 acres (51.7 square miles).

Big Creek Watershed
Comprises two main creeks:
Big Creek (29 km)
Little Creek (15 km)
PROBLEMS ADDRESSED

❖ Loss and fragmentation of natural habitat.

❖ Dramatically altered hydrologic systems.

❖ Sediment deposition in the wetlands.

❖ Land use and economic activities that are incompatible with the long term maintenance of ecological function.
Data

Actual Land use cover data from USDA-IL NASS (1999-2007)
Elevation (10m x10m resolution).
Soil maps (SSURGO) (soil type, crop productivity).
Digitized fields within the Big Creek Watershed.
Market prices for various crops (1996-2007)
Labor and Machinery requirements.

Arbitrarily defined farm boundaries using Arc Info (Sengupta et al., 2000).

Number of farms: 92
Average farm size: 220 acres.
Cropland: 7,585 acres
Pasture: 12,564 acres

Soil Loss:
USLE Soil loss equation (Wischmeier and Smith 1973)
Typologies of Farmers

• Step 1: Typology of Farmers
  - Type 1 - Profit Maximizers
  - Type 2 – Satisficer
  - Type 3 - Conservationist
  -- (Kraft et al., 1989)

  Satisficer: Bounded rationality (Simon 1957)

• Step 2: Distribution of Farm Behavior
Farmer typology distribution based on productivity index (CPI) and erosion index

PM : profit maximizer
Con: conservationist

X: random assignment for satisficers and conservationist
O: random assignment for profit Max and Satisficers

Productivity Index
Erosion Index

<table>
<thead>
<tr>
<th>X</th>
<th>X</th>
<th>Con</th>
</tr>
</thead>
<tbody>
<tr>
<td>PM</td>
<td>O</td>
<td>X</td>
</tr>
<tr>
<td>PM</td>
<td>O</td>
<td>X</td>
</tr>
</tbody>
</table>
ABM Framework

Exogenous variables (Scenario parameters)
• Crop prices Policies
• Biophysical parameters

Endogenous
• Labor & machinery

Agent Based Model

Legend
- Hay, Pasture
- Corn
- Soy
- CRP

Land use Output
Flow Chart- Genetic Algorithm (GA)
Human Decision Making Model

- Create sets of Initial Alternatives (Initial Population)
- Evaluate fitness
- Choose mates (pairing)
- Create offspring (crossover)
- Mutate

Optimal Solution

Genetic Algorithm is...
... Computer algorithm
That resides on principles of genetics and evolution

Holland (1975)
Type 1 - Profit Maximizers
Maximizing Gross Margin subject to Soil Loss Constraint 2T.

Type 2 – Satisficer
Minimizing Soil loss
Constraint. Gross Margin greater than goal (satisfaction level).

Satisfaction Level – (one third and three fourth of the profit maximizing level).
Randomly assign different satisfaction level to various size farms within the watershed.

Goal: gross margin/acre (parameter that changed based on relative change in commodity prices)

Type 3 – Conservationist
Minimizing Soil Loss subject to a Gross Margin Constraint.
Gross Margin greater than 0.
A: Profit maximizer
B: Satisficer
C: Conservationist
Constraints

Labor
Large Farms: - 1.25 unit of Labor
Medium Farms and Small Farms: - 1 unit Labor

Machinery
Large Farms: Equipment size was bigger.

Crop Prices

Years (1996-2007)

Land Use Choices
Corn, Soybean, Alfalfa, Grasslands, CRP
tillage type: no-till and conservation till
Historical landuse

Reference: USDA IL- NASS
Historical landuse (2001)

Create Initial landuse Population

Selection Operator

Farm 1 population

individual n
individual 2
individual 1

Field 1 Field 2 Field 3

Crossover and Mutation

Farm 2 population

Field 1 Field 2 Field 3 Field 4

Agent I: Profit Maximizer

Obj: Maximization

MAX: Gross Margin
Subject to: Labor & Machinery
Soil loss <= 2T

Agent II: Satisficer

Obj: Min soil loss

MIN: Soil loss
Subject to: D>0; &
Labor & Machinery
where D= Gross margin - Goal

Agent III: Conservationist

Obj: Minimization

MIN: Soil loss
Subject to: Labor & Machinery
Gross margin >= 0

Landscape

Farm 1

Corn Soy Wheat CRP
field1 field2 field3 field1

Farm 2

Corn Corn Soy
field2 field3 field4
### Introducing Crop Rotation Sequence

**Various options:**

<table>
<thead>
<tr>
<th>Last Year LU Options</th>
<th>Present Lu Options</th>
<th>Rule/Cost</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. CRP</td>
<td>CRP</td>
<td>No-change</td>
</tr>
<tr>
<td>2. Soybean</td>
<td>corn, pasture, wheat</td>
<td>Reduced fertilizer cost</td>
</tr>
<tr>
<td>3. Corn</td>
<td>corn, soybean, wheat</td>
<td></td>
</tr>
<tr>
<td>4. Pasture</td>
<td>corn, soybean, wheat</td>
<td>Increase cost</td>
</tr>
<tr>
<td></td>
<td>pasture</td>
<td>Increase yield and decrease cost.</td>
</tr>
</tbody>
</table>
5. Results

Agent Model

Population 1000
Generation: 500
Cross over probability: 0.6
Mutation probability: 0.2

---- time: approximately 5 min
Results
Validation of Model
Results: Three year rotation landuse: Historical landuse 2001

Prediction: 80%
Prediction: 82%
Prediction: 73%
### Prediction Based on Agent type

<table>
<thead>
<tr>
<th></th>
<th>Agent1 Profit Maximizer</th>
<th>Agent2 Satisficer</th>
<th>Agent 3 Conservationist</th>
</tr>
</thead>
<tbody>
<tr>
<td>Correct Prediction</td>
<td>82%</td>
<td>81%</td>
<td>75%</td>
</tr>
<tr>
<td>Pasture Under_prediction</td>
<td>11%</td>
<td>12%</td>
<td>11%</td>
</tr>
<tr>
<td>Crop Under_prediction</td>
<td>7%</td>
<td>7%</td>
<td>14%</td>
</tr>
</tbody>
</table>
Results: Three year rotation landuse: Historical landuse 2003

Prediction: 75%

2004: Corn $2.76/bu; Soy $8.40/bu; Hay $87/ton; CRP 68

Prediction: 84%

2005: Corn $2.29/bu; Soy $6.27/bu; Hay $90.17/ton; CRP 68

Prediction: 87%

2006: Corn $2.61/bu; Soy $6.00/bu; Hay $95.75/ton; CRP 68

Prices

- Crops-Crops
- Pasture-Underprediction
- Crop-Underprediction
- Pasture-Pasture
## Prediction Based on Agent type

<table>
<thead>
<tr>
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<th>Agent1 Profit Maximizer</th>
<th>Agent2 Satisficer</th>
<th>Agent 3 Conservationist</th>
</tr>
</thead>
<tbody>
<tr>
<td>Correct Prediction</td>
<td>84%</td>
<td>86%</td>
<td>84%</td>
</tr>
<tr>
<td>Pasture Under_prediction</td>
<td>4%</td>
<td>6%</td>
<td>14%</td>
</tr>
<tr>
<td>Crop Under_prediction</td>
<td>13%</td>
<td>8%</td>
<td>2%</td>
</tr>
</tbody>
</table>
Justification for using three agent types:

--Multi Agent model developed here is capturing the reality better than previously developed model of profit maximizing model (GEOLP) developed by Sengupta et al., (2000).
### Scenarios

<table>
<thead>
<tr>
<th>Policy Scenario=&gt;</th>
<th>Baseline- Ethanol No Compliance w/Drought</th>
<th>Ethanol No Compliance w/o Drought</th>
<th>Ethanol Compliance + riparian protection, No drought</th>
<th>Ethanol Compliance + riparian protection + fert tax, No drought</th>
<th>Baseline w/ ESS Payments</th>
<th>Baseline w/ ESS Payments &amp; no 2002 Farm Bill Payments: DP, CC</th>
<th>Ethanol w/ ESS Payments &amp; no Drought</th>
</tr>
</thead>
<tbody>
<tr>
<td>Policy Tool</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>value / compliance (Plan to keep land at T if land leaves CRP)</td>
<td>2T</td>
<td>2T</td>
<td>2T</td>
<td>T</td>
<td>T</td>
<td>2T</td>
<td>1.5T</td>
</tr>
<tr>
<td>Price of corn</td>
<td>$2.30</td>
<td>$5.60</td>
<td>$5.60</td>
<td>$5.60</td>
<td>$5.60</td>
<td>$2.30</td>
<td>$2.30</td>
</tr>
<tr>
<td>Price of Soybeans</td>
<td>$5.60</td>
<td>$13.60</td>
<td>$13.60</td>
<td>$13.60</td>
<td>$13.60</td>
<td>$5.60</td>
<td>$5.60</td>
</tr>
<tr>
<td>Price of Hay</td>
<td>$60.00</td>
<td>$100</td>
<td>$60</td>
<td>$60</td>
<td>$60</td>
<td>$60.00</td>
<td>$60</td>
</tr>
<tr>
<td>Price &amp; Yield of Switch Grass: $/ton@x yield/acre</td>
<td>N</td>
<td>N</td>
<td>N</td>
<td>N</td>
<td>N</td>
<td>N</td>
<td>N</td>
</tr>
<tr>
<td>CRP Rental Rate--Reg $/ac</td>
<td>$68.00</td>
<td>$68</td>
<td>$68</td>
<td>$68</td>
<td>$68</td>
<td>$68.00</td>
<td>$68.00</td>
</tr>
<tr>
<td>CRP Rental Rate--Contin $/ac</td>
<td>$118</td>
<td>$118</td>
<td>$118</td>
<td>N</td>
<td>N</td>
<td>N</td>
<td>N</td>
</tr>
<tr>
<td>Tax on Fertilizer % of Fert Costs</td>
<td>N</td>
<td>N</td>
<td>N</td>
<td>N</td>
<td>N</td>
<td>200%</td>
<td>N</td>
</tr>
<tr>
<td>Level of Fert Application Rate Ib/AC: N, P, K</td>
<td>N</td>
<td>N</td>
<td>N</td>
<td>N</td>
<td>N</td>
<td>N</td>
<td>N</td>
</tr>
<tr>
<td>payment for riparian area $/ac</td>
<td>N</td>
<td>N</td>
<td>N</td>
<td>$150</td>
<td>$150</td>
<td>$150</td>
<td>$150</td>
</tr>
<tr>
<td>Carbon Payment for Seq $/T</td>
<td>N</td>
<td>N</td>
<td>N</td>
<td>N</td>
<td>N</td>
<td>N</td>
<td>N</td>
</tr>
<tr>
<td>Carbon Payment for Storage $/T/year: No. of yrs &amp; amt of payment</td>
<td>N</td>
<td>N</td>
<td>N</td>
<td>N</td>
<td>N</td>
<td>N</td>
<td>N</td>
</tr>
<tr>
<td>Tax per ton of soil loss: $/ton of Soil</td>
<td>N</td>
<td>N</td>
<td>N</td>
<td>N</td>
<td>N</td>
<td>$10</td>
<td>N</td>
</tr>
<tr>
<td>Payment for Conservation Practices--CSP Adoption Fee</td>
<td>N</td>
<td>N</td>
<td>N</td>
<td>N</td>
<td>N</td>
<td>$45</td>
<td>$45</td>
</tr>
<tr>
<td>Carbon Payment for wildlife habitat $/ac</td>
<td>N</td>
<td>N</td>
<td>N</td>
<td>N</td>
<td>N</td>
<td>N</td>
<td>$30</td>
</tr>
<tr>
<td>Ind retention in CRP--Full Period Y/N</td>
<td>Y</td>
<td>Y</td>
<td>Y</td>
<td>Y</td>
<td>Y</td>
<td>Y</td>
<td>Y</td>
</tr>
<tr>
<td>Permit Hay harvest on CRP: Y, N</td>
<td>N</td>
<td>N</td>
<td>N</td>
<td>N</td>
<td>N</td>
<td>N</td>
<td>N</td>
</tr>
<tr>
<td>Permit Switch Grass on CRP: Y, N</td>
<td>N</td>
<td>N</td>
<td>N</td>
<td>N</td>
<td>N</td>
<td>N</td>
<td>N</td>
</tr>
<tr>
<td>Government Payments</td>
<td>Direct payments Y/N</td>
<td>Y</td>
<td>Y</td>
<td>Y</td>
<td>Y</td>
<td>Y</td>
<td>Y</td>
</tr>
<tr>
<td>Countercyclical Payments Y/N</td>
<td>Y</td>
<td>Y</td>
<td>Y</td>
<td>Y</td>
<td>Y</td>
<td>Y</td>
<td>Y</td>
</tr>
</tbody>
</table>
Comparison of Scenario: Baseline versus Ethanol
## Comparison of Scenario: Baseline versus Ethanol

<table>
<thead>
<tr>
<th><strong>Land use (Acres)</strong></th>
<th>No-till Corn</th>
<th>Conservation till Corn</th>
<th>No-till Soybeans</th>
<th>Conservation till Soybeans</th>
<th>Alfalfa Hay</th>
<th>CRP</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>577</td>
<td>3,714</td>
<td>153</td>
<td>1,375</td>
<td>10,044</td>
<td>3,947</td>
</tr>
<tr>
<td></td>
<td>3,000</td>
<td>5,021</td>
<td>276</td>
<td>605</td>
<td>7,265</td>
<td>3,516</td>
</tr>
</tbody>
</table>

### Economic Profit

<table>
<thead>
<tr>
<th></th>
<th><strong>Average gross margin ($)</strong></th>
<th><strong>Average gross margin/acre</strong></th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Average gross margin ($)</strong></td>
<td>24,233</td>
<td>65,553</td>
</tr>
<tr>
<td><strong>Average gross margin/acre</strong></td>
<td>117</td>
<td>314</td>
</tr>
</tbody>
</table>

### Ecosystem Services

<table>
<thead>
<tr>
<th></th>
<th><strong>Average soil loss (tons)</strong></th>
<th><strong>Average carbon sequestration (tons)</strong></th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Average soil loss (tons)</strong></td>
<td>782</td>
<td>892</td>
</tr>
<tr>
<td><strong>Average carbon sequestration (tons)</strong></td>
<td>60</td>
<td>39</td>
</tr>
</tbody>
</table>

### Agent Type

#### Profit maximizer

<table>
<thead>
<tr>
<th></th>
<th><strong>Average Gross Margin ($)</strong></th>
<th><strong>Average Soil Loss (tons)</strong></th>
<th><strong>Average carbon sequestration (tons)</strong></th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Average Gross Margin ($)</strong></td>
<td>33,202</td>
<td>1,592</td>
<td>37</td>
</tr>
<tr>
<td><strong>Average Soil Loss (tons)</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Average carbon sequestration (tons)</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

#### Satisficer

<table>
<thead>
<tr>
<th></th>
<th><strong>Average Gross Margin ($)</strong></th>
<th><strong>Average Soil Loss (tons)</strong></th>
<th><strong>Average carbon sequestration (tons)</strong></th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Average Gross Margin ($)</strong></td>
<td>19,479</td>
<td>175</td>
<td>85</td>
</tr>
<tr>
<td><strong>Average Soil Loss (tons)</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Average carbon sequestration (tons)</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

#### Conservationist

<table>
<thead>
<tr>
<th></th>
<th><strong>Average Gross Margin ($)</strong></th>
<th><strong>Average Soil Loss (tons)</strong></th>
<th><strong>Average carbon sequestration (tons)</strong></th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Average Gross Margin ($)</strong></td>
<td>15,152</td>
<td>142</td>
<td>72</td>
</tr>
<tr>
<td><strong>Average Soil Loss (tons)</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Average carbon sequestration (tons)</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
6. Conclusions

- The agent model developed here will help policy and decision-makers identify the various agents within the watershed and assess various policy options by predicting future land use decisions and production of commodities and ecosystem services resulting from varying market conditions and policies in a multifunctional landscape.

- The utilization of genetic algorithms in modeling human behaviors provides clear advantages of flexibility over traditional optimization methods and outperformed previous linear programming analysis using a single profit-maximizing agent.
Questions

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email: soman.sethuram@dsu.nodak.edu