CHANGING CLIMATE - CHANGING BEHAVIOR

Modeling abrupt structural shifts in complex socio-environmental systems (SES) from the bottom-up

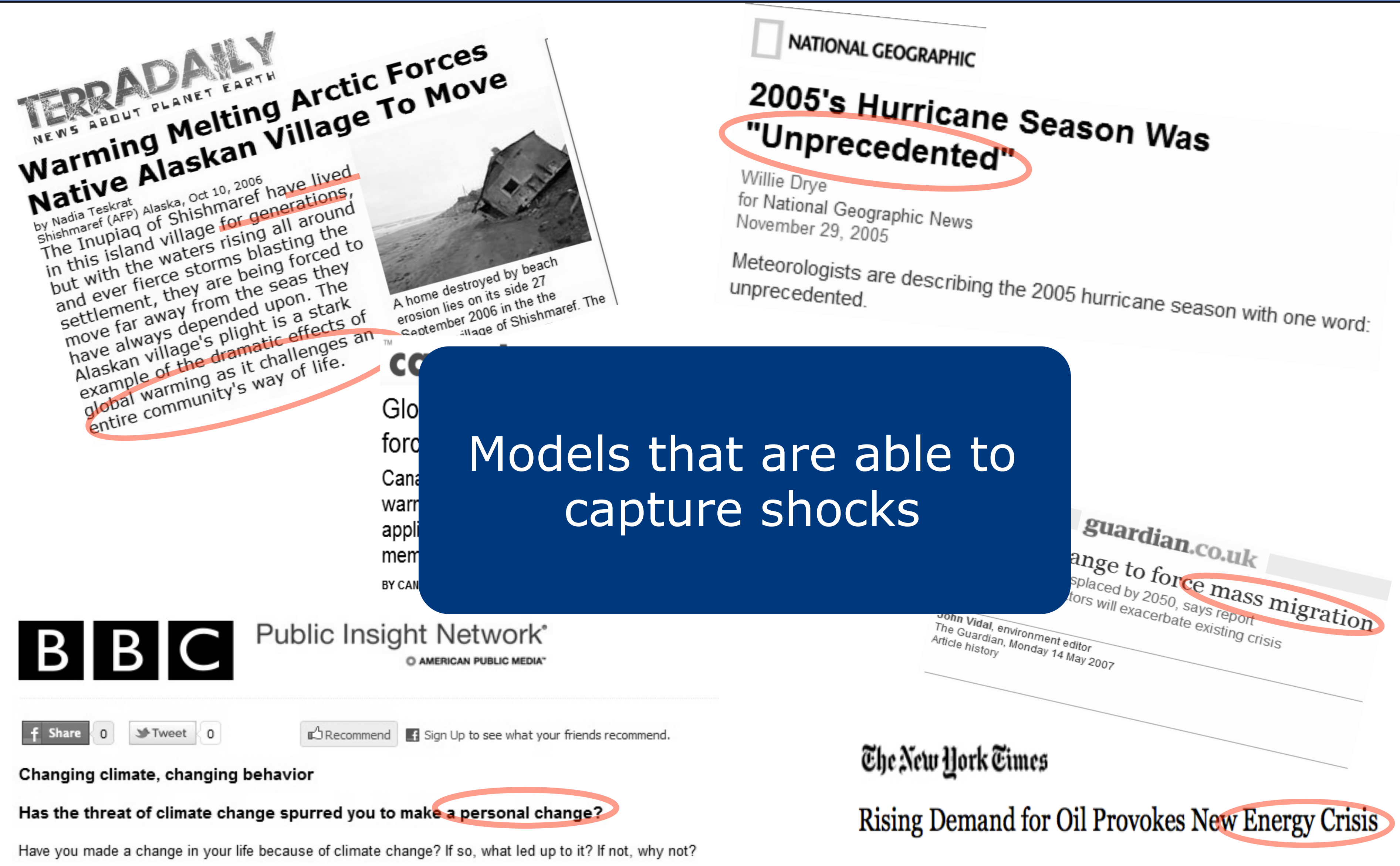
Tatiana Filatova

1 - University of Twente, Institute of Governance Studies, CSTM & LSEB
2 - Research Institute Deltares
The Netherlands

UNIVERSITY OF TWENTE

Deltares
Enabling Delta Life

Abrupt structural shifts in SES



Models that are able to capture shocks

What is ‘shock’?

- Shocking event (disturbance)[1]:

  an exogenous forcing

  - either in the form of an extreme change in an input parameter
  - or in the form of a hazard event

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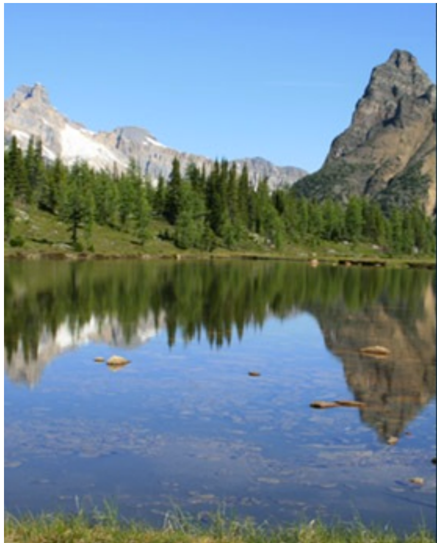
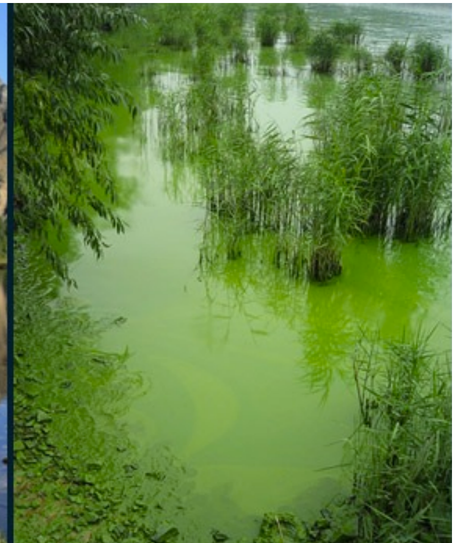




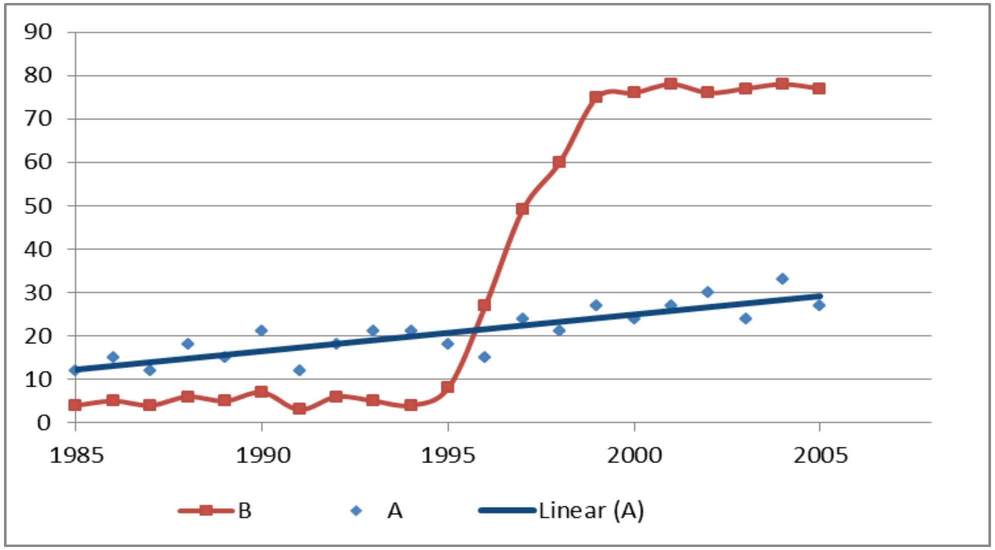
- Systemic shock[1]:
  - stands for a sudden structural non-marginal change in the system, i.e. regime shift

1 - Filatova T. and G. Polhill 2012

SES as complex adaptive systems

- Complex adaptive systems[1]:
  - constantly changing
  - co-adapting
  - perpetually in out-of-equilibrium

- Marginal vs. non-marginal change



- Marginal change:
  - gradual move along a certain trend
  - "convenient" for decision-makers (and modellers): prediction of future states can with certain confidence rely on the historic trends and historic data
- Non-marginal change[2]:
  - Abrupt sudden shifts from 1 system state to another
  - NEW properties, NEW structure, NEW feedbacks, and NEW underlying behavior of components or agents
  - Systemic shock

1 – Arthur et al. 1997; Folke 2006; 2 - Scheffer et al. 2009; Kinzig et al 2006; Stern 2008.

Typology of shocks

	Current system state is maintained	*Systemic shock (shift to a new system state)*
Shock as a driver (disturbance)	I. Recovery back to the same state	III. New state driven by exogenous shock
Gradual change	II. Remain in the same system state	IV. New state driven by endogenous gradual change

- Many simulation models now:
  - Past ≅ Today ≅ Future
  - Would reproduce systemic shock only if it was in the historic data => small sample or unprecedented event
- Simulation models driven by current needs
  - Past ≅ Today ≠ Future
  - Ability to accommodate new states
  - & to grow them endogenously

When it comes to modeling[1]….

- ‘Perfect storm’
  - Particular combination of a number of variables, each of which individually might not be thought extraordinary but collectively form a highly unusual set of circumstances

- Scales:
  - Interaction of processes on different temporal scales: time lag between action/event -> response of ecosystem -> ‘learning’ or expectation update -> change in individual behavior
  - Spatial correlation (domino effect)

- Other modeling issues:
  - Shock: endogenous or exogenous
  - Representation and registering of new states
  - Thresholds
  - Persistence and suddenness (time scale)
  - System boundaries

1 – Filatova, Polhill (2012)

When it comes to real data….

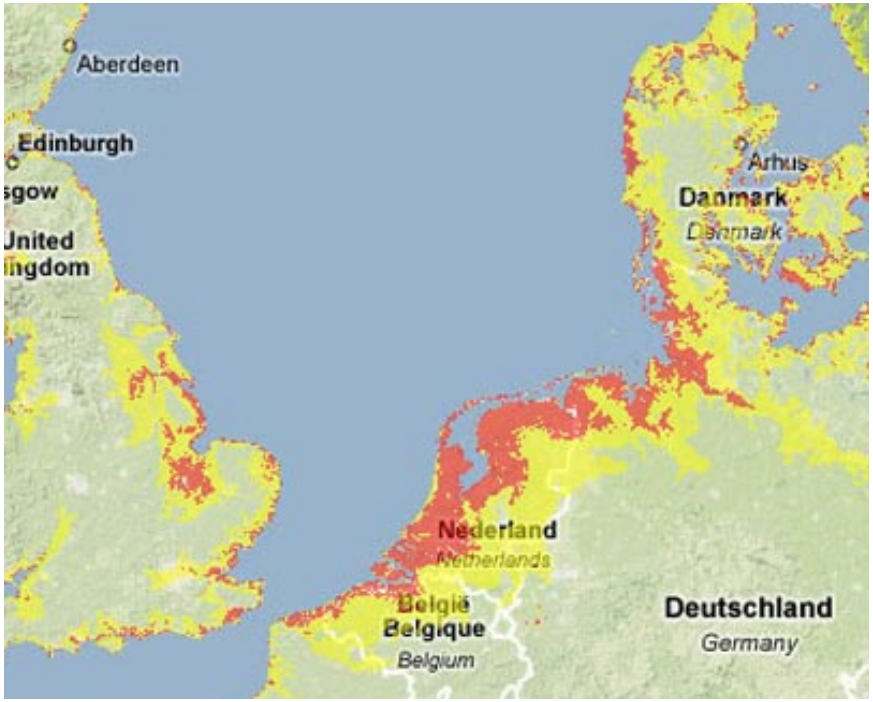
- Berger et al (2002)
- Windrum et al (2007)
- Robinson et al (2007):
  - Inform micro-level processes and provide macro-level validation
  - A snapshot in time: sample surveys, GIS and remotely sensed
  - Potentially dynamic: participant observation, field and laboratory experiments, and companion modeling – often capture past-present behavior transition
- Smajgl et al (2011):
  - 12 steps (incl. the identifying behavioral rules and the scaling up)
  - A snapshot in time: expert knowledge, social surveys, census data, dasymetric mapping
  - Potentially dynamic: participant observation, interviews, field or lab experiments, RPG
- Parameterization and validation is different when you expect shocks in SES to occur:
  - Has structural shift happened before in the system or is it expected?
  - Is it registered in your data (time horizon and sample)?

Example

- Changing climate – changing behavior:
  - Dutch NWO VENI grant 2012-2016
  - Land-use and non-marginal changes in hazard-prone areas
  - USA and NL

Climate change (CC): coastal and delta areas

- **2/3** of world population



- red – 2 m, yellow 25m

Katrina

Brisbane

Climate change, location and risks

changes in individual location behavior?
(changes in preferences and risk perceptions)

↓

changes in the future demand and supply
for land in flood-prone areas

↓

collectively changing land market dynamics
(land prices and spatial patterns)

Potentially: abrupt structural change

↓ changes in possible damage

↓ changes in pressure on spatial planners

"... and this glorious cliff-top property has recently been reduced by 50%..."

Existing models

- Land use models (geography):
  - Suitability of a certain land use in a certain location (regression analysis):
  - Past data (past or current climate)

- Hedonic models (economics):
  - Property price (Y) as a function of its spatial (X), neighborhood (Z) and structural (F) attributes[1]:

$$\ln Y = \alpha + \sum_i \beta_i x_i + \sum_j \gamma_j z_j + \sum_k \phi_k f_k + \varepsilon$$

$$\varepsilon = \lambda W \varepsilon + u,$$

  - Here β_i, γ_j and ϕ_k denote marginal willingness to pay (WTP) for an attribute, e.g. WTP to avoid flood risk
  - Past data (past or current climate)

1 – Bin et al 2008

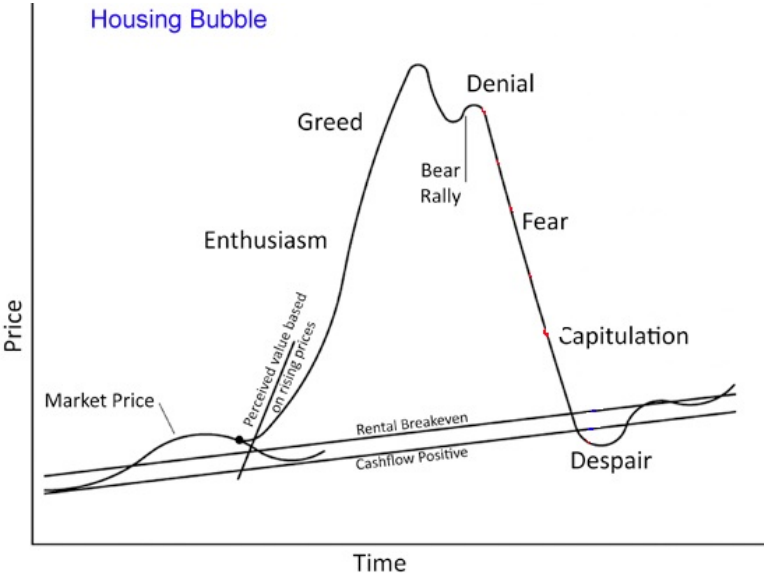
Empirical evidence: it is dynamic

- Price discount:
  - Prices for the properties in hazard-prone areas are lower that in safe (4%-10%)
  - Effect significantly increases after a flood event:
    - Price discount increased from 3.7% to 8.3% after Hurricane Floyd[1]
    - Properties with lower probabilities of flood (1:500) received price discount of 2-5% only after river floods[2]
  - Impact on non-flooded propertied: 19% price decline after a nearly-missed Hurricane Andrew[3,]
  - Effect disappears 5-6 years after the hazards event[4]
  - Marginal WTP is constant across households and quantity of flood security[5]

1 — Bin and Polasky 2004; 2 – Kousky 2010; 3 – Hallstrom, Smith 2005; 4 – Bin and Landry 2013; 5- Pryce, Chen 2011

Climate-changed world

- Stern (2007): CC is to cause non-marginal changes
  - Significant, sudden, structural



- Policy decision-support tools:
  - Economic equilibrium models →
  - Cost-Benefit analysis
  - Land-use statistical models

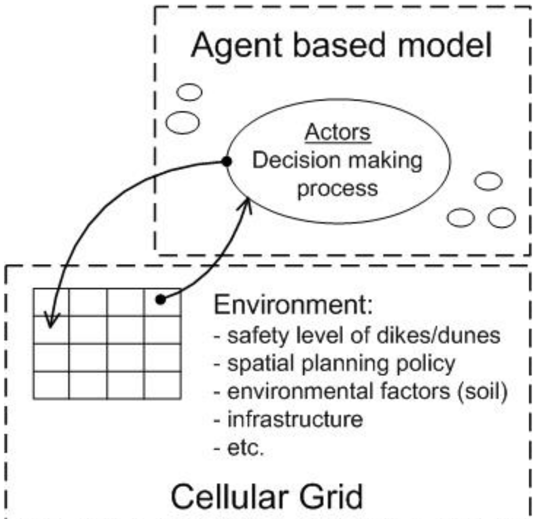
- marginal change!
- static behavior

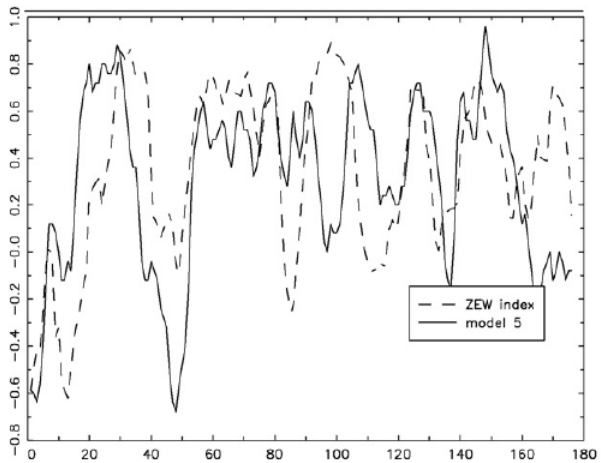
My approach

1.Agent-based modeling (ABM) & hedonic studies

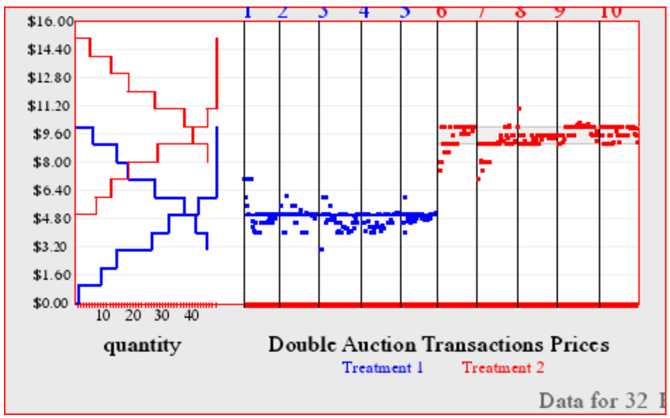
2.Evolution of risk perception (RP) & ABM

3.Lab experiments & ABM





Lux (2009)



Past probabilities and RP

Theory: possible future RP

Data: possible future RP

4.Policy implications:

simulation laboratory to explore individual spatial adaptation

1. Agent-based land market model

- ABM land markets (LM)
  - ALMA: urban LM in hazard-prone area

    biased individual RP
  - Filatova, Parker, van der Veen (2008, 2009) & US NSF SLUCE 2 project

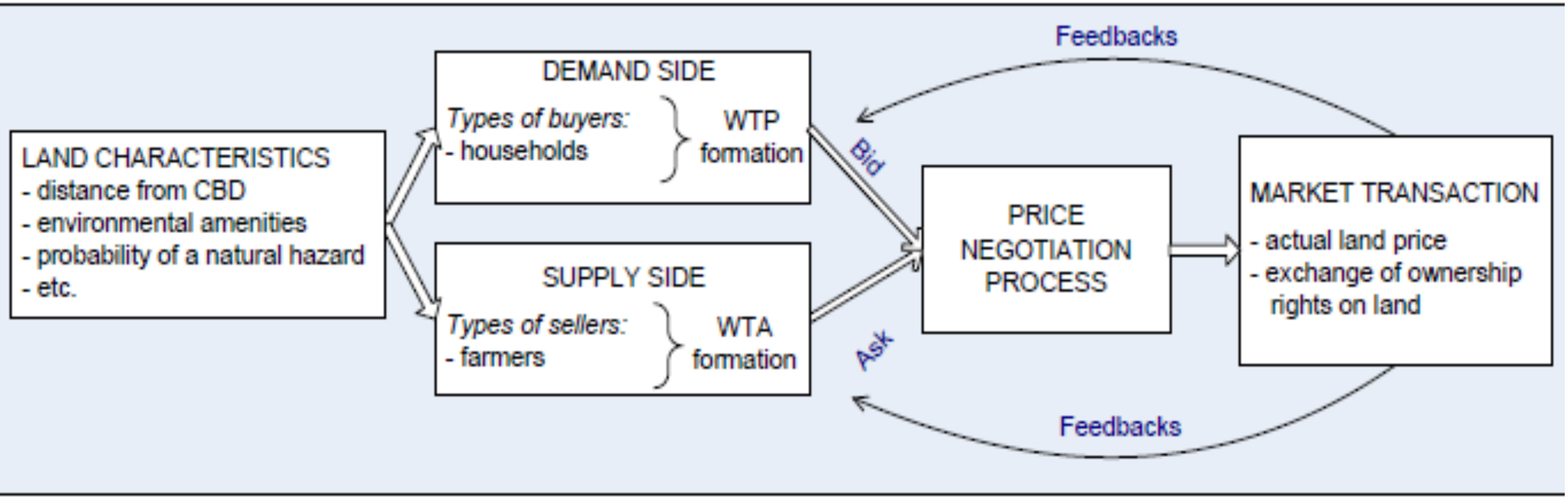
    ➡ Irwin (2010), Ettema (2011), Magliocca et al (2011), Chen et al (2012), Parker et al (2012)

- ALMA
  - Prof R.Axtell[1]: start from the conventional analytical model and gradually relax its assumptions
  - Start from urban economic models and decisions under uncertainty and relax assumptions:
    - equilibrium in 1 shot ⇔ bilateral trades
    - rationality and perfect information ⇔ bounded rationality
    - representative agent⇔ heterogeneous agents
    - opportunities to include social interactions

1 – Axtell, R. (2005).

ALMA: basic model

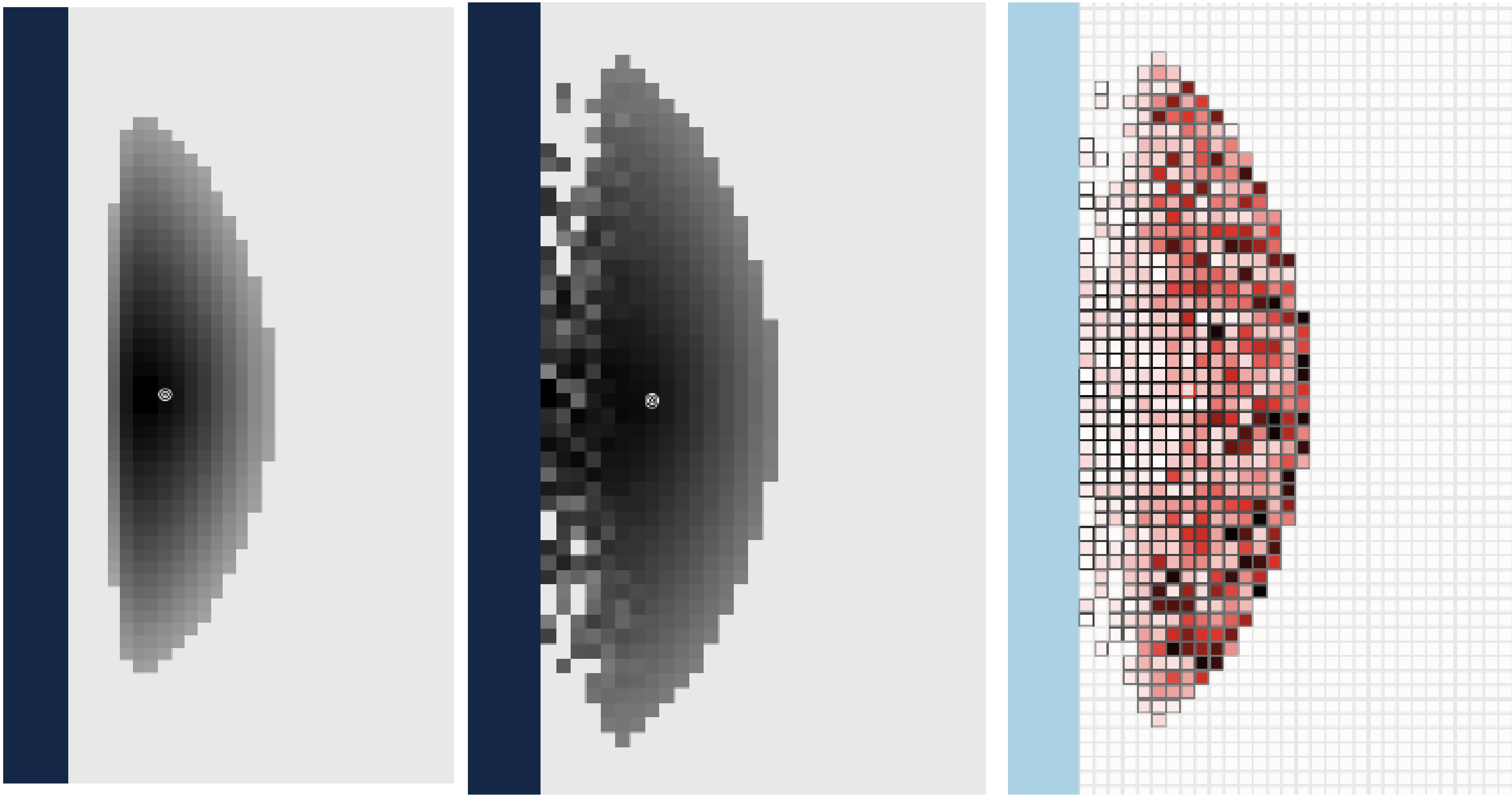
- Essence:
  - Agents are individuals selling land and buying properties
  - ALMA allows investigation of the emergence of aggregated patterns (prices and urban structure) under different assumptions about individual behavior



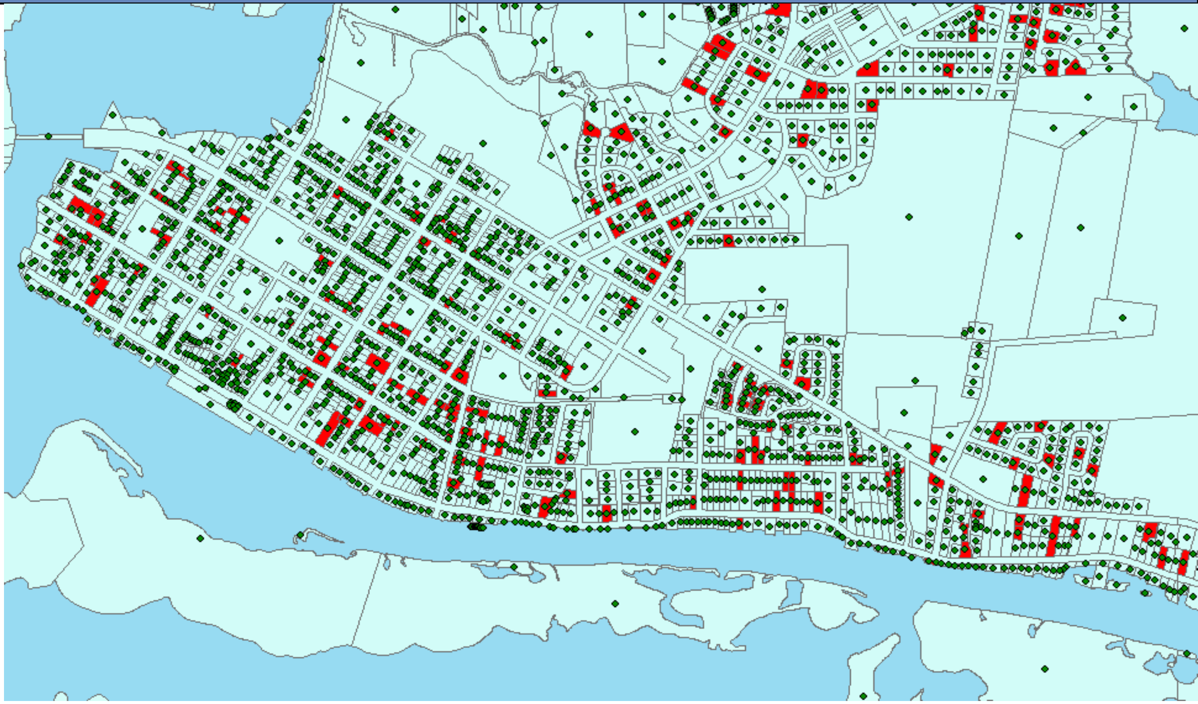
  - Decentralized transactions that allocate land to the highest bidder
  - Heterogeneity of landscape: flood risk and coastal amenities in a fully-modelled land market
  - Heterogeneity of agents in risk perception and use of survey data

ALMA: basic model

- Some results:



ALMA: empirical adaptive LMM

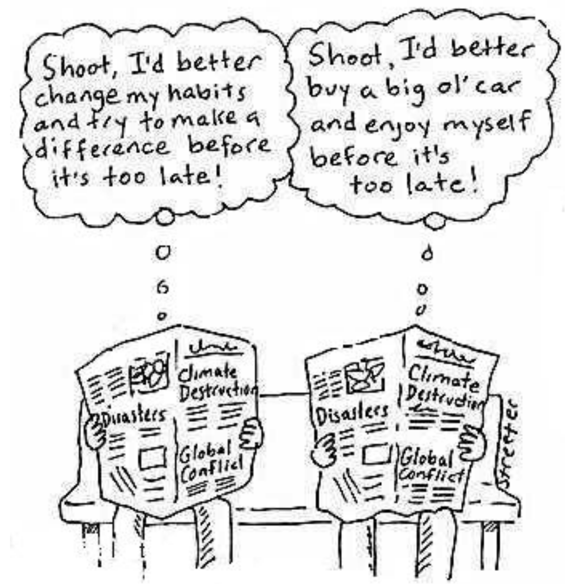


- Spatial landscape
  - Empirical data at initialization
  - CC scenario of changes in probabilities
  - USA: Carteret county (NC)
  - NL: Rijnmond area
- Agents behavior
  - Expected utility or prospect theory
  - Maximize utility under budget constrains
  - Expectation formation about risks => boundedly-rational
  - **Real estate agent**: expectation formation about prices
  - Bid or ask price: hedonic price function at initialization

2. ALMA: Evolution of RP (theory)

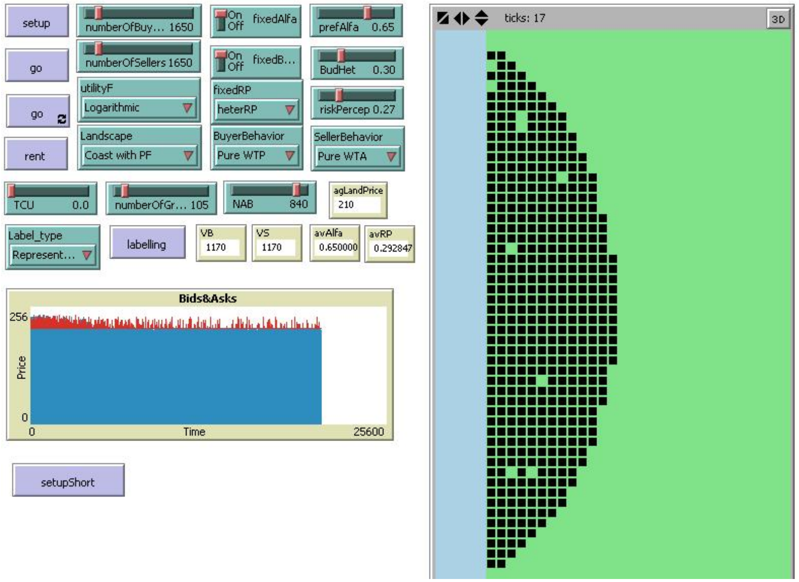
- Ex-post change in RP

Ex-ante change in RP



- Review of theories (*criteria*) → 2D landscape
  - Opinion dynamics
  - Innovation diffusion
- Evolution of RP → ABM land market
- New features:
  - Different levels of risk-aversion
  - Change in the RP bias
  - Structural change: swap of function

3. Evolution of RP: data



- Model simulations
  - Empirical micro-foundations for ABM

Laboratory experiments

- Extension of behavioral patterns (time &space)

4. Policy implications

- **Virtual lab to explore policy options**
  - Under various behavioral assumptions
  - Accounting for behavioral change
  - Giving rise to potential structural changes in SES in a climate-change world
- **Behavioral change**:
  - Change in agents' attributes or rules rather than just choices
  - Evolution of risk perception
  - Changes in demand and supply of properties in certain areas
  - Adaptive price expectations
- **Potential systemic shock**:
  - i.e. structural non-marginal change, regime shift, critical transition
  - Structural change in and swap in the slope of hedonic function => WTP => CBA
  - Mass outmigration from the areas that are currently highly attractive
  - Shift to a completely different risk management policy

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Simulation model:

- Adaptive behavior
- Learning
- Interactions

Data on behavior:

- Span across time (past/present, future)
- Elucidate thresholds
- Role of interactions

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Related work: modeling structural changes in SES

- **Farmers adaptation to droughts in the Netherlands (2010-2015)**
  - With R. van Duinen (PhD student UT, Deltares)
  - Survey (about 2000 respondents): on perceived risks and adaptation options
  - ABM to study cumulative effects of changes in risk perceptions, adaptation strategy diffusion, on the vulnerability of agricultural sector.

- **Climate-driven migration in Bangladesh (2010-2015)**
  - With M. Assaduzzaman (PhD at UT) and B. H. Mahmooei (Monash University)
  - Interviews (> 50 respondents): on perceived risks and livelihood options (incl. migration) in villages prone to coastal and river
  - ABM to study climate vulnerability and migration in Bangladesh

- **Farmers adaptation to droughts in Australia (2012-2013)**
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  - Interviews and stakeholder mental maps
  - ABM integrated with hydrological model

- **Transition to low carbon energy economy (2013-2016)**
  - Survey: on perceived CC risk, household energy consumption choices
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Open questions

- …when parameterizing and validating models of SES experiencing systemic shocks / non-marginal changes/ regime shifts:
  - Emergence of new system states
  - Limited time horizon/sample
  - Dynamic settings when acquiring data
  - Balance of theory and data

Thank you!

QUESTIONS ARE WELCOME

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