Biocomplexity Project Annual Report

Center for the Study of Institutions, Population, and Environmental Change
Indiana University

Year 3: January 1 – December 31, 2003

ACTIVITIES AND FINDINGS

RESEARCH AND EDUCATION ACTIVITIES

Data Development

Spatial/GIS Data

Project staff developed a time series of spatially explicit datasets for calibration and validation of the model. Two primary spatial datasets include land cover derived from aerial photography (1939–present) and parcel boundary data (1928–present). Both datasets have required significant labor resources to construct. In the previous years of this project we relied on spatial data compiled for one township, Indian Creek, in Monroe County. The parcel and land-cover data for this township was used to inform our initial modeling efforts. Each township in the county covers an approximately 6x6-mile area. Of the 12 townships in Monroe County Indian Creek is the least urban, excluding the townships that have significant amounts of federal or state forest land holdings. Historical aerial photography has been acquired for the following dates: 1939, 1958, 1967, 1975, 1980, 1987, 1993 and 1998. Visual interpretation and digitizing were performed to produce a feature dataset with forest and non-forest classes (we were unable to reliably identify pasture from row crops due to the spatial scale of some of the air photos). To evaluate the bias introduced by having one individual interpret land cover for the entire set of air photos, we had multiple individuals interpret features for a subset of the Indian Creek area using a clearly defined set of interpretation rules. Land-cover interpretations were in relative concordance across products produced by different staff with the exception of expected small spatial errors of about 5–10 m associated with the process of digitizing.

Land ownership is the link that allows the agents in the model to be assigned to specific landscape partitions making this a critical dataset for the modeling process. Planimetric maps were digitized and processed to produce land ownership layers for the following dates: 1928, 1957, 1967, 1971, 1980, 1990 and 1998. Attributes were assigned to parcels for owner identifiers from these maps, allowing us to identify cases when a parcel was sold to a new landowner or deduce when a parcel was split and passed on to members of the same family (based on first and last names). Parcel fragmentation is a key process in the study area, and this time series allows us to identify the rate of parcelization and to what degree subsequent land-cover changes are related to land exchanges and parcelization events.

A series of other layers have been integrated into the GIS. A Digital Elevation Model (DEM) has been acquired with a spatial resolution of 10 m. This allows for more accurate measurements of surface slope than traditional 30-meter DEM products. This DEM is being used as one layer in a land-use suitability dataset integrated into the model design.

In the past year we have additionally compiled spatial data for Van Buren Township (also in Monroe County). As of fall 2003 we have completed the air photo interpretation of this 6x6-mile area for the same time series dates as the Indian Creek Township series. Processing of the parcel data started in summer 2003 and is expected to be completed in mid-fall 2003. The importance of our processing lies in how we have applied this data to inform our model development. We have developed our model relying on the data from Indian Creek Township to help identify reasonable parameter estimates and model structure. We have tested the model using data from this same township. However, the most stringent test of a model is when it is tested on a geographic area which was not used for model development and calibration. The Van Buren Township information is this reservoir of reserved data that we will use for more robust evaluation of our model's performance.

Discussions with Experts

Collection and descriptive analysis of agricultural census, population census, and Bureau of Labor Statistics data continues. Carlson, Evans, Meretsky, Ostrom, and York held discussions with Monroe County Assessor, Indiana Department of Natural Resources officials, Sycamore Land Trust directors, Indiana Tree Farm Association President, foresters, planners, and older county residents to establish the context of land-use changes in Monroe County, as well as the institutions that impacted these changes. Information about government and non-government programs' impacts on land use in Indiana has been compiled. We have received several very valuable datasets to augment those we have compiled in earlier years. Indiana Department of Natural Resources Division of Forestry, for example, gave us a dataset identifying county levels of land within the Classified Forest Program from 1920 through the present, and the Sycamore Land Trust gave us landholding and easement information for southern Indiana.

Forest Data

Meretsky and Welch developed a methodology to sample forest cover on private lands for fieldwork in the summer and fall of 2003. Meretsky consulted with forest economists and ecologists at Purdue University concerning field methodology for compositional sampling. Sampling focuses on forests of middle age: forests that had grown up since about 1958. Using the multi-temporal forest-cover analysis of aerial photos, Welch identified potential sites and contacted private landowners to gain access to their property. The forest measurements included trees of merchantable, pole, and regeneration layers to help determine potential changes in forest composition and economic value over time. Teams led by Welch established transects based on landform characteristics. Additionally, Welch is leading teams that established transects in young forests (forests established approximately 20 years ago). The measurements in the younger forests will help to explain some of the dynamics in initial stages of forest succession. In addition to measuring forest patches, Welch asked landowners to describe past land use on the forest patches: such as past timber harvesting, cropping, or other actions that may have an impact on forest growth and composition.

Socioeconomic/Demographic Database and Metadata

VanWey and Gong gathered household-level demographic data from the 1920 United States Census from the Integrated Public Use Microdata Series. These data cover farm households from rural areas of 15 counties in south-central Indiana. These households are the first population to enter the agent-based model (ABM) and will be randomly assigned to parcels in the model. VanWey and Gong collected a second population of households that are spatially linked to parcels in the ABM. Data on these households were collected from handwritten records from the 1930 census. Using addresses from the census, names from property records, and maps of census enumeration districts, we matched these households to the parcels on which they lived. Data entry for these households is in progress.

Economic and institutional data collection and organization has continued. During the past year, the socioeconomic dataset has been expanded to include the new census-tract and block-group levels of Census 2000 socioeconomic variables for southern Indiana. Overall, the socioeconomic data includes temporal economic variables at multiple levels of aggregation. In this past year, York and Myint have created datasets that provide insights into zoning incentives and regulations, as well as government and private forest-management organizations.

We have developed an organizational structure for identifying and classifying relevant data that builds on the modular structure used to characterize the agent decision-making process. This structure will be used to classify and interpret data as it relates to implementation of the ABM and verification/validation of the model. Finally, there has been considerable progress in using the metadata structure being designed to organize all CIPEC data. These data organization and utilization tools will play a key role in facilitating more efficient data usage, both internally and externally.

Household Survey

In spring of 2003 we developed a household-level survey with the goal of collecting household data that can be used to provide greater insight into the land-management decision-making process. In particular, the household survey focused on these topics:

1. Household demographic composition
2. Land-use history
3. Respondent ranking of importance of sources of information for land management
4. Incentives and reasons for land-management decisions
5. Awareness and perception of institutional programs related to land management

The survey was mailed to approximately 1,000 landholders in Monroe County in early September, and we are currently receiving mailed responses. A modified random-sampling method was used in which 600 of the surveys were mailed to landholders randomly selected. Then surveys were mailed to landowners who owned landholdings adjacent to the initial set of landholders. This sample design will allow us to examine the spatial distribution of responses and the heterogeneity of key indicators. It also will be a tool that allows us to explore spatial dynamics of agents.

The survey was designed in coordination with colleagues at Purdue University in the School of Natural Resources. We have had several meetings with these researchers and have found common interests in our research projects. Although their study area falls in northern Indiana, we saw the household survey as an opportunity to explore not just local dynamics in southern and northern Indiana but also regional differences. A subset of questions from our form also was used in a household survey they will be mailing in fall 2003. We anticipate a series of joint analyses once both research groups have finished compiling responses.

Design and Execution of Psychological and Economic Experiments

A major component of this project is to use laboratory experiments to test some of the basic assumptions that are incorporated into the ABMs of land use. This project is one of the first to use evidence from experimental methodology to build the components of an ABM. The experiments currently being conducted or being planned for this coming year fall into two broad classes: (1) Individual Choice Resource Allocation Environments and (2) Spatially Oriented Environments.

Individual Choice Resource Allocation Experiments

Busemeyer, Baker, Kelley, Laine, Rieskamp, and Walker have several ongoing projects designed to examine the way agents make resource allocation decisions, which is one of the fundamental questions regarding land use. Landowners must decide how to allocate time, effort, money, and manpower to forest maintenance, agriculture production, and industrial work activities.

The resource allocation experiments are based on the following experimental paradigm. A valued quantity, represented as a continuum (or at least a very fine grain lattice), is used to define each resource. For example, capital (money) may be one resource, time is another resource, and manpower may be viewed as a third resource. The resources can be crossed to form a multi-dimensional space of options. For example, if we cross money, time, and manpower resources, then we have a three-dimensional space, and each point within the space represents one option. For simplicity, limit the problem to one resource (e.g., money), and the symbol R will be used to symbolize a positive real number that represents the total finite amount of available resource. There is a small set of n activities (e.g., n investments), and the resource is allocated across these activities. Let A_i denote the amount of the resource allocated to activity i ($i = 1,n$). For example, investors allocate capital to mutual funds, bonds, or money markets; landowners allocate available labor to alternative land-use opportunities or to on-farm and off-farm income-generating activities. Decision makers face a set of constraints on the allocations to activities. For example, the amount of capital to invest is bounded, $0 < A_i < R$, $i = 1,n$. There also may be more complex linear constraints, $\sum_{i=1 \text{ to } n} a_i A_i < C_j$ for $i = 1,n$.

At the beginning of an experimental session, the participant is informed about the resource, alternative income-generating activities, and constraints. Note that even in the simplest case where there is only one resource (e.g., money), and only two options (e.g., mutual funds and bonds), and the resource is bounded, the space of options contains an uncountable infinite number of choices when the resources are viewed as real numbers (or a very large number of options when the resources are defined on a densely spaced lattice, such as integers).

On each trial, t, of an experimental session, the participant chooses an option. That is, he or she selects values for A_i , $i = 1,n$, that satisfy the constraints. The allocation selected on trial t is denoted by a vector $A(t)$. After making this decision, the participant observes the payoff produced by this option. The payoff produced by an allocation of trial t is denoted $x[A(t)]$ or $x(t)$ for brevity. The total number of trials in the experiment is denoted T. The participant receives a cash payoff from the experiment based on his/her ability to find the optimal allocation of resources across activities.

The process used to generate the payoff, conditioned on the allocation, may be deterministic or probabilistic and may be static or dynamic, in the latter case depending on prior allocation decisions or exogenous disturbances. The decision environment can also be varied to alter information sets or resources available to subjects.

Using this experimental paradigm, we are designing experiments to address two broad theoretical puzzles. First, what is the basic nature of the learning process that is used to improve resource allocations with experience? Two candidate learning models are being compared and tested based on the experimental data. One is a local learning strategy, such as a hill-climbing or direction learning process (Busemeyer and Myung 1992; Selten 1991a, 1991b), and the other is a global learning strategy, such as a reinforcement learning model (Roth and Erev 1995). The local learning strategy uses only information based on the current allocation and the most recently selected allocations and takes a small incremental step in the direction going up hill. The global learning strategy probabilistically samples from the allocation space according to the expected payoff learned from past experience. Since the most appropriate learning model is determined from the experimental data, a second major theoretical question concerns the dynamic behavior of the learning process. In particular, if decision makers use a hill-climbing learning process, then the learning process should produce a smooth trajectory, which is sensitive to initial conditions, and the process can easily get trapped in local maxima and never find the optimal solution. If decision makers use a reinforcement learning process, then we expect a highly discontinuous trajectory, which becomes insensitive to initial conditions, and the process eventually finds the global maximum.

The second theoretical puzzle addresses the question of how subjects respond to changes in the complexity of the decision environment, and to alternative levels of information about payoffs from alternatives. This second puzzle builds on the first. Learning how subjects approach greater degrees of complexity allows the researcher to better understand approaches to learning, biases in decision making, and responses to changes in the decision-making environment and/or institutional setting.

Over this past year, the computer software designed for implementing this experimental environment has been enhanced to allow a broad set of decision settings. The program allows for changes in experimental factors by a menu-based interface that sets the program’s parameters. The experiments are run in two locations on the Indiana University Bloomington campus: one in a computer laboratory located in the Psychology Department, and the other in a laboratory located in the Economics Department. In this manner, we can compare different populations of participants in the experiments.

The initial study examined behavior in a deterministic setting in which one asset returned a constant/known return on investments. The second asset was created to yield two local maximums (one global maximum). The initial study focused on: (1) search patterns and their relation to the two theoretical candidates discussed above, (2) to what extent subjects were “trapped” at a local pay-off maximum and what types of search patterns led to such behavior, and (3) differences in behavior across subject groups.

Following this initial study, several other studies have been completed or are in progress. The first treatment investigates the impact that stochastic payoffs might have on individual’s resource allocation decisions. We expect to be able to infer information about agents’ risk preferences over assets that may have varying degrees of risk, i.e., return variance. Further, we expect to be able to investigate the generalizability of the result that the local learning model appears to best describe the decision and learning process for a resource allocation problem. This environment is being investigated under alternative levels of stochasticity. Following these experiments, we plan to further investigate this decision environment in a setting where individuals are allowed to discuss the investment alternatives, choosing an allocation based on a group consensus. The central question in this study focuses on whether groups will differ in willingness to take risks and their ability to optimize.

The second treatment extends the earlier studies with two or three assets to an environment with five or more asset allocation alternatives. This type of modification, although relatively straightforward, allows them to investigate whether a large number of allocation alternatives may cue complementarities or confounding effects for the agents' ability to learn and make optimal resource allocation decisions. Problems relating to the dimension of alternative space could account for a lower ability to achieve an optimal response given large numbers of alternatives, or for many cognitive biases observed in the decision-making literature.

The third group of treatments planned for the future introduces non-stationary and endogenous pay-off processes into the experiment. Specifically, the past resource decisions of an agent affect that agent's current pay-off opportunities. Again, the extent to which one can make optimal allocations is of interest. Such a treatment is of particular relevance to the decision problems faced by the farmer agents, as one's past agricultural decisions most certainly affect the profitability of current and future agricultural land uses.

Finally, a fourth set of treatments is planned that will create a market environment where several subjects simultaneously participate in an experiment, and their decisions endogenously affect one another. This type of experiment is similar to the market experiment or coordination game experiments that have been conducted in earlier experimental literature; however, we continue to use the resource allocation frame. Again, questions regarding the ability of agents to identify the optimal dynamic and endogenous resource allocation portfolio are of interest. Further, such a multi-subject framework allows questions regarding externalities and information diffusion to be investigated. The ultimate goal of these four additional treatments is to inform the construction of the agents for the ABM, and guide choices regarding decision and learning methodology.

Spatially Oriented Environments

Members of the research project are now pursuing the design of a set of new experiments to integrate spatial attributes into the decision environment. This spatial environment will initially expand the environment for examining individual choice resource allocation experiments. In addition, it will be designed to allow us to explore decision environments in which individual decisions impact other individuals (a group context). Such interactions can occur via information sharing and/or externalities across users.

The spatial decision task facing subjects can be characterized by Figure 1. A subject will observe a grid of one of the forms presented below. Their task can be viewed/presented in the context of land-use decisions. Subjects choose the type of land use to pursue on each cell of their parcel. In the following figures each parcel would be composed of a number of sub-parcels or cells, which can each be assigned a unique land-use classification. Subjects observe the land-use decisions of other agents, have access to feedback describing the profitability of various land uses, and have access to land-use advice via information networks.

a

b

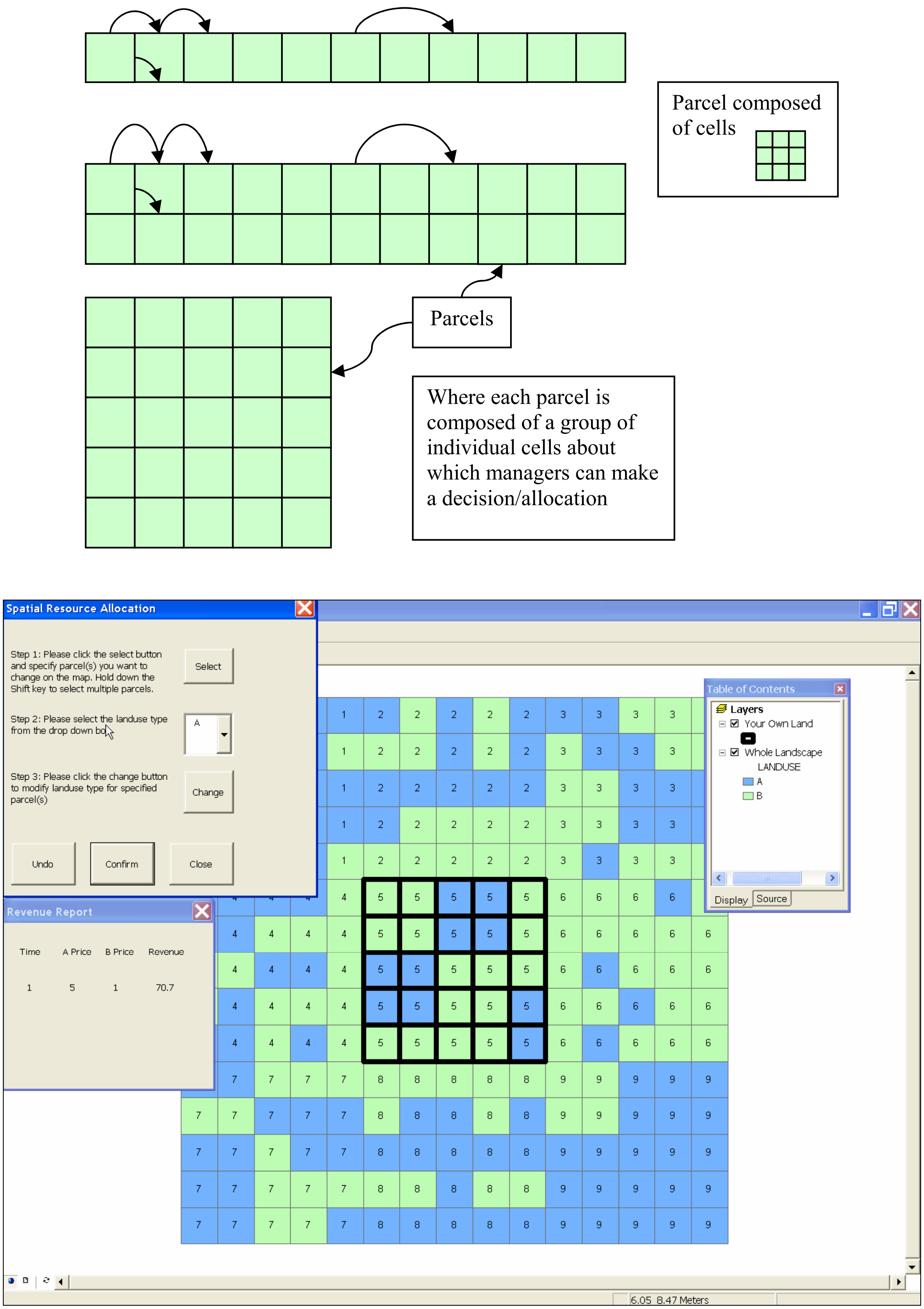

Figure 1. Initial Applications for the Spatial Experiments

By choosing particular cover classifications for a cell *i* (Figure 1a), an agent earns a payoff of the implicit form: Payoff = Σ_i f(prices, preference weights, suitability, externality spillovers, production costs). Depending on the assumptions made regarding preferences or land suitability, each cell *i* generates a payoff later converted into salient cash payouts to subjects.

Figure 1b is a screen print of the initial application for the spatial experiments. It includes (1) a main display frame which includes the spatial landscape, (2) a control menu that the user uses for selecting choices and implementing decisions at each turn, and (3) an indicator box reporting the results of the decisions (returns) from the previous turn.

The programming task necessary to create a laboratory environment sufficiently rich to examine a wide range of experimental paradigms is a very significant task. Over the past several months an initial working platform has been created and is ready for testing. Upon completion of initial testing of the software, several experimental projects will begin.

We will conduct a variety of treatment variations in the first set of experiments in order to explore the influence of landowner preference heterogeneities, land suitability heterogeneities, land-use externalities, and tax-based or zoning land-use management strategies. In the baseline treatment setting, subjects will face a decision environment with homogenous agents (i.e., subjects have homogenous pay-off functions), homogenous land suitability, and no externalities. Subsequent treatments will introduce heterogeneities in agents' preferences (induced via heterogeneous pay-off preferences), heterogeneous land suitability, and the presence of spatial land-use externalities. Policy experiments will explore the impacts of zoning restrictions and other management or incentive programs by placing restrictions on the types of uses for specific areas of land, or by introducing taxes or subsidies for pursuing particular land uses into agents' pay-off or objective functions. Finally, the last treatment in the first set of experiments will explore the role of spatial scale on the nature of agents' decisions and on the measures we use to quantify landscapes. Alternative scales can be induced by altering the numbers and areas of decision units over which agents must decide.

We believe these experiments will allow us to address a variety of questions that so far have only been investigated with ABM simulations, or spatial econometric analysis. This experimental approach provides a complement to earlier research, with a focus of the characteristics of agents' decisions when making inherently spatial decisions. First, we can generate more information regarding the relative influences of landowner vs. landscape-suitability heterogeneity. Second, we can investigate the spatial organization of land use that results from the absence of presence of land-use externalities. Even more basically, we can explore whether subjects who perform this task with the graphical interface perform quantitatively differently from subjects facing an identical task, but with a purely numerical interface. We also can investigate if the scale at which decisions are made influences the organization of the landscape. We can explore the role and optimal form of information networks for land-use decisions. Finally, we can assess the effectiveness of alternative land-use management strategies.

<u>Field Experiments</u>

As one of the methodological approaches to enrich and complement the data from the lab, conducting experiments in the field is being planned as a task for the summer of 2004. During the spring of 2004, we will adapt the spatial lab experiments currently designed and will develop a design that can be used in the field with landowners, farmers, and others who are currently using the land. This field experiment also will focus on spatially oriented environments. In the case of land-use changes in the last decades in the Amazon, and given the rich field and remote-sensing data already gathered there in the past by our research team, we will choose a sample of villages and villagers in the region of Brazil where the LUCITA ABM is focused. By using simple computational aids, such as personal digital assistants or tablet PCs, we will create a simple interface on which land users will make their choices in a simple manner and be able to relate such choices to incentives and to the spatial externalities involved (e.g., effects on neighbor parcels). This will enable us to examine the effect of their decisions on income and on the emergent patterns of land use.

We expect to complement the data gathered in the experimental lab in Bloomington with these replications in the field, and by discussing in in-depth interviews and in group discussions with villagers the parallels between the experiments and their actual experiences with decisions about land uses, the spatial relations derived from their decisions, and the rationale behind their choices. For instance, it should be of interest to explore issues like suitability of their parcels and their land-use decisions, or the awareness of these villagers about the spatial relations derived from land-use decisions and the effects on their income and income of their neighbors.

Development of ABM Models

Development of LUCIM/Matlab ABM Model

We employ a novel agent-based computational economy (ACE) that relates the dynamic spatial evolution of land use to individual landowners' heterogeneous, but interrelated, characteristics. The basic utility structure, representing landowners' production payoffs and land-use incentives, is adapted from Samuelson's (1958) overlapping-generation model.

We simulate the historical land-use decisions of 52 landowner agents whose parcels are defined by historical ownership records. Our hypothetical agents are constructed to simulate the land-use decisions of the actual owners. Agents' goals are to maximize their utilities, composed of agricultural profits and non-pecuniary aesthetic components by selecting their optimal labor and land allocations. Our simulated agents work with a rich historical database including: CBOT data describing market prices for the relevant products and inputs; DOA data describing the productivity of factor inputs; GIS information describing actual landscape slope and cover features of Indiana; federal wage, subsidy, and tax rate information; and finally, parcel boundary data.[1]

Given earlier evidence that risk factors are important for explaining agricultural activity (Parks 1995), we chose to utilize a constant-absolute-risk-aversion (CARA) utility structure to represent agents' payoffs. We assume owners use an approximately utility maximizing decision strategy for making their labor and land allocation decisions. Importantly, our individual agent application of this inductive maximization strategy, which estimates parcel-specific preference and productivity parameters, is unique and still allows our model to be classified as an ABM. We do not solve for a general equilibrium, but instead approximate each agent's best response to a land-use problem with externalities.

[1] Chicago Board of Trade (CBOT), Department of Agriculture (DOA), and Geographic Information Systems (GIS)

In our model, individual agents adapt their labor L_i and land M_i allocations across multiple activities with the goal of maximizing their utility. Agents' utility is a weighted sum of expected pecuniary or profit components, as well as non-pecuniary aspects. We also allow across-time and across-agent land-use production externalities to endogenously influence the productivity of their own and nearby neighbors' lands.

Since agents do not incorporate their expectations about other agents' actions, the labor and land allocation decision process for each agent would be considered an inductive approximation of the first best-utility maximizing factor allocation. Each year agents observe the new set of exogenous and endogenous features of their environment and re-approximate their own utility-maximizing factor allocations. In this setting, agents adapt their factor allocations as the environment changes. However, the deviation of the realized outcome from their expectations does not directly influence their decisions, as might be the case with a deductive reinforcement adaptation strategy.

Based on research suggesting landowners may display risk aversion regarding their income *I*, we posit the additively separable constant absolute risk aversion utility function $U = -e^{-2 \cdot RA \cdot I}$ (see Parks 1995). Also, we assume each agent has a time or labor constraint regarding the labor he/she can supply. *I* represents a scaled sum of expected *pecuniary* income and *non-pecuniary* 'output' derived from reforestation activities. *RA* represents the degree of risk aversion, and σ^2_I represents the variance of income, i.e. risk. The intuition describing this functional form is that agents derive utility from a scaled composite of pecuniary and non-pecuniary components *I*. However, all else being equal, they dislike variance in this measure.

This particular functional form imparts our agents with a desire to pursue multiple lands and labor uses in order to maximize their expected utility. This is achieved by balancing the marginal utilities obtained from expected pecuniary profits from production, income risk adjustments terms, and non-pecuniary aesthetic utility derived from the presence of forests. Importantly, agents' portfolios may differ since these factor allocations are conditional upon their unique preferences and differing land suitability.

Define λ as the Lagrange multiplier on an agent's labor constraint and *L* as the total available labor hours. The agents must then choose the L_is below in order to solve their unique, constrained expected utility-maximization problems:

$$E(U) = E(I) - RA\ \sigma^2_I + \lambda\ (L - L_{farm} - L_{tree} - L_{aes} - L_{off\ farm}) \quad (1)$$

Agents can supply labor inputs to $i = 4$ activities, respectively: growing crops (farm), harvesting trees (tree), growing trees (aesthetic), or working off the farm (off farm) in a manufacturing sector. Land can be used for three activities, including growing crops, growing or harvesting trees, or fallowing the land.

In each year, the sequence of possible actions for an individual agent are as follows: At the beginning of the year, given biophysical conditions and expectations about future prices, an owner agent makes a decision about the utility-maximizing *labor allocation*; conditional upon this allocation, an agent then selects the best cells for each activity on which to apply the labor. The agent compares the payoffs possible for each cell for each potential use, and ranks all cells for each possible activity. He/she then sequentially applies equal amounts of labor to the cells generating the highest potential utility until all labor has been applied. Over the year crops grow, dynamic biophysical properties of the landscape evolve and interact, and/or the agent earns an off-farm labor supply wage. At the end of the year, all unknown prices, wages, and tax rates are observed, all output is liquidated at the historical market price, and/or the agent is paid the historical non-agricultural wage. Finally, net revenue and overall utility are computed.

The key aspects of the market setting are that: (1) there are multiple potentially heterogeneous agents who can differ based on the quality and quantity of land owned, and in their preferences and in perceptions about the productivity effects of land suitability and land-use externalities; (2) agents make a labor allocation decision and then a land allocation decision each year; (3) agents are small producers relative to the overall market supply; (4) agents interact with one another via spatial production cost, or aesthetic pleasure land-use externalities; and (5) finally, agents are aware of the production, cost, and profit functions that describe the output, costs, and profits they can expect from the various productive activities.

More specifically, the analytical aspects of the model are summarized by the following production and cost functions, and the explicit utility function below. A Cobb-Douglas production function is used as an approximate description of the historical production environment facing owners. We have a corresponding cost function of the form:

$$C_i = (MC_i - \gamma_{e,i}\ external_i)\cdot Y_i \qquad (2)$$

MC_i represents the constant marginal or operating cost of production, $external_i$ represents the reduced marginal cost of production obtained if they pursue similar farming or timber harvesting production activities in close proximity to one another, and $\gamma_{e,i}$ represents the agents' perceived strength of these externality effects.

We introduce the production preference parameters α_i describing how an individual agent weights profits or aesthetic utility in their utility function (see equation 3 below). Two of these preferences are free parameters and are estimated in order to allow the simulated agents to mimic the actual owners' history of land use. The second non-pecuniary aspect of utility we allow is risk, based on the sum of commodity price and tax rate variance relevant for each activity.

Integrating all these components yields the constrained, expected utility expression (equation 3). The agents' decisions involve choosing the labor allocations across *i*, in order to maximize equation 3 subject to the land available for each activity and given the average parcel characteristics, i.e. average slope, number of similar adjacent cells, etc.

$$\begin{aligned} E_t(U) = {} & \alpha_f\,(\,(1-\tau_{farm})\ profit_{farm} - Y^2_{farm}\ RA\ \sigma^2_{farm}) \\ & + \alpha_t\,(\,(1-\tau_{tree})\ profit_{tree} - Y^2_{tree}\ RA\ \sigma^2_{fpr,tree}) \\ & + \alpha_g\,(\,(1-\tau_{graze})\ profit_{graze} - Y^2_{graze}\ RA\ \sigma^2_{graze}) \qquad (3) \\ & + \alpha_{of}\,(\,(1-\tau_{of})\ profit_{off\ farm} - Y^2_{off\ farm}\ RA\ \sigma^2_{wof}) \\ & + \alpha_{aes}\,(Y_{aes} - Y^2_{aes}\ RA\ \sigma^2_{fpr,aes}) \\ & + \lambda\,(L - L_{farm} - L_{tree} - L_{aes} - L_{off\ farm}) \end{aligned}$$

Each agent's labor allocation decision methodology is an approximation of a rational-expectation utility-maximization approach. *Rational expectation* refers to the fact that agents can form accurate mean predictions of future random commodity prices. *Utility maximization* refers to the fact that we assume the agents can chose labor supplies in such a way as to approximate the maximal utility they could derive, conditional upon their preferences and land suitability.

An agent's maximal labor allocation is that which simultaneously satisfies the following first order and Kuhn-Tucker conditions:

$$dU/dL_f = 0,\ dU/dL_t = 0,\ dU/dL_a = 0,\ dU/dL_{of} = 0,\ dU/d\lambda = 0 \qquad (4)$$

$$\lambda \geq 0, dU/d\lambda \geq 0, \lambda \cdot dU/d\lambda = 0 \quad (5)$$

This system of equations reduces to one equation with one unknown, the Lagrangian λ, which is numerically estimated to solve the equations in 4 and 5 for each agent and period. This yields an agent's maximizing labor allocation quantities $\{L^*_{farm}, L^*_{tree}, L^*_{aes}, L^*_{off farm}\}$ which must be applied to available acres of land M_i. The labor applied to an individual cell is then determined by the equal allocation rule to be $l_i^{cell} = max(L^*_i/M_i, 1)$ hours/cell.

Hill-Climbing Model

The Hill-Climbing Model differs from the Economic Model in several respects. This model does not assume utility-maximizing behavior, but the agents are expected to make decisions that are as good as possible given the feedback learned from previous years' decisions. The learning is based on a hill-climbing algorithm, which is a general purpose search method commonly used in optimization problems whose analytic solutions are hard to find. A hill-climbing decision maker adjusts the directions of decisions based on the success or failure of the previous decision(s). In the land-use decision framework the success and failure are defined in terms of increases and decreases in payoffs, received from different uses, from year to year: positive change means more successful trend, negative change implies failure.

Usually in the hill-climbing model, the feedback function, which reflects the amount of success or failure, is treated as black box; i.e., the decision maker does not necessarily know which specific component in the previous decision brought the success or caused the failure. By making small adjustments to the previous decisions, the hill-climbing decision maker tries to find the "hill-tops"—good areas in the search space. The major disadvantage of the hill-climbing model is that it may be attracted to locally good areas, rather than finding the globally best solution.

In the hill-climbing model, the agents representing the landowners make two decisions about how to allocate limited labor (number of working hours) between four different activities—productive farm work, off-farm employment, harvesting trees, and recreational activities—and which parts of their land to allocate to each of these uses. The first three activities are assumed to produce monetary profits, while the fourth one is taken to have mostly non-pecuniary benefits in the form of aesthetics from having trees around or recreational enjoyment such as hunting or hiking. However, the decision not to cut trees may be done with expectations of greater prospective gain from harvesting in future.

The labor allocation decision is made in two stages. In the first stage, the agents decide if they want to transfer more labor to off-farm employment and leave some of their previously farmed land to fallow or if they want to farm more. Then they decide either to cut trees or let them grow. The tree-cutting decision is not made every year, but in constant intervals defined by one of the estimated parameters.

The hill-climbing model uses the same landscape information and representation as the economic model, but it incorporates only a subset of other variables (economic, social, and political): agriculture and timber prices and minimum wages. Besides these exogenous factors, the payoff received from various activities depends on the quality of the land (soil and slope), education level of the agent, externality effects for farming and tree harvesting, and the ages of trees for harvesting. The feedback the agents learn from their previous decisions constitutes the payoffs from each activity separately rather than being the total sum. The amount of labor they allocate to certain use reflects the outcome of the last year's decision. For instance, if the previous decision was to increase the farmed area, and it produced better payoff than the alternative, off-farm employment, the labor allocation for farming is adjusted upward from the previous year's allocation; otherwise, it is adjusted downward. Similarly, a decision to harvest trees is made when the previous payoff from harvesting exceeds the non-pecuniary payoff from growing trees. The decision about where to conduct various activities is not directly influenced by the last year's decision, other than that the areas with deteriorated soil, due to previous farming, are very unlikely to be chosen as farmland again.

Currently, the model does not assume a heterogeneous group of agents. Instead, it tries to identify a small set of relevant variables that influence the performance. Besides the size of their parcels and their land type (soil quality and slope), agents differ from each other in level of education, frequency they tend to make logging decisions, and threshold for steepness of the land they want to farm. These are the three free parameters that are estimated, not for each individual agent separately, but for an attempted categorization of the agents into two or three distinct classes.

Besides understanding what the core variables in land-use decision making are, another goal is to explore the patterns of agent interactions and learning mechanisms they exploit. Therefore, in the first phase, a global learning component is added in which the agents learn from the outcomes of the actions of the whole community in addition to their own actions and feedback. In this case, the three parameters are estimated for each agent separately to better understand individual differences.

Development of LUCITA ABM

A second version of LUCITA has been implemented in Java using the RePast simulation toolkit. The simulation is more flexible than the previous version of LUCITA, implementing improvements in both the landscape model and the household model components of the system. This new version allows the user to alter the demographic composition, as well as the labor and capital resources, of individual households to observe changes in household behavior and resulting land-use/cover changes within their plots of land. In addition to these new heterogeneous household components, ecological variables related to soil and burn quality have been added. The degree of heterogeneity introduced through both household and ecological components add realism and affect the behavior of the model. A detailed discussion of the revised simulation components is described below.

Agent Model Development

The initial version of LUCITA, despite its simplicity, demonstrated some replicative validity when compared to general observations on land-use decision making as outlined in the trajectory of household development described by Brondízio, Moran, and others (Brondízio et al. 2002). While it produced interesting results, the "black box" nature of the modified classifier system employed for agent decision making in LUCITA version 1, made it difficult to dissect the important factors influencing specific agent decisions.

In the current version of the simulation, the household agent decision-making model has been completely redesigned, incorporating a heuristics-based approach to decision making. These heuristics are organized in a series of decision trees. At the upper level of the decision tree, agents evaluate whether their own subsistence requirements are met, and use knowledge of family characteristics such as labor and capital endowments, and soil quality to determine whether or not to leave land fallow, or to plant annuals, perennials, or pasture. Following this, lower branches of the decision tree are used to determine which specific crops are to be grown in a given cell and to adjust household characteristics.

Initially, only one type of agent has been developed to represent the land-use decisions of individual farming families. While the agents employ an identical decision-making mechanism, they display heterogeneity in such characteristics as time of arrival on the frontier, family size (available labor), reproduction rates, and household capital resources. The model is capable of tracking the individual household characteristics, and land-use decisions, for each household in the simulation. This allows the modeler to explore the effects of household size and available household capital on patterns of deforestation.

Landscape Model Development

LUCITA represents the landscape of the Altamira region of Brazil as a grid with a cell size of 1 ha. The landscape model within LUCITA retains its basic approach to representing secondary succession and changes in soil quality, while improving flexibility. Secondary succession is represented by the number of years since a cell in the landscape was left fallow. Cells transition from fallow through stages of secondary succession to a mature forest. Although forest in this mature state is clearly not the same as the original virgin forest of the region, it is indistinguishable from virgin forest in satellite imagery. Changes in soil quality, resulting from the clearing and burning of land and specific agricultural practices, are represented by a series of regression equations, originally developed by Fearnside (1986) for this region. The equations specify how soil quality variables, such as nitrogen, phosphorous, carbon, pH, and aluminum change in response to land-use activities. For example, when a cell in the land-cover grid is cleared and burned, nutrient values in the corresponding soil grid cell are altered to represent nutrient deposition. Similarly, when a crop is planted and harvested on a particular land-cover grid cell, nutrient uptake by the crop depletes the soil nutrient values in the corresponding soil grid cell.

Initial values for some soil parameters, soil changes through land-cover clearing and burning practices, and soil depletion and crop yield prediction are determined by regression equations developed by Fearnside (1984, 1986, 1988). Some of the parameters, such as those relating to climate or specific soil distribution levels, are based on documented statistics and fixed or randomly based within observed ranges. As more detailed spatial data on soil quality becomes available, the data can be added to cells of the soil grid.

The landscape model now allows the user to specify the dimensions of the grid prior to a model run. This allows the user to run simulations of any size, focusing on the behavior of a single property or on a much larger area. The pattern of road and plot infrastructure is automatically placed into the landscape based on the design standards used by the Brazilian government (INCRA, PIN) for colonization of the area in 1971 (Fearnside 1986). The landscape model now supports multiple georeferenced grids which can represent a wide variety landscape features. Currently two grids, representing soil quality and land cover, are used. Six annual or biennial crops (maize, rice, bitter manioc, sweet manioc, Phaseolus beans, and Vigna cowpeas) and two perennial crops (black pepper, cacao) are represented by LUCITA in addition to pasture. The sale price, yields, soil requirements, and decision strategies for the farming of each crop differ. Additional landscape factors such as slope, the location of water resources, and road conditions will be incorporated into a future version of the simulation.

Econometric/Landscape Analysis

The econometric/landscape analysis, conducted by Munroe and York, examines the economic structure of 40 southern Indiana counties using shift-share and location quotient analysis, and attempts to link these findings with observed private forest-cover change from 1969 to 1998. During the past year, we developed an econometric model of land-use shares based on the net benefits to agriculture, forestland, and urban uses for 1970–1990 that explicitly controls for changes in regional economic structure. Munroe and York will expand the current analysis to incorporate the impact of rural amenities on economic development in the 40 southern Indiana counties. We also are developing a finer-scale analysis of forest-cover change using demographic data at the U.S. census-tract level.

There is a complimentary analysis of the impact of zoning on land cover by Munroe, Croissant, and York (under review). This research explores the spatial pattern and composition of the landscape near Bloomington, Indiana, where urban and suburban development is expanding into formerly agricultural and forested areas. We address this issue by investigating the statistical relationship between landscape fragmentation and various socioeconomic, biophysical, and spatial variables associated with land use and land cover at the scale of individual, privately owned parcels. However, the estimated relative contribution of these factors on fragmentation can be misinterpreted if one does not account for the mitigating impact of zoning. This research expands on efforts to incorporate socioeconomic and policy factors into studies of landscape composition and configuration, and provides data and analyses with some policy application.

Forest Growth Model

Meretsky and Welch are analyzing the Forest Inventory and Analysis database to provide tree density, composition, and growth-rate parameters for the forest-growth model. We have consulted with forest modelers in the Forest Service and in academia regarding environmental variables to consider for the requisite modeling scale. Welch has been operationalizing topographic descriptors for forest community types selected from the regional Ecological Classification System. These GIS models will be combined with other variables, such as watershed position indices, to provide a coverage that indicates the expected forest types/compositions over the landscape. The dataset used to generate the Ecological Classification System is also being prepared for data analysis to assist in parameter estimation. Conversations with regional foresters continue to be used to provide regional detail. Analysis of the topography of the landscape to be modeled has revealed differences relating to the severity of slope conditions as compared to the area where the Ecological Classification System was created. This finding may point to the need for altering this system to better suit the landscape conditions in the study area.

Institutions

The decision problem of private landowners is influenced by incentives from governmental and non-governmental organizations at various levels of scale. For example, a large diversity of programs targets private landowners, but surveys show that a small percentage of landowners participate in these programs. The puzzle is why landowners do not take advantage of supposedly beneficial incentives.

Carlson, Janssen, Ostrom, and York study the incentive structures of land-use–related programs. Four types of programs are identified: cost-share, tax incentives, certification, and easements. Based on discussions with program officers and local experts, material from land-use programs, and survey material from a 1998 study in Monroe County, we analyze the incentive and organizational structures of four programs operating in Indiana. These programs are: (1) the Forestry Incentives Program (FIP), a federal cost-share program; (2) the Indiana Classified Forest Program (CFP), a state tax-incentive program; (3) the American Tree Farm Program (ATFP), a nationwide private stewardship program; and (4) the Sycamore Land Trust, a local private conservation organization which relies largely upon conservation easements.

Other studies have shown that private landowners' views have changed and became more diverse over the last century. Earlier, many landowners viewed a forest as a timber production resource. Now, more view a forest as a resource for many ecosystem services. Many programmatic goals have not adjusted to this change and are still based on the original timber production goals. Thus, there is an increasing gap between demands of the private landowners and the available programs. Many, especially governmental, programs have few strong incentives to adapt to a changing population of landowners, explaining the relatively low participation rate. We are especially evaluating the incentives and organizational structures of the programs that determine whether or not they effectively address the needs of landowners. The landowner survey currently in progress will provide data to test a number of hypotheses related to the characteristics of landowners who join the programs.

Related Work

Robustness of Social-Ecological Systems

Janssen, Ostrom, and Marty Anderies (Arizona State University) look at the institutional configuration that affects the interactions between resource, resource users, public infrastructure providers, and public infrastructure. The question is: What are the important elements of social-ecological systems that explain why and how some of those systems persist for so long, while others have collapsed? The aim is to derive a general framework that helps us to identify potentially vulnerable parts of a social-ecological system to internal and external disturbances. The tensions between resource users and public infrastructure providers are especially key in potential robustness of the social-ecological system. Finally, some long-established institutions are examined to unravel why they may have been more resilient than other institutions. The existence of long-established institutions shows the importance of the need for increasing our understanding of nested institutions as biocomplex adaptive systems. A systematic analysis of historical cases is ongoing, and the creation of a dataset is started.

Janssen developed a computational model on the evolution of cooperation in one-shot games by including the ability of agents to learn to recognize which agents are trustworthy based on the displayed symbols on the agents. The question was why agents who are genetically unrelated, and do not frequently interact, still are able to cooperate. He found that the use of symbols is especially important to include in the analysis of cooperation, which is echoed in our empirical studies of land-use programs and their use of signs and symbols. He also found that the problem of a significant proportion of potential participants' not wanting to participate in a governmental program is due to a lack of trust. The next step in this analysis is the emergence of social networks as a consequence of trust relationships.

Janssen and T. K. Ahn (Florida State University) did a project on the development of a theory-based multi-agent model that is able to generate the main statistics of laboratory experiments on public good experiments. We have written a paper on public good laboratory experiments that test alternative models of decision making, a forward-looking model with strategic pulsing, and a learning model. The next step is to use a larger dataset and develop a methodology of identifying agent types that are able to explain individual- and group-level statistics of laboratory experiments.

Evolution of Norms

The work on evolution of norms consists of agent-based modeling activities designed to explore the emergence and evolution of social norms. The model was specifically developed to explore the dynamics of norms in environmental governance activities, but it has general utility. At a general level, this model simulates how autonomous agents can come to be following the same rules in the absence of central authority and communication. The model demonstrates that this result can be achieved through the actions of a norm entrepreneur and by endowing the agents with a desire to act in a similar fashion to the rest of the agents (without copying other agents—they can't "see" any of the other agents) or, in other words, forcing them to act on the basis of what is socially acceptable. Ongoing work with this model has concentrated on extensions of the original model—rigorously assessing the boundary conditions for norm emergence, and exploring a number of extensions to the agent specifications and spatial context. In addition, during this past year, Hoffmann began to investigate the self-organized criticality characteristics of norm emergence and evolution, testing the model results for power law behavior and distributions.

This work has applicability to our larger Biocomplexity project in a number of ways. First, it allows Hoffmann to more fully explore rules-based decision-making methods in a way that can be transferred to the agents in our large model when we have a better sense of what rules "real" agents are following. Second, this model is a potential foundation for modeling the emergence of institutions in general. Rules are at the foundation of institutions, and if we can understand/model how particular rules emerge from numerous (infinite?) possibilities in a population of heterogeneous, interacting agents, then we have begun to understand modeling institutions. The modeling work undertaken in this past year also points toward a new way to understand institutions—through the lens of self-organized criticality.

In the course of this year, Hoffmann has concentrated on sensitivity analysis and presenting the results of the original model and the power law investigations. He presented the model and results in two invited lectures at the University of Delaware and the University of Pennsylvania. In addition, he presented the power law investigation at the annual meeting of the North American Association of Computational Social and Organizational Sciences.

Papers Presented at Meetings, Conferences, and Colloquia in 2003

Ahn, T. K., and Marco A. Janssen. 2003. *Computational Models and Multi-Level Experimental Data: A Study of Behavior in Public-Goods Provision Experiments*. Presented at the Annual Meeting of the Public Choice Society and Economic Science Association, Nashville, Tenn., March 21.

Anderies, J. Marty, Marco A. Janssen, and Elinor Ostrom. 2003. *Design Principles for Robustness of Institutions in Social-Ecological Systems*. Presented at the conference on "Robustness of Coupled Natural and Human Systems," Santa Fe, N.Mex., May 16–18.

Anderies, J. Marty, Marco A. Janssen, and Elinor Ostrom. 2003. *Design Principles for Robustness of Institutions in Social-Ecological Systems*. Presented at the IASCP Northern Polar Regional Meeting, Anchorage, Alaska, August 17–21.

Berger, Thomas, and Dawn C. Parker. 2003. *Multi-Agent System Modeling of Spatial Dynamics in Socio-Economic and Environmental Systems*. Presented at the international conference "Framing Land-Use Dynamics: Integrating Knowledge on Spatial Dynamics in Socio-Economic and Environmental Systems for Spatial Planning in Western Urbanized Countries," Utrecht University, The Netherlands, April 16–18.

Deadman, Peter J., and Derek T. Robinson. 2003. *LUCITA: Agent-Based Simulations of Land-Use Change near Altamira, Brazil*. Presented at the international conference "Framing Land-Use Dynamics: Integrating Knowledge on Spatial Dynamics in Socio-Economic and Environmental Systems for Spatial Planning in Western Urbanized Countries," Utrecht University, The Netherlands, April 16–18.

Deadman, Peter J., Derek T. Robinson, Emilio F. Moran, and Eduardo S. Brondízio. 2003. *LUCITA II: Agent-Based Simulation Modelling of Farmer Household Decision Making on Land Use/Land Cover Change in the Brazilian Amazon*. Presented at the Association of American Geographers Annual Meeting, New Orleans, La., March 5–8.

Evans, Tom P., Hugh Kelley, and Leah VanWey. 2003. *Incorporating Demographics into Agent-Based Models of Landcover Change*. Presented at the 68th Annual Meeting of the Population Association of America, Minneapolis, Minn., May 1–3.

Evans, Tom P., Charles M. Schweik, and J. Morgan Grove. 2003. *Connecting Landcover Change Models to Policy Needs by Spatial Scale*. Presented at the international conference "Framing Land Use Dynamics: Integrating Knowledge on Spatial Dynamics in Socio-Economic and Environmental Systems for Spatial Planning in Western Urbanized Countries," Utrecht University, The Netherlands, April 16.

Gibson, Clark, John Williams, and Elinor Ostrom. 2003. *Rule Enforcement and Local Level Forest Management*. Presented at the XII World Forestry Congress, Quebec City, Canada, September 16.

Goosen, H., and Marco A. Janssen. 2003. *Mediation Support Tools for Integrated Water Management*. Presented at the international conference "Framing Land Use Dynamics: Integrating Knowledge on Spatial Dynamics in Socio-Economic and Environmental Systems for Spatial Planning in Western Urbanized Countries," Utrecht University, Utrecht, The Netherlands, April 18.

Hoffmann, Matthew J. 2003. *Deforestation and Reforestation in Indiana: An Agent-Based Model*. Presented at the Michigan Technological University, Houghton, Mich., March.

Hoffmann, Matthew J. 2003. *Self-Organized Criticality and Norm Avalanches*. Presented at the North American Association of Computational Social and Organizational Sciences Annual Meeting, Pittsburgh, Pa., June.

Janssen, Marco A. 2003. *Agent-Based Modeling and Natural Resource Management*. Presented at the Center for Environmental Studies, Arizona State University, Tempe, Ariz., May 13.

Janssen, Marco A. 2003. *Agent-Based Modeling of Land Use Land Cover Change*. Presented at the Lunch Seminar, School of Marine Sciences, University of Maine, Orono, Maine, April 24.

Janssen, Marco A. 2003. *Agent-Based Modelling and Institutional Analysis and Development for Ecosystem Governance*. Series of eight lectures for a doctoral course at the Royal Academy of Science, Stockholm, Sweden, April 7–11.

Janssen, Marco A. 2003. *Agent-Based Modelling and Land-Use/Land-Cover Change*. Presented at the Lunch Seminar at National Institute for Public Health and the Environment, Bilthoven, The Netherlands, April 3.

Janssen, Marco A. 2003. *Laboratory Experiments and Agent-Based Modeling*. Presented at the First CABM/HEMA Workshop "Agent-Based Modelling of Social, Economic and Biophysical Systems," Melbourne, Australia, July 11–12.

Janssen, Marco A. 2003. *Predicting Change or Assessing Resilience of Social-Ecological Systems? Challenges and Opportunities for Sustainable Impact Assessment Modeling*. Presented at "Sustainability Impact Assessment of Trade Agreements and New Approaches to Governance," EU Workshop, Louvain-La Neuve, Belgium, March 27.

Janssen, Marco A. 2003. *Robustness, Institutions and Environmental Management*. Presented at the Workshop on "New Modelling Approaches for Sustainable Development," National Institute for Public Health and the Environment, Bilthoven, The Netherlands, April 3.

Janssen, Marco A., and T. K. Ahn. 2003. *Adaptation and Anticipation*. Presented at Research Group Workshop on "Testing Theoretical Models of Individual Behavior in Dynamic Social Dilemmas," Indiana University, Bloomington, Ind., January 25.

Janssen, Marco A., and T. K. Ahn. 2003. *Adaptation vs. Anticipation in Linear Public Good Games*. Presented at the First Conference of the European Social Simulation Association, Groningen University, Groningen, The Netherlands, September 19–21.

Janssen, Marco A., and T. K. Ahn. 2003. *Adaptation vs. Anticipation in Public-Good Games*. Presented at the American Political Science Association meetings, Philadelphia, Pa., August 27.

Janssen, Marco A., and T. K. Ahn. 2003. *Comparing Behavioural Models on Experimental Data from Public-Good Games*. Presented at the international workshop "Model to Model," Groupement de Recherche en Economie Quantitative d'Aix-Marseille, Marseille, France, March 31.

Janssen, Marco A., Tom P. Evans, and Vicky Meretsky. 2003. *Validation of Land Use Change Models: Towards a Practical Framework*. Presented at the international conference "Framing Land Use Dynamics: Integrating Knowledge on Spatial Dynamics in Socio-Economic and Environmental Systems for Spatial Planning in Western Urbanized Countries," Utrecht University, The Netherlands, April 16–18.

Kelley, Hugh, and Tom P. Evans. 2003. *Decision Strategies and Landcover Change: A Multi-Agent Model of Household Landuse Decisions in a Reforestating Landscape*. Presented at the international conference "Framing Land Use Dynamics: Integrating Knowledge on Spatial Dynamics in Socio-Economic and Environmental Systems for Spatial Planning in Western Urbanized Countries," Utrecht University, The Netherlands, April 16–18.

Meretsky, Vicky. 2003. *South-Central Indiana Forests: Conservation and Modeling Implications of Land-Use History*. Presented at the "Ecology of Forest Systems – Challenges and Opportunities" symposium, sponsored by National Science Foundation and Indiana University Research and Teaching Foundation, Indiana University, April 11–13.

Ostrom, Elinor, John M. Anderies, and Marco A. Janssen. 2003. *The Robustness of Multi-Level Social-Ecological Systems*. Presented at the American Political Science Association meetings, Philadelphia, Pa., August 27–September 1.

Parker, Dawn C., and Robert Najlis. 2003. *Using Multi-Agent System Models to Link Spatial Externalities and Landscape Fragmentation: A `Pseudo-Inductive' Analysis*. Presented at the international conference "Framing Land Use Dynamics: Integrating Knowledge on Spatial Dynamics in Socio-Economic and Environmental Systems for Spatial Planning in Western Urbanized Countries," Utrecht University, The Netherlands, April 16–18.

Rieskamp, Jörg, Jerome R. Busemeyer, and Tei Laine. 2003. *Comparing Two Learning Models for Resource Allocation Tasks*. Presented at SPUDM19, Biannual Conference on Subjective Probability, Utility and Decision Making, Zurich, Switzerland, August.

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Findings

Spatial/GIS Data

We have completed an analysis of land-cover change in a two-township area in Monroe County (Van Buren and Indian Creek townships) and compared to the pattern of topography in the area. Both townships experienced reforestation in the period 1939–1998 (see Figure 2). Indian Creek increased from 43% to 60% forest cover in this period while Van Buren Township increased from 29% to 48% forest cover. These general trends match our expectations and modeling goals: an effort to explain the processes leading to forest-cover regrowth in south-central Indiana.

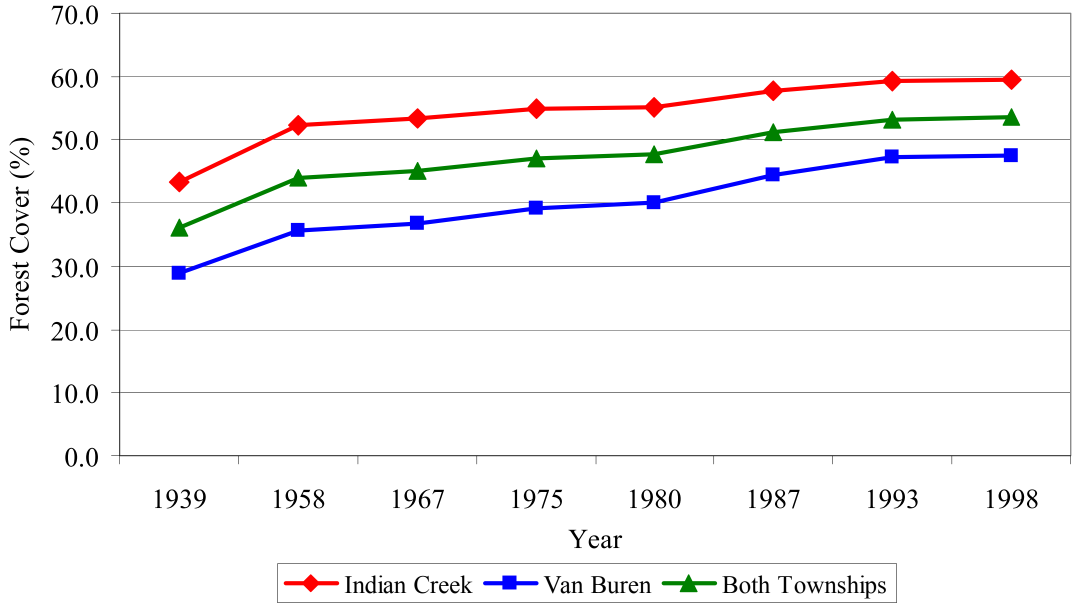

Figure 2. Percent Forest Land Cover by Year, 1939–1998, in Indian Creek and Van Buren Townships, Monroe County, Indiana

The spatial distribution of land-cover change in Indian Creek shows a pattern of decreasing heterogeneity with reforestation occurring in areas proximal to pre-existing forested areas. In Van Buren the pattern of reforestation is slightly different, with forest regrowth occurring in isolated areas that were largely non-forested. This heterogeneity of reforestation is partly a product of the fact that Van Buren started with a lower total amount of forest cover in 1939 than Indian Creek. Figure 3 shows the pattern of land-cover change in Indian Creek and Van Buren townships.

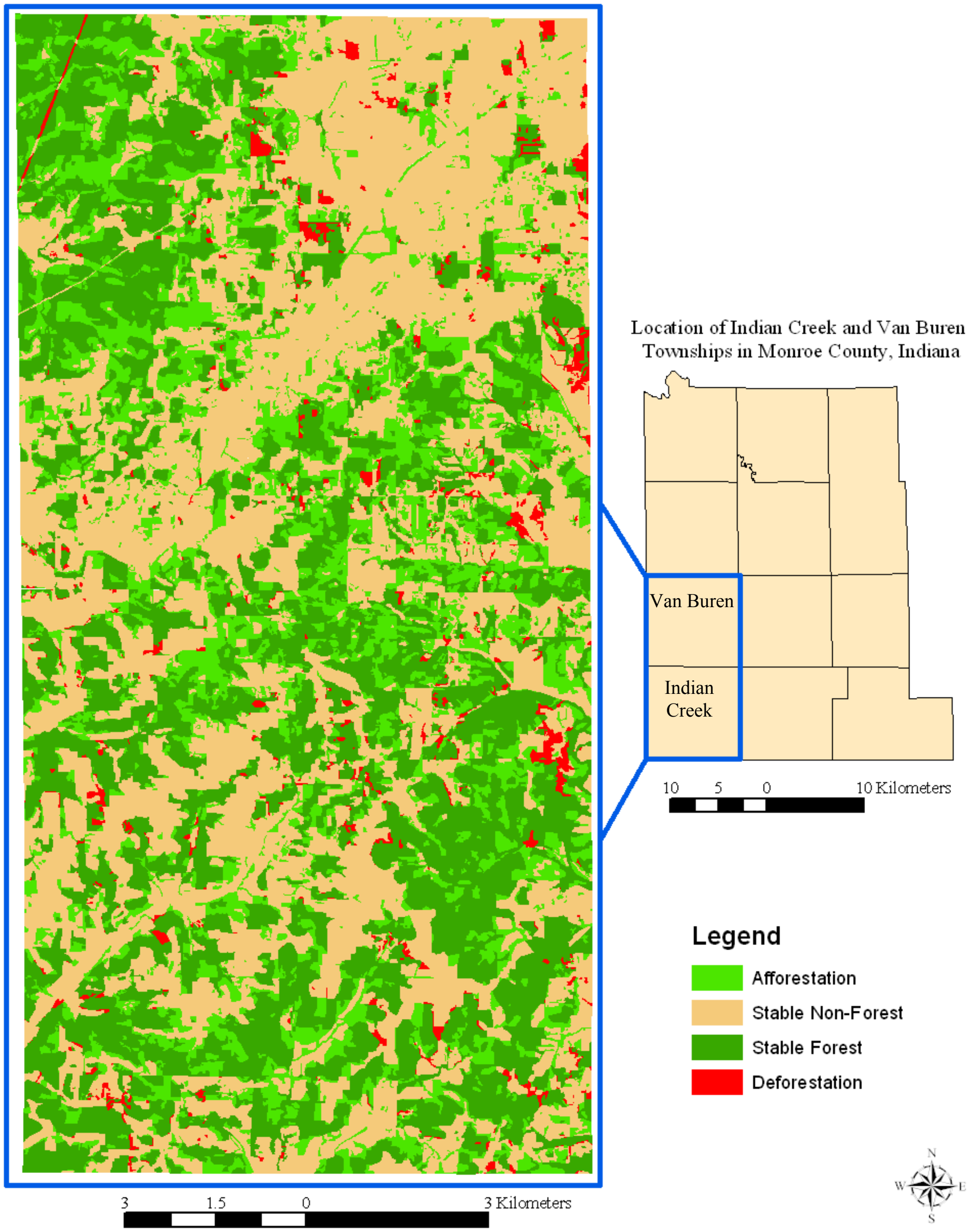

Figure 3. Land-Cover Change, 1939–1998, in Indiana Creek and Van Buren Townships, Monroe County, Indiana

Within these two townships the most stable topographic categories are very steep (> 20% slope) and very flat (< 5% slope) areas (see Table 1). Moderate-slope categories were more likely to experience reforestation from 1939 to 1998, but all topographic classes exhibited more reforestation than deforestation. The proportion of steep terrain reforestation was surprisingly less than the proportion of flat terrain reforesting (11.9% compared to 13.5%, respectively).

Table 1. Forest-Cover Change in Indian Creek and Van Buren Townships, Monroe County, Indiana, 1939–1998, Normalized by Slope Class

Slope (%)	Reforestation (%)	Deforestation (%)	Stable (%)
0–5	13.5	1.9	84.5
5–10	21.8	2.2	76.0
10–15	25.4	2.5	72.1
15–20	20.2	2.2	77.5
>=20	11.9	1.7	86.4

Table 2 presents the same data normalized by land-cover change class. Of the area that did reforest from 1939 to 1998, the majority was in moderate-slope categories. Of the area that deforested, the majority was in flatter topographic categories and these same topographic zones were the most stable (i.e., exhibited no change).

Table 2. Forest-Cover Change in Indian Creek and Van Buren Townships, Monroe County, Indiana, 1939–1998, Normalized by Land-Cover Change Class

Slope (%)	Reforestation (%)	Deforestation (%)	Stable (%)
0–5	17.0	22.1	26.6
5–10	30.6	27.9	26.7
10–15	31.7	27.8	22.5
15–20	15.8	15.7	15.2
>=20	5.0	6.5	9.0

The results presented here are aggregate data for both the Van Buren and Indian Creek townships. Earlier findings presented in previous annual reports were for only Indian Creek and showed a stronger relationship between land-cover change and topography. Indian Creek is more rural and less residential than Van Buren, and relatively steep areas in Indian Creek were most likely to reforest. Van Buren Township has experienced more residential development from the suburban development of Bloomington. In Van Buren, the relationship between topography and land cover is weaker, suggesting that land-management decisions are possibly less tied to extractivist land uses (e.g., agriculture, timber harvesting) than in Indian Creek. These data are being more completely analyzed for a series of forthcoming publications this year.

Discussions with Experts

Metadata entry is up-to-date, and the current searchable CIPEC metadata repository contains 289 individual dataset records, most of which are spatial datasets or spreadsheets containing demographic, price, or agricultural census data. Janssen, York, Meretsky, and Caldanaro met with Purdue Foresters to discuss details of modeling both forest growth and forest-related institutions. Meretsky, Donnelly, Caldanaro, Sun, Welch, and Carlson spent a day in the woods with IDNR District Forester Ralph Unversaw to better understand timber valuation in southern Indiana forests. Laura Carlson and Marco Janssen have begun attending the biannual Indiana Forest Stewardship Coordinating Committee meetings, where State Forestry officials and representatives of industry and non-governmental organizations meet to discuss forest policy issues and implementation.

Forest Data

Fieldwork is revealing a wide range of forest conditions within just the relatively narrow age range we are investigating. In some areas, eastern red cedar has established a near-complete dominance and will block hardwood succession for one or more decades to come. Harvest and land-use history has obviously varied widely over the townships of interest. Some areas are regenerating from previous harvest, whereas in others, young forests have grown up over abandoned pastures and fields. The proportion of merchantable species in the three size classes (saplings, pole-sized, and harvestable) ranges from close to zero to 100 percent.

In contacting landowners to arrange access to private lands, we have learned that several of the largest forest holdings are under some form of forest management, with state and private foresters contributing to the management plans. Thus, although work with forest institutions suggests that opportunities for support of forest management are underutilized on the basis of the proportion of landowners involved, it appears, on the basis of the proportion of land involved, that forest management affects considerable acreage.

Preliminary findings from fieldwork in young forests have revealed a high degree of heterogeneity due to differences in land use and varying densities of invasive exotic plant species. The density of seedlings generally decreases from old forest edges into old fields. There is some evidence that seedlings of canopy trees that can establish deeper into the old field are larger than those closer to the old forest edge, possibly making competition important in initial stages of succession. Further analysis of this fieldwork will contribute to predicting composition and structure of forests through time.

Individual Resource Allocation Experiments

Procedures

In the resource allocation experiment, subjects repeatedly divide an endowment into two assets. One asset (Asset 1) offers a constant return of 10% for each dollar invested. The other asset (Asset 2) offers a variable return. We examine two decision environments, one where the return from Asset 2 is deterministic and the second where it is stochastic. In the deterministic environment, the return from Asset 2 varies from 3% to 77%. In the stochastic environment, a random element, drawn from a mean-zero normal distribution, is added to the return from Asset 2. Therefore, a repeated investment into Asset 2 in the stochastic environment may not offer the same return trial after trial. The standard deviation used in the stochastic treatment is four, with the bounds on the random element being three standard deviations to each side. The total pay-off function is linear with a local and global maximum, which might make it difficult for subjects to find the optimal allocation, since the local maximum serves as a distraction from the optimal allocation. Figure 4 summarizes the pay-off space for the two treatment conditions.

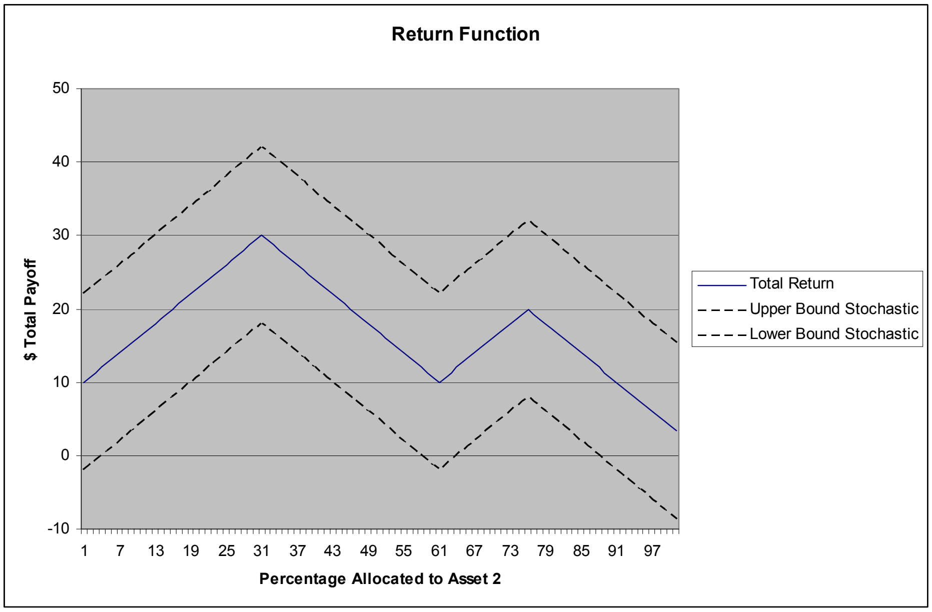

Figure 4. Pay-Off Range from Asset 2 for Stochastic Treatment Conditions

<u>Summary of Results</u>

In the experiment, subjects are given a $100 loan each trial to allocate between Assets 1 and 2. Subjects make their allocations by adjusting the percentage invested in each asset using a computing tool "slide rule." Subjects only know the return from Asset 1, the nature of the return from Asset 2 (deterministic or stochastic), and that there is an allocation that maximizes their return. After subjects submit their allocation in each trial, they forecast their earnings for that trial by adjusting a slide rule on the computer screen. The range of the forecast is -$50 to $50. Subjects are paid according to their cumulative forecasting accuracy. The $100 loan is repaid after each trial, meaning a subject's earnings are the returns from his investments. Subjects also are given access to their past decisions. A table on the computer screen tabulates all past allocations, payoffs, and cumulative payoffs. Therefore, subjects can easily recall which past allocation resulted in the highest return. The availability of past decisions to subjects is seen as an important treatment variable that may influence the type of learning algorithm used by subjects.

Subjects in the deterministic environment were quite adept at locating the allocation that yielded the maximum return. This is somewhat surprising given the minimal information regarding payoff from Asset 2 and the fact that Asset 2 had both a local and global maximum. The overall mean subject efficiency was 88% (Efficiency = (actual earnings – min. possible earnings)/(max. possible earnings – min. possible earnings)). Subjects learned the location of the global maximum return fairly quickly. Eighteen of 20 subjects were able to locate the global maximum allocation. Of those who found the global maximum allocation, allocations stabilized at the global maximum location on average by round 32.

The addition of the random element increased the complexity of the problem. The overall mean subject efficiency in this environment fell to 72%. Subjects also had more trouble locating the global maximum allocation. Nine of 20 subjects either never settled on an allocation or settled on an allocation that was not close to the global maximum. Ten subjects stabilized within a range of 10 percentage points around the global maximum, on average after round 37. The remaining subject settled on the global maximum allocation in round 19. Overall, the search pattern was more volatile in the stochastic environment, where subject average total squared deviation from the optimal allocation increased by 54%. A summary of the results is given in Figure 5.

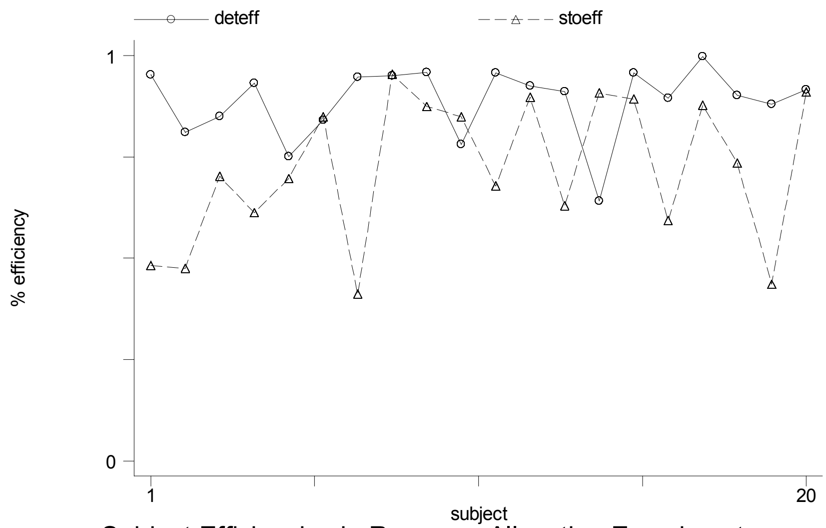

Figure 5. Summary of Behaviors in Deterministic and Stochastic Environments

Findings in the Development of Agent-Based Models (ABMs)

<u>LUCIM/Matlab ABM</u>

There are four general findings from our investigation of the ABM: (1) the simulated landowner agent who makes land-use decisions to maximize their utility, and is sensitive to economic and biophysical incentives, provides a good description of most individual landowners in our sample area; (2) the restriction of landowner preference homogeneity is strongly rejected; (3) the magnitudes of estimated parameters and the model's ability to reproduce the owners' actual histories of land use varies depending on whether composition (percent forest) or pattern (forest edge) spatial metrics are used to compare the actual and simulated landscapes; and (4) landowners' heterogeneities are observed to play at least as important role as land suitability in accounting for land-use decisions.

The results follow from two types of analyses which summarize the empirical descriptiveness of this ABM. We first conduct a by-agent parameter-fitting exercise exploring the extent to which utility-maximizing landowner agents can be parameterized and make land-use decisions that are representative of the actual owners' historical decisions. We then conduct a sensitivity analysis of the spatial organization of the landscape, given perturbations to agents' fitted preferences and suitability parameters.[2] The goals of these empirical analyses are: first, to quantify the degree of heterogeneity in the agents' fitted parameters, thereby addressing whether a homogenous agent assumption is accurate; and second, to compare the extent to which equal percentage perturbations to the estimated preference and land suitability parameters influence the spatial organization of the landscape.

Our ACE model of post-1940s land use in southern Indiana identifies important similarities, heterogeneities, and interactions in the land-use decisions of historical owners. In general, both the historical and simulated agents make land-use decisions that are influenced by unique preferences and land suitability. However, the best-fitting or most descriptive agent-based simulation requires agents who have different production preferences, different perceived productivity influences of land suitability, and different perceived productivity influences of land-use spatial externalities.

In order to allow our ABM to accurately reproduce each agent's observed history of land use we estimate five parameters which quantify the implied strength of the three influences. For all landscape comparisons the characteristics of the actual and model-generated landscapes are summarized by pattern (forest edge) and composition (percent forest) spatial metrics. The best-fitting parameters are those that maximize a model goodness-of-fit measure we call Null_R2. This Null_R2 compares the sum-of-squared-error (SSE) describing deviations between the simulated and actual landscapes' metric values to the SSE describing deviations of the "null" model from the actual landscapes. Here the 'null' model is the one that uses the base year 1940 landscape metric values as the "model" prediction for future landscape metric values.

Overall, our results indicate that the ACE model with approximately maximal agents provides predictions that are superior to the null model for 85% of owners. Also, agents' estimated parameters displayed significant heterogeneity, consistent with an important stylized fact regarding parcels in our sample. Third, the estimated parameters and Null_R2s showed differences depending on which metric was used to measure goodness of fit. Fourth, externalities are estimated to positively influence an agent's likelihood of pursuing proximate agricultural, timber harvesting, or reforestation activities. Fifth, for the majority of subjects, slope (the inverse of land suitability) is estimated to have a negative influence on the likelihood of pursuing agricultural or timber harvesting land uses. Additionally, it is likely that the assumption of risk aversion implicate with our CARA utility structure is associated with agents' decisions to pursue a balanced portfolio of land uses in the face of price risk. Finally, results of a sensitivity analysis indicate that equal percentage perturbations to agents' estimated preference parameters have an equal or larger spatial influence compared to changes in the agent's estimated land suitability weight.

Another research track has been to explore the scale dependence of ABMs by scaling the input data to the model (e.g., parcel data, land-cover data, slope data) and running the model at a range of spatial scales (Evans and Kelley, under review). This analysis showed that the proportion of agent types (as defined by the distribution of agent parameter weights) changed as a function of slope. The model performed poorly at coarse spatial scales because of the errors introduced by aggregating information on the landscape. The model performed best at moderate spatial scales since this created enough variation in the dependant variable to meaningfully fit parameters of

[2] Key refers to parameters a priori predicted to strongly influence the likelihood of an agent pursuing the two major activities in this area: agricultural production and timber harvesting.

the model. These results also are linked to the fact that we are running a household-level model and the pattern and composition of land distribution in the area (e.g., suitability) vary significantly within a parcel. However, the main finding is that ABMs should be run at multiple spatial scales of analysis because of the scale dependence of the results.

Overall, our simulations, calibrated with the estimated parameter values, produce landscape dynamics consistent with the stylized facts describing southern Indiana land use. First, we do see a gradual trend of reforestation resulting from the land-use decisions of our simulated agents. Second, the across-parcel estimated parameters display substantial heterogeneity. However, reproducing the third regularity, the non-monotonic evolution of forest edge as percent forest monotonically increases was less successful. Instead, we tended to see monotonic changes in the amount of forest edge on simulated agents' parcels, given monotonic increases in percent forest. However, two types of agents were observed, those for which there was a positive correlation between edge and percent forest, and those for which there was a negative correlation. These across-parcel correlation differences could in principle reproduce the non-monotonic response of edge if the mix of agents, or their preferences, are changing through time.

Interestingly, the variations in the sign of the correlation between the percent forest and edge metrics can be shown to result from an interaction among agents' estimated production preference and externality parameters. For example, an agent with strong preferences for reforestation, moderate preferences for farming, and no estimated externality influences will want to reforest, but only on marginally productive agricultural land. If the agricultural suitability of their land varies substantially within their parcel, the reforestation will then occur in a spatially dispersed way. As a result, percent forest may increase, and so will the forest patch edge, leading to a positive correlation between these metrics. Alternatively, another agent with the same production preferences and land suitability, but perceiving strong externality effects, will want to reforest proximate to other forests. This is because the externality spillovers they get from reforesting on suitable farm land near other forests off sets the loss from having to farm other less suitable land. And as a result, the latter agent could produce both more forest and a declining forest edge, and therefore a negative correlation between the metrics.

<u>LUCITA ABM</u>

Simulation runs in LUCITA are set up to run for 30 iterations, such that the first iteration represents 1970 and the beginning of colonization in the area, iteration 15 corresponds to 1985, and so on. Households are allocated to plots at 0–50 per iteration to a site comprising 234 100-hectare plots on a grid representing an area of 15 km by 20 km. The assignment of 50 households per iteration allows all plots to be potentially filled by incoming farmers within five years; however, it is most likely that all plots are allocated within the six- to eight-year range.

A set of 50 simulations were run in which the parameters were left at constant settings. Differences between individual simulation runs can be attributed to the stochastic elements of the model, including the timing and location of the introduction of individual households to the simulation run, the individual attributes (family size and capital) of each household agent, and the individual household decision making regarding crop selection that occurs throughout the simulation. A preliminary analysis of the second version has yielded the following findings.

Overall rates of deforestation observed in LUCITA are similar to those observed through the analysis of remotely sensed images of the Altamira region. The simulation indicates a pattern of early rapid deforestation, followed by increasing amounts of land in fallow or some stage of secondary succession. Trends of mature forest and fallow/secondary succession show an inverse relationship such that when mature forest is decreasing, secondary succession and fallow are increasing, and vice versa. The patterns of deforestation in LUCITA reflect land-use patterns found by Mausel et al. (1993) and Brondízio et al. (2002). While an exact numerical match is not found, trends in percentages of land-cover types recorded over time are similar. Deforestation results of 43% at iteration 15 approach 1985 observed values by Mausel et al. (1993) of approximately 55% in a subset of their study. Mausel et al. (1993) also note that from 1985 to 1988 and from 1988 to 1991 an additional 4% and 1.5% were deforested, respectively. Under iterations 15–18 and 18–21, LUCITA shows a lower decrease in deforestation with corresponding values of 2% and 1.5%, respectively.

Aggregating fallow and secondary succession recorded by Mausel et al. (1993) to match categorization within LUCITA (fallow, secondary succession, and perennials) we find a close similarity in 1985 of 33% and 37.7%. The difference is small in 1988 (42% vs. 41.1%) yet increases over time to show similar long-term trends with greater variance (1991: 53% vs. 43%). Despite differences between observations and LUCITA, the percentage of secondary succession and fallow show similar increasing trends over periods from 1971 to 1991.

Land-use trends produced by LUCITA for perennials and annuals follow a pattern that is similar to those predicted by the theoretical trajectory model for the Altamira region. The simulation produces a general pattern of household land use characterized by the growing of annuals in the years following arrival and a transition to growing pasture or perennials over time. Continued refinements are required to improve the representation of pasture cultivation in the simulation. Crop percentages recorded by Mausel et al. (1993) and LUCITA demonstrate a higher level of agreement than comparisons made between deforestation or secondary succession and fallow levels. From 1985 to 1991 LUCITA produces a slow decrease in the amount of area in crop production (1.7–1.4%). Throughout this period of decline in annuals, perennial production begins to stabilize. Despite a similar decline in cropping observed by Mausel et al. (1993) from 2.4% to 1% over the same period, measurements in 1988 spike to almost 5% of their sub-site in crop. It is not unlikely that such spikes occur, as they may be attributed to a number of external or stochastic variables not modeled within LUCITA.

Last, pasture trends decrease in time from 1985 to 1991. While values observed by Mausel et al. (1993) are markedly higher, with a dramatic decline (19–6%), LUCITA pasture results decrease slightly from 3.1% to 1.8%. The difference in the magnitude of decline is attributed to higher levels of forest and problems incurred during LUCITA development, which will be addressed in future work.

Findings from Econometric/Landscape Analysis

Munroe and York's analysis of the economic structure of 40 southern Indiana counties has resulted in their creation of an econometric model of land-use shares for 1970–1990. We have found strong evidence that changing agricultural profitability is leading to private forest regrowth. We also are finding that changes in residential land values and regional employment trends are highly significant drivers of forest loss, indicating that urban growth also increases the opportunity cost of extractive land uses, but not uniformly across space.

Institutions

An overview paper on programs in the USA was written (York et al. 2003) in which we identified four types of programs: tax incentives, cost-share, certification, and easements. Preliminary findings of the analysis of four programs in Indiana show that especially governmental programs embedded in complex bureaucratic systems do adapt slowly to changes in characteristics and preferences of private landowners but have incentives not to adapt, since their actions are not evaluated on statistics of the impacts of the programs.

<u>Robustness of Social-Ecological Systems</u>

In Anderies et al. (under review) we present a general framework on social-ecological systems in which we identify the relevant parts and how they are linked (Figure 6). Five "entities" are identified that are normally involved in social-ecological systems based on common-pool resources (*A* in Figure 6) used by groups of individuals over time. Two of these entities are composed of humans. These are the resource users (*B* in Figure 6), who are the population of those harvesting from the resource, and the public infrastructure providers (*C* in Figure 6), who receive monetary taxes or contributed labor and make policies regarding how to invest these resources in the construction, operation, and maintenance of a public infrastructure. There may be a substantial overlap in the individuals in *B* and *C* or they may be entirely different individuals depending on the structure of the social system governing and managing the social-ecological system.

The public infrastructure (*D* in Figure 6) combines two forms of human-made capital—physical capital and social capital. The physical capital includes a variety of engineered works, and the social capital includes the rules actually used by those governing, managing, and using the system that create opportunities and constraints in the action-outcome linkages available to participants. The social capital also includes the monitoring and enforcement of these rules, the way individuals have learned to work together, and various investments in research and development that may be undertaken to keep the system operating over time in a changing environment.

The resource (*A* in Figure 6) is most frequently a biophysical system or a form of natural capital that has been transformed for use by *B* through the efforts of *C* to invest in *D*. (In fully engineered systems such as a computer network or a highway system, the distinction between *D* and *A* might not be needed, but we will focus in this paper on the problem of achieving robustness related to ecological systems that have not been constructed entirely by humans.) If one is going to examine robustness or resilience, one needs to include external disturbances (*E* in Figure 6), which can include biophysical disruptions like floods, earthquakes, landslides, and climate change that impact on *A* or socioeconomic changes like population increases, change in economic opportunities, depressions or inflations, and major political changes that impact on *B*.

The framework is currently used to compare a variety of historical case studies of social-ecological systems, and is used to study the incentives structures of four land-use policy programs in Indiana, as mentioned above.

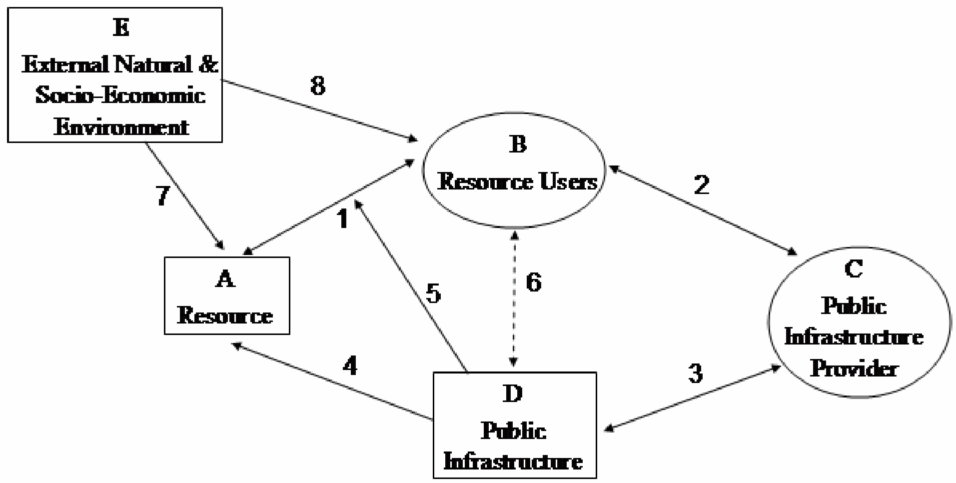

Figure 6: A Conceptual Model of a Social-Ecological System

The work on trust and evolution of cooperation resulted in a paper in which we show that high levels of cooperation can be derived when agents are able to learn to recognize others who are trustworthy (Janssen and Stow under review).

The use of laboratory experiments on public goods to test alternative decision making leads to the finding that to explain the data, it is essential to include other-regarding preferences, and assume heterogeneity within the population of agents. Both the tested learning model and the forward-looking model performed significantly better than Nash-equilibria of selfish-rational agents and random decisions, but no clear distinction could be made between them.

Related Work

<u>The Dynamics of Social Norms</u>

The first set of findings from the social norms modeling investigations derived from the power law analysis of the modeling results. The model, built from the insights of social constructivism, is a driven threshold system. An entrepreneur's suggestions represent a stimulus to a population of interdependent, adaptive actors, and this stimulus potentially catalyzes a number of different responses:

- No change—The actors are resistant to the stimulus and continue their behavior, and the current social patterns and relationships continue unchanged.
- Limited cascade—Some actors change their behavior, but their altered behavior is insufficient to significantly alter the current social patterns and relationships.
- Substantial—Some (or many) actors change their behavior, and their altered behavior transforms the current social patterns and relationships.

Substantial cascades could signal normative/institutional breakdown (if the current social pattern is structured by a stable norm) or normative emergence (if the current social pattern is norm contestation or lack of a norm). The size of the norm cascade or change—the spread of a norm to the whole population and the length of time a norm remains in force—and the stability of existing norms/patterns are dependent upon the connections and interconnections of the actors as well as the characteristics of the stimulus itself (how clearly communicated, normative value, power of the entrepreneur, significance of the rare event). Initial analyses on multiple runs suggest that under certain conditions, norm cascades do follow a power law distribution. Thus the model points to the conditions that govern normative dynamics, providing significant insights for empirical work on social norms. Second, the model confirms that the norm life cycle exhibits characteristics of self-organized criticality, suggesting that understanding norm dynamics (and institutions more generally) empirically may directly entail exploring self-organized criticality.

Empirically, the modeling results have driven Hoffmann's continued studies of global environmental governance. The original model results were at the foundation of his study of the governance of ozone depletion and climate change. In addition the model has opened up two new areas of inquiry—norm competition and the application of self-organized criticality, empirically. Insights into norm competition, an especially important concept in any institutional study, flowed from the notion of competing norm entrepreneurs and informed the analysis of a chapter in Hoffmann's (under review) recent book manuscript. Norm competition and the power law investigations were also at the foundation of an additional NSF grant application crafted by Hoffmann to explore these issues explicitly in the context of the governance of climate change.

References for Findings

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TRAINING AND DEVELOPMENT

Training

Janssen provided a Ph.D. training course on “Agent-Based Modelling and Institutional Analysis and Development for Ecosystem Governance” at Royal Academy of Science, Stockholm, Sweden, April 7-11, which was based in part on the material from this Biocomplexity project.

Janssen provided a lecture during the CIPEC Summer Institute training the Biocomplexity project, especially on agent-based modeling and land-use change.

Janssen taught a graduate course, V685 “Integrated Modeling of Humans and the Environment,” at Indiana University’s School of Public and Environmental Affairs, which was based in part on the Biocomplexity project

Janssen was a guest lecturer in the “Data Mining and Modeling” course at Indiana University’s School of Library and Information Science on new modeling techniques based on the Biocomplexity project.

Graduate Student Research

PhD. Student: Ronald Baker, Economics, Indiana University
Thesis: “Comparing group and individual decision making in risky environments.” Experimental methods are used to examine group decision making and compare group decisions to individual decisions in salient and risky environments that involve decisions over asset allocation experiments and lottery choice experiments.
Advisors: Arlington Williams, Hugh Kelley, James Walker

Ph.D. Student (Masters Graduate May 2003): Shanon Donnelly, Geography, Indiana University
Ph.D. Thesis: “The dynamics of land tenure and ownership patterns in land-use and land-cover change.” This research examines the effects of decreasing parcel size on forest-cover and institutional responses.
Masters Thesis: “Linking landscape pattern to social process: a multi-scale analysis of farm woodlots in northern Indiana.” This research addressed the degree to which the current pattern of forest in Indiana can be explained by the rise and fall of agriculture as a dominant land use.
Advisor: Tom Evans

Ph.D. Student: Tei Laine, Joint Ph.D. in Computer Science and Cognitive Science, Indiana University
Thesis: “Compared to what? Evaluation of complex real-world decision-making models.” The topic of the study is to develop and test methodologies for comparing and evaluating computer models of complex real-world decision making against real data.
Advisors: Michael Gasser, Computer Science; Jerome Busemeyer, Cognitive Science

Masters Student: Derek Robinson, Geography, University of Waterloo
Research: Development of the second version of the agent-based simulation. Involved in conceptual design, model development, analysis of model output. Presented findings at two conferences and has participated in the completion of two academic papers related to his work. Robinson is continuing his work in this area as a Ph.D. student at the University of Michigan.
Advisor: Peter Deadman

Ph.D. Student: Wenjie Sun, Geography, Indiana University
Pursuing her Ph.D. degree since spring 2003. Her research interest focuses on investigating individual and group-level land-use decision-making processes through spatially explicit experiments that employs GIS technologies.
Advisor: Tom Evans

Ph.D. Student: David Welch, Environmental Science, Indiana University
Thesis: "Multiple perspectives on forest dynamics in southern Indiana." This study considers questions regarding spatial patterns of forest change in order to reveal the ecological and social processes driving these dynamics.
Advisor: Vicky Meretsky, School of Public and Environmental Affairs

Ph.D. Student: Abigail York, Joint Ph.D. in Public Policy, Indiana University
Thesis: "How does zoning impact land-use change? Assessment from the air, ground, and laboratory." This is a multiple scale and multiple method approach to the study of zoning through game theory, experimental economics, institutional analysis, land-cover change analysis, and spatial statistics.
Advisor: Elinor Ostrom, Political Science

OUTREACH ACTIVITIES

Resiliance, Complex Systems, and Agent-Based Modeling

Janssen shared information about the Biocomplexity project activities through his attendance at the following invited meetings:

Annual Science Meeting of the Resilience Alliance, Morenco, Costa Rica, Nov. 11-15, 2002.

Workshop on "New Modelling Approaches for Sustainable Development," National Institute for Public Health and the Environment, Bilthoven, The Netherlands, April 3, 2003.

"Resilience, Ecology, and Archaeology in the American Southwest," Center for Environmental Studies, Arizona State University, Tempe, Ariz., May 7-8, 2003.

"Robustness of Coupled Human-Environmental Systems," Santa Fe Institute, Santa Fe, N.Mex., May 16-18, 2003.

First CABM/HEMA Workshop "Agent-Based Modelling of Social, Economic and Biophysical Systems," Melbourne, Australia, July 11-12, 2003.

Rangeland Complex System Science Workshop, Townsville, Australia, July 14-19, 2003.

Janssen was one of the organizers of the first conference of the European Social Simulation Association, September 18-21 2003, University of Groningen, The Netherlands.

Open Source Modeling Workshop

In August 2003 a group of researchers met in Boston, Mass., for a workshop titled "Initiating an Open Source\Content Landcover Modeling Effort." This workshop was co-organized by Tom Evans (Indiana University), Charlie Schweik (U. Mass.) and Morgan Grove (U.S. Forest Service). The purpose of this workshop was to discuss the potential for developing a community of modelers interested in contributing to the development of open-source/open-content (OS/OC) models of land-cover change. The workshop covered issues of model design, collaborative infrastructure, OS/OC incentives and funding opportunities.

ABM/LUCC Workshop

During the past year, two versions of the final report of the October 2001 Special Workshop on Land-Use/Land-Cover Change, co-sponsored by CSISS, the LUCC Focus 1 Office, and CIPEC have been published. The first was a summary version published as LUCC Report No. 6, which has received wide international distribution in both hard copy and pdf format. A longer version was published on-line in spring 2003 through CSISS (http://csiss.org/events/other/agent-based/additional/proceedings.pdf).

Land-Use Modeling Workshop

In November 2002, Parker gave an invited lecture and a hands-on workshop on theoretical foundations of agent-based models at the LUCC-sponsored graduate workshop on land-use–modeling techniques. Around 40 young scholars participated in the workshop and completed lab sessions using the Java/RePast model, which has an interactive user interface, to explore a series of hypothetical scenarios.

Other Indiana Land-Use Modeling Efforts

Members of the Biocomplexity project have begun an ongoing dialogue with researchers at Purdue University Department of Forestry and Natural Resources working on the Upper Wabash Ecosystem Project (http://www.agriculture.purdue.edu//fnr/ECASE/objectives.html) focusing on a watershed in glaciated northern Indiana. Through this working relationship we have

- Created coordinated surveys using common questions to maximize spatial and landowner heterogeneity within our survey respondents.
- Begun plans for a one-day information-sharing session with a third group doing land-use modeling in Indiana at The Center for Urban Policy and the Environment at Indiana University/Purdue University, Indianapolis (IUPUI)
- Become involved in several of the committees listed in the next section

Indiana Land-Use–Related Groups

Carlson represented the Biocomplexity project on the following committees:

Natural Resources Leadership Development Institute Advisory Board
The goal of the Institute is to develop leaders who can build collaborative relationships with others around contentious natural resource issues. Training for 30 participants from extension offices, the Indiana Department of Natural Resources, industry, and non-governmental organizations will take place this year.

Stakeholder Advisory Council for Sustaining Private Forests in the Central Hardwood Region and Engaging Citizens as Steward of Ecosystems (ECASE)
Members participate in discussions of the usefulness of models of land-use change to land-use planners and community leaders, and the usefulness of a proposed interactive management model to individual landowners, implementation strategies for research results by individual landowners, multiple ownerships, and land-use planners.

Yellowwood Lake Watershed Group
This group of state employees, watershed landowners, and expert advisors successfully sought a federal grant for watershed planning, which includes the development of a robust GIS database of this state forest–dominated, multiple-ownership watershed.

Monroe County/City of Bloomington CIRCUIT group
This monthly meeting of representatives from city and county offices who use GIS involves discussion of technical issues, coordination of data use and update, and transfer of resources between these government entities and CIPEC/Indiana University.

Meretsky and Welch are both active participants with the Sycamore Land Trust (SLT)
SLT is a non-profit conservation organization dedicated to conserving greenspace, wildlife habitat, and biodiversity in south-central Indiana by acquiring land and conservation easements. The group's work with spatial data has helped SLT organize its spatial data to monitor and manage the properties it owns and to set priorities for future acquisitions. The conversations researchers have had with SLT officials have benefited the development of policy within the organization.

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