Sensitivity Analysis in Agent-Based Models of Socio-Ecological Systems: An Example in Agricultural Land Conservation for Lake Water Quality Improvement

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Arika Ligmann-Zielinska, Daniel Boyd Kramer, Kendra Spence Cheruvelil, Patricia A. Soranno
Michigan State University, East Lansing, Michigan

Synopsis

- We employ sensitivity analysis (SA) to investigate the behavior of an agent-based model of agricultural land conservation.
- We use SA to estimate uncertainty, simplify the model, and reduce output variance.
- We demonstrate that models of complex socio-ecological systems are prone to interactions among inputs that need to be explicitly investigated to illuminate the dynamics of the studied system.

Research Problem

This project evaluates the ecological impact of land conservation programs intended to improve lake water quality. We focus on voluntary government-sponsored land retirement under the Conservation Reserve Program (CRP) in southwest Michigan.

We employ agent-based models (ABMs) to study the interactions between the extent of CRP enrollment and the reduction in nutrient loading to lakes under different human decision making scenarios in spatially complex lakesheds. Because ABMs typically have many parameters, **it is challenging to identify which parameters contribute to the emerging macro-scale patterns.**

Methodology

Our ABM is composed of *farmer agents* who make decisions related to participation in CRP. We also include the *Farm Service Agency (FSA) agent*, who selects enrollment offers made by farmers and announces the signup results leading to land use change. The model is executed using Monte Carlo (MC) simulation to generate a distribution of maps of fallow lands that are used for calculating nutrient loading to lakes.

Our simulations include three computational experiments. First, we run MC using the full parameter set (FPS). Second, using the results of the baseline scenario: (a) we simplify the ABM by reducing FPS to influential inputs only, and (b) we fix the value of the most influential input, leaving the rest of FPS unchanged.

Acknowledgements

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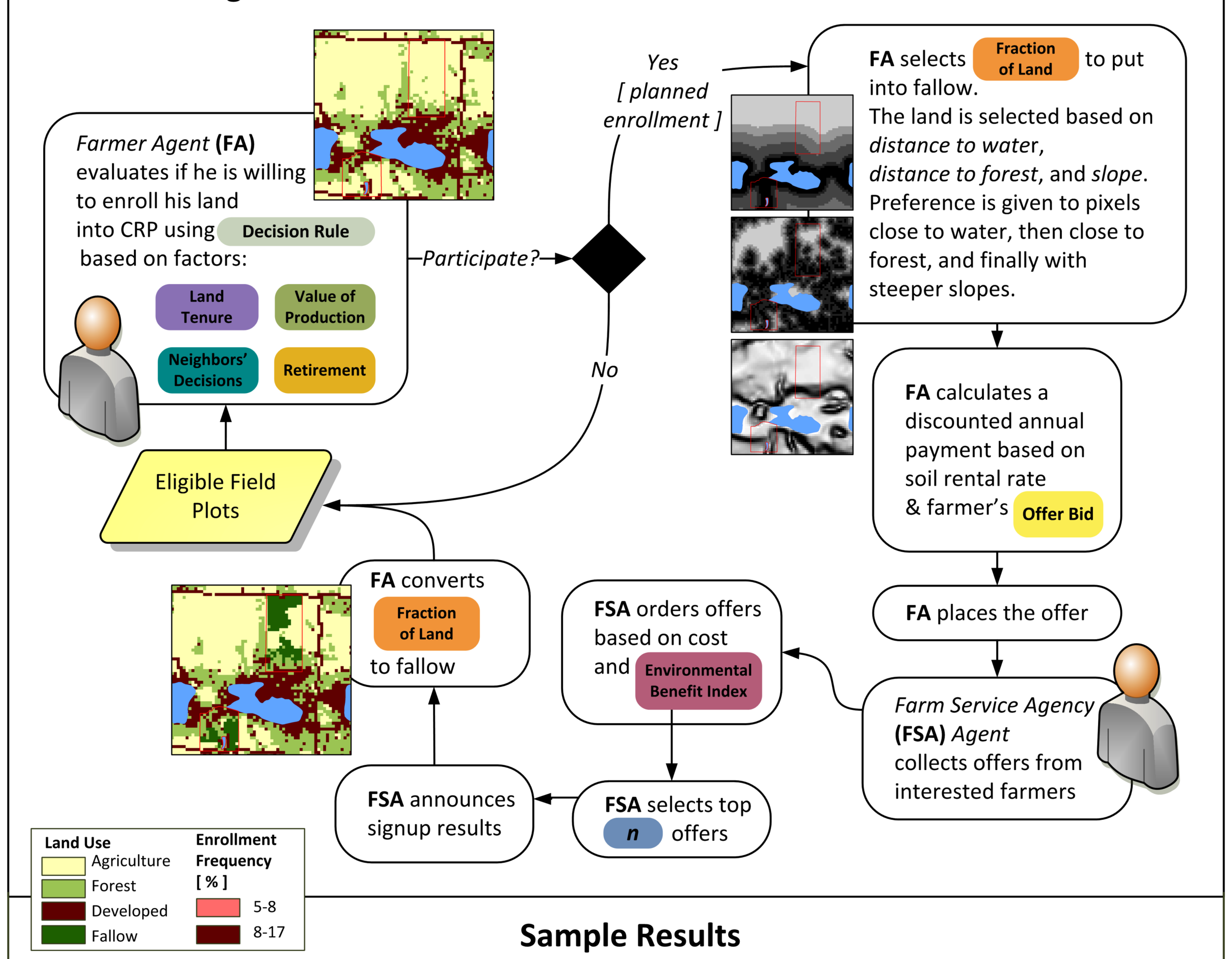
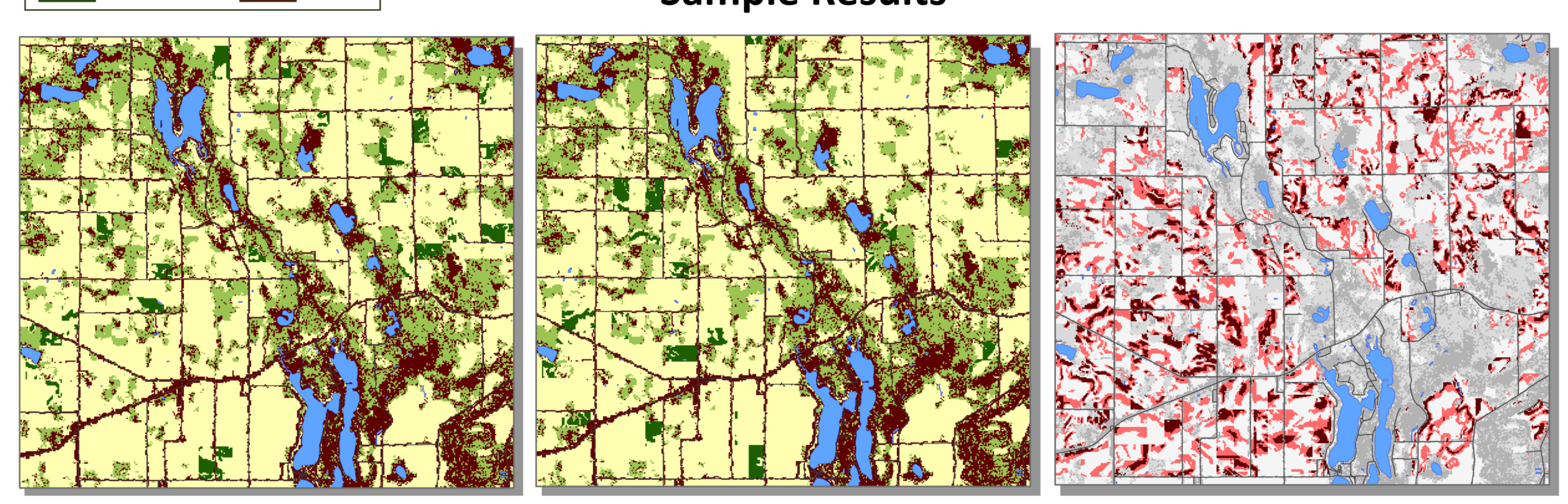
Agent-Based Simulations of Land Conservation Enrollment



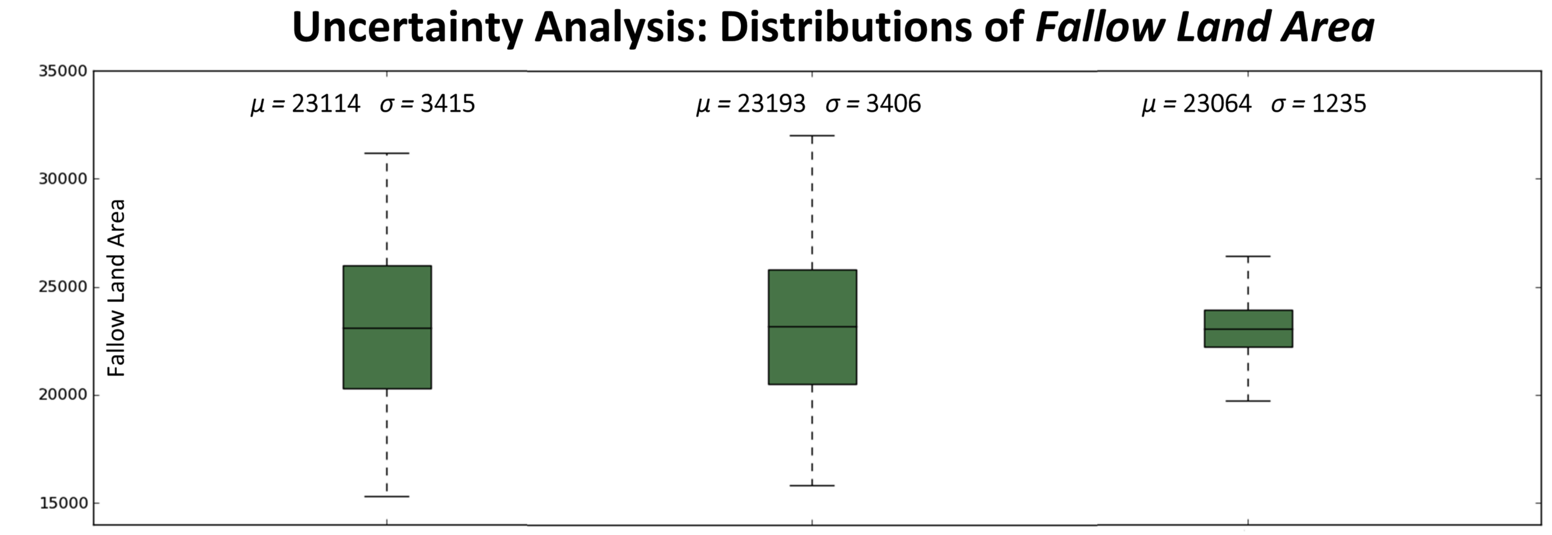
Sample Results



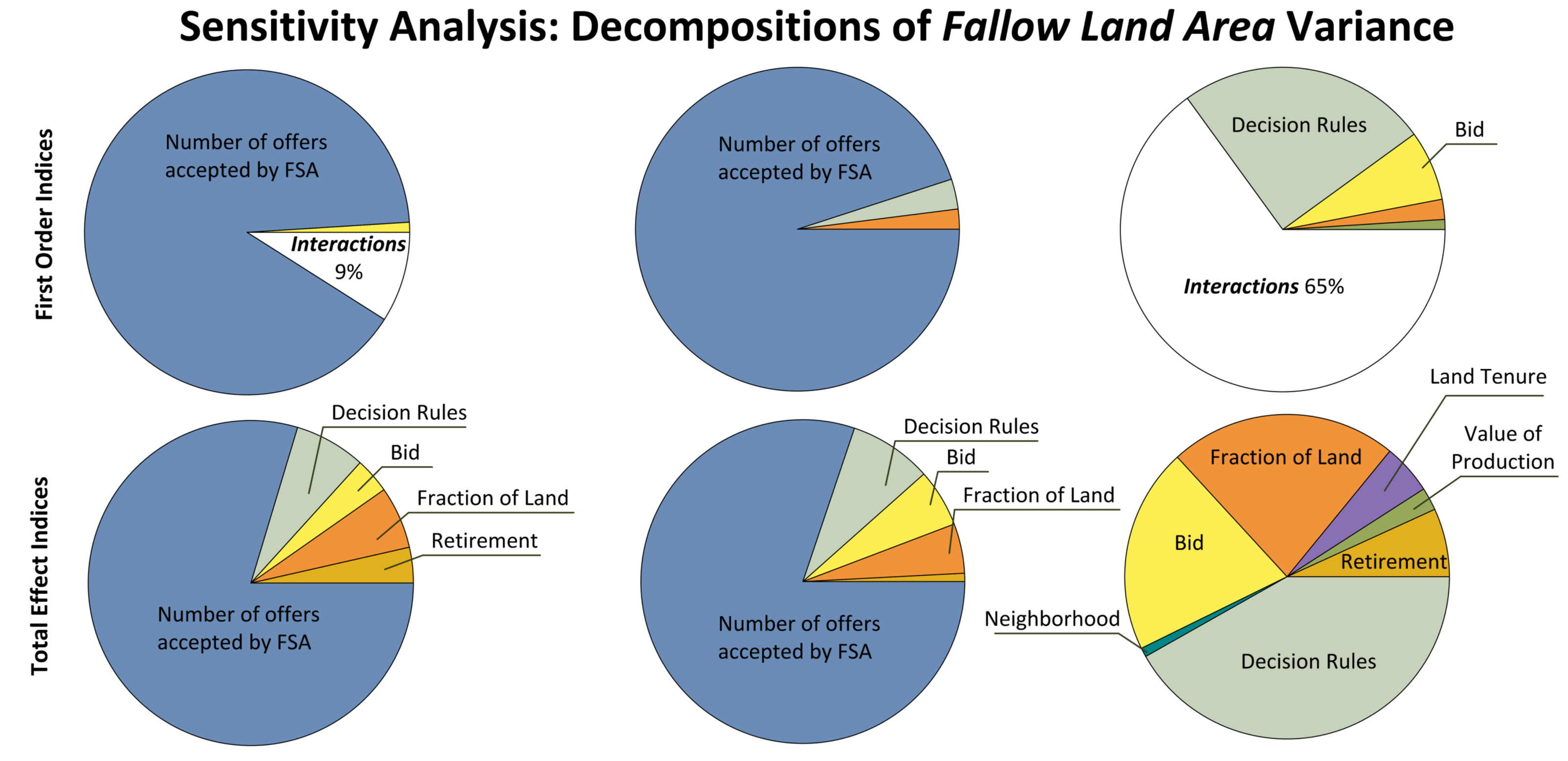
Maps of Land Use Change

Map of Enrollment Frequency

Uncertainty Analysis: Distributions of *Fallow Land Area*



Sensitivity Analysis: Decompositions of *Fallow Land Area* Variance



Variance Decomposition

We utilize output variance decomposition, in which the variability of land use change is broken down and apportioned to changes in model inputs that are represented singly and in combinations with an increasing level of dimensionality.

We calculate **first order sensitivity indices** to measure the relative contribution of ABM parameters to output uncertainty. To account for parameter interactions, common in complex systems models, we also compute **total effect sensitivity indices**.

Results

We observe that farmland conservation is first and foremost driven by the FSA signup choices. Farmer decision rules (functional relationships) and decision criteria play a secondary role in *farmland-to-fallow-land* conversion. Farmer decision making is mainly influenced by the perception of risk (embedded in the decision rules) and the willingness to reduce the potential annual payments.

Our uncertainty and sensitivity analysis demonstrate the efficacy of variance decomposition in modeling socio-ecological systems:

1. Experiments one and two show how to perform model simplification without compromising its **exploratory power** embedded in outcome variability.
2. Experiments one and three show that, by estimating and fixing the value of the most influential parameter, we can increase ABM **explanatory power** by reducing the total output variance.

We also show how to isolate the effects of the interconnected explanatory variables on the simulated emergent phenomena. The results indicate that some of the parameters exert influence on model outcomes only if analyzed in combination with other parameters (e.g. the decision rules in experiment one).

Contact

Arika Ligmann-Zielinska
ligmannz@msu.edu
Department of Geography
673 Auditorium Rd, Room 121
Michigan State University
East Lansing, MI 48824
Phone: 517-432-4749

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