Capturing Human/Environment Feedback Processes in an Agent-based Model

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1. Introduction

In this paper we present *work-in-progress* on the investigation of complex human-environment interaction using an agent-based modeling approach. We are specifically interested in how public opinion evolves (or fails to evolve) in support of sustainable land management practices in response to changes in environmental quality. The study is motivated by land use dynamics in the U.S. Rocky Mountains north of Yellowstone National Park. This work is part of an interdisciplinary project that includes experts in geographic information science, resource economics, political ecology, social networks, physical geography, and public policy. From the perspective of geographic information science, we seek to better represent and model the complex set of feedbacks that drive human-environment interactions in general and land use/land cover change (Brown et al. 2005), in particular. Particular emphasis is placed on the representation of consensus building and collaboration, agent-based learning, and agent-agent and agent-environment interaction.

2. Objective

The objective of the work presented here is to extend an existing agent-based modeling framework (see Bennett et al. in review; cf. Bennett and Tang 2006; Tang 2008) of environmental decision-making and land use change to represent connections among social dynamics, public opinion, local politics, and environmental outcomes. Feedback is viewed as crucial to land use dynamics: 1) stakeholder satisfaction is determined by how well the built and natural environment meets individual needs; 2) dissatisfaction and stakeholder interaction changes individual and community-level opinions and behaviors; 3) changes in behavior produce changes in the built and natural environment (e.g., perceived environmental quality improves).

This ABM framework will be used to explore alternative hypotheses about how humans adapt to changing social, political, and environmental conditions. Hypotheses being explored include:

- Incremental socio-demographic change leads to incremental and appropriate changes in public policy (i.e., self-regulate produces what people want)
- Asymmetric relationships in power and influence lead to episodic change (e.g., tipping points are produced).
- Human perception and behavior can restrict opportunities for change to narrow temporal windows.
- Heterogeneity of opinion and high migration rates inhibit the formation of consensus.

3. Study Site and Empirical Data

The study area includes three counties in southwest Montana, USA (Park, Madison, and Beaverhead). Historically large family-owned ranches dominated the region's social, political and economic activity. Culturally, these individuals tended to be conservative, independent, wary of governmental control, and protective of private property rights. Over the past two decades, however, the region has experience significant growth as so-called "amenity buyers" drove land use change and development. The cumulative effect of changing land use is to degrade the very amenities that people came to the region to enjoy. The aim of the larger research effort is to understand the social and political conditions that lead to more sustainable land use practices, and which accelerate current trends toward a fundamentally different regional character. A survey was conducted to better understand what area residents valued in their county, what they thought important to future prosperity, and whether public regulation is an appropriate tool for producing desirable outcomes. Differences in attitudes about growth and regulation were, in part, related to the length and intensity of development pressure (Table 1). Survey respondents were clustered into four classes based on the degree to which the supported regional population growth and the use of land use regulation to control development.

Table 1. Residents in the study area were surveyed to better understand attitudes on growth and land-use regulation.

County	For regulation	Against regulation
Beaverhead	19%	81%
Madison	27%	73%
Park	36%	64%

County	For growth	Against growth
Beaverhead	49%	51%
Madison	33%	67%
Park	37%	63%

4. Model Design

We developed an ABM framework to support our investigation (Figure 1). Agent satisfaction is based on the level and rate of change in natural and cultural amenities produced within the region (*satisfaction module*). The preference weights for alterative amenities were calibrated using the survey results. As the region becomes more developed, natural amenities decline and cultural amenities increase (*amenity module*). An agent's opinion about the role of land use regulation in controlling growth may change through interaction with other agents. The magnitude of this change is a function of individual characteristics (e.g., willingness to listen to the opinions of others) and the individual's *satisfaction* with the current state. More formally, change in opinion is modeled as in Equation 1 (see Weisbuch et al. 2002):

$$\begin{cases} O_{t+1}^i = O_t^i + U^{ij}(O_t^j - O_t^i) & \text{if } d_{ij} \le \varepsilon^{ij} \\ O_{t+1}^j = O_t^j + U^{ji}(O_t^i - O_t^j) & \text{if } d_{ij} \le \varepsilon^{ji} \end{cases} \tag{1}$$

Where:

O_{t+1}^i, O_{t+1}^j : vector of opinion values for agents *i* and *j* at time *t*+1;

O_t^i, O_t^j : vector of opinion values for agents *i* and *j* at time *t*;

U^{ij} : convergence coefficients representing the impact of agent *j* on agent *i*;

U^{ji} : convergence coefficients representing the impact of agent *i* on agent *j*;

ε^{ij} : opinion threshold of agent *i* when communicating with agent *j*; open/narrow mindedness

ε^{ji} : opinion threshold of agent *j* when communicating with agent *i*; open/narrow mindedness

d_{ij}: opinion distance between agent *i* and *j*.

Agent interaction is driven by social networks formed by proximity (e.g., neighbors), common socio-demographic characteristics (e.g., new amenity buyers, tradition ranchers), and belief structures. Satisfaction is assumed to be a sigmoid function of perceived resource levels (Equation 2 and Figure 2). The values of U and ε vary as a function of ideological separation (distance in opinion space d_{ij}) and an agent's satisfaction with the current system state (Equation 2).

$$\begin{cases} s_i = g(R) \\ \varepsilon^{ij} = h(d_{ij}) \\ U_{ij} = u(s_i) \end{cases} \tag{2}$$

Where s_i represents the satisfaction of an agent *i*, *R* denotes a vector of cultural and natural resource levels, and *g*, *h*, and *u* are functions.

This model assumes, for example, that an individual who values openness and natural amenities, but holds tightly to private property rights will be more willing to listen to (higher ε) and be affected by others (higher *U*) who support land use regulation if they perceive region's natural resources to be seriously threatened but not yet destroyed (region B in Figure 2). Several factors can, however, impede this process (e.g., stage C in figure 2 is reached before policy can be agreed on), newcomers might prefer the higher levels of cultural amenities supported by growth and fail to see the environmental degradation (i.e. heterogeneous satisfaction functions). The resulting system is, therefore, driven by a complex set of agent-agent and agent-environment feedbacks.

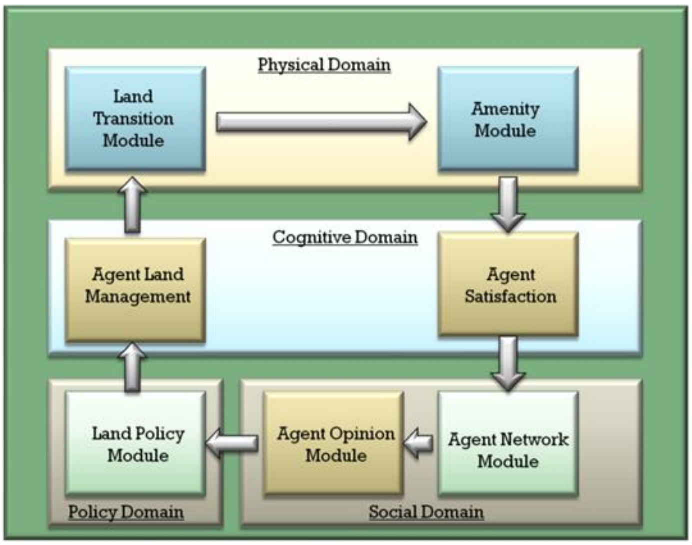
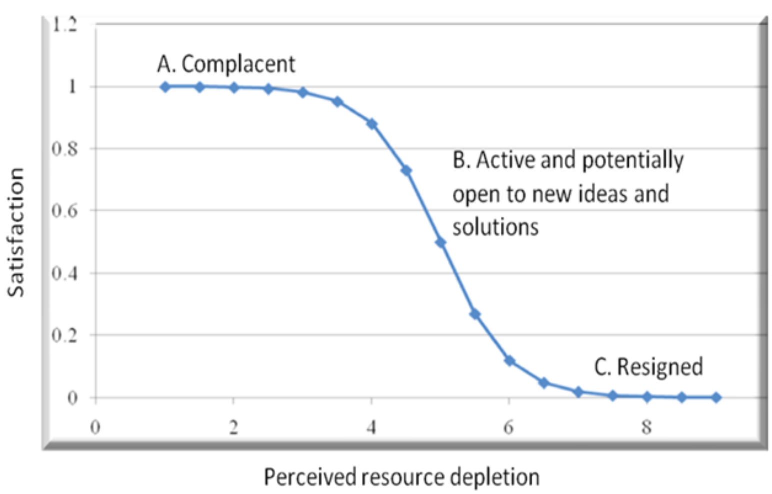


Figure 1. Model schematic.



A: if the quality and quantity of resources is perceived to be high and constant, agents will be complacent and unwilling to change their ideological perspective.
B: As the rate of resource depletion becomes significant, satisfaction declines rapidly and more individuals accept new ideas and solutions.
C: If change does not occur and resources are depleted past some threshold, individuals become disengage from the decision-making process.

Figure 2. Satisfaction curve of an agent in response to resource levels.

5. Results

Figures 3 and 4 illustrate outcomes given alternative assumptions about the willingness of stakeholders to adapt opinion in response to social interaction and perceived resource degradation. Values above 500 represent support of land use regulation. Figure 3 suggests that "dead-lock" quickly develops when stakeholders refuse to interact and hold to traditional views. In figure 4 those who want neither growth nor regulation, slowly change opinion in support of regulation (cluster above 500), while those who are pro-growth and anti regulation form a tightly grouped minority coalition.

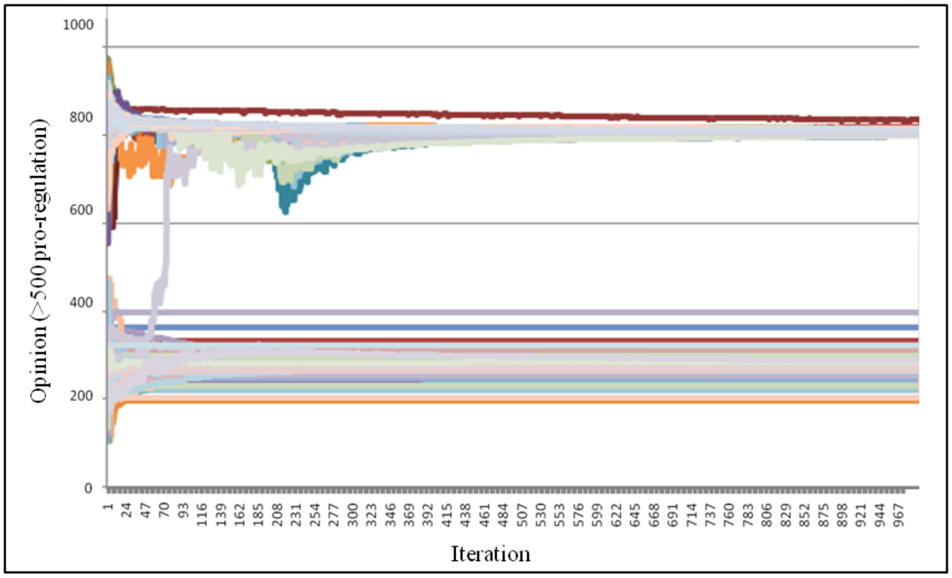


Figure 3. Opinion patterns showing that political dead-lock occurs when social interaction is limited.

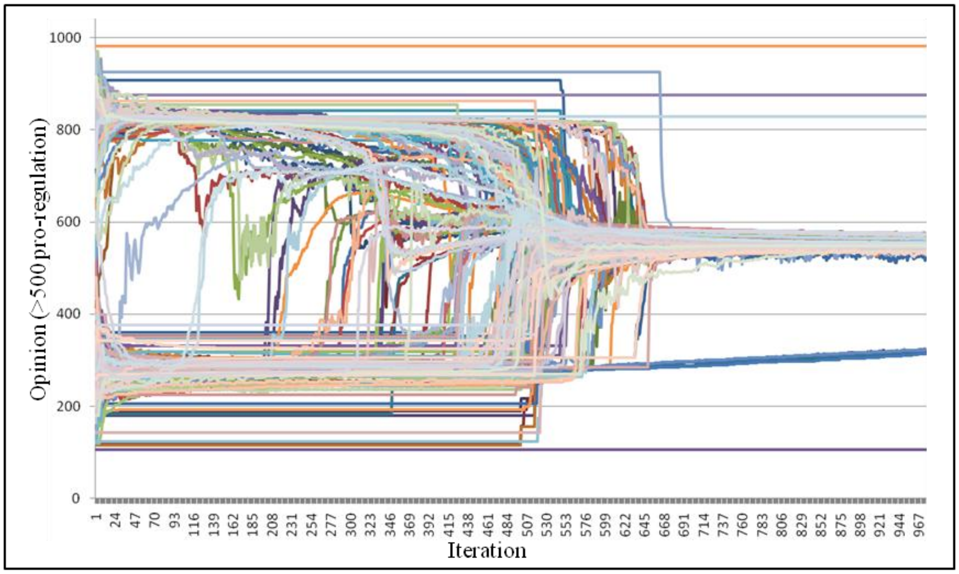


Figure 4. Opinion patterns showing that public opinion shifts toward support of regulation with interaction and compromise.

6. Conclusions

Nonlinear feedback processes drive interactions among humans and between humans and their environments, which often operate across various spatial, temporal, and social scales. ABMs can be used to explore and capture these feedback processes and, thus, help provide greater insight into how human adapt, or why they fail to adapt, to the rapidly changing environment in which they live. This research advances ABMs by explicitly modeling the effect of opinion formation on public policy, linking policy to landscape change, and closing the feedback loop by connecting landscape change back to public opinion.

Acknowledgements

This research is supported by the US National Science Foundation Human Social Dynamics #0624292. “Collaborative Research: AOC Social Complexity and the Management of the Commons”.

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