Dynamic microsimulation of location choices with a quasi-equilibrium auction approach

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Outline

1) Motivation
2) The bid-auction approach to location choice modeling
3) Bid-auction framework for microsimulation of location choice (market clearing)
4) General framework for a land use model
5) Brussels case study (some preliminary results)
6) Conclusions

Motivation

- Spatial distribution of agents and activities in a city affects:
  - Travel demand / energy consumption / pollution / social welfare
- Cities are complex systems:
  - Interaction of different markets
  - Many heterogeneous agents
  - Externalities
- Land use models allow to understand and forecast (?) the evolution of cities
- Location choice models are a fundamental element of land use models
- **Microsimulation/agent-based** models are flexible and detailed, making possible to evaluate complex scenarios

Motivation

Approaches to location choice modeling:

- **Choice:** agents (households and firms) select location of maximum utility as price takers
- **Bid-auction:** real estate goods are traded in auctions where prices and locations are determined by the best bidders

Real estate markets:

- Quasi-unique good: all locations are different
- Inelastic demand: every agent needs to locate somewhere

➔ Conflicts are solved through **market clearing** mechanisms

Motivation

Market clearing can be modeled by:

- Solving an equilibrium problem
  - Aggregated
  - Strong assumptions (supply=demand)
  - Difficult to introduce dynamics
- Simulating individual transactions
  - Computationally expensive
  - Data hungry

Method to simulate market clearing in location choice?

Bid-auction approach to location choice

Why bid-auction?

- Real estate goods (housing, land) are quasi-unique and usually scarce ➔ competition between agents
- Explicit explanation of the price formation process (best bid in an auction)
- Bid prices can be sensitive to scenarios of demand or supply surplus
- Estimation: no price endogeneity

Bid-auction approach to location choice

- B_{hi} : willingness to pay of agent *h* for location *i*.

$$B_{hi} = f(x_h, z_i, \beta)$$

x_h : characteristics of agent h (household, firm, …)
z_i : attributes of location i (housing unit, parcel of land, …)

- Probability of agent *h* being the best bidder for a location *i* (Ellickson, 1981):

$$P_{h/i} = \frac{\exp(\mu B_{hi})}{\sum_{g \in H} \exp(\mu B_{gi})}$$

H: set of bidding agents

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Bid-auction approach to location choice

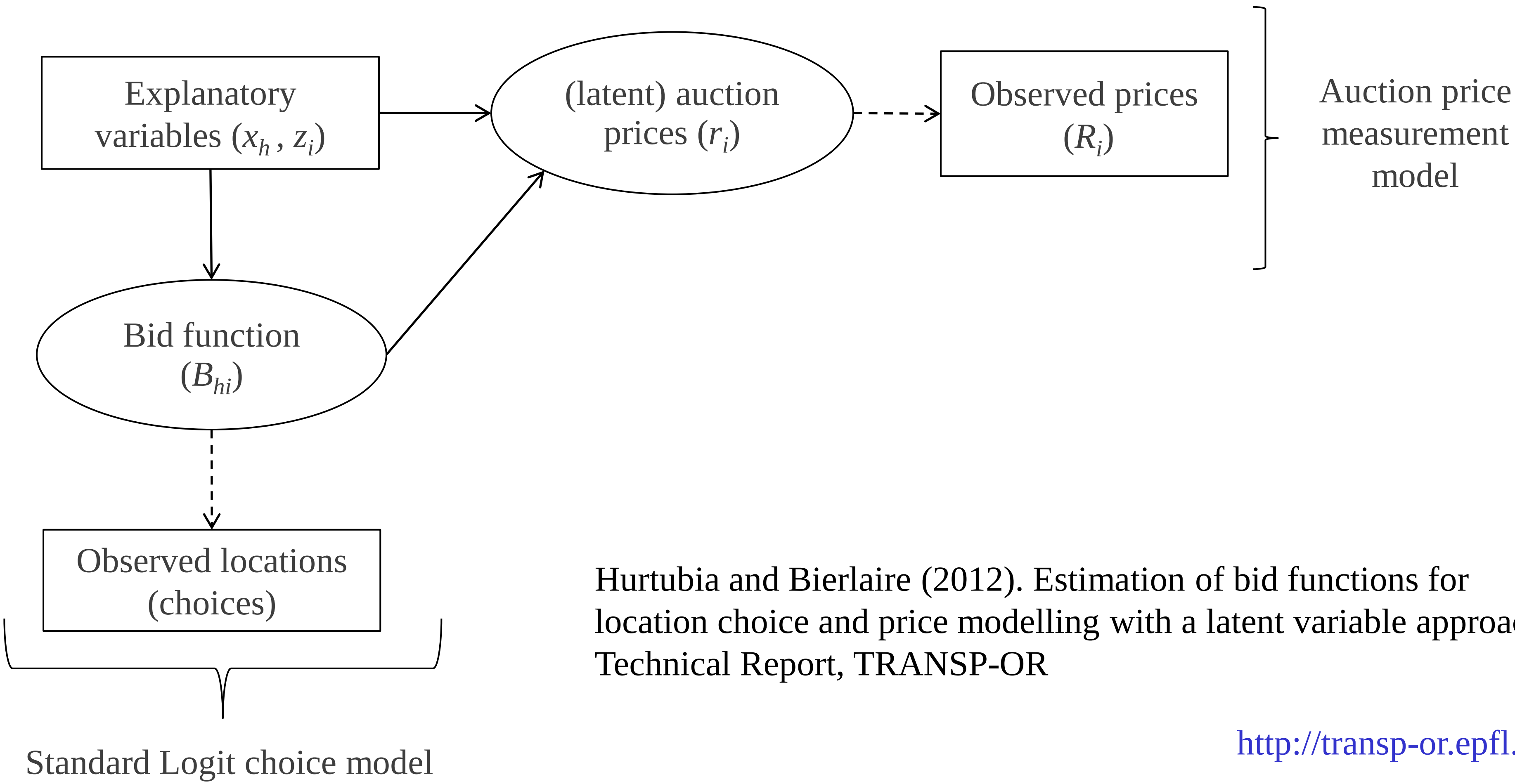
- Price or rent for one location:
  - Deterministic: bid of the winner of the auction
  - Stochastic: expected maximum bid

- r_i : rent/price of i (expected value of the maximum bid):

$$r_i = \frac{1}{\mu} \ln\left(\sum_{g \in H} \exp(\mu B_{gi}) \right) + C$$

H: set of bidding agents
C: unknown constant

Estimation of bid function



Hurtubia and Bierlaire (2012). Estimation of bid functions for location choice and price modelling with a latent variable approach. Technical Report, TRANSP-OR

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Market clearing for agent-based bid-auction models

Microsimulation with a bid approach

- When bids are simulated we get:
  - Spatial distribution of agents
  - Real estate prices
- But, in order to account for competition between agents for scarce goods, we need market clearing:
  - Through hedonic price models (UrbanSim)
    - Simple but not real market clearing
  - Individual auctions (ILUTE)
    - Expensive in computational terms, requires knowing choicesets
  - Equilibrium (MUSSA, RURBAN)
    - Aggregated approach

The market clearing problem

Joint probability of household *h* occupying location *i*:

$$P(i,h) = P(i \mid h)P(h) = P(h \mid i)P(i)$$

$P(h \mid i)$ Maximum bid probability

$P(i \mid h)$ Maximum surplus (utility) probability

$P(i)$ Selling probability

$P(h)$ Locating probability

Re-visiting Equilibrium

- In equilibrium models it's usually assumed that supply (*S*) equals demand (*H*)

$$P(h) = P(i) = 1 \quad \forall h, i \quad \Rightarrow H = S$$

- Possible equilibrium conditions:

$$\sum_h P(i,h) \Rightarrow \sum_h P(i \mid h) P(h) = P(i) = 1 \quad \forall i$$ **(everything is sold)**

$$\sum_i P(i,h) \Rightarrow \sum_i P(h \mid i) P(i) = P(h) = 1 \quad \forall h$$ **(everyone is located)**

Re-visiting Equilibrium

- Market clearing can be achieved by imposing one of the equilibrium conditions and finding prices/bids that produce them

$$\exists r_i : \sum_h P(i \mid h) = 1 \quad \forall i$$

(prices clear the market)

$$\exists b_h : \sum_i P(h \mid i) = 1 \quad \forall h$$

(bids clear the market)

Due to interdependence, these are usually fixed point problems

Re-visiting Equilibrium

- If we have an auction market and the best bidder rule is observed, adjusting prices or bids is equivalent in equilibrium
  - Same spatial distribution of agents
  - Not necessarily same prices (rents or maximum bid)
- Equilibrium implies:
  - aggregation of agents in groups
  - solving complex fixed point problems
  - Assuming that all agents re-locate
- Idea: quasi-equilibrium:

Quasi-equilibrium

- Periodical location of new and re-locating agents, given exogenous supply
- Assumption: all households looking for a location are located somewhere $P(h)=1 \quad \forall h$
  - Total supply must be greater or equal than total demand $\Rightarrow H \leq S$
  - Not all locations are necessarily used $P(i)\leq 1 \quad \forall i$

Quasi-equilibrium

- No equilibrium ➔
  - no perfect information (only aggregate supply level and previous prices are observed)
  - No iterative negotiation/bidding
  - No absolute adjustment of bids/prices
- Instead, adjustment of “perception” of agents that goes in the direction of an equilibrium but does not solve it.

Quasi-equilibrium

- Algorithm (in each period):
  - All agents (H) observe the market: prices and supply $\left(r_i^{t-1}, z_i^{t-1}, S_i\right)$
  - All gents (simultaneously) adjust their bids, attempting to make their expected number of winning auctions equal to one:

$$\sum_{i \in S} q(h \mid i) = 1 \quad \forall h$$

q(h|i): perceived probability of being the best bidder for *i*

  - All agents bid at the same time for all locations ➔ prices and location distributions are defined
  - The assignment mechanism is an auction ➔ for each location a best bidder and a price is determined

Quasi-equilibrium

Bid function: $B_{hi} = I_h - U_h + V_h(z_i) = V_h(z_i) - b_h$

- Perceived (expected) location probability:

$$q(h \mid i) = \frac{\exp\left(V_h(z_i^t) - b_h^t\right)}{\sum_{g \in H} \exp(B_{gi}^{t-1})} \approx \exp\left(V_h(z_i^t) - b_h^t - r_i^{t-1}\right)$$

$$\sum_{i \in S} q(h \mid i) = 1 \quad \Rightarrow \widehat{b_h^t} = \ln\left(\sum_{i \in S} \exp\left(V_h(z_i^t) - r_i^{t-1}\right)\right)$$

Advantage: no fixed point, just evaluation of equation ➔ it is possible to apply to large populations without excessive computational cost

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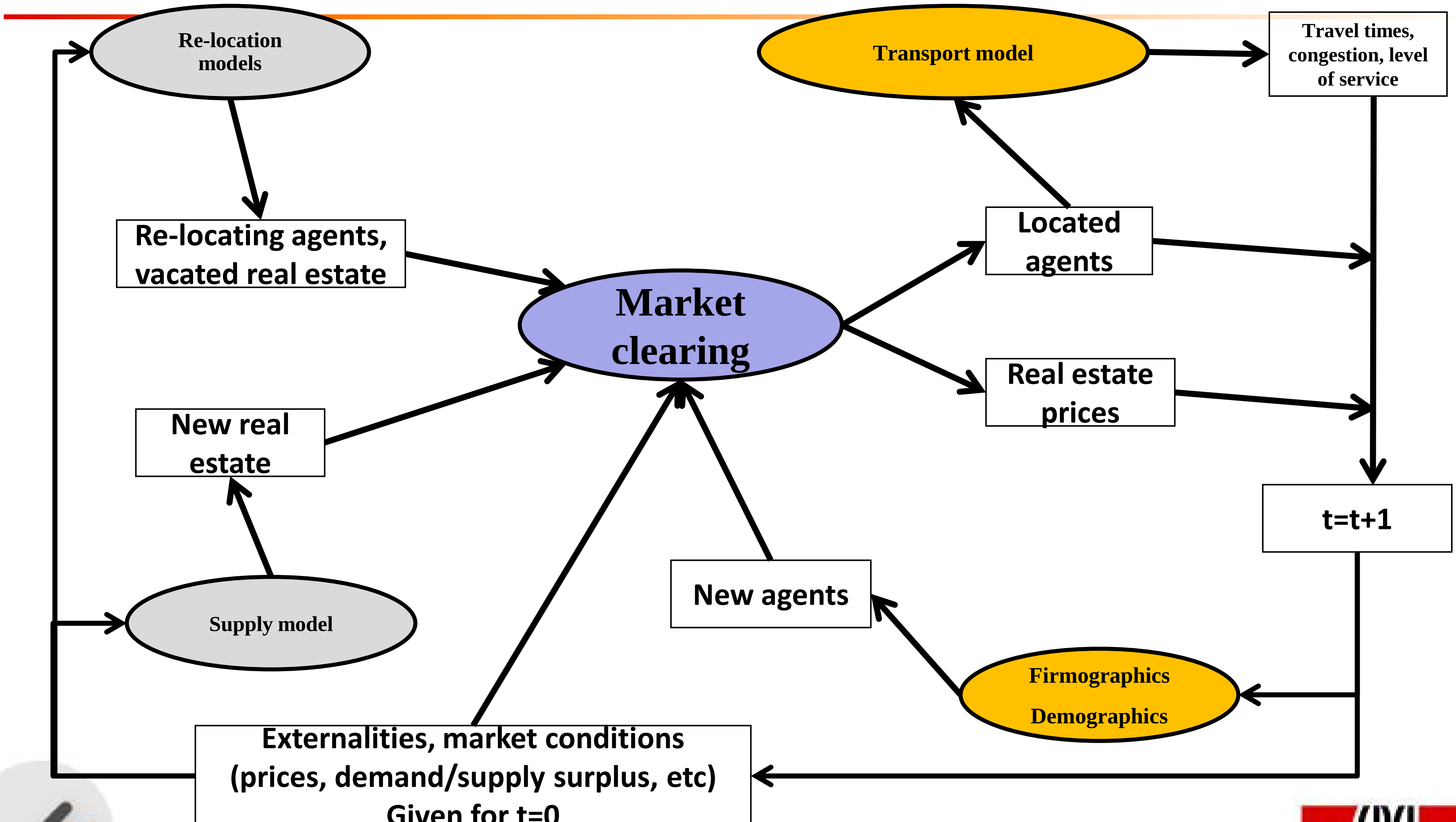
General framework for land use modeling

General framework



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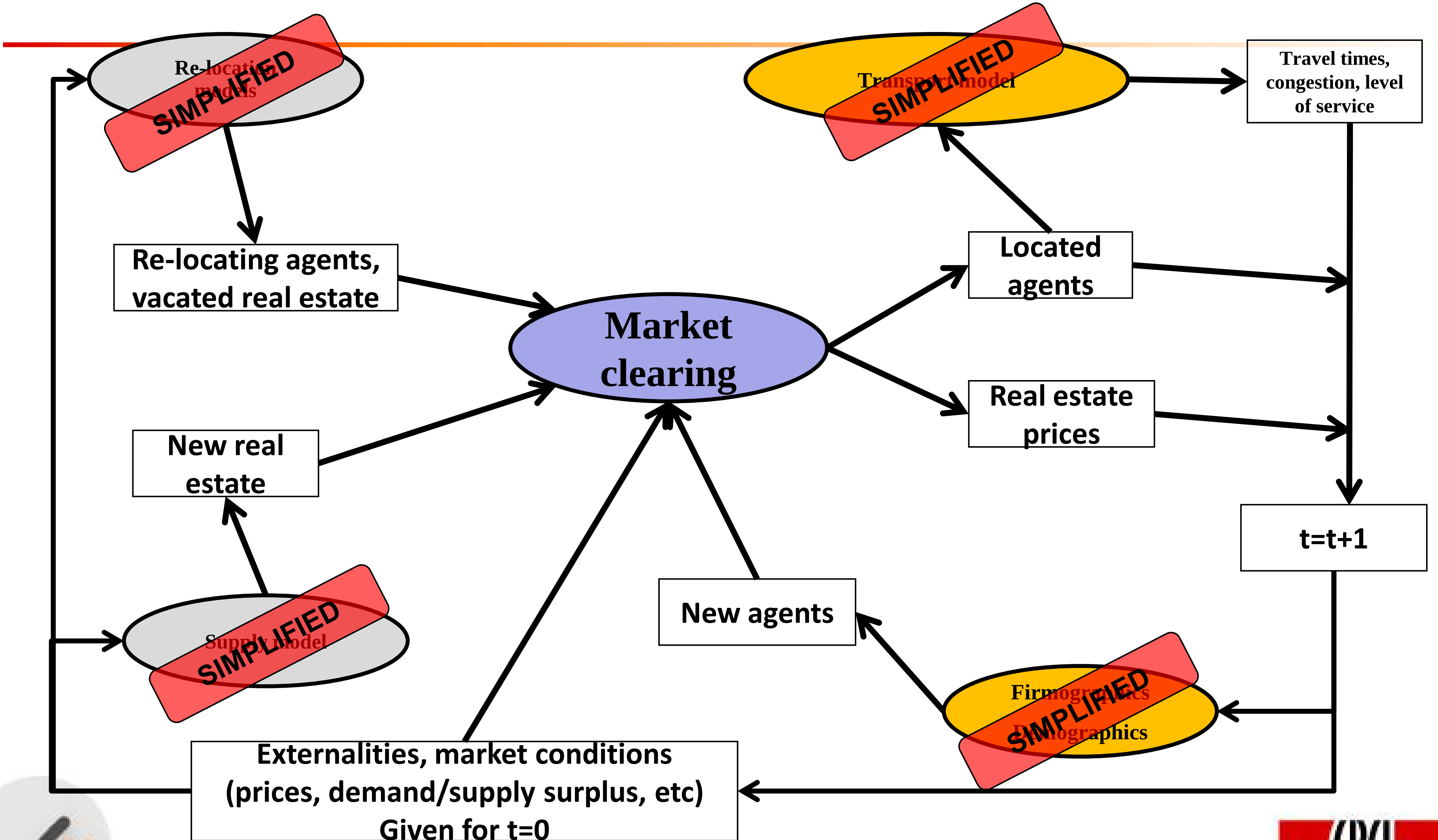
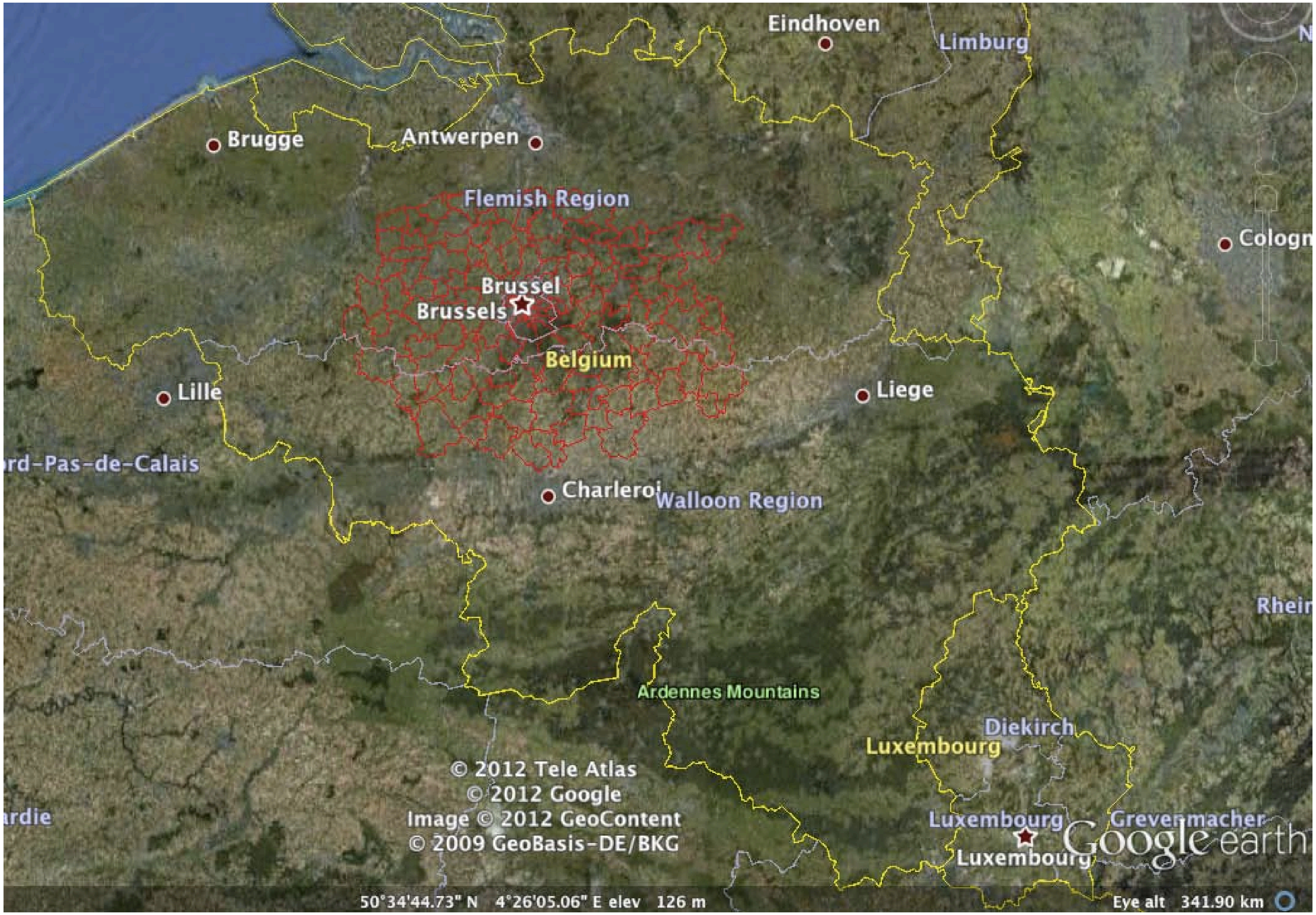
General framework (this application)



Case study:
Brussels

Area of study



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Area of study

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Data

- Data collected for a project financed by the European Union (SustainCity)
  - Census 2001 (aggregated information by zone)
  - Household survey 1999 (~1300 observations)
  - Average transaction prices by commune and 2 types of dwelling (house or apartment) from 1985 to 2008
  - Other geographical, land use databases
- 1267997 households, 1274701 dwellings
- 151 communes
- 4975 zones
- 4 types of dwelling (with average attributes per zone)
  - Isolated house
  - Semi-isolated house
  - Joint house
  - Apartment

Bid function specification

Parameter	spatial attribute	×	household (hh) attribute
ASC_2	-		income level constant (745-1859 Euros)
ASC_3	-		income level constant (1860-3099 Euros)
ASC_4	-		income level constant (3100-4958 Euros)
ASC_5	-		income level constant (>4959 Euros)
B_educ_zone	% of education jobs in zone i	×	dummy for hh's with children
B_educ_comm	% of education jobs in commune c	×	dummy for hh's with children
B_house1	dummy for isolated house	×	dummy for hh's with more than 2 people
B_house2	dummy for semi-isolated house	×	dummy for hh's with more than 2 people
B_house3	dummy for attached house	×	dummy for hh's with more than 2 people
B_income_23	% of hh's of income level 2 and 3 in zone i	×	dummy for income level 2 or 3
B_income_45	% of hh's of income level 4 and 5 in zone i	×	dummy for income level 4 or 5
B_indu_zone	% of industry jobs in zone i	×	dummy for income level > 3
B_indu_comm	% of industry jobs in commune c	×	dummy for hh's with active workers
B_service_zone	% of service (office and hotel) jobs in i	×	dummy for hh's with active workers
B_shop_comm	% of retail jobs in commune c	×	dummy for hh's with active workers
B_surf_h	surface of dwelling v	×	dummy for multi-person hh's with inc level > 3
B_surf_m	surface of dwelling v	×	dummy for multi-person hh's with inc level $= 3$
B_trans	public transport $acces_i$ (facilities/km^2)	×	dummy for hh's with 0 cars
B_trans2	public transport $acces_i$ (facilities/km^2)	×	dummy for hh's with 2 or more cars
B_univ_comm	% of people with university degree in c	×	dummy for hh's having integrants with univ degree

Bid function estimation results

Parameter	Value	Std error	t-test
ASC_2	-0.0496	0.21	-0.24*
ASC_3	-0.442	0.224	-1.97
ASC_4	-0.751	0.181	-4.15
ASC_5	-0.96	0.233	-4.13
B_educ_zone	0.269	0.12	2.25
B_educ_comm	0.562	0.528	1.07*
B_house1	0.755	0.0828	9.11
B_house2	0.935	0.0799	11.7
B_house3	1.12	0.0717	15.62
B_income_23	-0.327	0.231	-1.41
B_income_45	1.91	1.08	1.77*
B_indu_zone	-5.36	2.62	-2.04
B_indu_comm	0.247	0.11	2.25
B_service_zone	0.243	0.0542	4.49
B_shop_comm	3.13	0.458	6.84
B_surf_h	0.00916	0.00197	4.66
B_surf_m	0.00642	0.00124	5.16
B_trans	0.739	0.0811	9.12
B_trans2	-0.548	0.0989	-5.55
B_univ_comm	3.11	0.134	23.25
α	1.84	0.708	2.6
γ	0.659	0.0505	13.04
σ	-1.87	0.0182	-102.42

* Parameter not significant at the 95% level

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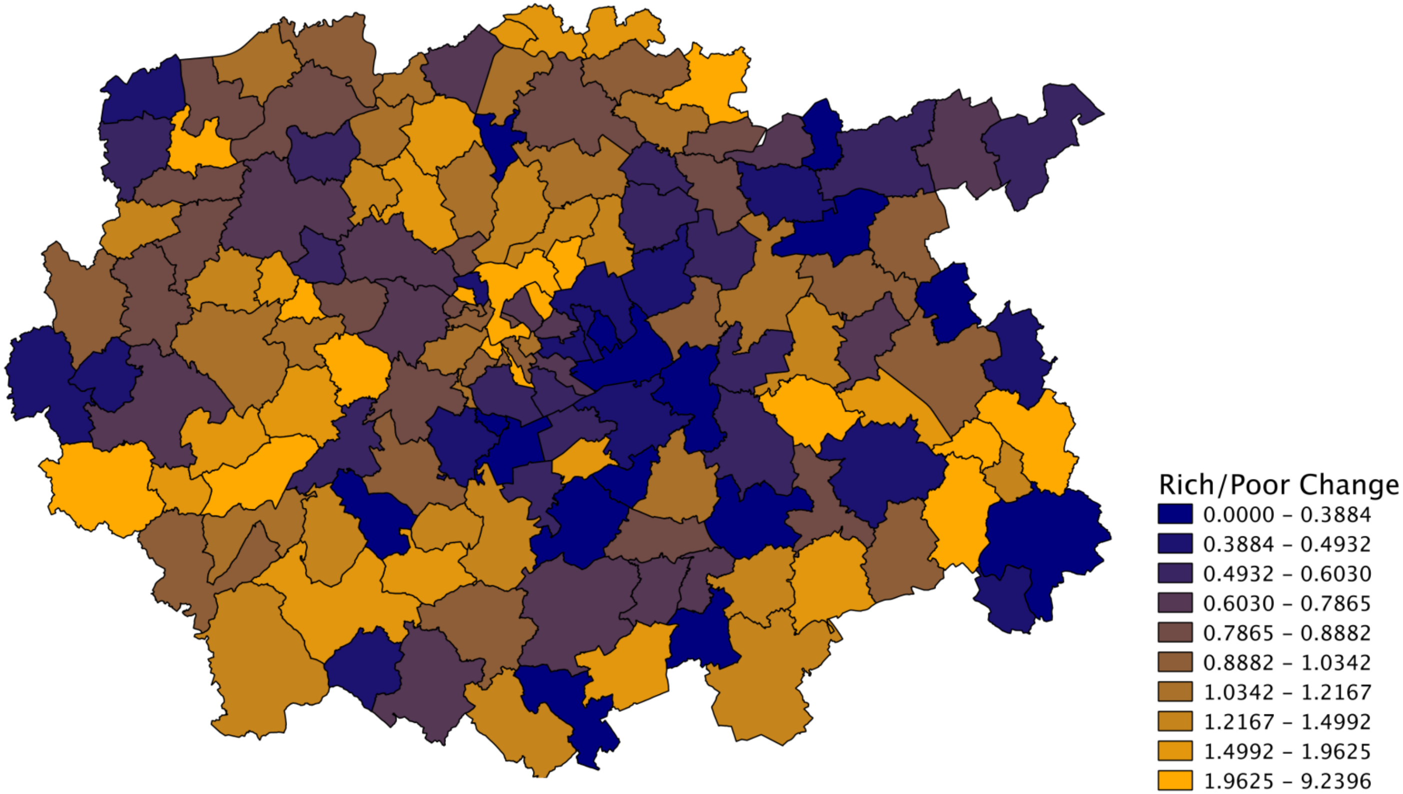
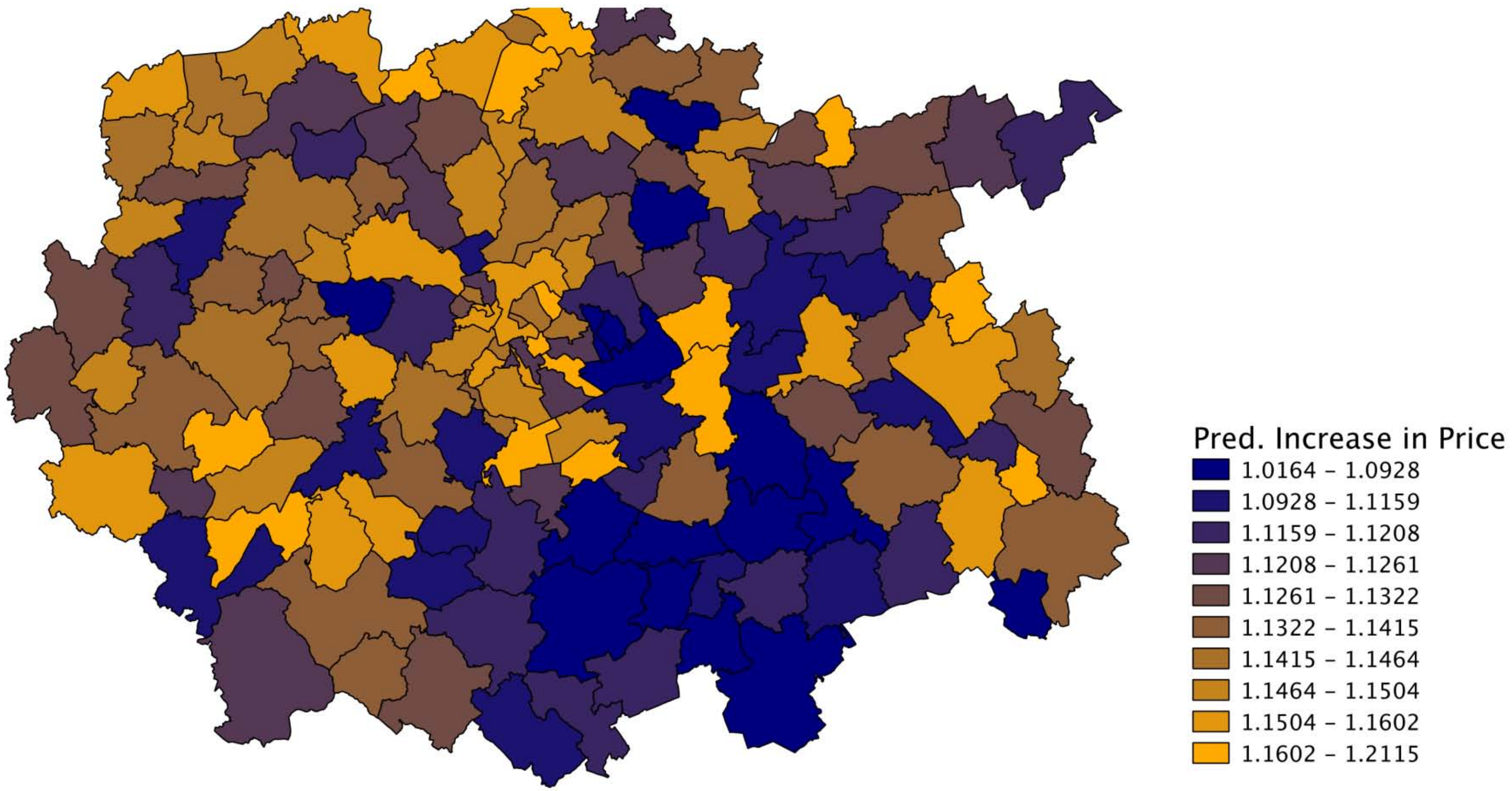
Results

- Change in income distribution (2001-2008)



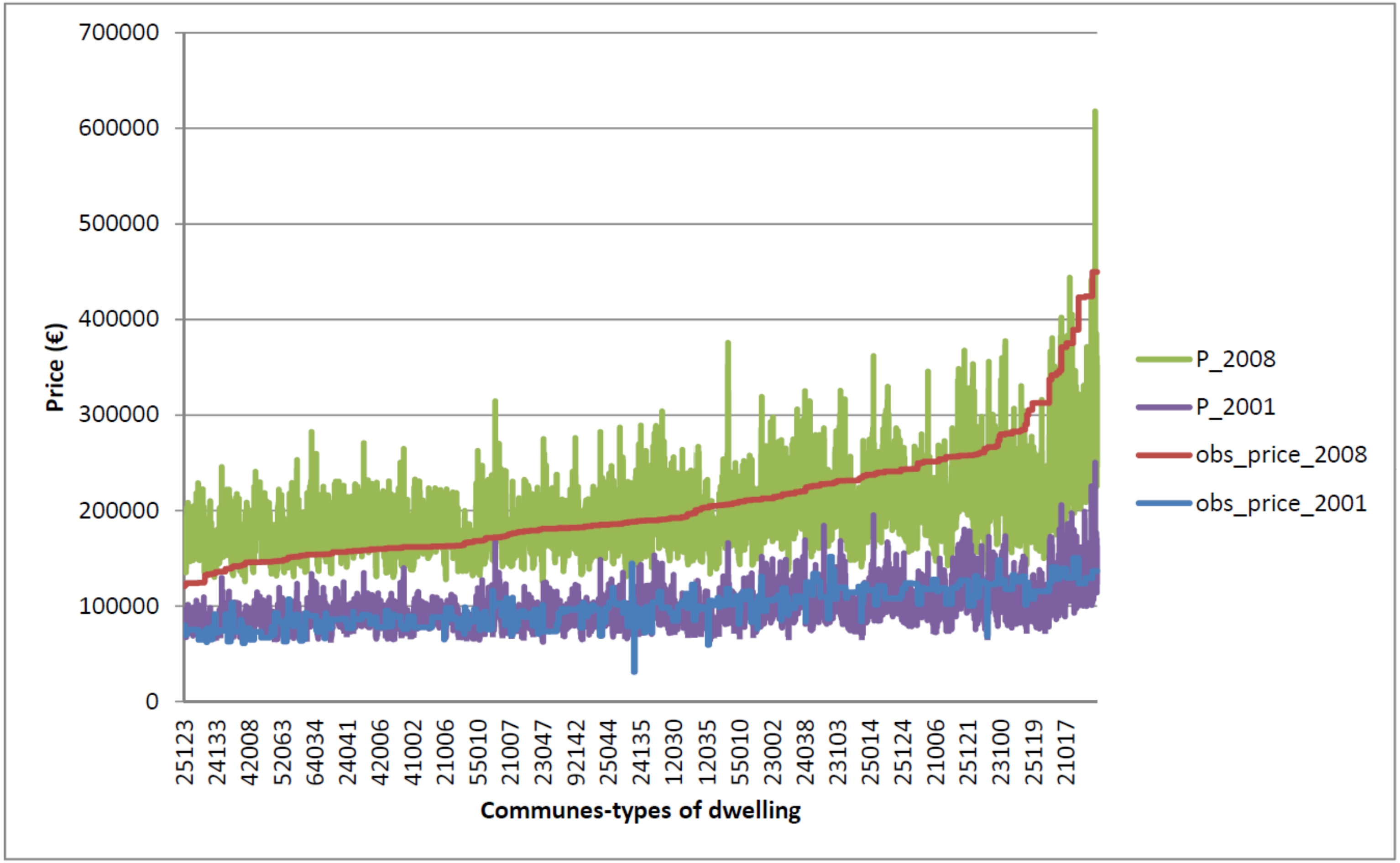
Results

- Increase in prices (2001 -2008)



Results

- Evolution of prices (2001 – 2008)



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Conclusion

- A model for location choice is proposed. Adjustment of agent's preferences goes (partially) in the direction of equilibrium market clearing
- Results show the proposed model is able to forecast the price trend
- Further work considers improving other components of the model and a comparison with UrbanSim

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Thank you