Incorporating land markets in agent-based models

Dawn Cassandra Parker

Qingxu Huang, Derek Robinson (UW)
Tatiana Filatova (U of Twente)
Shipeng Sun, Daniel G. Brown, Rick Riolo (U of Michigan)

Prepared for “Spatial land use in integrated assessment models”, Snowmass, CO, USA, 23-24 July 2012

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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
- However, most LUC models only partially account for land market drivers and/or dynamics.
- What effect does this have on the land change outcomes produced by the models?

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Land market issues: Regional and global context

- Housing market crash and global financial crisis
- Rising gas prices and fall of residential land values in low-accessibility areas
- Global trends towards urban migration and urbanization
- Biofuel initiatives, rising agricultural commodity prices, and agricultural land markets
- “Land Grabs”
- REDD and emerging carbon markets
- More?

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What is a land market?

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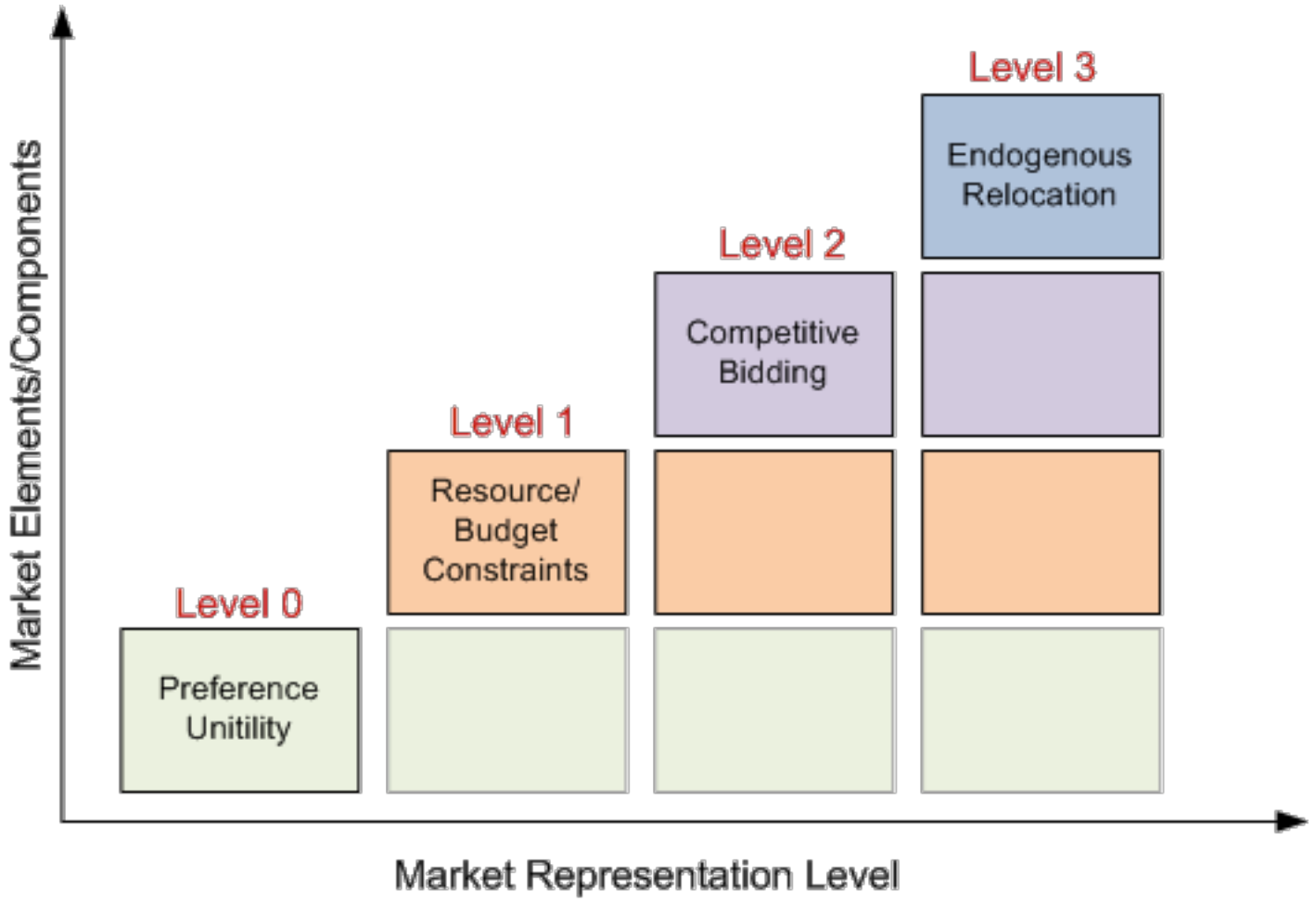
Levels of Market Representation



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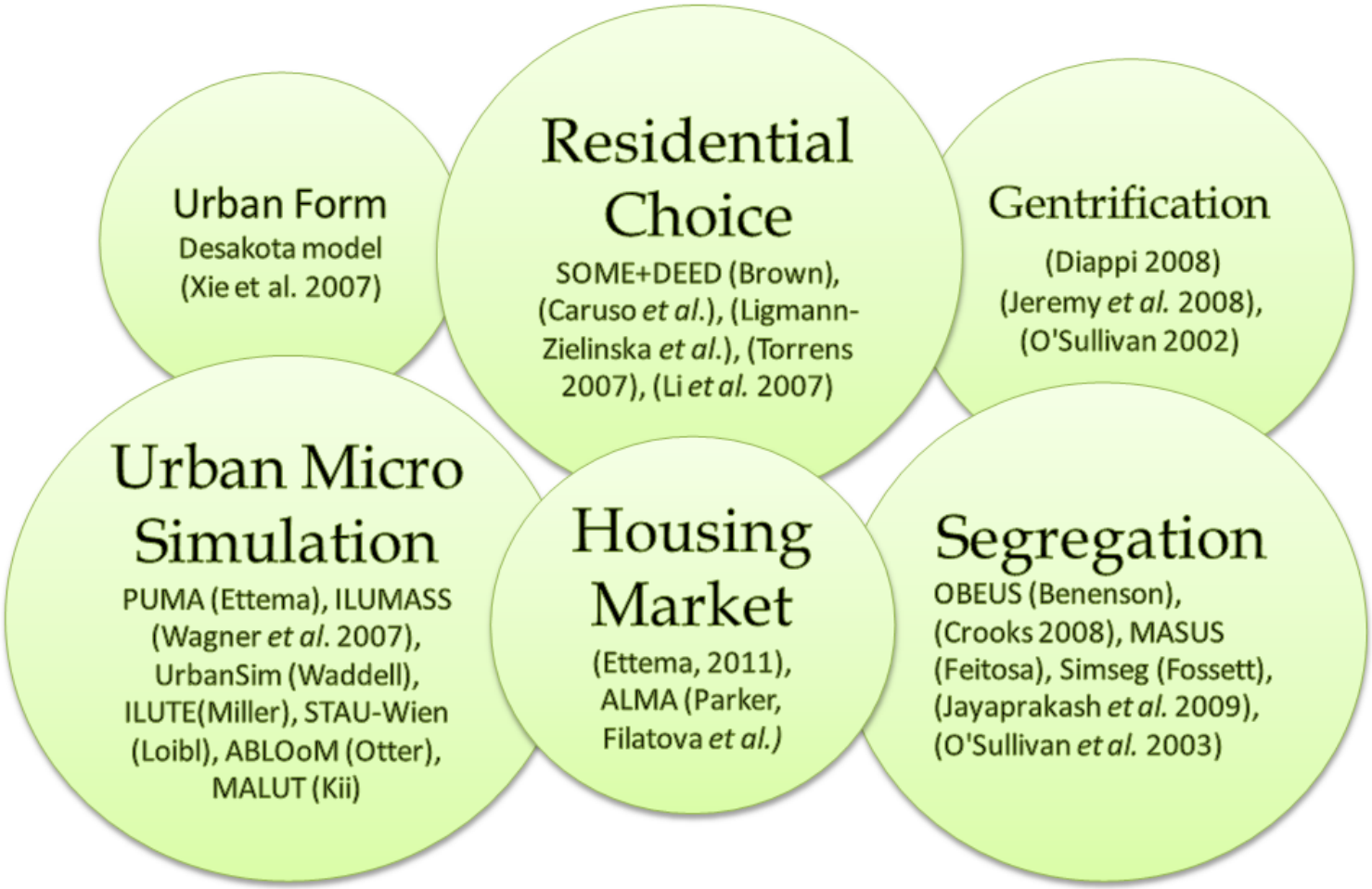
Examined LUCC models (Huang, in prep)



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Land market and agent heterogeneity in existing models

Elements	Type	Number
Budget Constraint	No Constraints	18
	Budget Constraints	29
Competitive Bidding	No Bidding	26
	Simple bidding	10
	Unknown	11
Endogenous Relocation	No Relocation	17
	With Relocation	25
Effect of Agent	Not mentioned	41
Heterogeneity	Tested	6

* Total number of examined LUCC/ABMs is 47.

Our application: Amenity-driven Land-use Change Models

- Variety of fine-scale models of land-use/land-cover change driven by amenities
  - Neighborhood quality such as green space, school quality etc.
  - Accessibility to work, to recreation, to health services, etc.
- Succeed at replicating patterns of fragmented urban development
- LUCC projections can be linked to ecosystem services, especially carbon sequestration (SLUCE II Project).

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Residential development and landscape change

Model Design

- Landscape
  - Abstract, featureless, monocentric with two land uses
- Agents
  - Buyers: residential households with heterogeneous preference and budgets
  - Sellers: with reservation price for the land
- Market Institution
  - Sellers supply a single parcel on the market at an asking price.
  - Buyers search the market and bid on a single parcel with the highest utility.
  - Utility for buyers based on proximity to centre and open-space amenities

Fixed market element: Preference

- Amenities
  - Proximity: accessibility to urban center
  - Open space: the density of undeveloped land in the local neighborhood
- Utilities
  - Cobb-Douglas utility based on amenities
  - Implies substitutability (trade-off between travel costs and environmental amenities
- Combined with budget constraint in a WTP function

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Questions for Analysis

- What difference does the level of land market representation make on aggregate outcomes?
  - Quantity of change
  - Landscape patterns
  - Socioeconomic metrics
  - Projected land rent gradients
- How do specific market elements work?
  - Locational Preference
  - Budget constraints
  - Competitive bidding
- What role does agent heterogeneity play?

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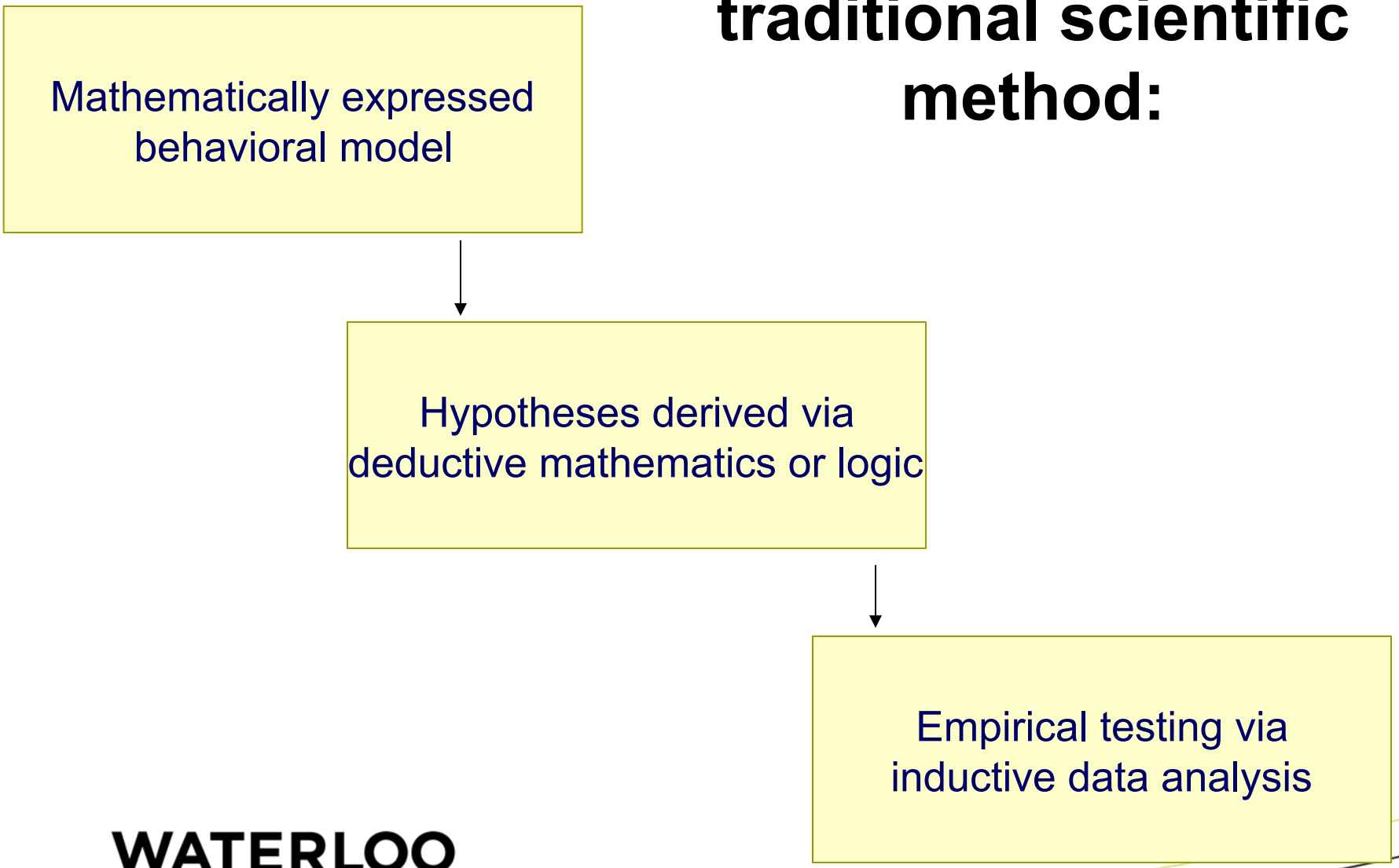
Scenic detour: How do we use computational models for land-use change research?

1. Build rules for actors and their interactions based on our best understanding of how our systems works;
2. Generate simulated output data for many runs (sensitivity and/or scenario analysis);
3. Analyze this output data to try to understand linkages between model assumptions (actor preferences and resources, transport networks, policies) and landscape-scale outcomes as parameters change?

Modeling in the traditional scientific method:



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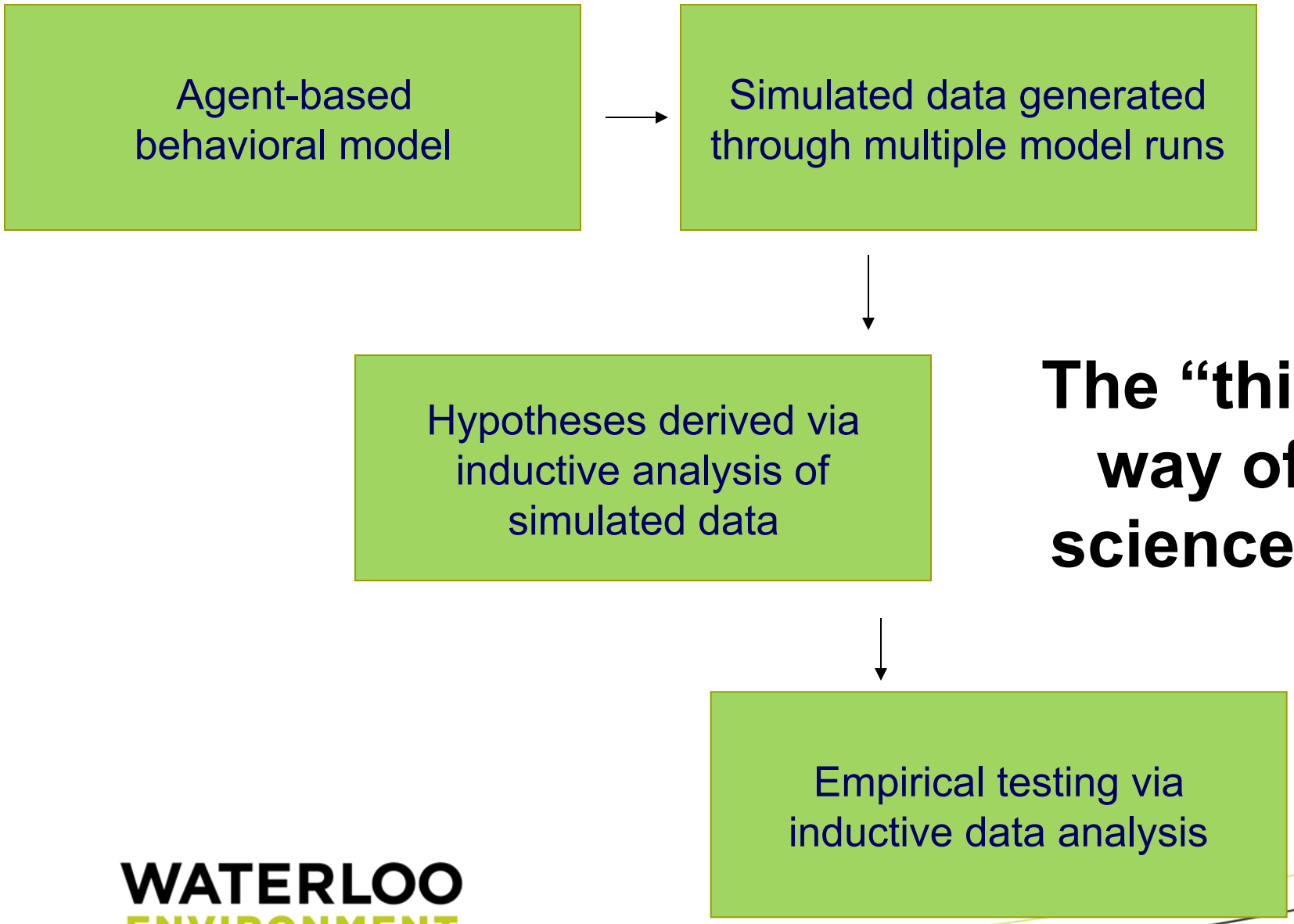

The "third way of science":

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Approach 1: Estimating land rent functions

- **Question:** Does the kind of market respresentation affect land rent patterns?
- Hedonic (econometric) land rent function/ gradient models are estimated using simulated transaction data
- Econometric methods can control for both spatial and buyer/seller characteristics
- This approach is standard in economics

Rent gradient estimates

	Level 0 hetero-budget	Level 0.5 no constraint but bidding	Level 1 resource constraints	Level 2 all bids
Linear regression: TP ~ f(distance, OSA, budget, preference)				
r^2	99.81%	99.90%	99.74%	99.86%
Intercept	2.60	0.12	1.95	0.50
Distance	-1.44	-1.62	-1.45	-1.44
osa	10.60	17.92	10.26	8.57
budget	0.82	0.81	0.83	0.85
Beta (preference)	-12.53	-11.94	-12.37	-11.37

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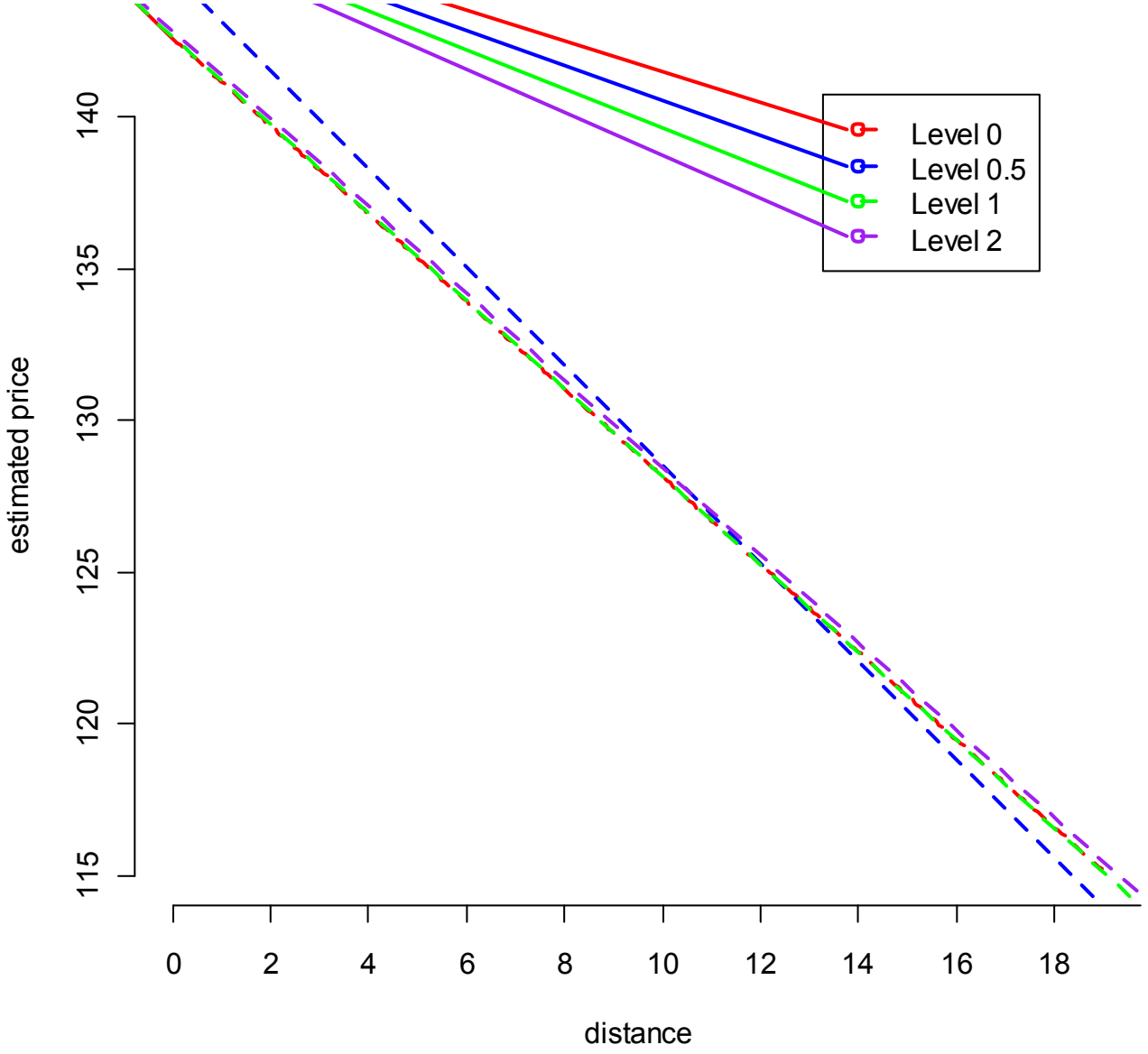
Land Rent Gradient: all market levels



Taking a closer look: 2 and 3 D visualizations

- Comparing levels 0,1 and 2 (suitability, budget constraints, competitive bidding)
- Things to notice
  - Is there a relationship between land prices and distance?
  - How does the budget constraint change the simulated transactions?
  - How does the relationship between land prices and distance change when competitive bidding is added?

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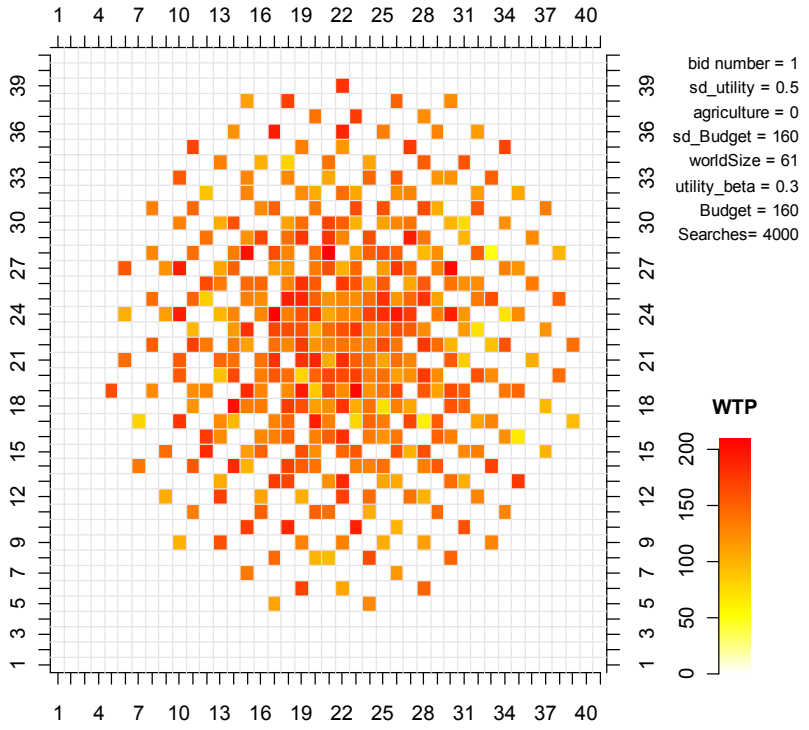
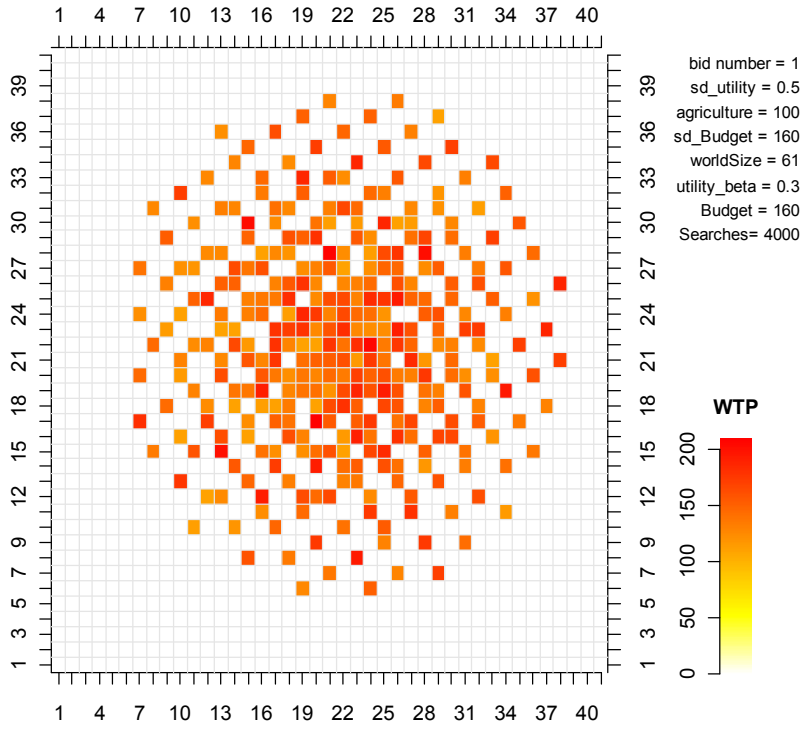
Market Level 0 vs. Level 1

Level 0 + budget constraints



Willingness to Pay



Willingness to Pay

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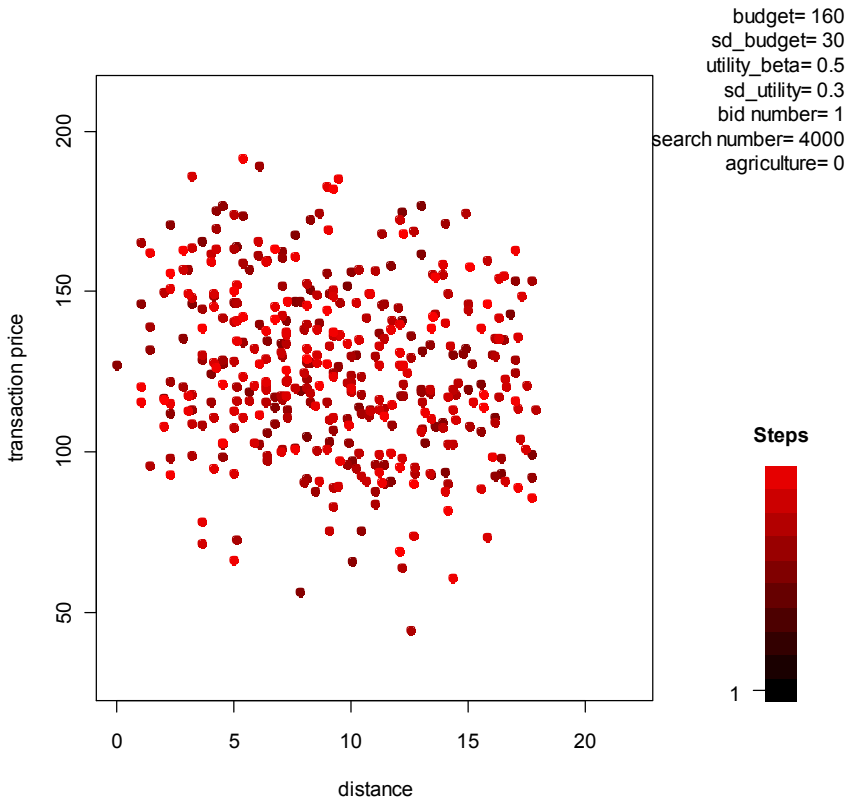
Market Level 0 vs. Level 1

Level 0 + budget constraints



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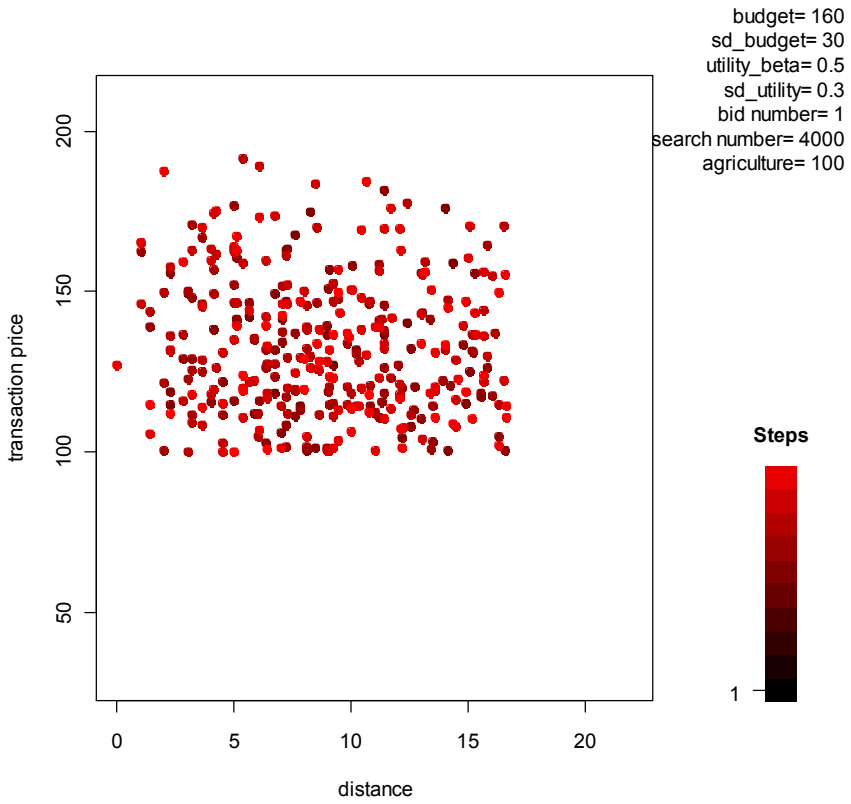

Willingness to Pay

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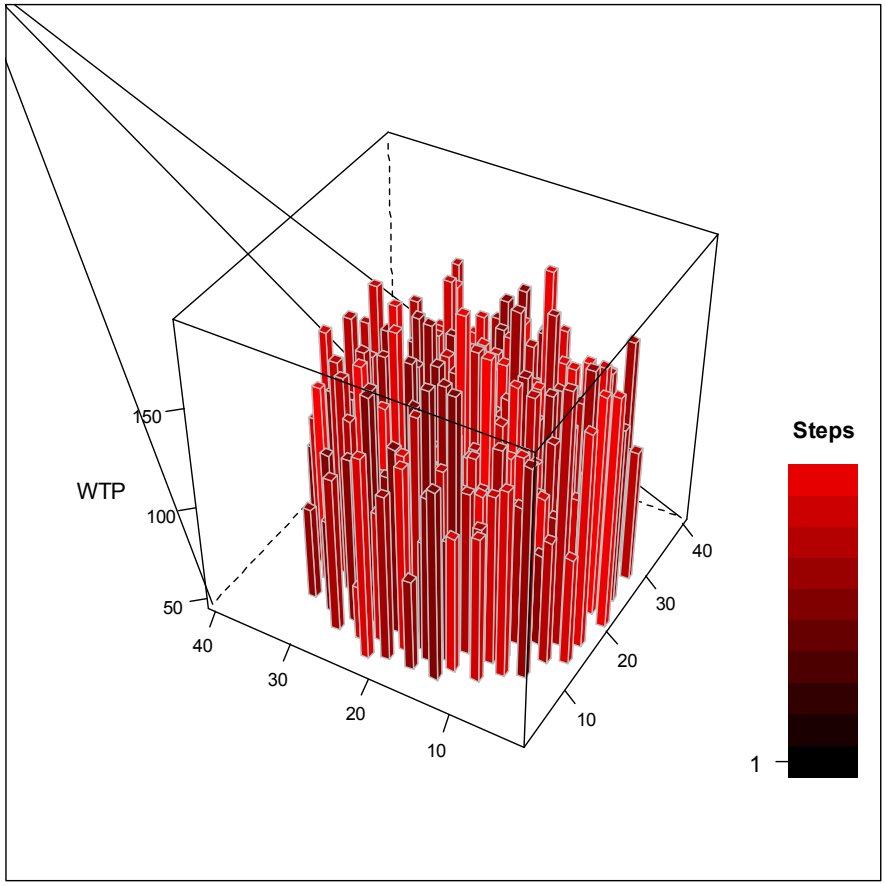
Market Level 0 vs. Level 1

Level 0 + budget constraints



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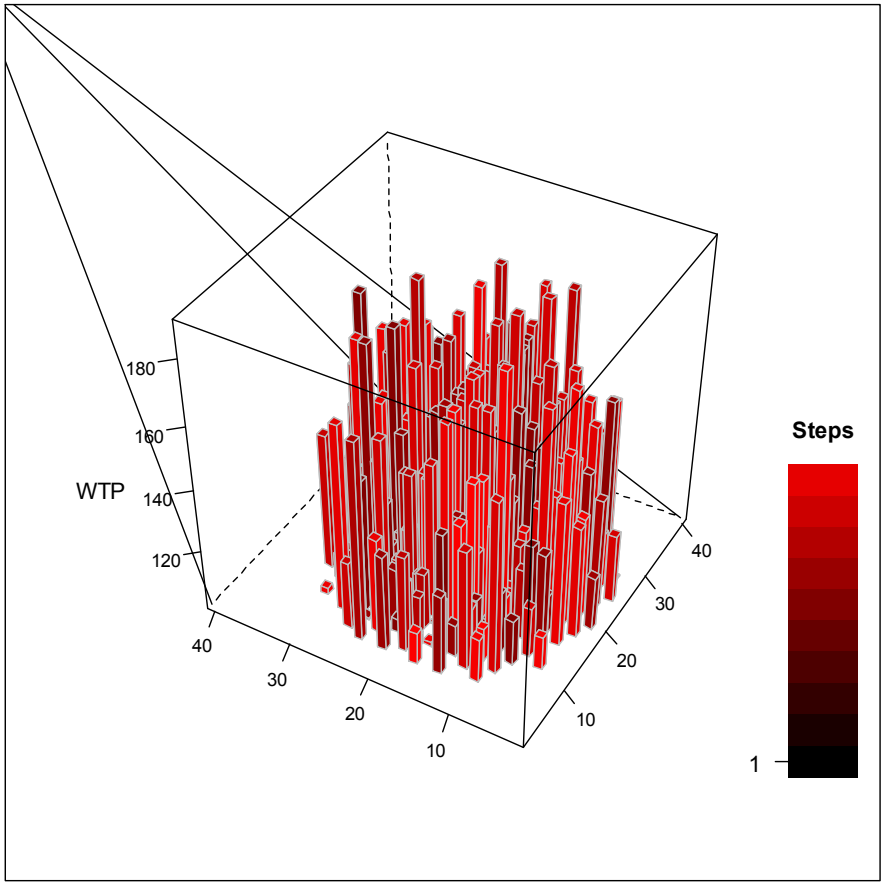
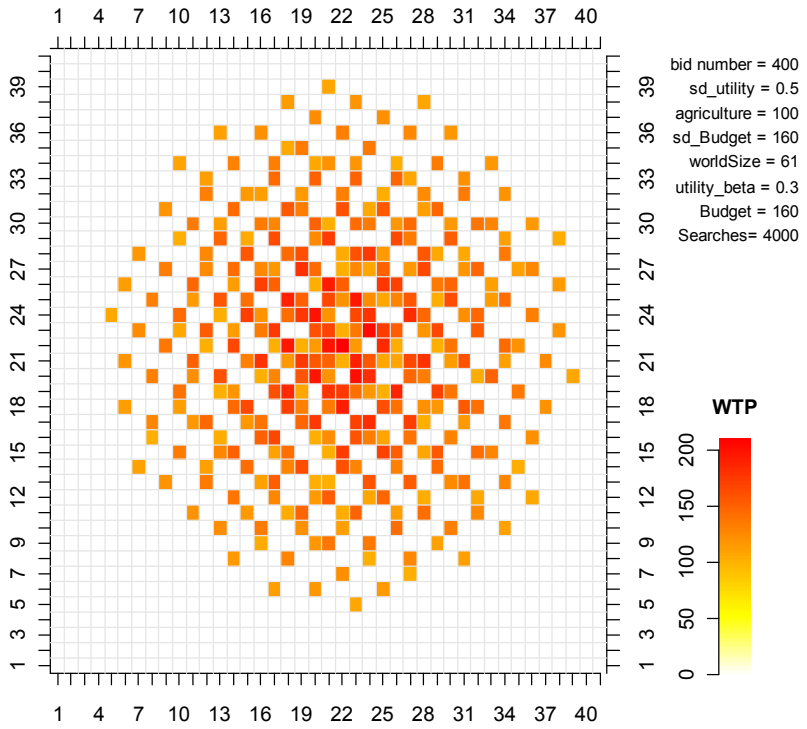


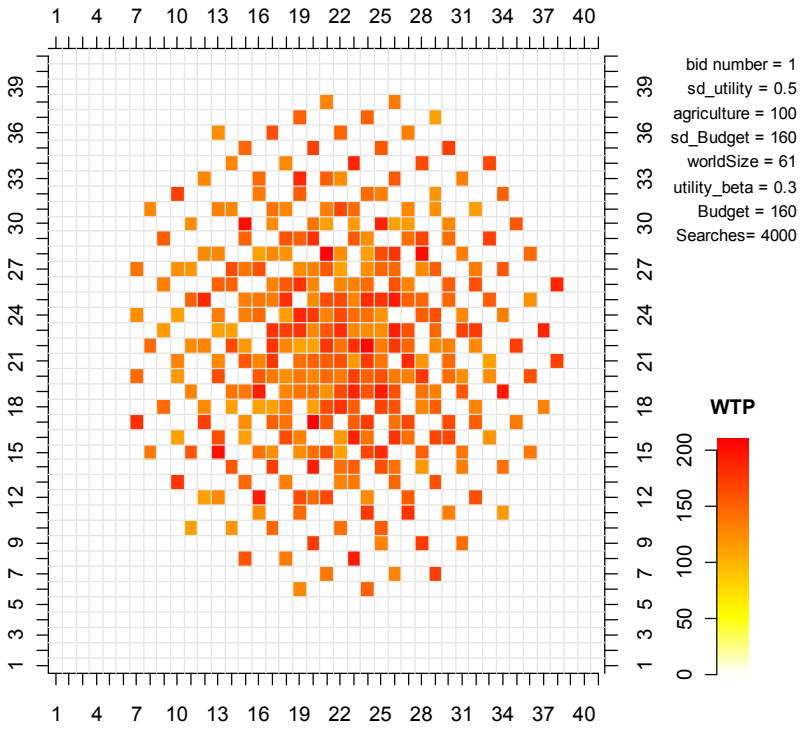
Willingness to Pay

Market Level 1 vs. 2

Heterogeneous Preference and Budgets

Level 0 + budget constraints + competitive bidding





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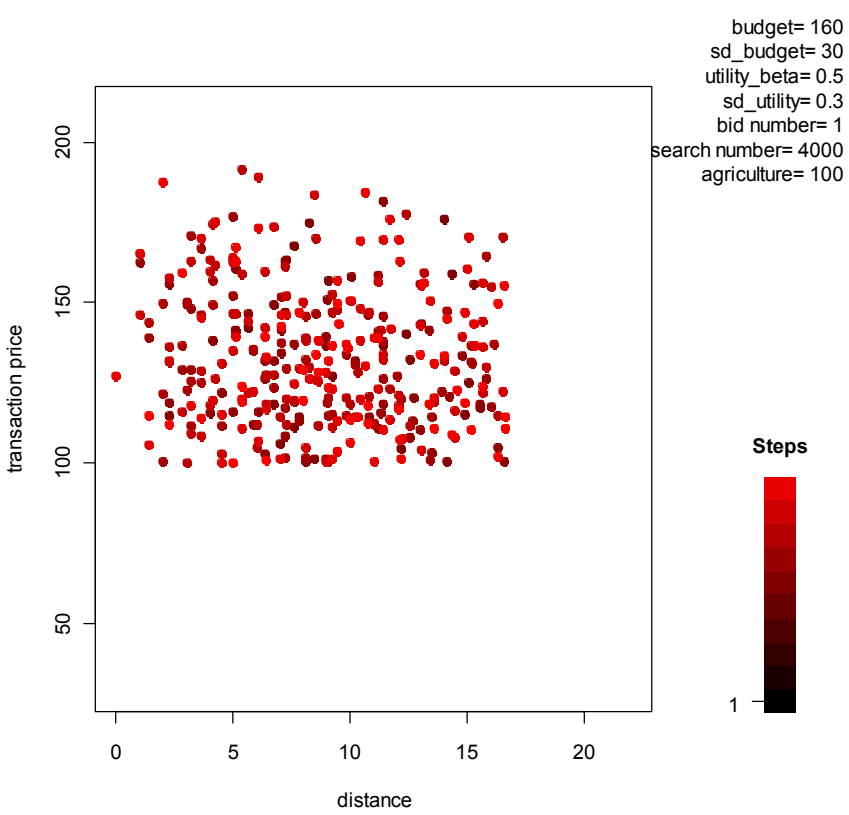
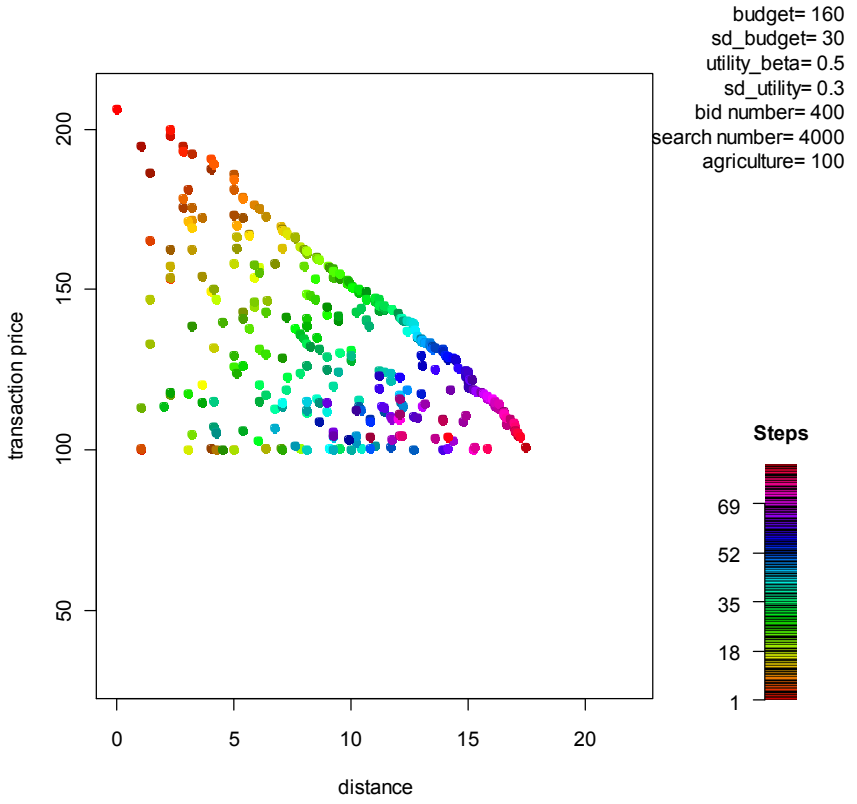
Market Level 1 vs. 2

Heterogeneous Preference and Budgets

Level 0 + budget constraints + competitive bidding





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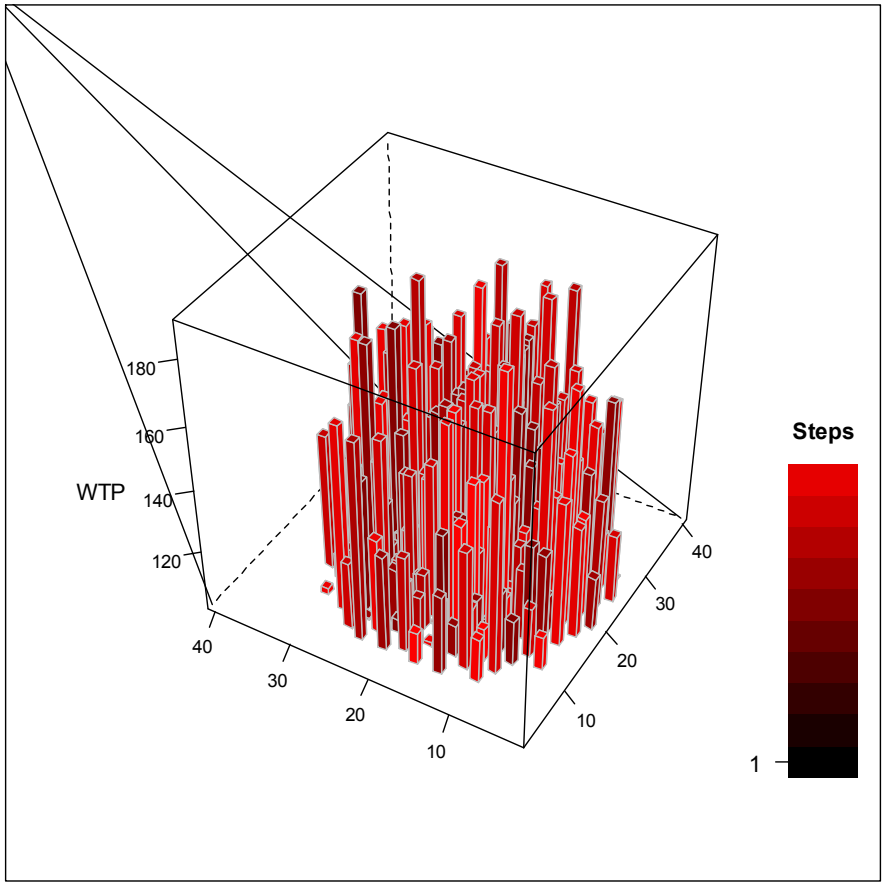
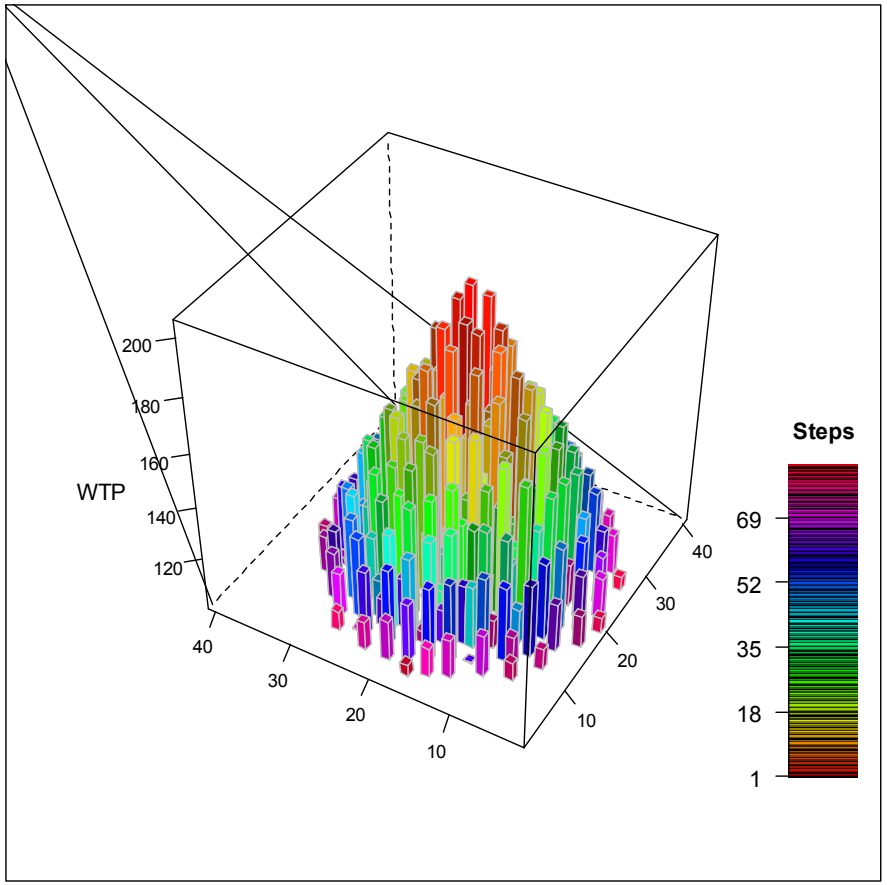
Market Level 1 vs. Level 2

Budget Constraints



… Plus Bidding



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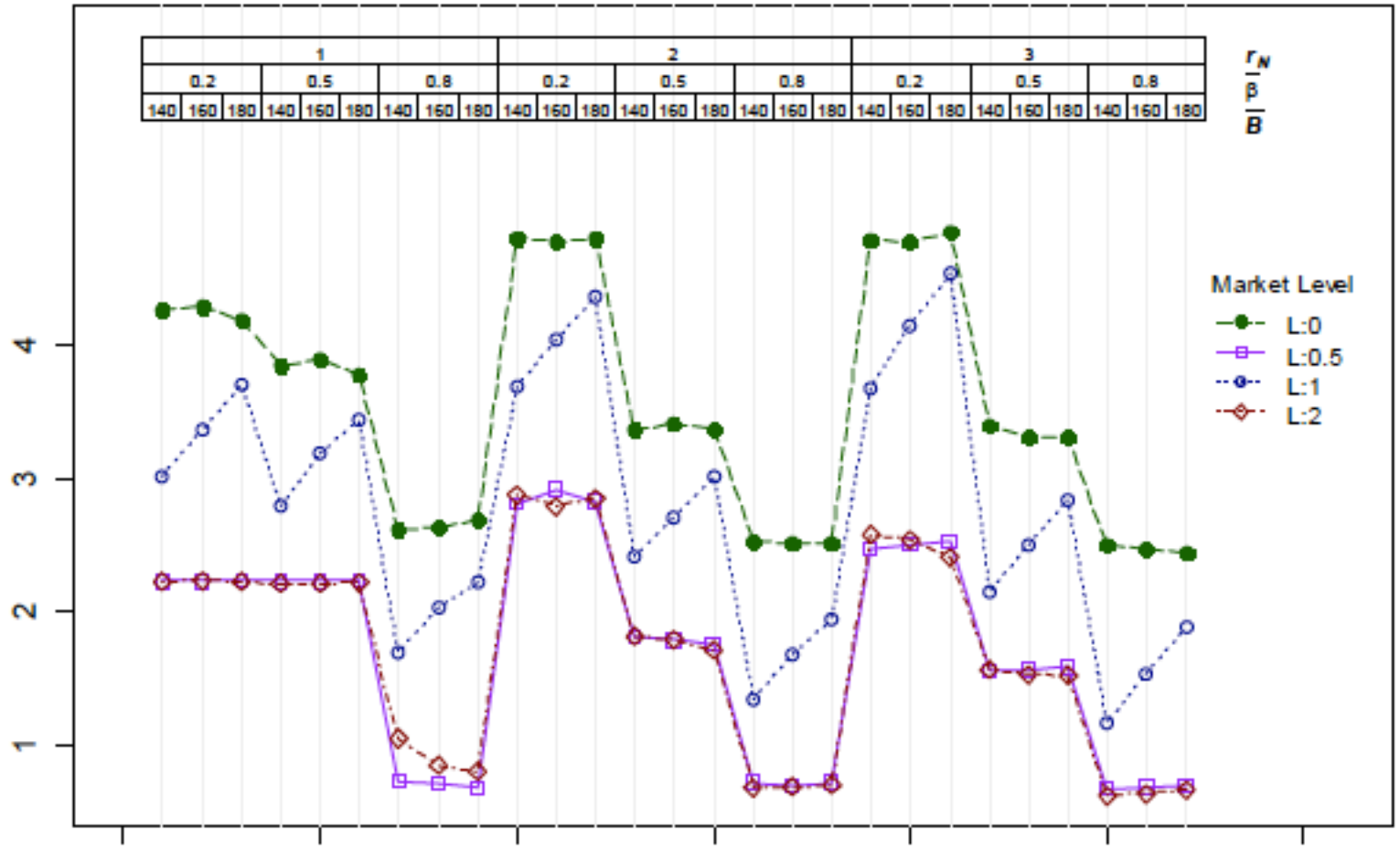
Looking more generally

- How can we look across variations in preferences, budgets, relative land values, etc?
- Can some results be considered robust for all cases?
- For which results does “it depend”?
- Approach is 2-D plot that shows outcomes across parameter values, developed by post-doc Shipeng Sun

Market representation and sprawl



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Digging deeper

- These examples are for particular preferences for open-space amenities vs. proximity and relative values of urban and rural land
- How can we generally relate parameter settings to real-world real-world cases?
- For which real-world cases might the level of market representation matter) the most, or least?

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Creating storylines: suburb lover and city lover

Case 1: suburb lovers

- Agents, on average, have higher preference for open space amenity and lower preference for proximity to downtown.
- They also use a relatively large area to evaluate neighborhood quality.

Case 2: city lovers

- Lower preference for open space, higher preference for proximity.
- Evaluate neighborhood quality locally.

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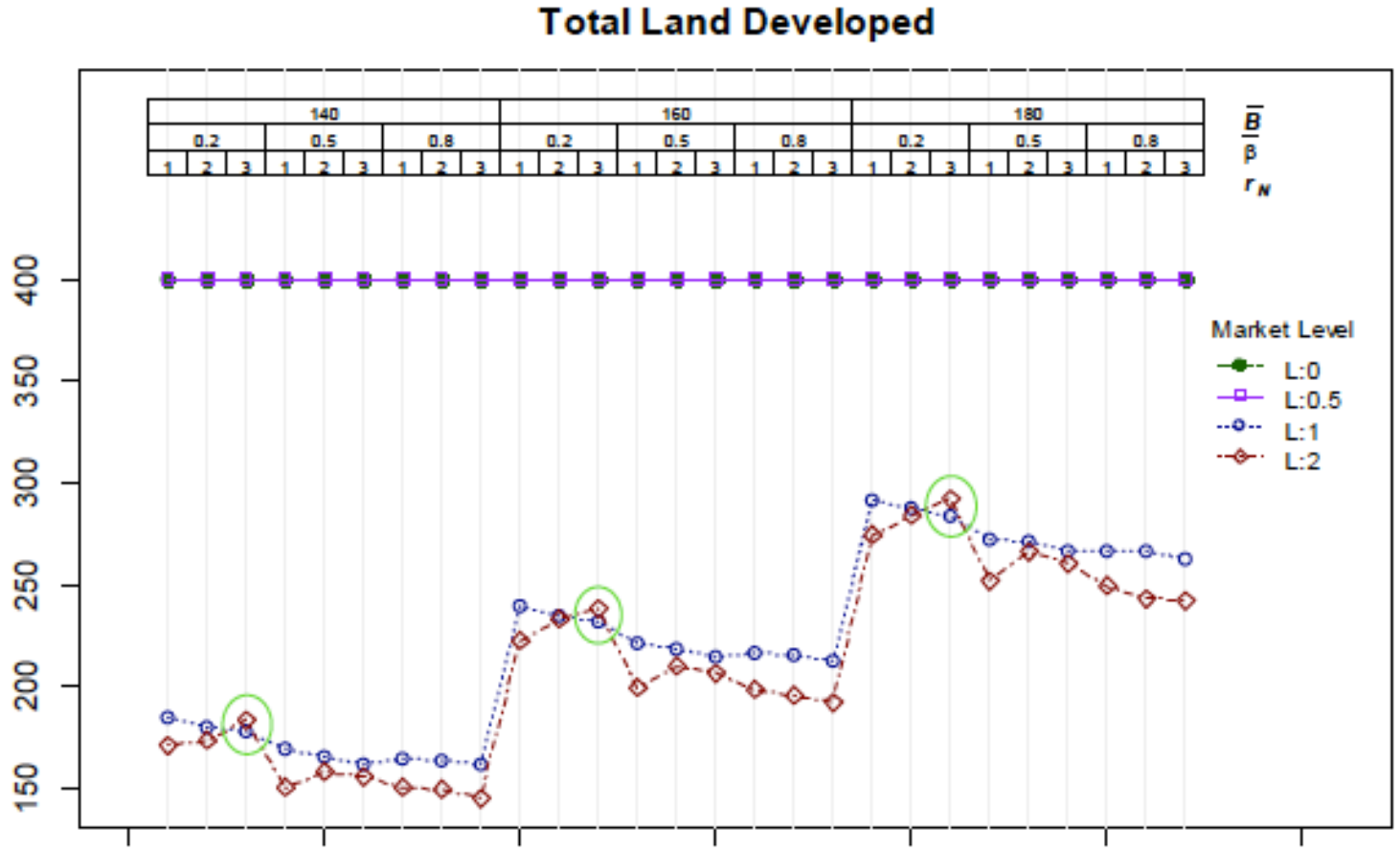
Comprehensive plot: Suburb lovers



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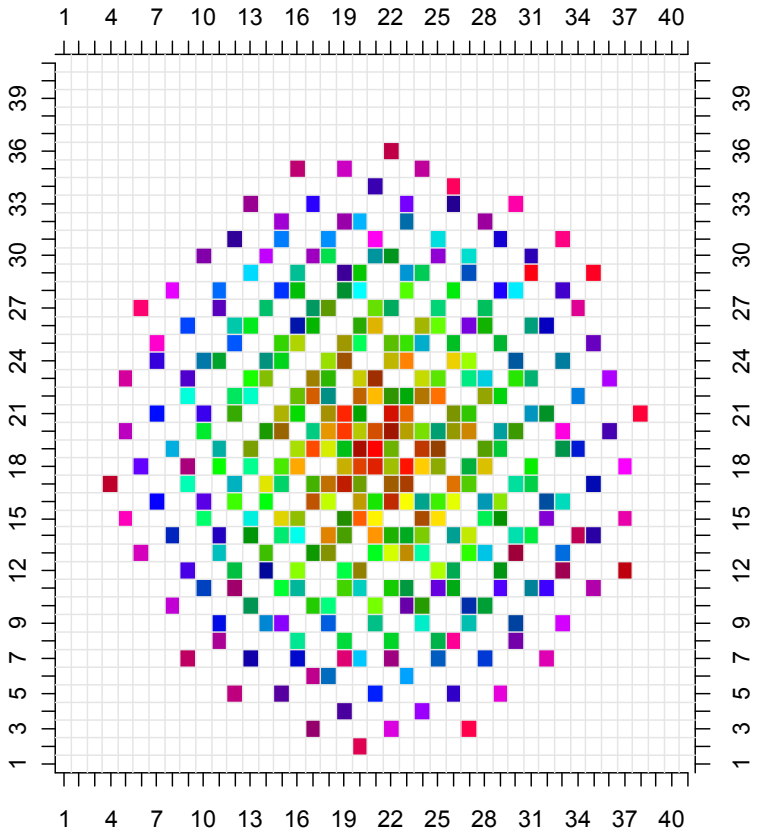
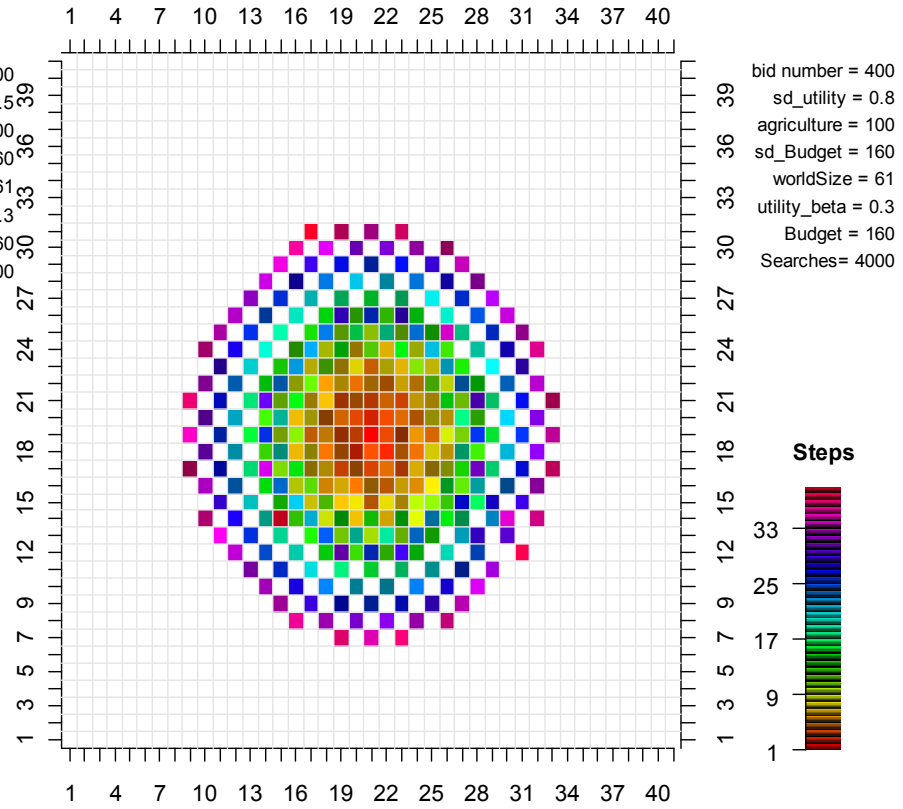
Suburb Lovers vs. City Lovers

Allocation Sequence-Level 2





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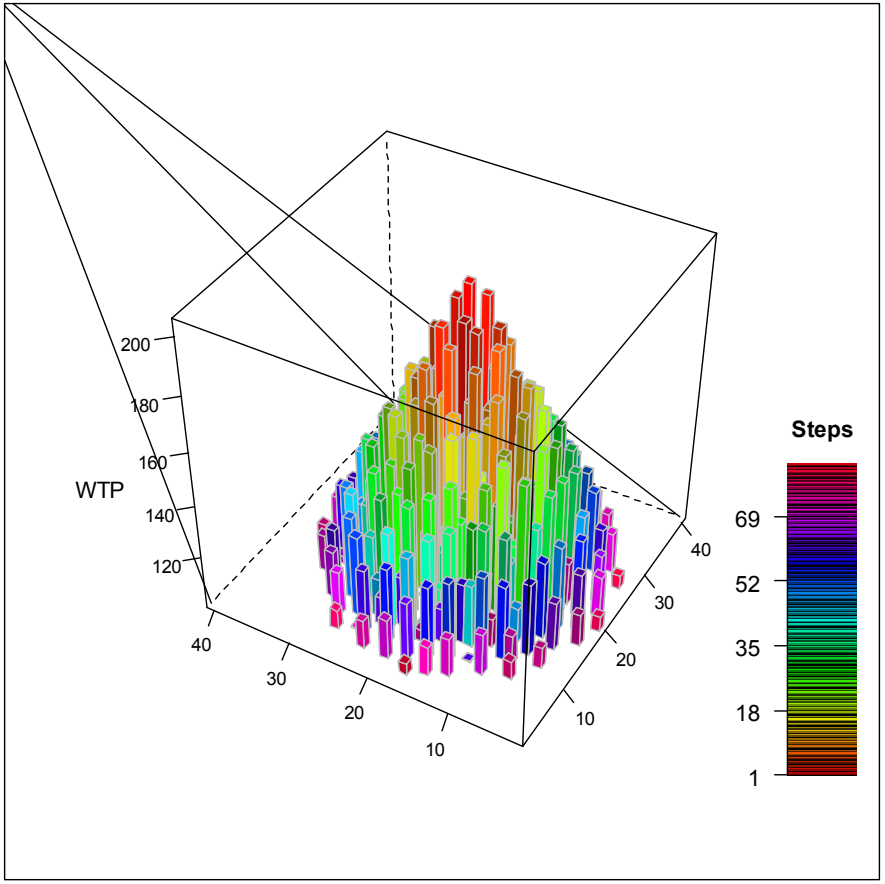
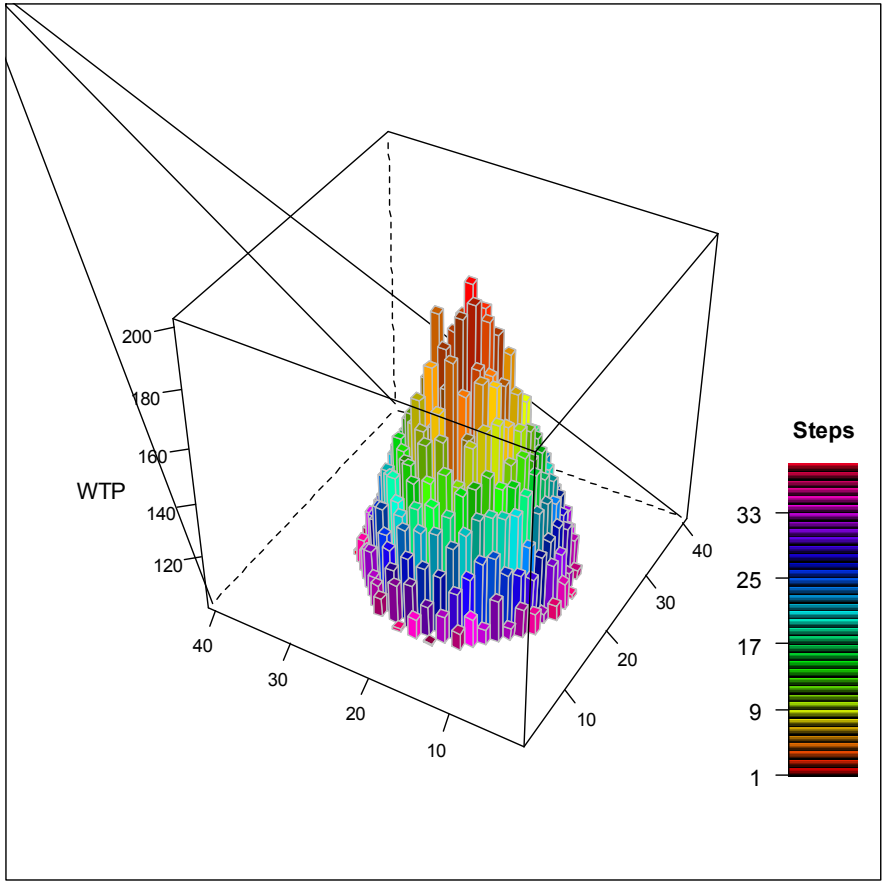
Suburb Lovers vs. City Lovers

Price (height) and Allocation Sequence (color)





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Heterogeneous agents in an ABM

- Heterogeneity among agents play a pivotal role in determining the spatial pattern of land use and land cover change
  - preference for amenities
  - risk perception
  - income differences
  - household characteristics
  - land development and management strategies
  - Etc.
- However, the complex interactions of agent heterogeneity and their significance has not been systematically evaluated in existing research

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Huang et al. in review: Three experiments across four market levels

Homogenous vs. Heterogeneous

Sequentially increase degree of single source of heterogeneity

Simultaneously increase both sources of agent heterogeneity

Level 0

Budget constraint	Competitive bidding

Level 0.5

Budget constraint	**Competitive bidding**

Level 1

Budget constraint	Competitive bidding

Level 2

Budget constraint	**Competitive bidding**

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Three experiments

	standard deviation of preference	standard deviation of budget
Experiment 1	0	0
	0	30
	0.3	0
Experiment 2	0.1, 0.2, 0.3, 0.4, 0.5	0
	0	10, 20, 30, 40, 50
*Experiment 3	0.1, 0.2, 0.3, 0.4, 0.5	10, 20, 30, 40, 50

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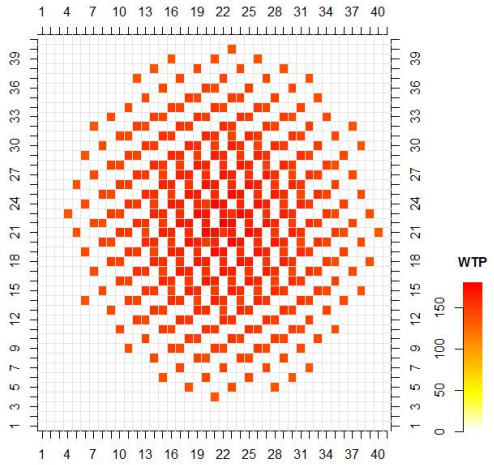
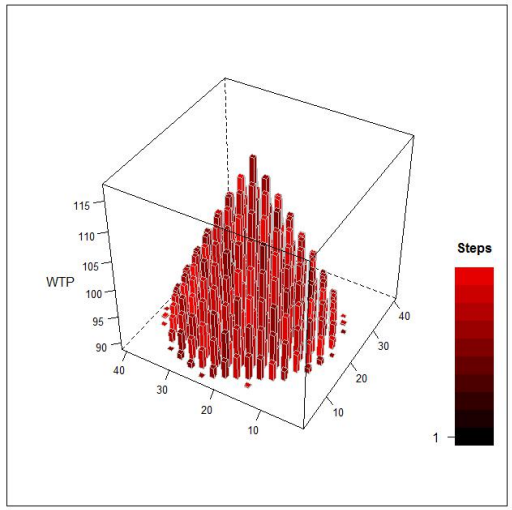
Experiment 1: homogeneous vs. heterogeneous

- *How does agents' heterogeneity in incomes and in locational preferences affect emergent land-use patterns across four market levels?*
  - Landscape patterns
  - Socioeconomic outcomes

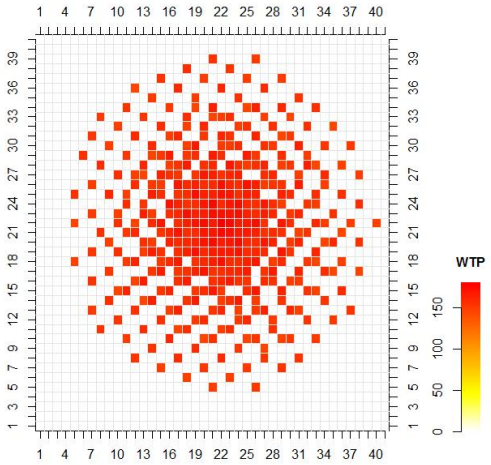
Level 0: first-come first-serve

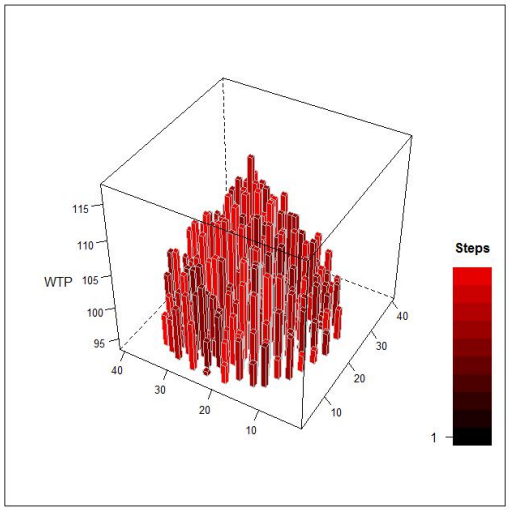
homogeneous



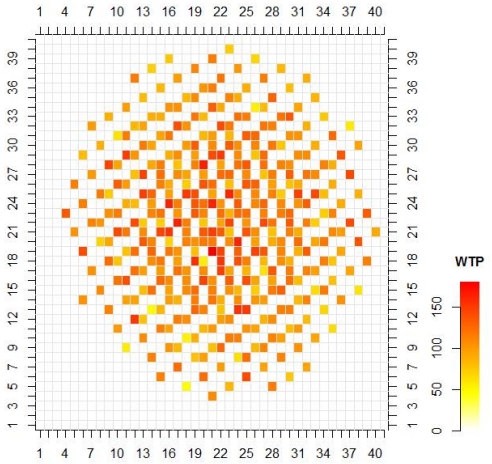


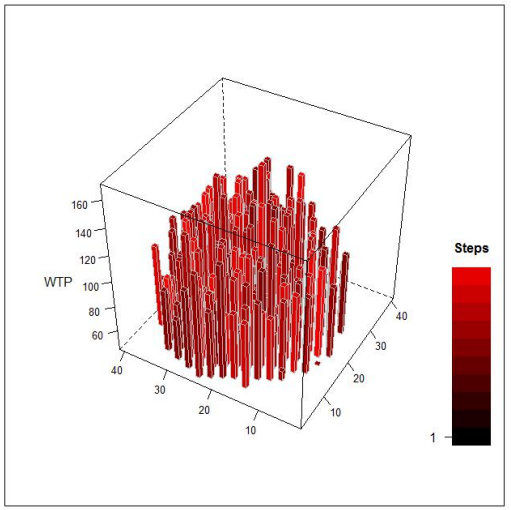
hetero-preference





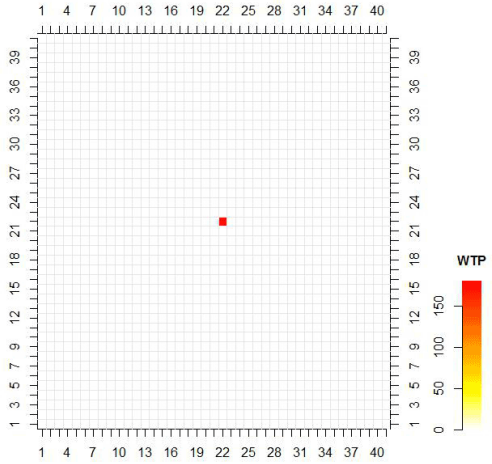
hetero-budget

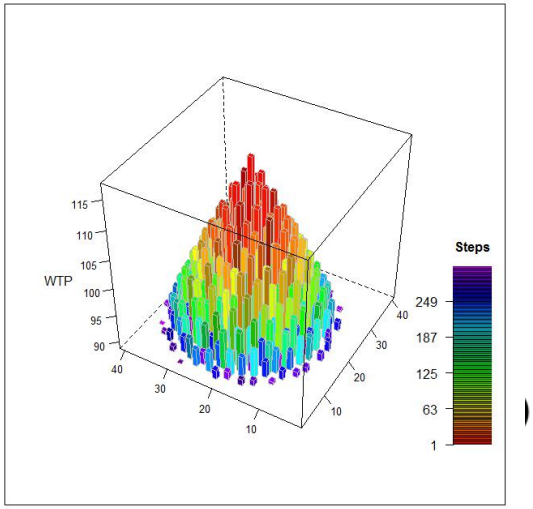




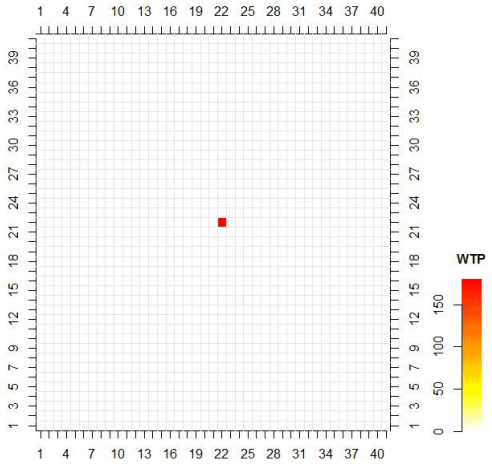
Level 0.5: competitive bidding

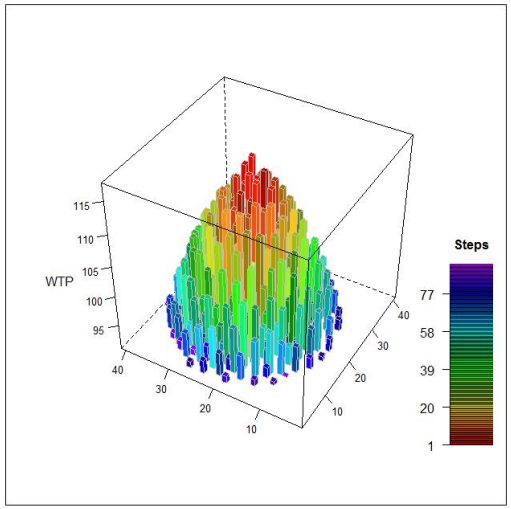
homogeneous



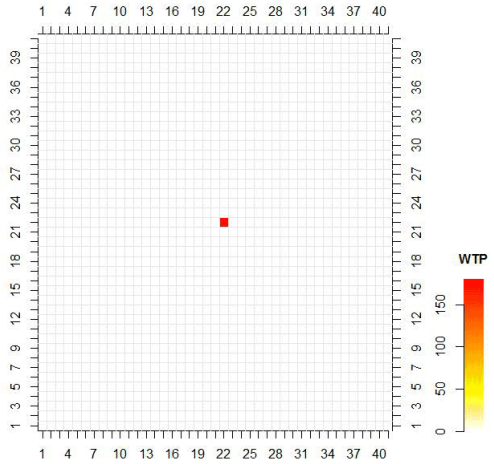


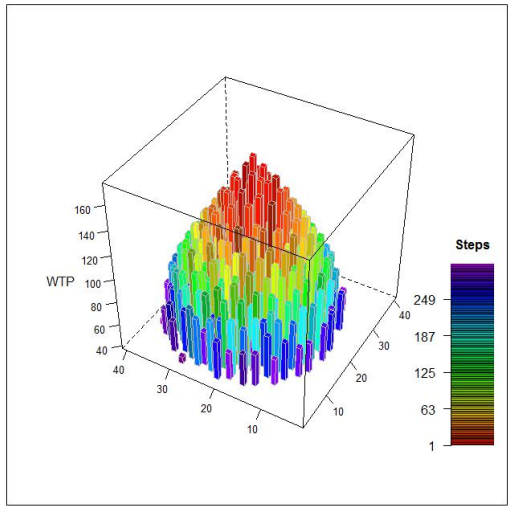
hetero-preference





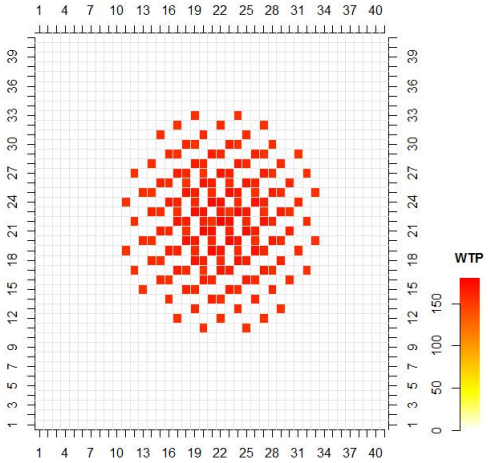
hetero-budget

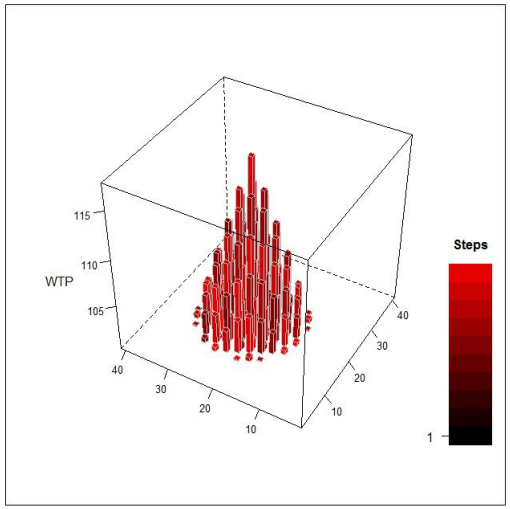




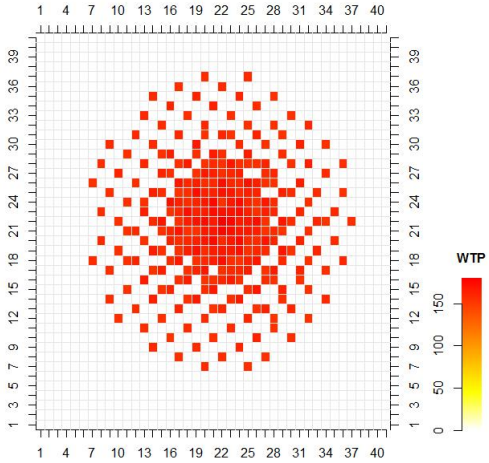
Level 1: budget constraint, “city” range

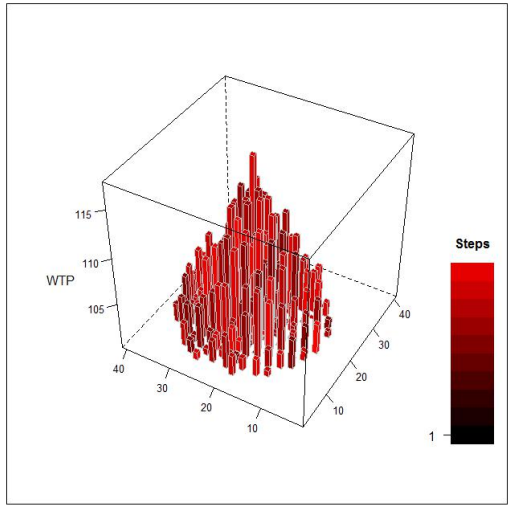
homogeneous



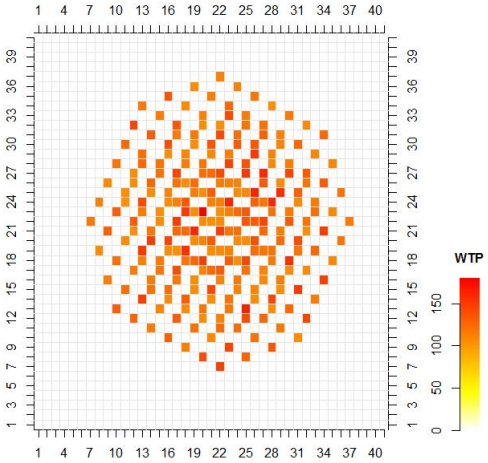


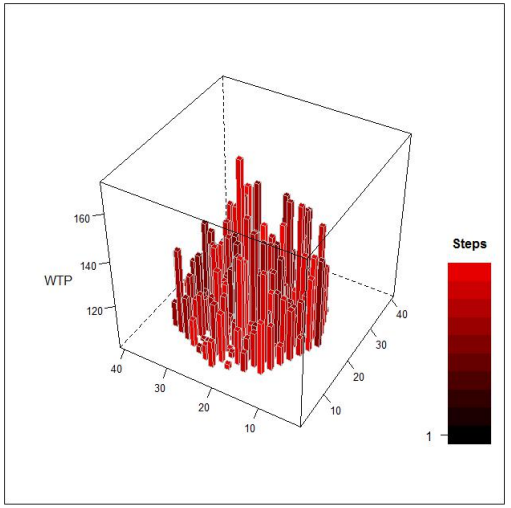
hetero-preference





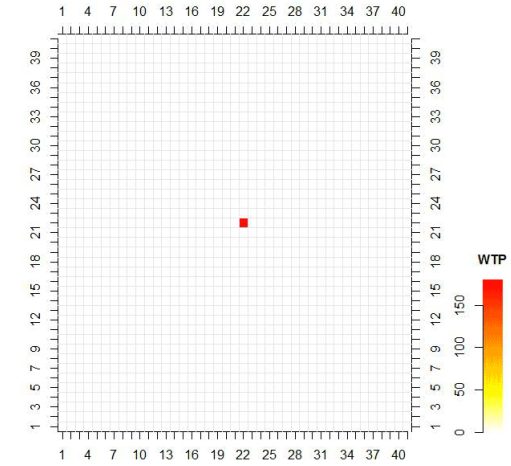
hetero-budget

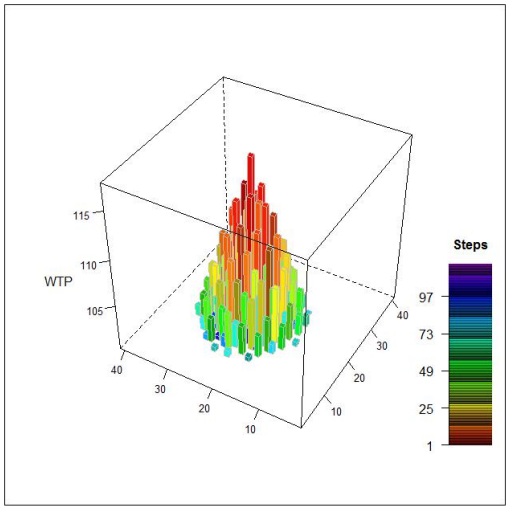




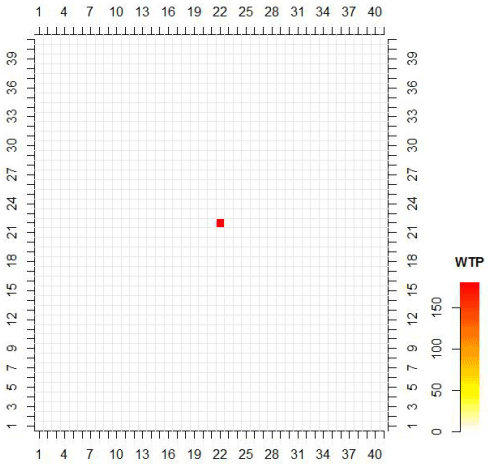
Level 2: bidding+constraint

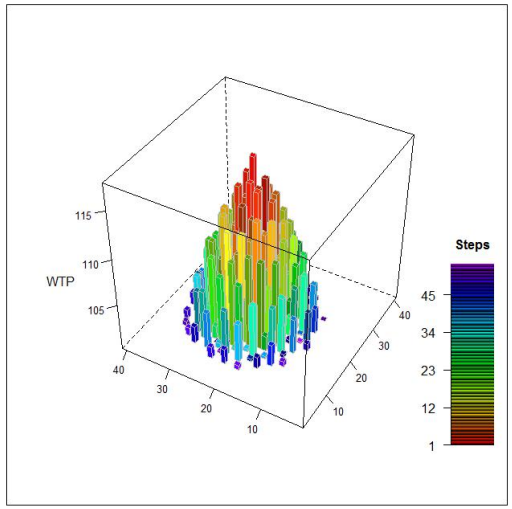
homogeneous



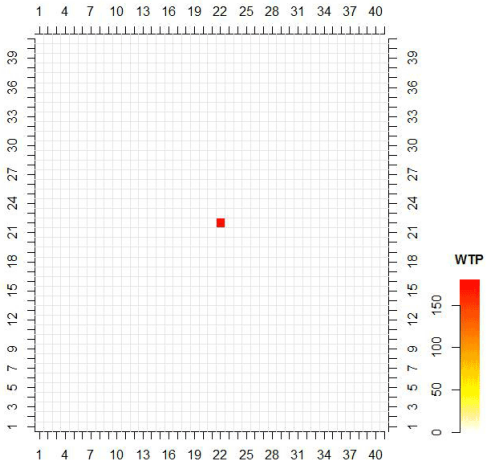


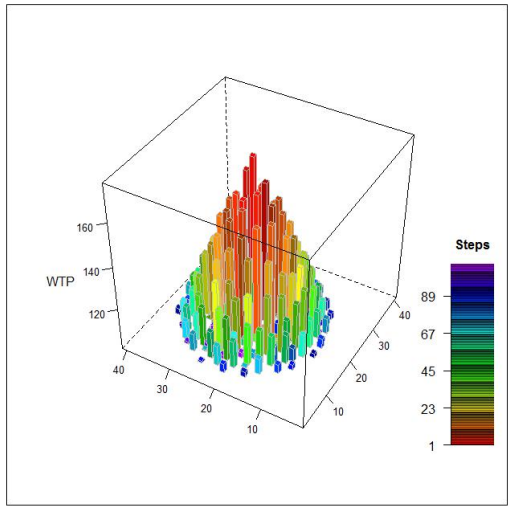
hetero-preference





hetero-budget



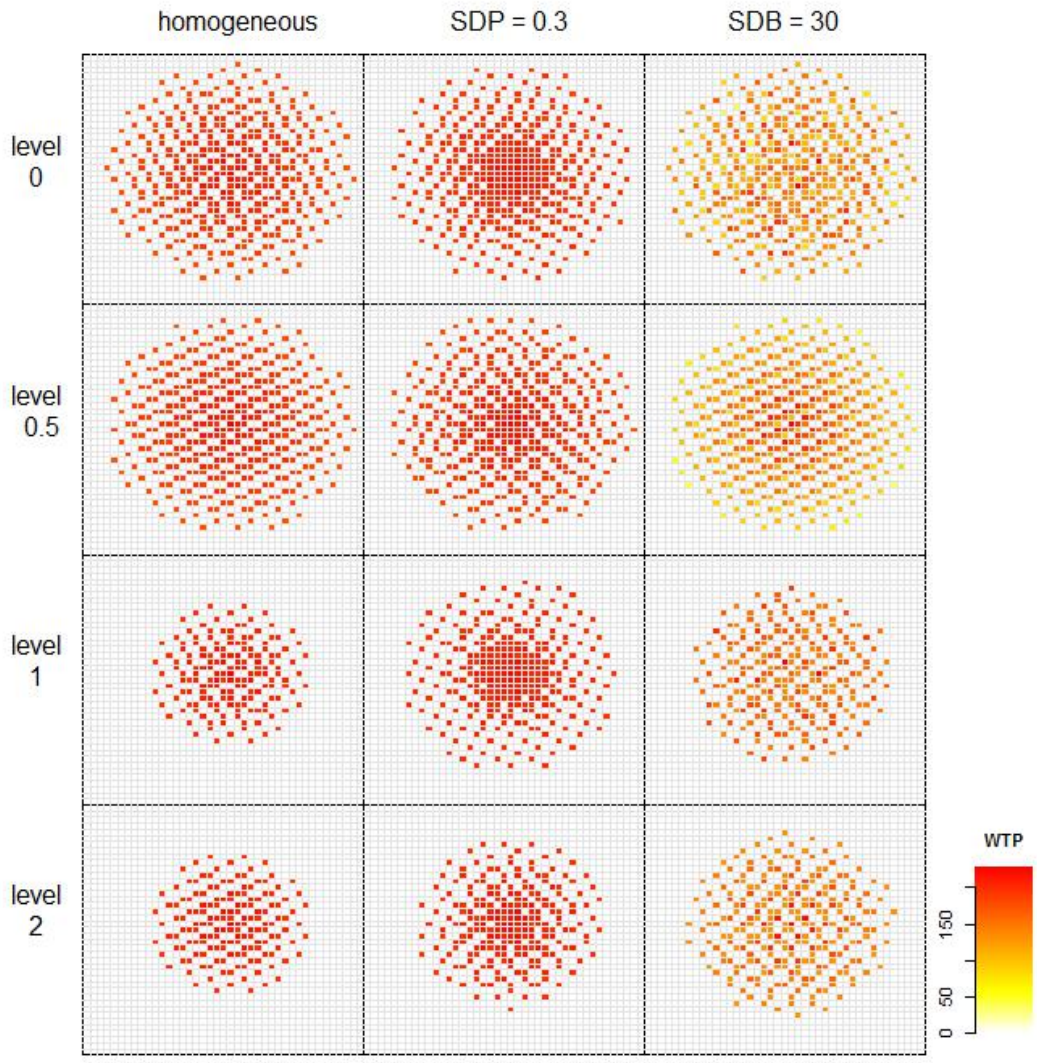


Exp. 1: homogeneous vs. heterogeneous

Level	SDP	SDB	MTC	TDP	ED	MU	MTP	Theil
L0	0	0	10.39 n/a	400 n/a	2.62 n/a	0.84 n/a	98.88 n/a	N/A
	0.3	0	9.52***	400 n/a	2.19***	0.87***	101.94***	N/A
	0	30	10.39	400 n/a	2.62	0.84	98.66	0.02***
L0.5	0	0	10.39 n/a	400 n/a	2.63 n/a	0.84 n/a	98.87 n/a	N/A
	0.3	0	10.13***	400 n/a	2.46***	0.86***	100.93***	N/A
	0	30	10.39	400 n/a	2.63	0.84***	99.40***	0.02***
L1	0	0	6.75 n/a	160 n/a	2.71 n/a	0.89 n/a	105.07 n/a	N/A
	0.3	0	8.14***	281***	2.22***	0.89***	104.65***	N/A
	0	30	8.61***	238***	2.90***	0.87***	115.32***	0.01***
L2	0	0	6.76 n/a	161 n/a	2.71 n/a	0.89 n/a	105.04 n/a	N/A
	0.3	0	7.50***	233***	2.28***	0.90***	105.34***	N/A
	0	30	8.61***	252***	2.75**	0.87***	114.31***	0.01***

- As the market representation becomes more complex, the results become more different between homogeneous agents and heterogeneous agents

Exp. 1: homogeneous vs. heterogeneous



- Most of measures show significantly different patterns between homogeneous and heterogeneous agents

- Heterogeneity in budget and preference plays very different roles in affecting the spatial and socioeconomic patterns

- Market mechanisms affects paths and patterns of outcomes

Further results (summary)

- Budget heterogeneity generally affects socioeconomic outcomes.
- Preference heterogeneity has stronger effects on landscape pattern
- The effects of heterogeneity are non-monotonic and increase with market representation
- Differing market representations can potentially reconcile some existing conflicting findings from previous literature

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Take-home messages

- Land market mechanisms have an important effect on projections of land-use change
- These effects may vary under different real-world conditions
- It is important to represent and control for agent heterogeneity—even more so in the context of a market model

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Next steps!

- Evaluating econometrics land-use change projections from a land market context (Filatova, Parker, et al.)
- SLUCE2: Adding developers and modelling land and housing markets
- New project: Integrated agent-based residential housing market/transportation model of Waterloo Region, Ontario, Canada
- Goal is to explore effects of new light rail on densification, property values, transit use, and land management

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Acknowledgements

- SLUCE II Project
  - University of Michigan
  - Dan Brown, Bill Currie, Joan Nassauer, Scott Page, Rick Riolo, Derek Robinson, Meaghan Hutchinson, and additional members of the Project SLUCE team (http://www.cscs.umich.edu/sluce/)
  - Funding for grant development from NSF BCS-0119804, new funding from NSF CNH-0813799
- ALMA
  - University of Twente
  - Tatiana Filatova and Anne Van der Veen
  - Funding from NWO-ALW (LOICZ-NL) project 014.27.012 and NSF 041406
- Chinese Scholarship Council and ESPRE (Beijing Normal University)

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