A Dynamic Model of Housing Supply

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Housing Market Dynamics

- Housing markets typically volatile in both prices and quantities
  - Housing constitutes two-thirds of the average household’s asset portfolio
  - Home owners face uninsurable risk and can’t diversify
  - 10 million employed in construction sector
- Volatility has potentially large welfare costs
San Francisco Price levels
1978–2006

Note: Real price levels. 1980 real price level normalized to 100

Year


Price level

100 150 200 250
Housing Market Dynamics

Permits – Bay Area
1980–2006

single family permits *10000
Year
1980−2006

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A Dynamic Model of Housing Supply
Existing literature examines patterns using aggregate data

Interesting housing patterns across metro areas and through time.

For example:
- Predictability of prices: Case and Shiller (1989)
- Construction volatility: Glaeser and Gyourko (2007)

A constraint on the current literature has been the lack of micro data.
Microfoundations of Housing Supply

- What underlying factors determine housing supply?

1. Where does new construction occur?
2. When does new construction occur?
   - Given predictable prices, observed construction trends are puzzling.
   - What role does timing and expectations play in construction volatility?
3. How does new construction occur?
   - What explains size of building?
Overview

- New Construction
  - Large Scale Developments
  - Small Scale Infill Construction

- What determines the rate of small scale infill construction?
  - Includes vacant and “under-utilized” parcels.
  - Excludes greenfield developments and all large housing developments.

- Covers approx 55% of construction in Bay Area (1988-2004)
Overview

- Estimate the parameters of the profit function using a dynamic model.
- Parcel owners choose the optimal period to develop their parcel.
- They also choose the type/size of construction.
- Parcel owners take into account future prices and costs.
Preview of Results

- Price appreciation caused by increase in value of buildable parcel
- Build big when return on size high
- Don’t build that much more when prices high
- Costs are pro-cyclical
  - Explains puzzling building patterns
  - Cost trends combined with forward looking behavior dampen volatility
- Strong evidence that build decision is when-and-not-if.
Data

Data is formed from two primary sources:

- Dataquick dataset is a transactions dataset that provides information on every house that sold in Bay Area between 1988 and 2004.
- California Statewide Infill Study provides a geo-coded parcel inventory.

Data from six core counties of Bay Area between 1988 and 2004.

Observe characteristics parcels that were vacant/underutilized in 1988.

Observe when, where, and how any parcel gets developed.
Motivation for Dynamic Approach – Descriptive Analysis

- Agents take into account expectations about future prices and costs.
- In the Bay Area there were significant changes in the housing prices between 1988 and 2004.
- Large cross section variation in price appreciation.
Note: Real price levels. 1988 real price level normalized to one.
Parcel owners make a sequence of decisions that maximize the discounted sum of expected per-period profits.

Parcel owners make two decisions in each period

1. Build or don’t build a residential unit
2. If build, choose how much housing services to provide.

Building ends the process ⇒ optimal stopping problem

3 outcomes: 2 choices plus sales prices

Parcel owners have (rational) expectations about future prices and costs
Model - Notation

- $x_{njt}$ can be divided into two components:
  1. parcel level variables, $x_{nt}$
  2. tract level variables, $x_{jt}$.

- $\Omega_t$ is the information set at time $t$

- The discrete decision variable is $d_{nt} \in \{0, 1\}$

- $h$ is the level of housing services

- $\pi_d(x_{njt}, h_{nt}) + \epsilon_{dnt}$ is the per period profit function
Model – Per-period Profits

- **Sales price**
  \[ P_{nt} = \rho_{jt} h_{nt}^{\gamma_1 t} x_{n}^{\gamma_2 t} e^{\nu_{nt}} \]

- **Variable costs that vary with the level of housing services provided**
  \[ VC_{nt} = (\alpha_{0jt} x_{n}^{\alpha_1} e^{\eta_{nt}}) \cdot h_{nt} \]

- **Fixed costs associated with any construction**
  \[ FC_{nt} = \delta_{ct} \]
Model - Decision Two: Housing Services

- If a parcel owner decides to build, that period becomes the terminal period and lifetime expected profits become the per-period profits.

\[ \pi_{nt} = \rho_{jt} h_{nt}^{\gamma_{1jt}} x_n^{\gamma_{2jt}} e^{0.5\sigma_n^2} - \left( \alpha_{0jt} x_n^{\alpha_1} e^{\eta_{nt}} \right) h_{nt} + \delta_{ct} + \epsilon_{nt} \]

- Conditional on building, a parcel owner chooses \( h \) to maximize profits.

- First order condition yields the optimal housing services, \( h^* \):

\[ h_{nt}^* = \left( \frac{\gamma_{1jt} \rho_{jt} x_n^{\gamma_{2jt}} e^{0.5\sigma_n^2}}{\alpha_{0jt} x_n^{\alpha_1} e^{\eta_{nt}}} \right) \frac{1}{1 - \gamma_{1jt}} \]
Determinants of parcel owner’s decision are:

- unobserved shocks in period $t$, $\epsilon_{nt} \sim$ i.i.d. Type 1 Extreme Value
- observed variables affecting per-period profits in period $t$, $x_{nt}$
- Any variables that predict future values of $x$, which I denote by $\Omega_{nt}$.

$\pi_0(x)$ is normalized to zero $\Rightarrow$ $v_0(\Omega)$ is simply the continuation value

Absorbing decision $\Rightarrow$ $v_1(\Omega)$ is simply per period profits

\[
v_0(\Omega) = \sigma_\epsilon \beta \left( \int \log \left[ \exp \left( \frac{v_0(\Omega')}{\sigma_\epsilon} \right) + \exp \left( \frac{\pi_1(x')}{\sigma_\epsilon} \right) \right] q(\Omega'|\Omega) d\Omega' \right)
\]

\[
v_1(x) = \pi_1(x)
\]
Estimation Overview

- There are three outcomes associated with the model.
  - The binary decision to build or not in each period.
  - The housing service provision decision made conditional on building.
  - Sales price of properties that sell.

- Model is estimated in 3 stages
Estimation Overview

1. Using observed sales, estimate price equation (for each tract and year)
2. Using observed construction size and Step 1 estimates, estimate housing service equation
3. Using observed timing of development, and Step 1 & 2 estimates, estimate remaining fixed cost parameters.
Use all previous sales to estimate the following regression equation separately for each tract/year combination.

\[ \log(P_{nt}) = \log(\rho_{jt}) + \gamma_{1jt} \log(h_{nt}) + \gamma_{2jt} \log(x_{n}) + \gamma_{3jt} \text{old} + \nu_{nt} \]
Results - Hedonic Price Regressions

Figure: Price of Typical House by Year

New House Price
sqft = 1670, lot = 6800

Year


$5 \times 10^5$
Results - Hedonic Price Regressions

Figure: Distribution of the Marginal Price of Square Foot in a Typical House

Marginal Price of Square Foot
sqft = 1670, lot = 6800, new house
Results - Hedonic Price Regressions

Figure: Time Trend of the Marginal Price of Square Foot in a Typical House

Year


Marginal Price of Square Foot

Sqft = 1670, lot = 6800, new house

120 125 130 135 140 145 150 155 160
Estimation - Variable Cost Parameters

\[ VC_{nt} = (\alpha_{0jt} x_n^{\alpha_1} e^{\eta_{nt}}) \cdot h_{nt} \]

\[ h_{nt}^* = \left( \frac{\gamma_{1jt} \rho_{jt} x_n^{\gamma_{2jt}} e^{.5\sigma^2}}{\alpha_{0jt} x_n^{\alpha_1} e^{\eta_{nt}}} \right)^{\frac{1}{1-\gamma_{1jt}}} \]

\[(\gamma_{1jt} - 1) \log(h_{nt}) + \log(\gamma_{1jt}) + \log(\rho_{jt}) + \gamma_{2jt} \log(x_n) + .5\sigma^2_v = \]

\[ \log(\alpha_{0jt}) + \alpha_1 \log(x_n) + \eta_{nt} \]

- Estimating by least squares yields estimates of \( \alpha_{0jt}, \alpha_1 \)
- Compare with RS Means cost data
Estimation - Variable Costs - Identification

Figure: Time Trend of Mean Square Foot

![Graph showing the time trend of mean square foot over years from 1988 to 2004. The graph indicates a steady increase in mean square foot, with a peak around 1992 and a more pronounced increase from 2000 onwards.]
Results - Variable Costs

Figure: Distribution of the Cost per Square Foot in a Typical House
Figure: Time Trend of the Cost per Square Foot in a Typical House
Letting “hats” on variables denote their estimates from the first step, I can rewrite the choice specific value functions as:

\[ v_0(\Omega; \delta) = \beta \left( \int \left( \pi_1(x') - \log \left[ \hat{P}_1(\Omega') \right] \right) \hat{q}(\Omega' \mid \Omega) d\Omega' \right) \]

\[ v_1(x; \delta) = \pi_1(x) \]

Parcel owner will choose to build if \( v_1(x; \theta) + \epsilon_{1nt} > v_0(\Omega; \theta) + \epsilon_{nt} \)

Given the distribution of \( \epsilon \), this is a binary logit model

I estimate \( \delta \) using maximum likelihood
Results - Fixed Costs

$$FC_{nt} = \delta_{ct}$$

- Estimate county-by-year dummies.
- Actually estimate $$(\beta E_t \delta_{ct+1} - \delta_{ct})$$
- Roughly interpreted as expected growth in the latent fixed costs
Results – Expected Fixed Cost Growth by County

Figure: Time Trend of Expected Fixed Cost Growth by County

\[ \beta E \delta_{ct+1} - \delta_{ct} \]

\[ \times 10^4 \]

Year


-4 -2 0 2 4 6

Alameda
Contra Costa
Marin
San Francisco
San Mateo
Santa Clara

By County

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“Last, you might consider the potential effect on construction and design costs as the housing market continues deflating. However modest the price deflation may be in Marin County, contractors are becoming less and less busy as the housing frenzy abates. That means prices for materials and labor are already falling, and may well continue to fall for months.”
Implications of Dynamic Behavior

- Without cost considerations, model underpredicts construction during the boom of the late 1990s.
- Rising costs discourage parcel owners from only building at peak.
- Cost trends and forward looking behavior dampen volatility.
- Fully dynamic model necessary to understand the primitives that drive observed aggregate trends.
- A static model yields fixed cost estimates in excess of $2 million.
  - Evidence that parcel owners choosing when and not if to build.
Conclusion

- Combine dynamic discrete choice and static continuous choice problems.
  - a very large state space.
  - fine geographic levels.
  - time varying parameters
- Use model to explain where and when construction occurs
  - quantities
  - timing & volatility
Bay Area: Counties and Tracts

- Marin
- Santa Clara
- Alameda
- Contra Costa
- San Mateo
- San Francisco

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