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
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


http://transp-or.epfl.ch/
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 ($H$)
  \[ P(h) = P(i) = 1 \quad \forall h, i \quad \Rightarrow \quad H = S \]

- Possible equilibrium conditions:
  \[ \sum_h P(i, h) \Rightarrow \sum_h P(i \, | \, h)P(h) = P(i) = 1 \quad \forall i \quad \text{(everything is sold)} \]
  \[ \sum_i P(i, h) \Rightarrow \sum_i P(h \, | \, i)P(i) = P(h) = 1 \quad \forall h \quad \text{(everyone is located)} \]
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 \( P(h) = 1 \ \forall h \)
  - Total supply must be greater or equal than total demand \( \Rightarrow H \leq S \)
  - Not all locations are necessarily used \( P(i) \leq 1 \ \forall i \)
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 $\mathcal{H}$ observe the market: prices and supply $(r^{t-1}_i, z^{t-1}_i, S_i)$
  - All gents (simultaneously) adjust their bids, attempting to make their expected number of winning auctions equal to one:
    \[
    \sum_{i \in S} q(h | i) = 1 \quad \forall h
    \]
    \(q(h|i):\) perceived probability of being the best bidder for $i$
  - All agents bid at the same time for all locations $\Rightarrow$ prices and location distributions are defined
  - The assignment mechanism is an auction $\Rightarrow$ 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:

\[
q(h \mid i) = \frac{\exp(V_h(z_{i}^{t}) - b_{h}^{t})}{\sum_{g \in H} \exp(B_{gi}^{t-1})} \approx \exp(V_h(z_{i}^{t}) - b_{h}^{t} - r_{i}^{t-1})
\]

\[
\sum_{i \in S} q(h \mid i) = 1 \quad \Rightarrow \quad \hat{b}_{h}^{t} = \ln \left( \sum_{i \in S} \exp(V_h(z_{i}^{t}) - r_{i}^{t-1}) \right)
\]

Advantage: no fixed point, just evaluation of equation \(\Rightarrow\) it is possible to apply to large populations without excessive computational cost
General framework for land use modeling
General framework

- **Re-location models**
- **Transport model**
- **Located agents**
- **Real estate prices**
- **New agents**
- **Firmographics (Demographics)**

**Market clearing**

- **New real estate**
- **Supply model**
- **Externalities, market conditions (prices, demand/supply surplus, etc)**
  - Given for $t=0$

**Re-locating agents, vacated real estate**

- **Travel times, congestion, level of service**
- **$t=t+1$**
General framework (this application)

- Re-locating agents, vacated real estate
- New real estate
- Externalities, market conditions (prices, demand/supply surplus, etc) Given for t=0
- Located agents
- Real estate prices
- New agents
- Travel times, congestion, level of service

Market clearing

Supply model

Firmographics

Demographics

New agents

t=t+1
Case study: Brussels
Area of study
Area of study
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

<table>
<thead>
<tr>
<th>Parameter</th>
<th>spatial attribute</th>
<th>household (hh) attribute</th>
</tr>
</thead>
<tbody>
<tr>
<td>ASC&lt;sub&gt;2&lt;/sub&gt;</td>
<td>-</td>
<td>income level constant (745-1859 Euros)</td>
</tr>
<tr>
<td>ASC&lt;sub&gt;3&lt;/sub&gt;</td>
<td>-</td>
<td>income level constant (1860-3099 Euros)</td>
</tr>
<tr>
<td>ASC&lt;sub&gt;4&lt;/sub&gt;</td>
<td>-</td>
<td>income level constant (3100-4958 Euros)</td>
</tr>
<tr>
<td>ASC&lt;sub&gt;5&lt;/sub&gt;</td>
<td>-</td>
<td>income level constant (&gt;4959 Euros)</td>
</tr>
<tr>
<td>B Educ Zone</td>
<td>% of education jobs in zone i</td>
<td>dummy for hh’s with children</td>
</tr>
<tr>
<td>B Educ Comm</td>
<td>% of education jobs in commune c</td>
<td>dummy for hh’s with children</td>
</tr>
<tr>
<td>B House1</td>
<td>dummy for isolated house</td>
<td>dummy for hh’s with more than 2 people</td>
</tr>
<tr>
<td>B House2</td>
<td>dummy for semi-isolated house</td>
<td>dummy for hh’s with more than 2 people</td>
</tr>
<tr>
<td>B House3</td>
<td>dummy for attached house</td>
<td>dummy for hh’s with more than 2 people</td>
</tr>
<tr>
<td>B Income 23</td>
<td>% of hh’s of income level 2 and 3 in zone i</td>
<td>dummy for income level 2 or 3</td>
</tr>
<tr>
<td>B Income 45</td>
<td>% of hh’s of income level 4 and 5 in zone i</td>
<td>dummy for income level 4 or 5</td>
</tr>
<tr>
<td>B Indu Zone</td>
<td>% of industry jobs in zone i</td>
<td>dummy for income level &gt; 3</td>
</tr>
<tr>
<td>B Indu Comm</td>
<td>% of industry jobs in commune c</td>
<td>dummy for hh’s with active workers</td>
</tr>
<tr>
<td>B Service Zone</td>
<td>% of service (office and hotel) jobs in i</td>
<td>dummy for hh’s with active workers</td>
</tr>
<tr>
<td>B Shop Comm</td>
<td>% of retail jobs in commune c</td>
<td>dummy for hh’s with active workers</td>
</tr>
<tr>
<td>B Surf h</td>
<td>surface of dwelling v</td>
<td>dummy for multi-person hh’s with inc level &gt; 3</td>
</tr>
<tr>
<td>B Surf m</td>
<td>surface of dwelling v</td>
<td>dummy for multi-person hh’s with inc level = 3</td>
</tr>
<tr>
<td>B Trans</td>
<td>public transport acces&lt;sub&gt;i&lt;/sub&gt; (facilities/km&lt;sup&gt;2&lt;/sup&gt;)</td>
<td>dummy for hh’s with 0 cars</td>
</tr>
<tr>
<td>B Trans2</td>
<td>public transport acces&lt;sub&gt;i&lt;/sub&gt; (facilities/km&lt;sup&gt;2&lt;/sup&gt;)</td>
<td>dummy for hh’s with 2 or more cars</td>
</tr>
<tr>
<td>B Univ Comm</td>
<td>% of people with university degree in c</td>
<td>dummy for hh’s having integrants with univ degree</td>
</tr>
</tbody>
</table>
### Bid function estimation results

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
<th>Std error</th>
<th>t-test</th>
</tr>
</thead>
<tbody>
<tr>
<td>ASC₂</td>
<td>-0.0496</td>
<td>0.21</td>
<td>-0.24*</td>
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<tr>
<td>ASC₃</td>
<td>-0.442</td>
<td>0.224</td>
<td>-1.97</td>
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<td>ASC₄</td>
<td>-0.751</td>
<td>0.181</td>
<td>-4.15</td>
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<tr>
<td>ASC₅</td>
<td>-0.96</td>
<td>0.233</td>
<td>-4.13</td>
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<tr>
<td>B_educ_zone</td>
<td>0.269</td>
<td>0.12</td>
<td>2.25</td>
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<tr>
<td>B_educ_comm</td>
<td>0.562</td>
<td>0.528</td>
<td>1.07*</td>
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<tr>
<td>B_house1</td>
<td>0.755</td>
<td>0.0828</td>
<td>9.11</td>
</tr>
<tr>
<td>B_house2</td>
<td>0.935</td>
<td>0.0799</td>
<td>11.7</td>
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<tr>
<td>B_house3</td>
<td>1.12</td>
<td>0.0717</td>
<td>15.62</td>
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<tr>
<td>B_income_23</td>
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<td>0.231</td>
<td>-1.41</td>
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<tr>
<td>B_income_45</td>
<td>1.91</td>
<td>1.08</td>
<td>1.77*</td>
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<tr>
<td>B_indu_zone</td>
<td>-5.36</td>
<td>2.62</td>
<td>-2.04</td>
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<tr>
<td>B_indu_comm</td>
<td>0.247</td>
<td>0.11</td>
<td>2.25</td>
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<tr>
<td>B_service_zone</td>
<td>0.243</td>
<td>0.0542</td>
<td>4.49</td>
</tr>
<tr>
<td>B_shop_comm</td>
<td>3.13</td>
<td>0.458</td>
<td>6.84</td>
</tr>
<tr>
<td>B_surf_h</td>
<td>0.00916</td>
<td>0.00197</td>
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<td>B_surf_m</td>
<td>0.00642</td>
<td>0.00124</td>
<td>5.16</td>
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<td>B_trans</td>
<td>0.739</td>
<td>0.0811</td>
<td>9.12</td>
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<td>B_trans2</td>
<td>-0.548</td>
<td>0.0989</td>
<td>-5.55</td>
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<tr>
<td>B_univ_comm</td>
<td>3.11</td>
<td>0.134</td>
<td>23.25</td>
</tr>
<tr>
<td>α</td>
<td>1.84</td>
<td>0.708</td>
<td>2.6</td>
</tr>
<tr>
<td>γ</td>
<td>0.659</td>
<td>0.0505</td>
<td>13.04</td>
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<tr>
<td>σ</td>
<td>-1.87</td>
<td>0.0182</td>
<td>-102.42</td>
</tr>
</tbody>
</table>

* Parameter not significant at the 95% level
Results

- Change in income distribution (2001-2008)
Results

- Increase in prices (2001 - 2008)
Results

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
Thank you