Modeling residential location choice and real estate prices with a bid-auction approach

Ricardo Hurtubia
Francisco Martínez
Michel Bierlaire

Seventh Workshop on Discrete Choice Models,
August 25-27, 2011
Lausanne, Switzerland
Outline

1. Motivation
2. Bid approach for location choice
3. Proposed method
4. Brussels case study
5. Discussion
6. Further research
Motivation

- Evolution of land use (location choice) models:
  - Aggregated ➔ Disaggregated
  - Equilibrium ➔ Dynamic microsimulation

- Market clearing / location distribution:
  - Bid-auction
  - Choice

- Bid approach: consistent with economic theory. Usually implemented in equilibrium models (e.g. MUSSA)

- Choice approach: easier to implement in a microsimulation context (e.g. UrbanSim). Requires hedonic rents/prices
Motivation

- Bid-auction approach applied to microsimulation
  - Price formation problem
    - Consistency with observed prices
    - Reaction to market conditions
  - Dynamics (pseudo-equilibrium)
  - Active bidders in the auction (choice set)
Bid approach for location choice

- Assumptions:
  - Real estate goods (locations) are traded in auctions
  - Agents bid their willingness to pay for each location ($B_{hi}$)
  - For each location the best bidder is selected
  - The amount/value of the best bid determines the rent/price
Bid approach for location choice

- Probability of agent $h$ being the best bidder for location $i$:

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

- Expected maximum bid (rent):

$$r_i = \frac{1}{\mu} \ln \left( \sum_{g \in H} \exp(\mu B_{gi}) \right)$$
Bid approach for location choice

- Problems:
  - Requires equilibrium between supply and demand (or at least demand > supply)
  - In the case of supply surplus it not clear which locations are not selected
  - Logsum ($r_i$) doesn’t necessarily reproduce observed prices or rents
Proposed framework

- Bid based location choice model
- Assumptions:
  - Goods (locations) traded in auctions, period-wise
  - Agents bid their willingness to pay for each location
  - Agents adjust the level of their bids as a reaction to market conditions (represented by observed prices)
  - Agents are myopic regarding the outcome of future and present auctions
Proposed framework

- Bid function:

\[ B_{hi}^t = b_h^t + b_{hi}^t \]

Bid adjustment (utility level)\hspace{1cm} Willingness to pay for attributes

\[ b_{hi}^t = f(z_{t-1}^i, x_h^t, \beta) \longrightarrow \text{estimated via max log-likelihood, assuming } b_h^t = 0 \]
Proposed framework

- Bid adjustment:
  - Bidding households attempt to ensure winning, on average, at least one auction:

\[
\sum_i P_{h/i}^t = \sum_i \frac{\exp(b_{h_i}^t + b_{hi}^t)}{\sum_{g \in H} \exp(B_{gi}^t)} = 1 \quad \forall h
\]

But… households do not observe bids of other households in the same period. They can only observe transaction prices in previous periods.

* \( \mu = 1 \)

\( H : \) full choiceset
Proposed framework

- Bid adjustment:

\[
\sum_{i \in S} P_{h/i}^t = \sum_{i \in S} \frac{\exp(b_h^t + b_{hi}^t)}{\sum_{g \in H} \exp(B_{gi}^{t-1})} = 1
\]

\[
\sum_{g \in H} \exp(B_{gi}^{t-1}) = \exp(r_{i}^{t-1})
\]

S: full choice set of dwellings/locations
Proposed framework

- In each period:

\[
b_h^t = -\ln \left( \sum_{i \in S} \exp \left( b_{hi}^t - r_i^{t-1} \right) \right)
\]

- In the base year (calibration year):

\[
b_h^0 = -\ln \left( \sum_{i \in S} \exp \left( b_{hi}^0 - r_i^* \right) \right)
\]

Observed prices at the base year.
Price dynamics

- Simulation of a supply surplus scenario with synthetic data

![Graph showing price dynamics with supply shock (increase)]
Brussels case study

- Data collected for the SustainCity project:
  - Census 2000 (aggregated data by zone)
  - Household survey 2000 (disaggregated data, ~1000 obs)
  - 1985-2008 average transaction prices by commune and dwelling type

- 1267997 households, 1274701 dwellings
- 157 communes
- 4975 zones
- 4 types of dwelling
  - Detached houses
  - Semi-detached houses
  - Attached houses
Brussels case study

**Bid function specification:**

\[
b_{hv_i} = \beta_{surf} \cdot surf_{vi} \cdot \ln(N_h) + \beta_{sup} \cdot Q_i^{sup} \cdot N_h^{sup} + \beta_{house} \cdot \chi_{vi}^{house} \cdot N_h + \\
\beta_{trans} \cdot Y_{i}^{trans} \cdot \gamma_{i}^{cars=0} + \beta_{trans2} \cdot Y_{i}^{trans} \cdot \gamma_{i}^{cars>1} + \beta_{comm} \cdot Y_{i}^{comm} \cdot \ln(N_h) + \\
\beta_{off} \cdot Y_{i}^{off} \cdot W_h + \beta_{green} \cdot Y_{i}^{green} \cdot W_h + \ln \phi_{h}
\]

- \(surf_{vi}\): average surface of a residential unit in buildings type \(v\) in zone \(i\) (calculated from the census).
- \(N_h\): number of individuals in a household.
- \(W_h\): number of active individuals (workers) in a household.
- \(N_h^{sup}\): number of persons in the household who achieved a university degree as their maximum education level.
- \(Q_i^{sup}\): percentage of the population in zone \(i\) with a superior level education-degree.
- \(Y_{i}^{trans}\): measurement of the quality of public transport (accessibility).
- \(Y_{i}^{comm}, Y_{i}^{off}, Y_{i}^{green}\): measurement of the presence of commerce, offices and public green areas.
- \(\phi_{vi}\): correction factor for the household-sampling protocol.
Brussels case study

- Estimation results with PythonBiogeme

<table>
<thead>
<tr>
<th>Name</th>
<th>Value</th>
<th>Std_err</th>
<th>t-test</th>
<th>p-value</th>
<th>Robust Std_err</th>
<th>Robust t-test</th>
<th>p-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>B_surf_s</td>
<td>0.00832</td>
<td>0.00265</td>
<td>3.14</td>
<td>0.00</td>
<td>0.00274</td>
<td>3.04</td>
<td>0.00</td>
</tr>
<tr>
<td>B_superior</td>
<td>0.484</td>
<td>0.105</td>
<td>4.62</td>
<td>0.00</td>
<td>0.104</td>
<td>4.63</td>
<td>0.00</td>
</tr>
<tr>
<td>B_trans</td>
<td>0.344</td>
<td>0.138</td>
<td>2.50</td>
<td>0.01</td>
<td>0.144</td>
<td>2.39</td>
<td>0.02</td>
</tr>
<tr>
<td>B_trans2</td>
<td>-0.454</td>
<td>0.157</td>
<td>-2.69</td>
<td>0.00</td>
<td>0.159</td>
<td>-2.87</td>
<td>0.00</td>
</tr>
<tr>
<td>B_house</td>
<td>0.419</td>
<td>0.0622</td>
<td>6.74</td>
<td>0.00</td>
<td>0.0638</td>
<td>6.57</td>
<td>0.00</td>
</tr>
<tr>
<td>B_comm</td>
<td>-1.48</td>
<td>0.286</td>
<td>-5.17</td>
<td>0.00</td>
<td>0.293</td>
<td>-5.05</td>
<td>0.00</td>
</tr>
<tr>
<td>B_green</td>
<td>-0.336</td>
<td>0.0736</td>
<td>-4.57</td>
<td>0.00</td>
<td>0.0771</td>
<td>-4.36</td>
<td>0.00</td>
</tr>
<tr>
<td>B_prof</td>
<td>-0.179</td>
<td>0.0906</td>
<td>-1.98</td>
<td>0.05</td>
<td>0.0933</td>
<td>-1.92</td>
<td>0.05</td>
</tr>
</tbody>
</table>

- Likelihood ratio test against null model 219.4
Brussels case study

- Number of people by commune

![Graph showing the number of people by commune in Brussels case study.](image)
Brussels case study

- Number of people with university degree by commune
Brussels case study

- Logsums for each location
Brussels case study

- Logsum for each location after adjustment of $b_h$
Discussion

- Framework allows for supply or demand surplus
- Changes in (aggregate) market conditions are captured in the price
- Adjustment of $b_h$ produces maximum expect bids close to observed prices

- Scale of prices
  - Arbitrary? (positive or negative $b_h$)
  - Estimation of $\mu$?
  - Should bid’s be also adjusted location-wise ($b_i$)?
  - Relative importance of $b_{hi}$? (re-estimation of betas?)
Further research

- **Active bidders (choice set generation)**
  - Price is affected by who is “competing” for the location
  - Choice set generation or importance sampling?
  - Relevance of the scale of the logsum

- **Location assignment**
  - Monte Carlo simulation following max bid probabilities?
  - Simultaneous location assignment?
Thanks
Choice approach for location choice

- Assumptions:
  - Each agent selects the location that provides maximum utility
  - Agents are price takers
  - Prices (usually) defined as function of the location attributes
Choice approach for location choice

- Assumption: consumer surplus is a proxy of utility:
  \[ V_{hi} = B_{hi} - r_i \]

- Probability of location \( i \) providing maximum utility to agent \( h \):
  \[ P_{i/h} = \frac{\exp(\mu(B_{hi} - r_i))}{\sum_j \exp(\mu(B_{hj} - r_j))} \]
Choice approach for location choice

- **Problems:**
  - Price-taker assumption (not good for quasi-unique goods)
  - Market conditions usually not captured by hedonic rents

- **Advantages:**
  - If prices are the outcome of an auction, the location distribution is the same for the bid and choice approaches