Representing economic mechanisms in agent-based models of socio-ecological systems: how far have we come?

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Outline

- Defining “economics” and “markets”
- The role of some important economic processes and their effects in models (focus on agriculture)
- Modeling land markets—why do it, and a progress report
- Open challenges and suggestions for research directions

Some recent economically-driven events

- Global commodity price spikes caused in part by new incentives for bio-fuel production
- The US housing/foreclosure crisis and the resulting global financial crisis
- Changes in housing prices in ex-urban areas due to high energy prices and resulting high transport costs
- Question: How can we better model these events, their social impacts, and their ecological impacts?

What is economics?

- *Economics* is the study of how scarce resources are allocated among competing uses
- Resources are said to be *scarce* if, at a zero price, more is wanted than is available
- Scarcity forces us to make choices regarding how to allocate resources
- Economics encompasses choice related to both market and non-market allocation of scarce resources

What are markets?

- Markets are a means of balancing competition for scarce resources among agents.
- In principle, markets will allocate resources to their highest privately valued use; in practice, a true equilibrium is never reached.
- Private and public values often diverge, especially in relation to ecosystem service provision

Why model markets?

- Markets (those that exist and those that don't) influence the use of natural resources and the provision of ecosystem services

Including markets can:

- Increase the realism and explanatory power of landscape models
- Better reflect the incentives faced by land managers
- Provide additional policy-relevant outputs to the models

Note: Modeling markets does not require assuming perfectly rational profit-maximizing behavior.

Potential Economic/Market Mechanisms for land-use change Models

- Output/commodity prices
- Labor markets
- Fixed costs of adopting new land use
- Risk management and portfolio diversification
- Economies of Scale
- Capital markets (lending and borrowing)
- Land markets

Output prices (exogenous or endogenous)

- Local or global scarcity of a valuable commodity can create incentives for innovation
- Incentives created by global commodity price shifts can lead to production increases at a local level, creating boom and bust cycles (coffee, rubber, lychee, etc. etc.)
- Therefore, some model of commodity price shifts should be needed to successfully model agrarian land-use transitions

Endogenous Output Prices

- If markets for a product are local, the price received may fall as production increases, so oversupply of a locally traded commodity can cause a fall in local prices and incomes
- Alternatively, an endogenous local price creates high payoffs for an innovator--if very little is produced, the price received for the very scarce commodity will be high.
- This is very easy to model!
- Endogenous output prices also assure that some of that product will be produced in the landscape (a local necessity).

Key challenge for output price models

- Many models use fixed output prices to assess individual production incentives at an agent level
- But, models of price expectation formation are needed to create effective models of farmer's supply decisions
- Move from this formulation of the supply question: "At price P_i, what Q_i would the farmer supply?
- To: "Expecting output price P_j, the farmer decides to supply quantity Q_j"

Labor markets

- Most important in developing country models
- A household's land-use decisions may be constrained by available labor if there is no labor market
- A labor market balances demands for additional labor for some households with supply of surplus labor by others, resulting in different production patterns.
- Outside labor opportunities may also facilitate capital accumulation by households.

Fixed Costs to Change Land Use

- Often, there are substantial start-up costs when a manager changes land uses: physical conversion, new knowledge, new equipment, transition periods, certification
- If fixed costs are present, payoffs for conversion may need to be quite high (and certain) to induce conversion
- Fixed costs can explain managers who stick with less profitable strategies
- In general, fixed costs will slow the rate of transitions in landscape models

Risk Management and Portfolio Diversification

- Farming is an incredibly high risk activity due to uncertainty related to input prices, output prices, and weather.
- This risk may lead managers to diversify their outputs.
- By creating a portfolio of outputs that negatively co-vary (i.e., when prices for one are likely to be low, prices for the other are likely to be high, farmers can reduce the overall risk for a given income threshold or subsistence constraint
- The availability of crop insurance may also play an important role in decision making.
- Inclusion of risk can lead to fewer transitions and increased heterogeneity of strategies.

Economies of Scale

- If average cost of production fall as farm size increases, economies of scale are present.
- Fixed costs lead to economies of scale. (Example: tomato harvester in US, also precision farming, soya production and grazing in Brazil)
- The large increase in farm size in the US has been widely attributed to economies of scale.
- Including scale economies in models should lead to more consolidation.

Capital Markets (Borrowing and Lending)

- Access to capital plays an important role for farmers in terms of investments to meet fixed costs of transitioning to new outputs and managing risk
- Capital markets are also important for assessing the long-run value of an investment
- Modeling capital markets can reveal linkages between credit availability, interest rates and land management strategies.
- If long-term investments play an important role in profitability, forward-looking decision models are very important.

Putting the pieces together

- Fixed costs, risk and uncertainty, and scale economies all lead to greater success of large land management operations
- Helps to explain near extinction of small farms in the US
- Also helps to explain the prevalence of urban and residential land developers

Land market processes

- Land markets drive land-use change through:
  - Relative values of urban and rural land
  - Credit availability/Interest rates
  - Institutional incentives/constraints
  - Intensity of competition/price expectations
  - Other drivers of economic land scarcity (population growth, transport costs)
- However, most LUC models do not account for land market drivers and/or dynamics
- What effect does this have on the land change outcomes produced by the models?

My focus-modeling land markets

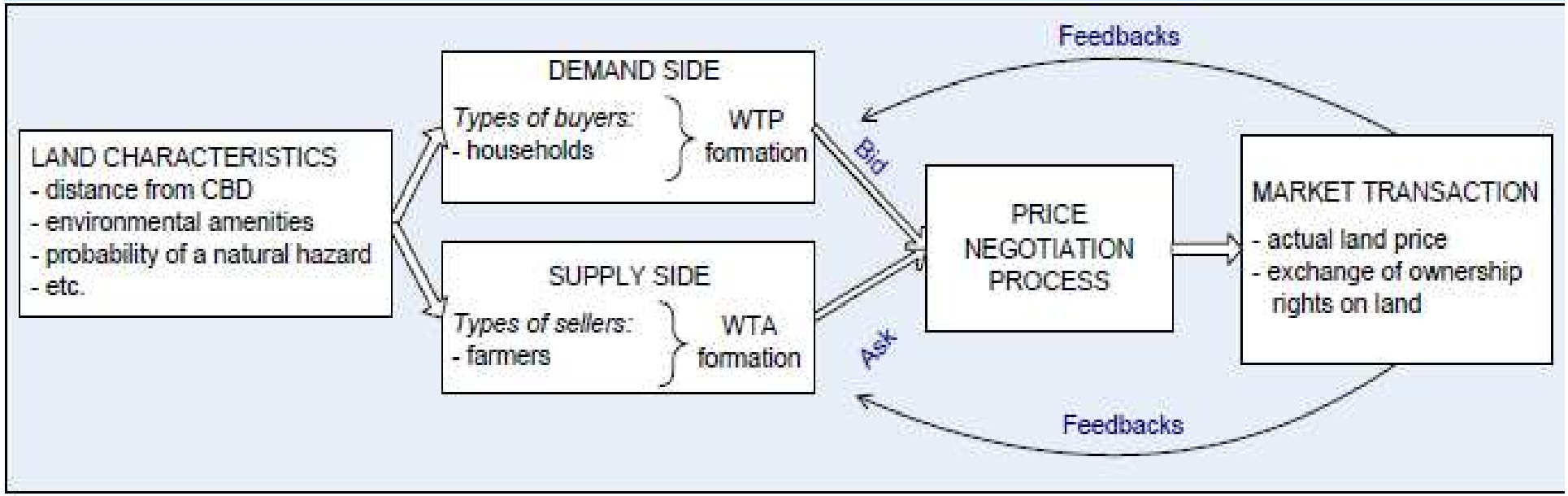
- Why and how should land markets be included in integrated models?
- What difference might emerge when land market models are included?
- Why take an agent-based approach to land market modeling?
- What new questions (and answers) emerge from agent-based land market models?

Activities

- SLUDGE model (Simple market and non-market drivers of landscape pattern)
- FEARLUS-ELMM (Adding a land market to FEARLUS, with G. Polhill and N. Gotts)
- ALMA (A bilateral agent-based land market model, with T. Filatova and A. Van der Veen)
- SLUCE2 project (land markets in ex-urban residential landscapes, with U. Michigan group)
- 2009 GLP workshop on agent-based land-market models (15 international participants)
- Continued sessions/discussions at IEMSS 2010

ALMA – Agent-based Land Market (Filatova PhD)

- Conceptual scheme



- Centralized price determination is replaced by a set of bilateral trades

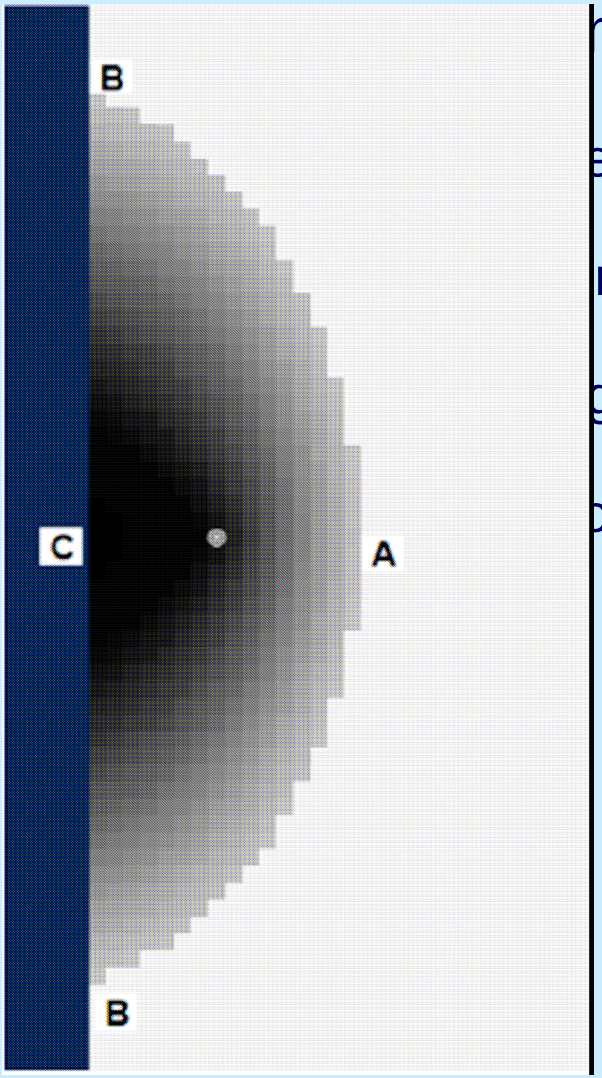
New features compared to previous models

- Detailed representation of drivers on the buyer side
- Agent heterogeneity on both the buyer and seller side
- Decentralized transactions that allocate land to highest bidder
- Separation of underlying valuation (WTP/WTA) from bid/ask price
- Division of gains from trade that depends on relative advantage in the market

Model experiments (CJAE 2010; ESSA 2009)

- I. What land rent patterns emerge in a coastal urban land market? (heterogeneous landscape; agents with homogeneous objective flood risk perception):
  - Monocentric urban model with coastal amenities
  - Monocentric urban model with coastal amenities and disamenities (flood risk)
- II. How do outcomes changes when participants have heterogeneous risk perceptions?
  - Agents risk perception parameterized with uniform (unbiased) distribution

Exp I.1: Coastal urban land market



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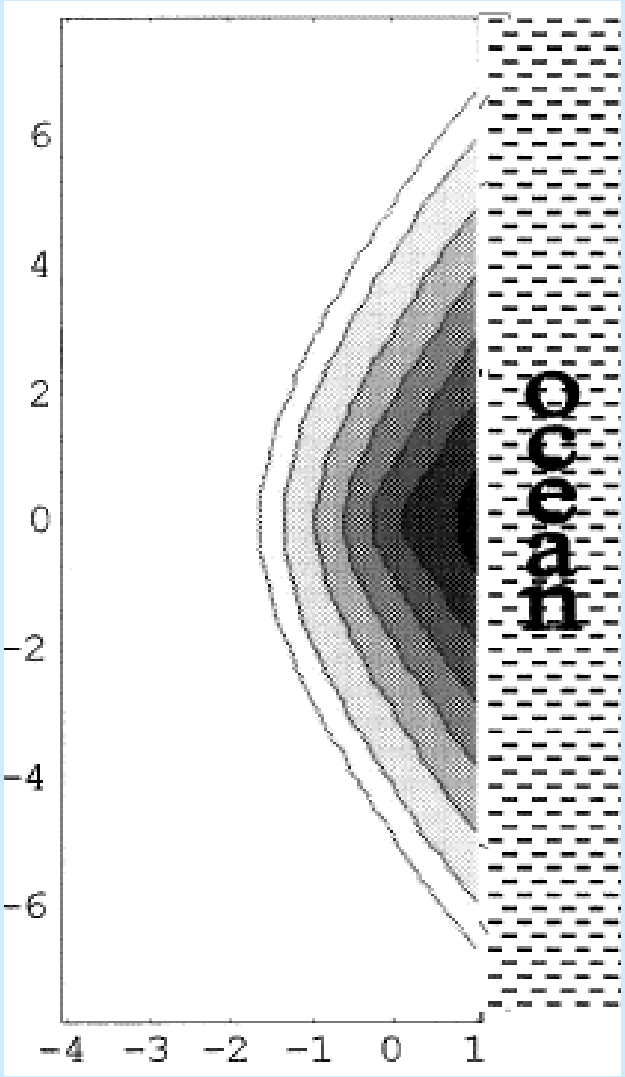
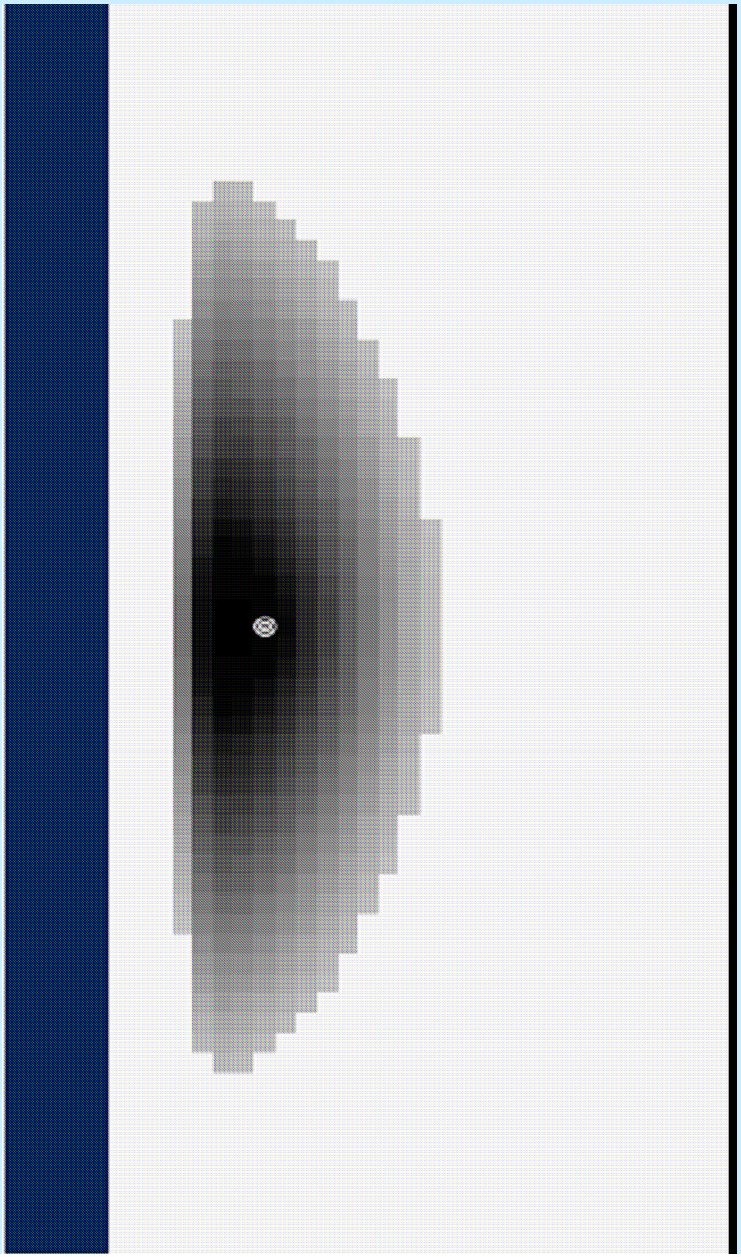


Figure from Wu (2001)1

1 - Wu, J. (2001). "Environmental Amenities and the Spatial Pattern of Urban Sprawl." American Journal of Agricultural Economics 83(3): 691-697.

Exp I.2: Adding flood risk



- Settings:
  - Landscape:
    - coastal amenities (coastal view)
    - disamenities (probability of erosion)
  - Agents:
    - homogeneous preferences for location
    - objective perception of erosion probability, i.e. near-rational decision makers
- Things to see:
  - Equal rents at equal distances
  - Rent gradient goes down with the distance from the CBD
  - Probability of erosion, if perceived, moves urban developments away from the coast

Model experiments

- I. Coastal urban land market (heterogeneous landscape; agents with homogeneous objective flood risk perception):
  - Monocentric urban model with coastal amenities
  - Monocentric urban model with coastal amenities and disamenities (flood risk)
- II. How do outcomes changes when participants have heterogeneous risk perceptions?
  - Agents risk perception parameterized with uniform distribution

Exp II.1: heterogeneous risk perceptions

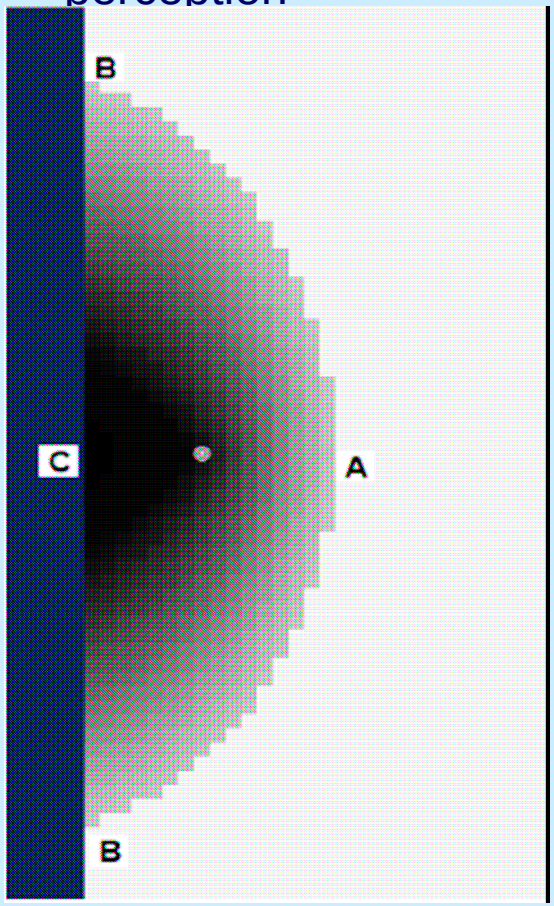
- Settings:
  - Landscape:
    - coastal amenities (coastal view)
    - disamenities (probability of erosion)
  - Agents:
    - homogeneous preferences for location
    - heterogeneous perception of erosion probability, $E(RP_{dev}) = 0$

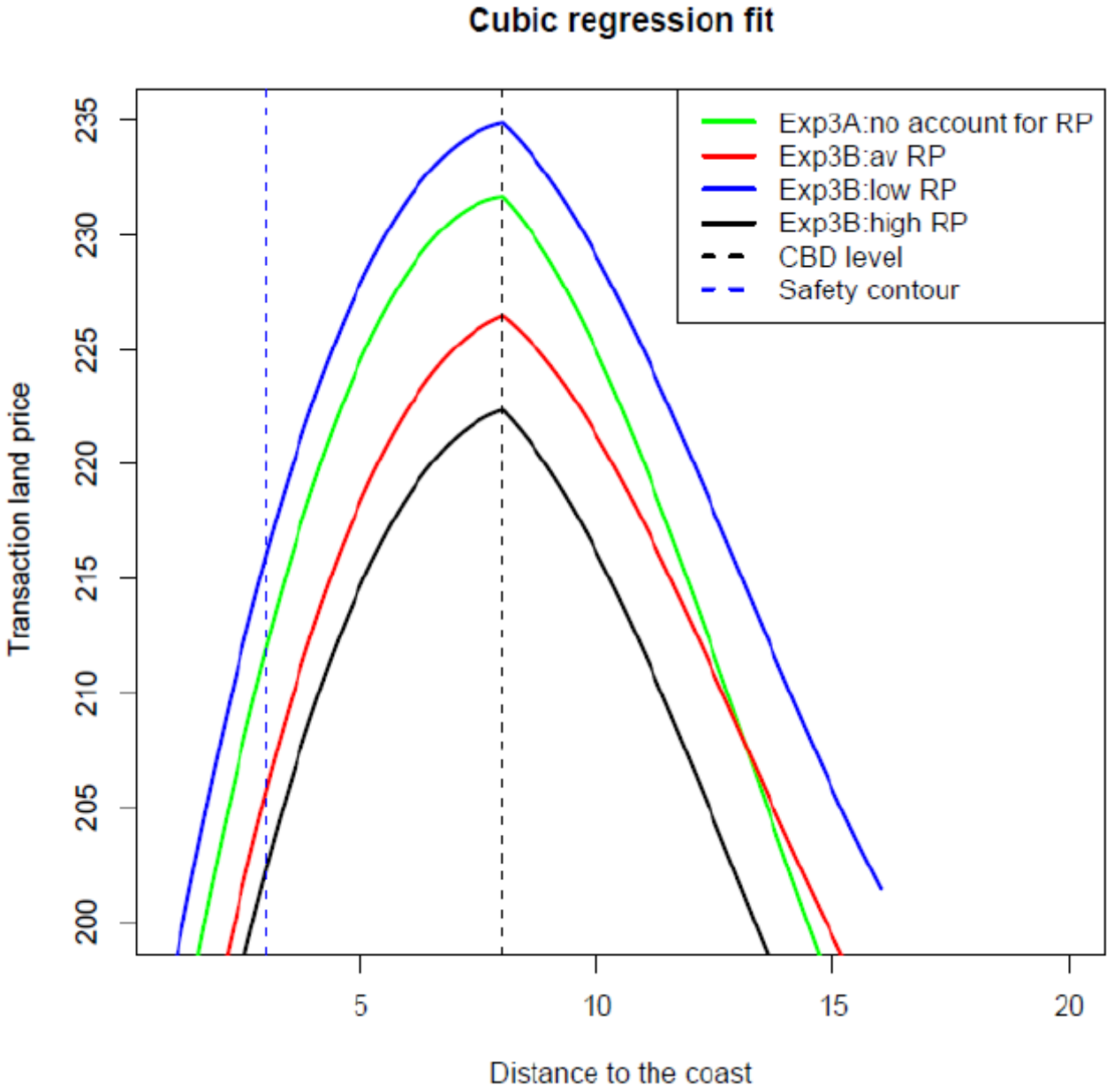
$$PF_i = PF_{obj} \pm RP_{dev}, \quad PF_i \in [0;1]$$

- Things to see:
  - Rents at equal distances are not equal
  - Developments occur in the risky zone that did not with uniform risk perception-risky buyers and sellers drive the

Exp II.1: 2D rent gradient

- Land rent gradient under different assumptions of individual risk perception





SLUCE2: Exploring residential land use, land management, and carbon profiles

- Goal is to develop agent-based models of residential suburban and ex-urban land markets that:
  - Connect land market and land management behavior of residential agents
  - Allow exploration of the relative contributions of land-use vs. land-management change (categorical change and change in intensity) to carbon sequestration in ex-urban landscapes
- Collaborative research in Southeastern Michigan with Project SLUCE team (Dan Brown et al.;)
- Explore the value added of the land market component through comparison to a similarly structured model without a land market component

Models of amenity-driven land-use change

- Variety of fine-scale models of land-use/land-cover change driven by open-space amenities
  - Cellular automaton
  - Neural network
  - Spatial econometric
  - Agent-based
- Successful at qualitative replication of fragmented, leapfrog development patterns at the urban-rural fringe

Need for comparative analysis

- Modeling approaches differ greatly in terms of their degree of process representation
  - CA based on land-cover patterns are highly inductive, pattern based
  - ABM incorporating both social and spatial data are highly processed based, potentially “pseudo-inductive”
  - Beyond structural differences, models include different drivers and assumptions regarding land-use change mechanisms
- Very few structured comparisons done

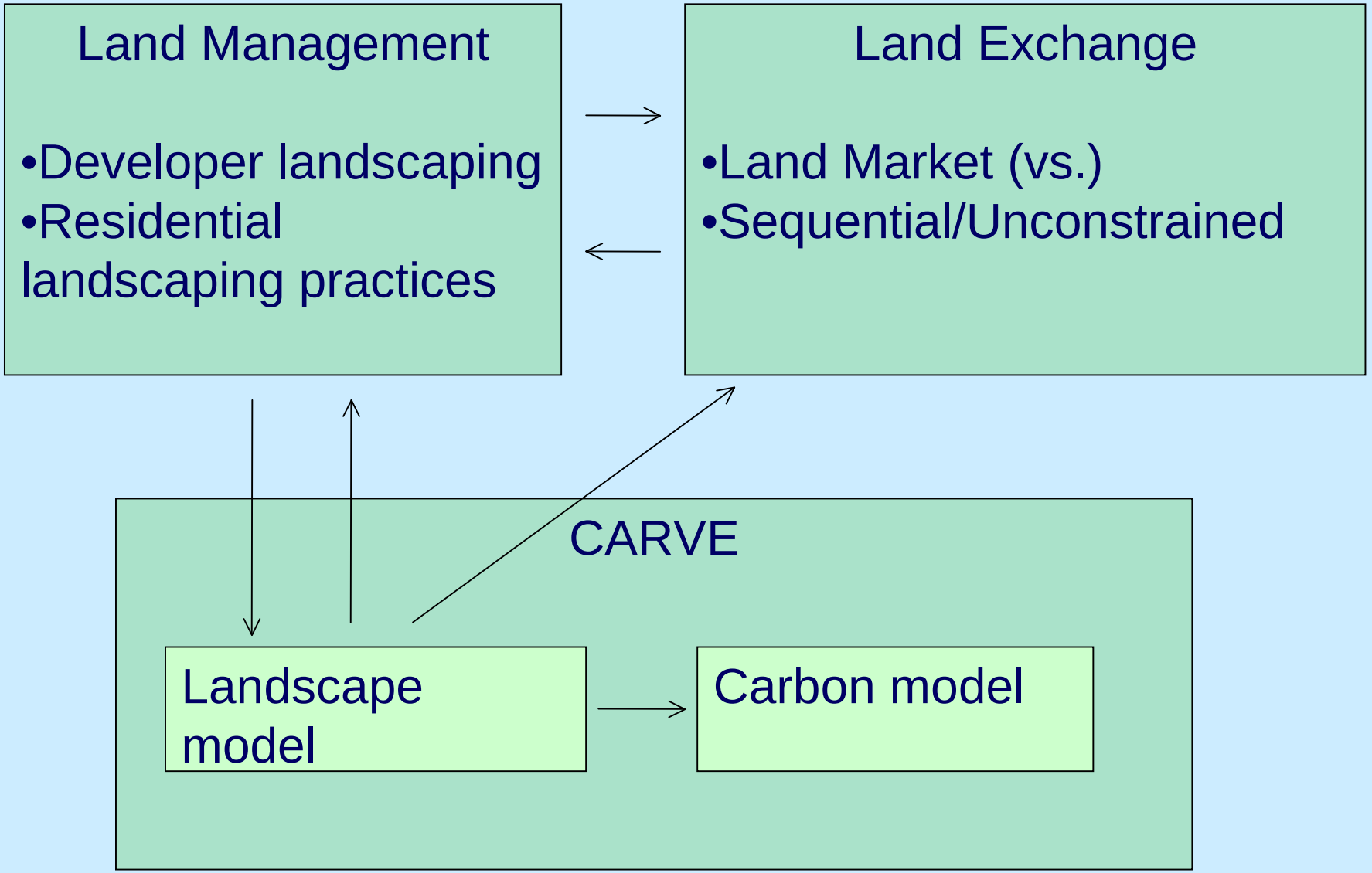
Environmental impacts of residential development

- Suburban and ex-urban development bring about environmental change
- Evaluation of impacts requires understanding of:
  - *Location and timing of land-use change
  - Characteristics of new or modified development
  - Land management behavior of new residents
- Three factors are jointly determined via land market interactions

Role of land markets in addressing research questions

- Land markets determine both:
  - The location, timing, and pattern of residential conversion;
  - The socioeconomic and cultural characteristics of new residents.
- These two factors influence:
  - The character/intensity of the new land use;
  - The environmental behaviors of new residents.

SLUCE 2 components



Current work

- Starting with very simple model, urban residents and rural sellers only
- Defining “land market” was a challenge- broken down into several key elements
- Presenting model framework and experimental design today
- Design sequentially introduces additional market elements
- First experiments planned to be completed in April, 2010

Land market dynamics: modeling challenges

- What is a “land market,” and how do you turn it on and off?
  - Introduce resource constraints
  - Introduce competitive bidding
  - Introduce endogenous relocation (decision to sell)
- How do in-migrating and out-migrating buyers and sellers influence markets? Can you have a dynamic market model without them?

Overview: Levels of market representation

Table 1. Degrees of market representation: Model levels and their definitions

Level 0	Level 1	Level 2	Level 3	Level 4
No LM	Add Resource Constraints	Add Competition	Add Strategic Behavior	Add endogenous Supply Decisions
No resource constraints, competitive bidding, strategic behavior, or endogenous supply decisions	Level 0 plus resource constraints for buyers and sellers	Level 1 plus allocation via competitive bidding	Level 2 plus strategic bid/ask price formation	Level 3 plus modeled decision to sell rural parcel

Some research questions: Land market dynamics

- Assuming some fixed underlying value (WTP/WTA), how are the bid and ask prices of buyers and sellers influenced by:
  - Expectations regarding other bids/future prices?
  - Past sales in local neighborhoods?
  - Global trends in previous sales?
- Can price expectation formation and/or strategic bidding lead to:
  - Path-dependent spatial variation in properties of comparable quality?
  - Endogenous housing price bubbles?

Which economic mechanisms have we included so far?

- Endogenous output prices-yes
- Labor markets-no
- Fixed costs of adopting new land use-In progress
- Risk-yes
- Economies of Scale-In progress (Developers)
- Capital markets-In progress (interest rates and credit availability)

ABM moving slowing into traditional economics..

- Special workshop, "The economics of land use: Advancing the Frontiers," organized by Jackie Geoghegan and Lori Lynch (2009)
- Organized session: "Applications of Economic Agent-Based Urban Growth and Land Use Models" at the 2009 North American Regional Science Association International meetings (Organized by Resources for the Future staff)
- Special Issue of the Canadian Journal of Agricultural and Resource Economics on Computational economics v6 (8) (several) spatial and biophysically oriented models)

What is the motivation?

- Limitations of traditional modeling tools for accomplishing specific research goals are being recognized;
- A recognition that agent-based models more effectively incorporate heterogeneity than traditional modeling methods;
- A desire by North American economists to participate in large, interdisciplinary funding initiatives;

Important open areas-Price expectation formation

- Every difficult spatial economic ABM model challenge requires some model of price expectations for decision makers—because models can no longer be “solved” for prices (see Nolan et. al CJAE intro discussion)
- Big challenge for economists—lesson learned from financial economics could be applied

Important open areas-coupling with CGE models

- “Computable General Equilibrium” (CGE) models are widely used for regional modeling and agricultural policy analysis
- These models are based on empirically estimated supply and demand models
- Could supply and demand relationships generated from agent-based models be used to provide the lower-level inputs to CGE models?
- How can a dialog be started with traditional agricultural economists around these questions?

Non-market values and created markets

- Many resources have value but are not traded in markets
- Many “ecosystem services” fall in this category: water purification, climate regulation, biodiversity, etc.
- ABM may be useful to explore the implications of market creation and of different institutional structures for markets

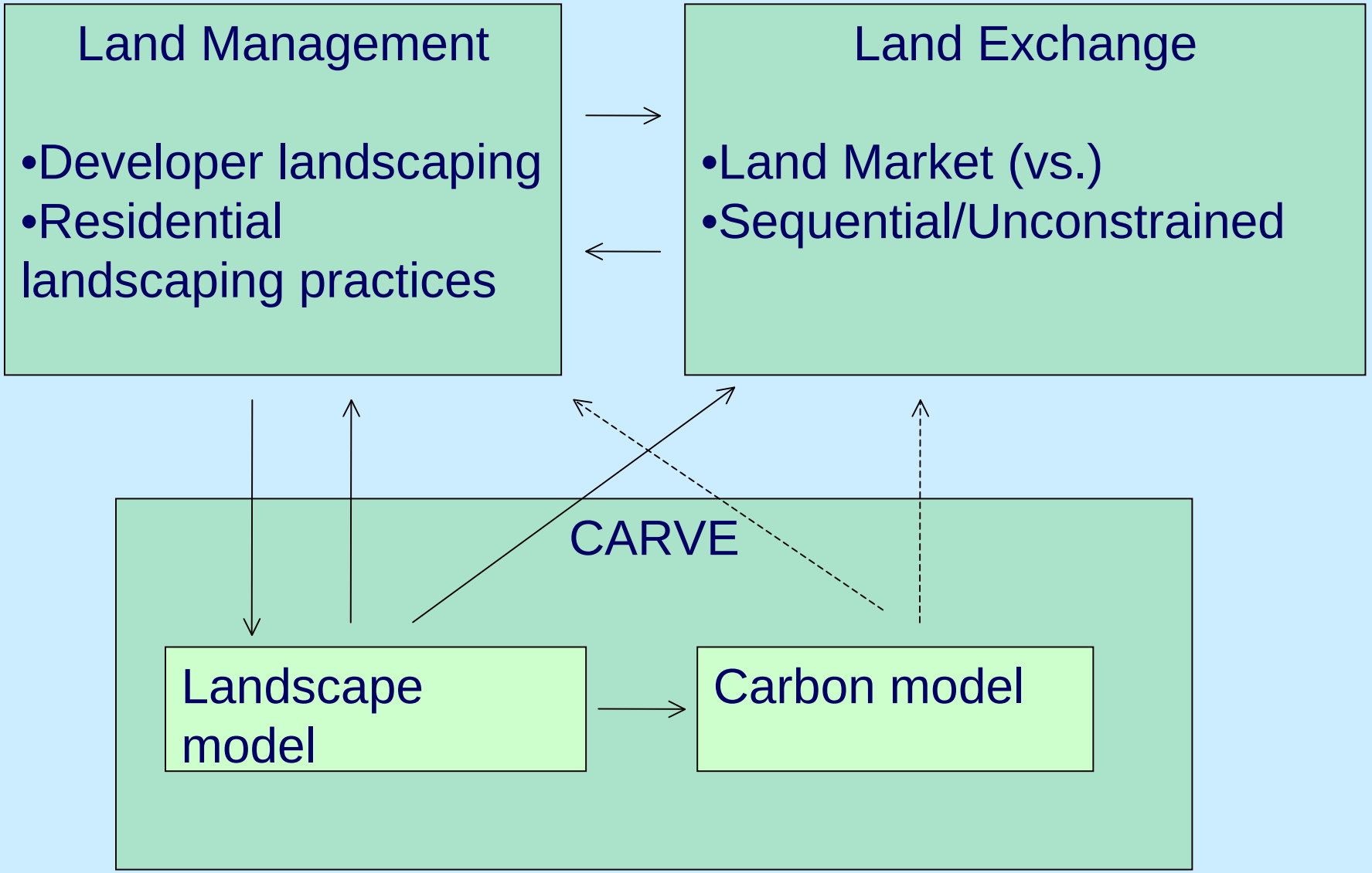
Important open areas-market-based instruments

- Market-based instruments such as tradable permits, targeted subsidies, etc. are potentially useful when differences between economics actors (individual or spatial heterogeneity) create potential “gains from trade” or efficiency gains
- Many potential examples:
  - Individual tradable quotas in fisheries;
  - Water quality trading;
  - Spatial subsidies for habitat preservation (BAMIÈRE , this conference)

ABM and carbon markets

- Can we develop ABMs to assess potential participation in terrestrial carbon markets?
  - Agricultural
  - Forestry/forest preservation
  - Ex-urban and suburban residential landscapes
- Can these models be used to assess effects of carbon market incentives on other ecosystem services?

Dashed arrows = carbon market feedbacks



SLUCE2-- Carbon market questions

- What payments might development receive under status quo conditions?
- Would these payments be sufficient to alter developer incentives? (what is their capitalized value?)
- Would they alter land market outcomes?
- Could the social signaling of carbon market participation have a social value out of proportion to its economic value?
- Are there thresholds in carbon payments that would cause a discrete switch by developers to more carbon-friendly landscapes?

Conclusions/Take-home points

- Economic incentives influence landscape outcome!
- Their inclusion can change (and maybe even improve) the performance of integrated landscape models
- Work is underway, but much needs to be done
- Most important work may be building stronger ties with the economics community-requires cultural evolution from both sides

Acknowledgements

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