Agent-based modeling of rural and urban land systems

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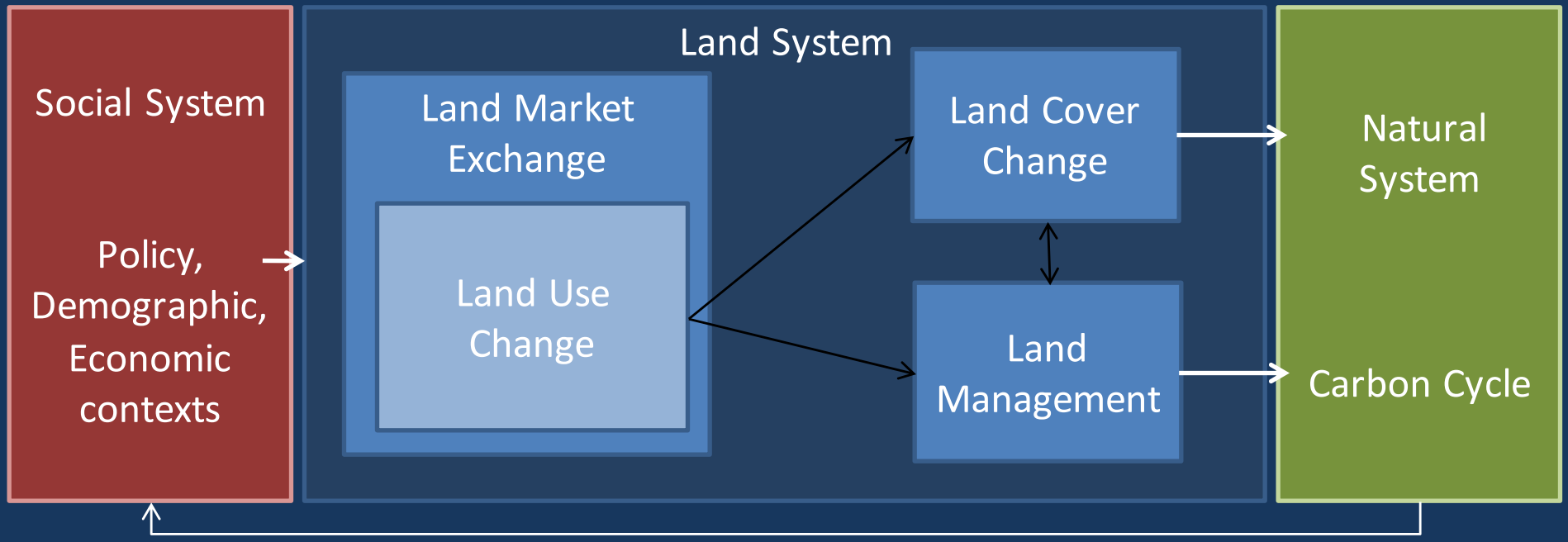
Three points

- Dynamic human-environment modeling at the landscape scale helps us identify how complex dynamics can produce sensitive and non-linear social and environmental outcomes.
- Endogenous institutions complexify dynamics.
- More work is needed to evaluate the value of models developed at multiple scales for representing landscape-scale processes in global models.

Agent-Based and Earth System Models for Exurban Settlement



Scenarios

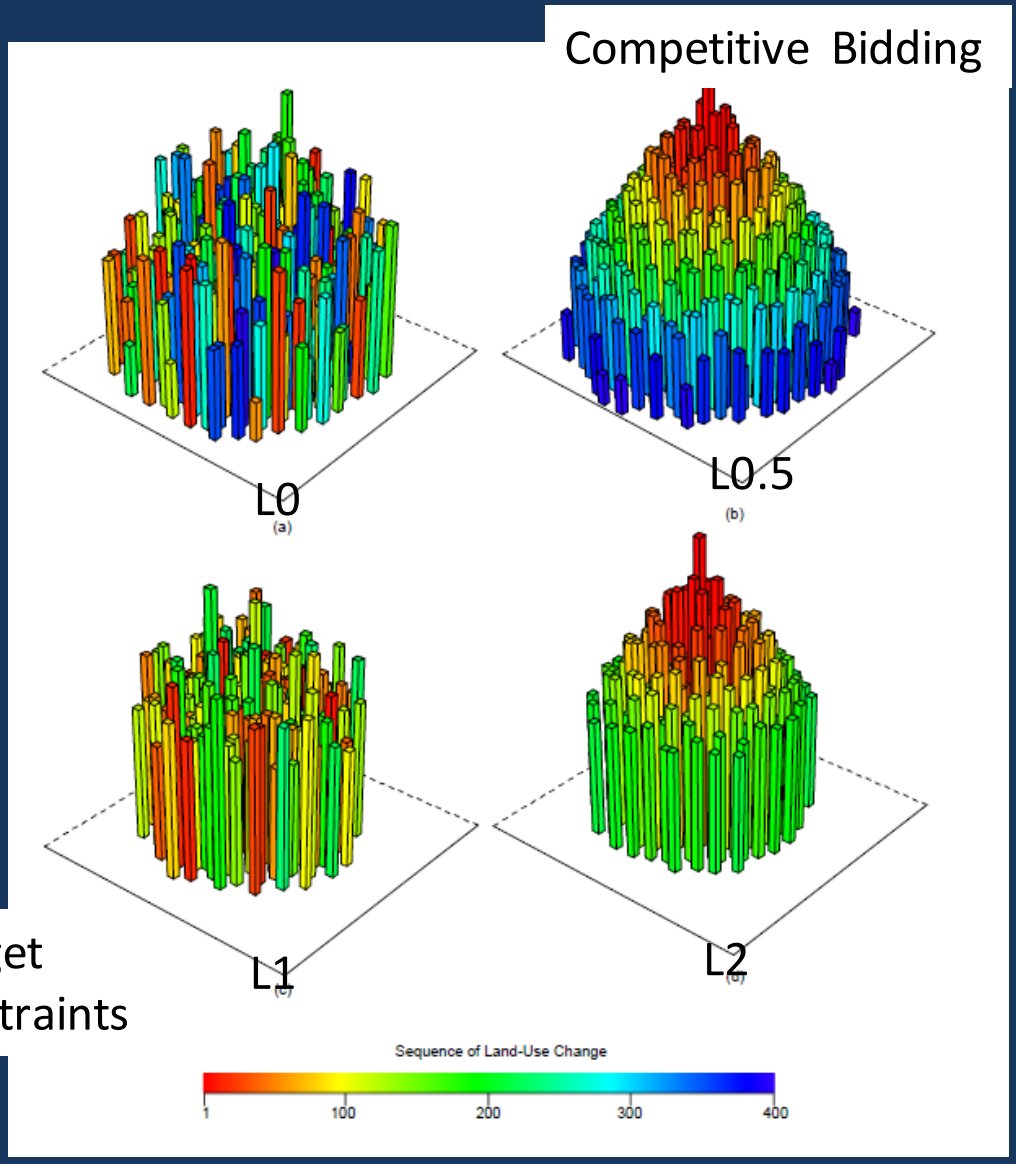
Agent-Based Model

Biome-BGC

Key Land-Change Processes Affecting Carbon Storage in Exurbia

- Land markets
  - Drive land-use change through relative land values; credit availability; institutional structures; competition
- Developer choices
  - Affect vegetation patterns through choices about lot size, vegetation removal and planting.
- Land management
  - Affect vegetation and carbon through choices about managed area, specific actions (e.g., irrigation, litter removal, fertilization).

Land market processes affect development patterns



Homebuyer budget constraints reduce the projected quantity of development.

Competitive bidding disadvantages agents with more strict budget constraints.

If market elements are excluded from a LUC model, one may over-project the extent of LUC and the degree of sprawl

Sun et al. 2014. *Annals of AAG*, 104(3): 460-484

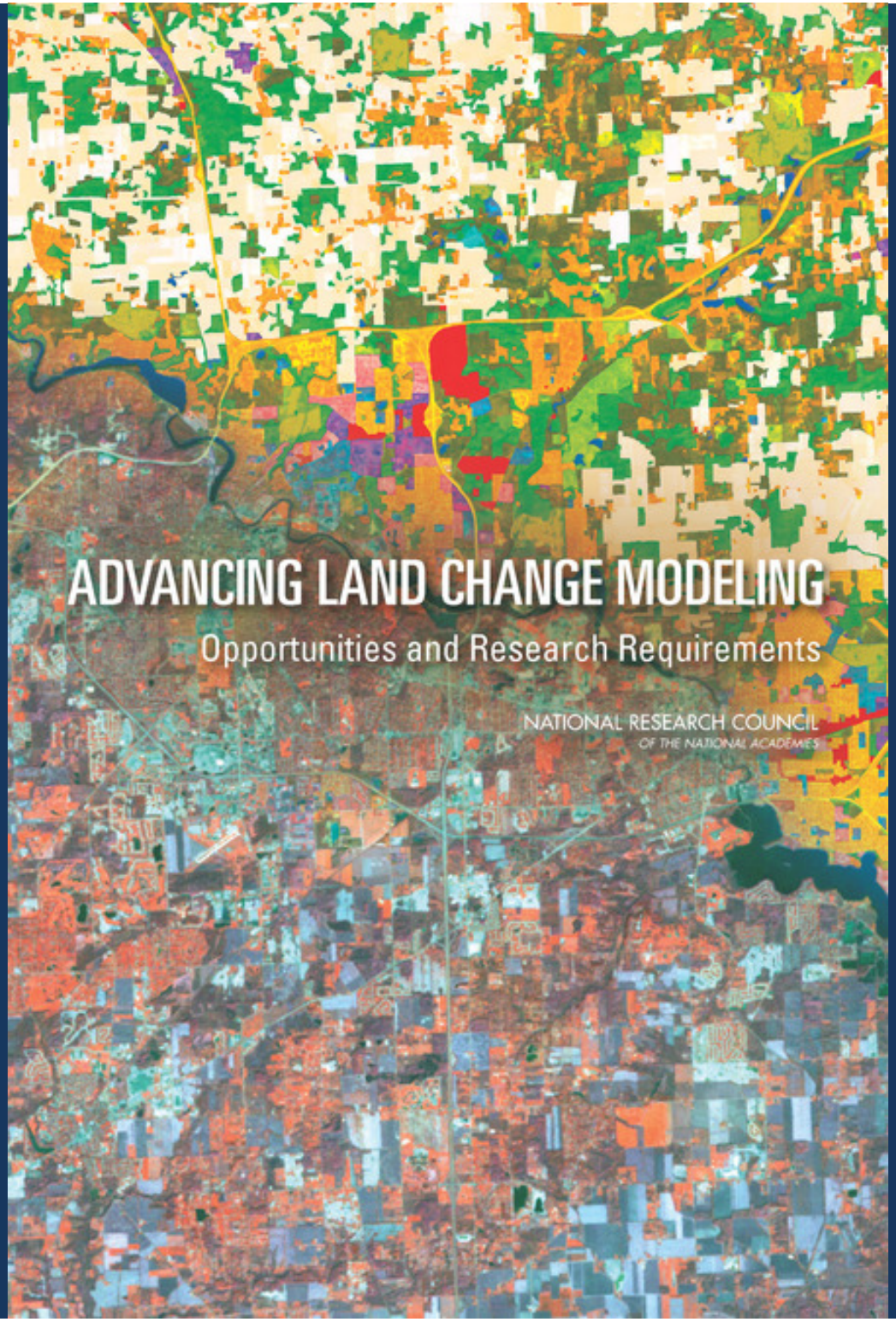
Height is land value; color is timing of development

By representing market interactions…

- we can evaluate the effects of heterogeneous incomes on development patterns;
- we include the actions of developers, a key actor in shaping landscapes. We do that by classifying and representing development types;
- Incorporate market interventions on outcomes related to development and carbon storage.

Land Management Choices

- Once residents choose a lot, they engage in management activities that can affect carbon storage.
- Includes both choices about land cover (e.g., trees) and management, including
  - Frequency of mowing, pruning
  - Fate of leaves (removal, mulch, piles)
  - Irrigation and fertilizer
- Choice of these is related to neighbors, lot size, preference.
  - Supported by survey and RS data and interviews (Nassauer et al. 2009; 2014, *Landscape & Urban Plan*; Robinson 2011, *Urban Ecosys*)



Committee Membership

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Eric Lambin, Stanford and Louvain
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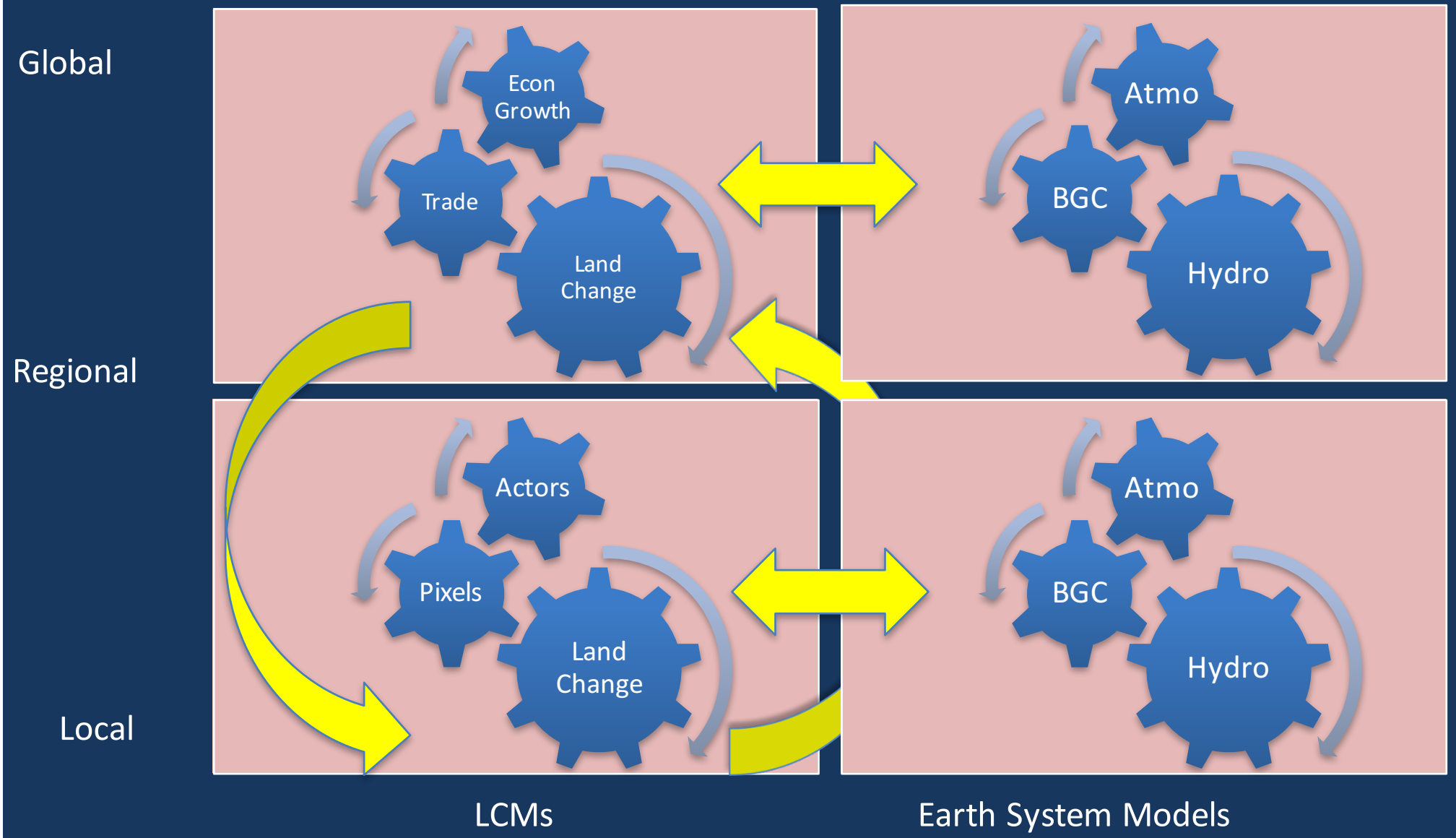
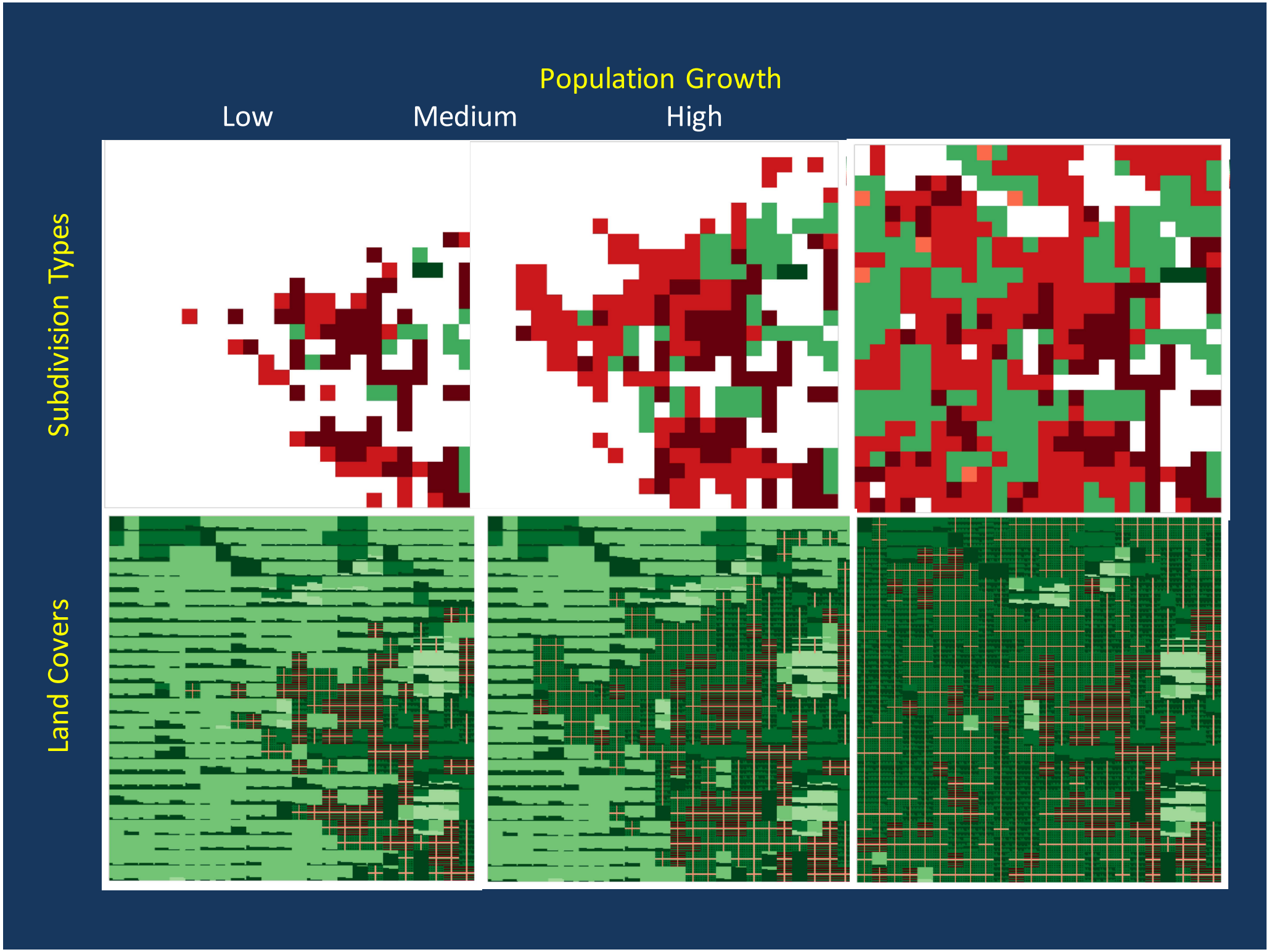
Opportunities to Integrate Process Models



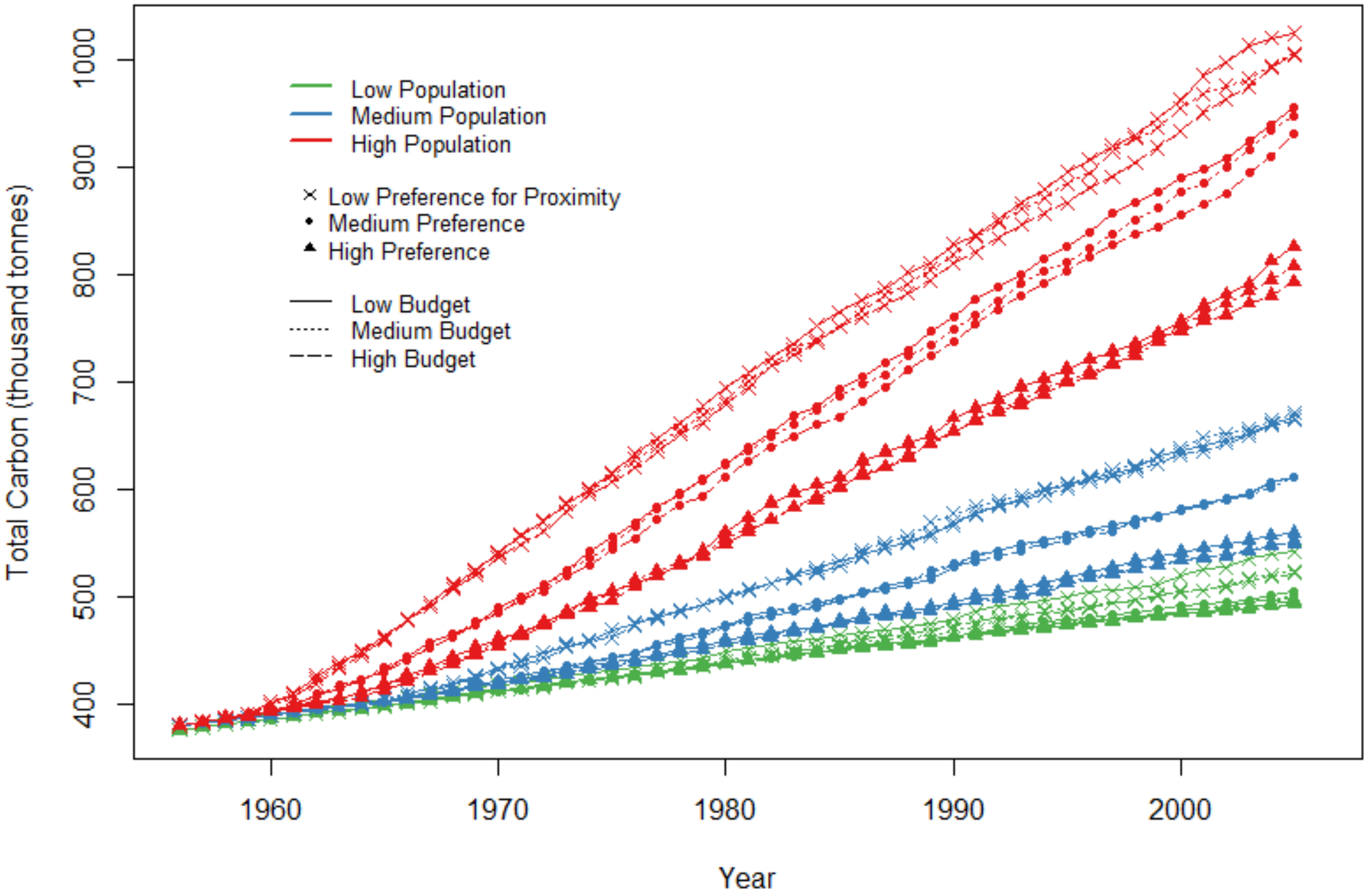
Coupling our ABM with BIOME-BGC

- Agents make decisions about landscape composition and management
- Agent decisions affect input files to BIOME-BGC (restart file and meteorology file)
- BIOME-BGC runs to increment biogeochemical processes and reports carbon sequestration and storage
- Currently only represents grass and trees. Current dissertation project to represent two layered canopy (Kiger)

Robinson et al. 2013. *Environmental Modelling and Software*, 45


Population Growth
Low
Medium
High
Subdivision Types
Land Covers

Exploring mechanisms



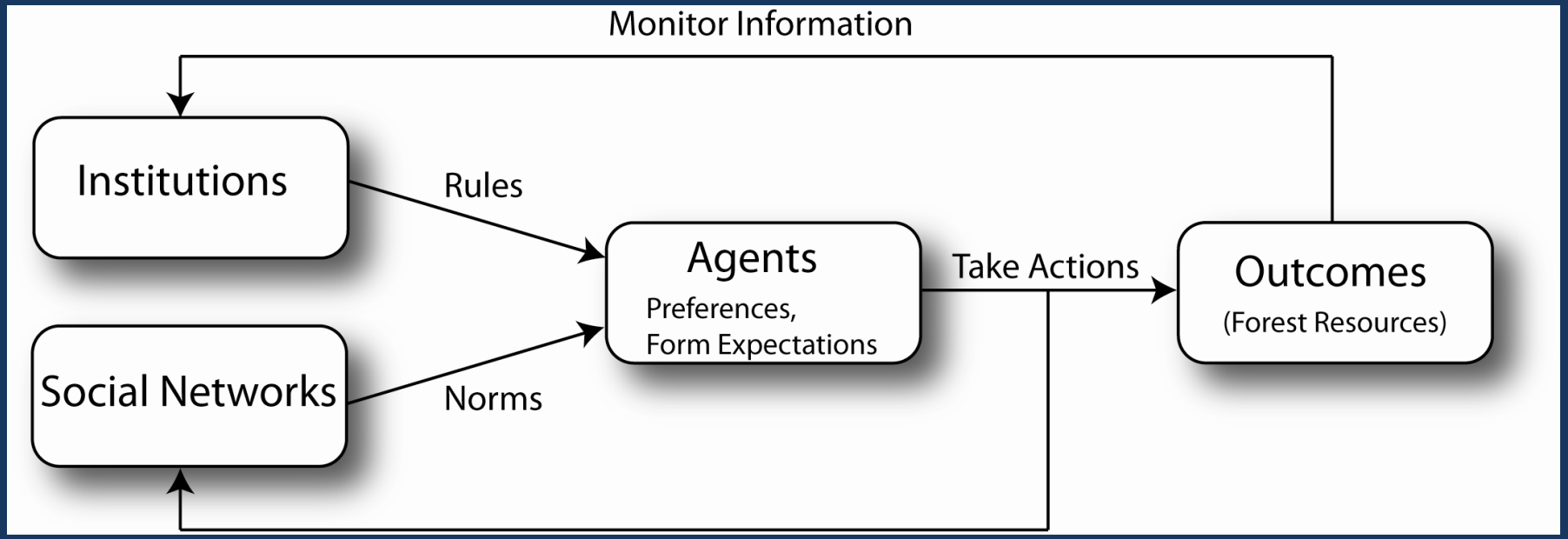
Endogenous Institutions in ABMs

Process: *formal institutions* (like rules about resource use) interact with *informal institutions* (like norms formed within social networks).

We used simulation experiments to explore what effects these interactions have on outcomes in common-pool resources?

Agrawal et al. 2013. *Environmental Science and Policy*, 25: 138-146.

Simple Model



Agents decide how much of the resource to use based on:

a. preference for following rules or their neighbors
b. the payoff from consumption
c. a payoff from not working too hard to consume (i.e., leisure)

Model parameters calibrated with data from forest users in Himachal Pradesh India

Computational Experiments

Evaluate how resource outcomes in the model varied with

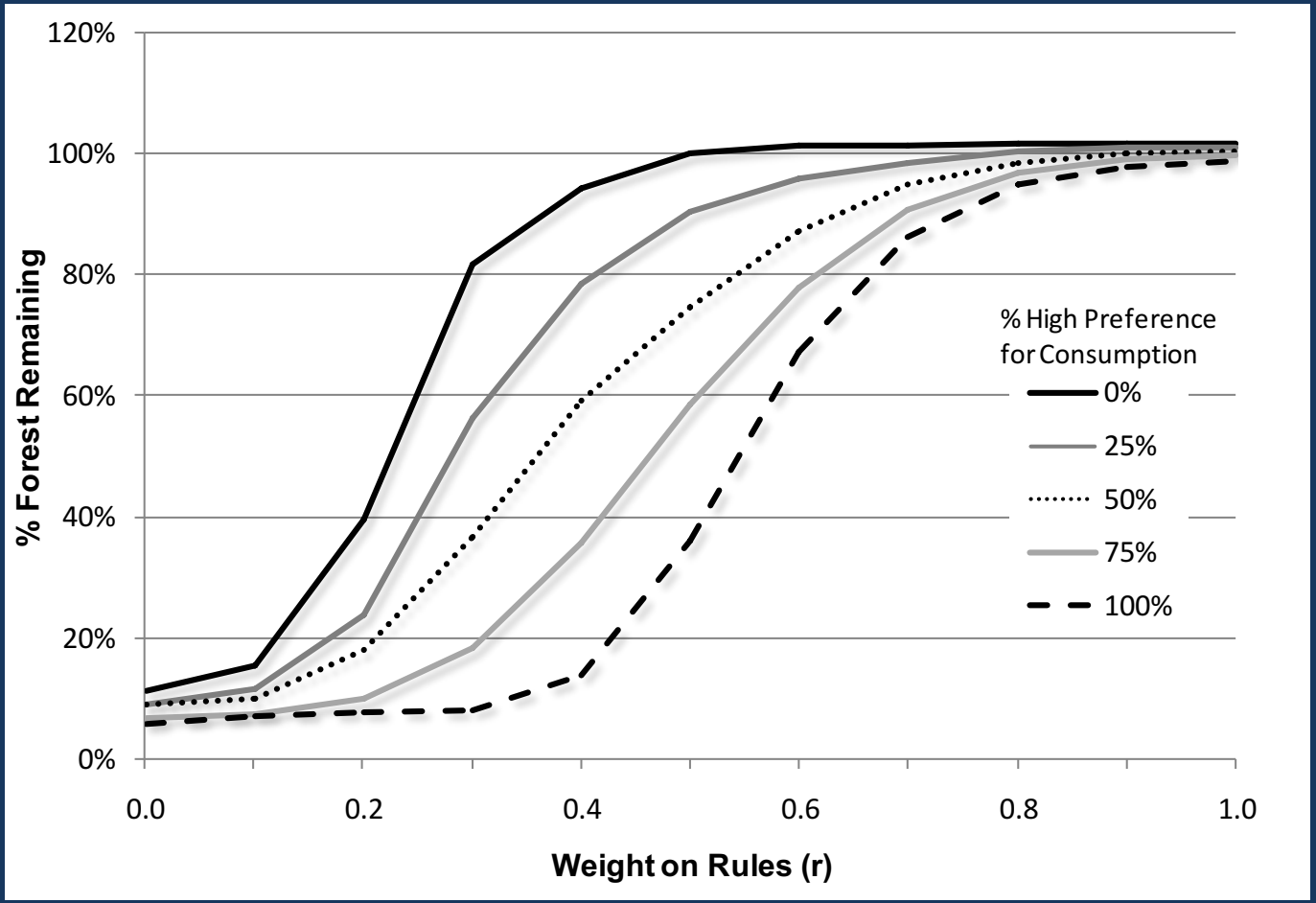
1. Differences in importance to agents of rules versus norms
2. Proportion of agents with high preference for consumption
3. *Structure of the social network*

Results

- Experiment 1: Increases in the importance to agents of following the rules had non-linear effect on resource use
- Experiment 2: Increasing proportion of greedy agents (high preference for consumption) required higher level of preference for rule adherence to achieve same level of resource remaining.

Results

Experiments 1 & 2



Lessons from Institutional Model

- We learn that land- and resource-use outcomes in common-property resources are affected by:
  - Interactions between formal and informal institutions in affecting behavior
  - Diversity in preferences of agents
  - Structure of interactions
  - Feedbacks between outcomes and agent behavior (e.g., imitation)

Opportunities to Bridge Scales

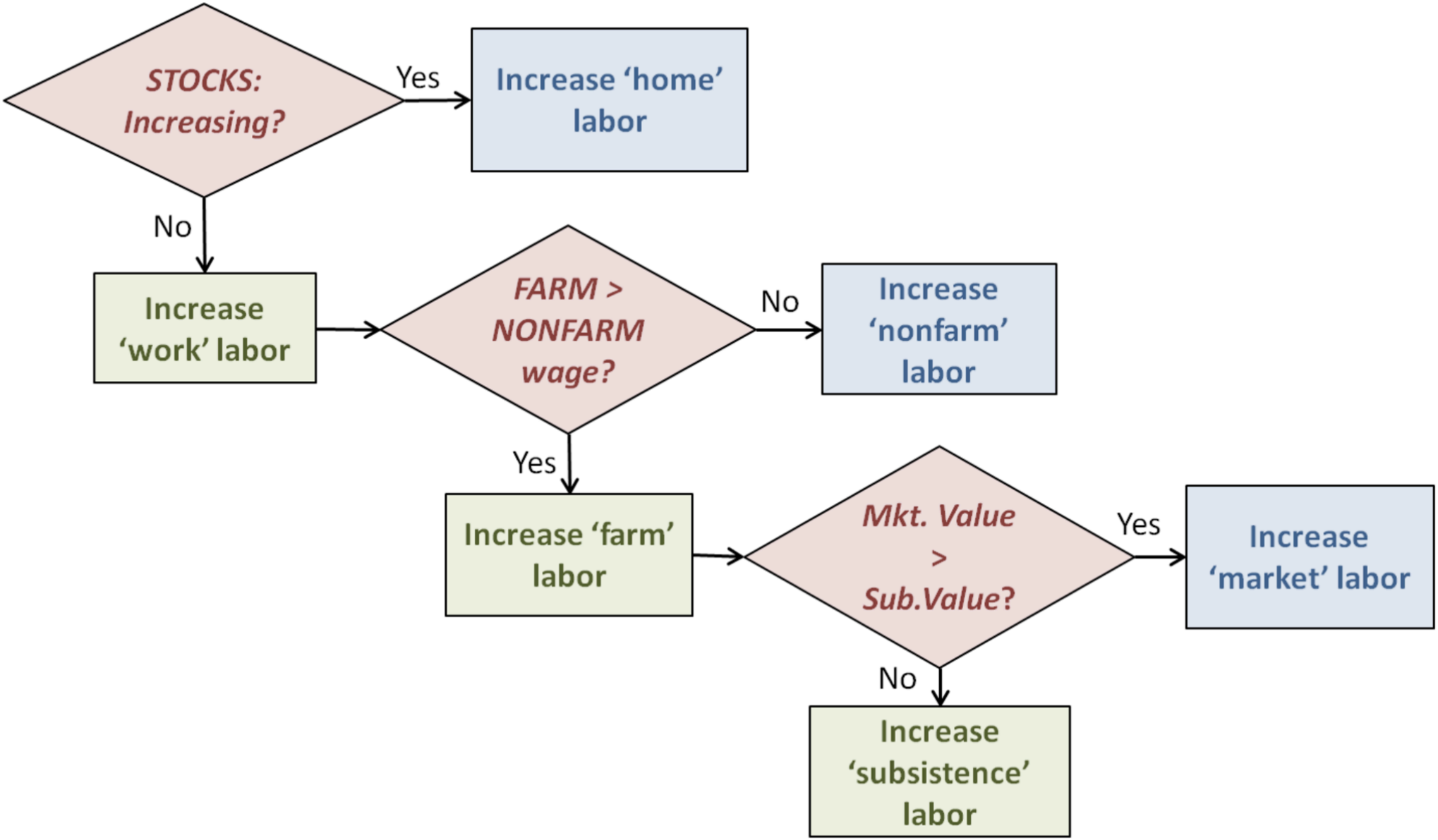
- Integrated assessment and other global and regional models can link our understanding of land system dynamics with global change, globalization, and tele-coupling.
  - Limited by aggregate nature of models
- ABMs provide opportunities to represent
  - Agent heterogeneity and interactions
  - Learning and adaptation
  - The role of institutions and governance
  - Cross-scale feedbacks
  - Limited by lack of generalizable models and computational and data challenges in scaling.

Rounsevell et al. 2014. *Earth System Dynamics*

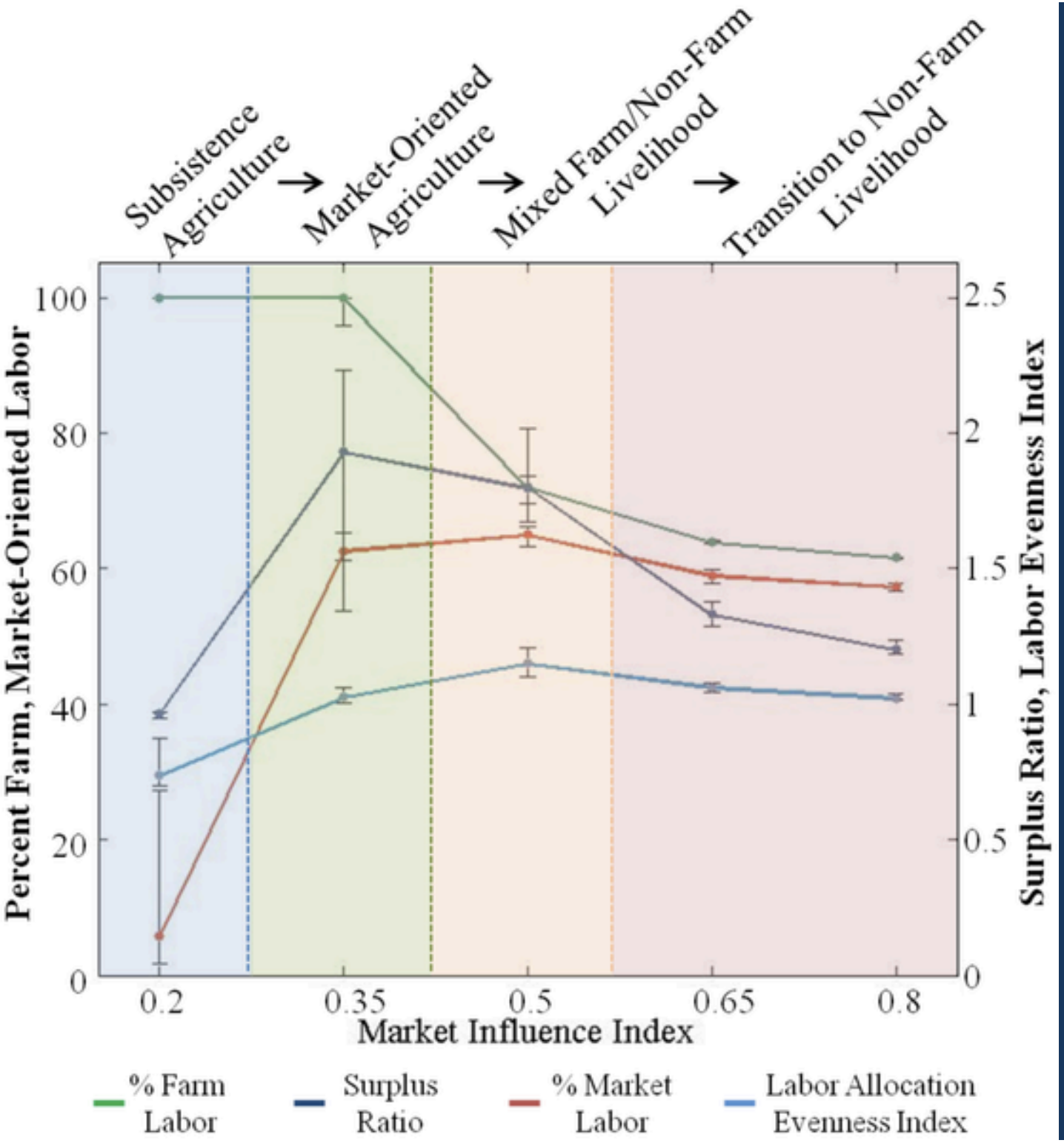
Paths Forward

- Increasing resolution of global models
  - IAMs have gone from 10s to 100s of regions globally
  - Still not capturing agent heterogeneity and interaction
- Scaling up local process models
  - Means going from $10^{3\text{-}4}$ agents to $10^{8\text{-}9}$ agents
  - Computation and model parameterization challenges

Generalized Agent Land-Use Processes



Magliocca et al. 2013. *PLOSOne*, 8(9)


Subsistence Agriculture
Market-Oriented Agriculture
Mixed Farm/Non-Farm Livelihood
Transition to Non-Farm Livelihood
Percent Farm, Market-Oriented Labor
Surplus Ratio, Labor Evenness Index
0
20
40
60
80
100
0
0.5
1
1.5
2
2.5
0.2
0.35
0.5
0.65
0.8
Market Influence Index
% Farm Labor
Surplus Ratio
% Market Labor
Labor Allocation Evenness Index

Paths Forward (cont.)

- Nesting models
  - Involves managed integration of global models that represent inter-regional flows, regional models that represent differences in governance and market location, and local models that represent local decision making.
  - Presumes that local models (and therefore local processes) are will produce different results than models using representative agents for entire regions and sectors.
    - We need to evaluate this

Nesting Options

- Sampling
  - Regionalization of global models provides structure within which runs of regional and local models are sampled.
  - Regional dynamics are derived from aggregation of sampled local landscapes.
- Responsive Simulation
  - Analyze regional conditions under which results from local models diverge from those of aggregate global models.
  - Use sampling approach to run local models only under conditions in which global models are unlikely to produce accurate dynamics.

Three Points

- Dynamic human-environment modeling at the landscape scale helps us identify how complex dynamics can produce sensitive and non-linear social and environmental outcomes.
- Endogenous institutions complexify dynamics.
- Nesting models developed at multiple scales may be a reasonable approach to integrating landscape-scale processes with global models.