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Using Smoothing Methods in the Computation of Hedonic Imputed Price Indexes for Properties and their Land and Structure Components

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Using Smoothing Methods in the Computation of Hedonic Imputed Price Indexes for Properties and their Land and Structure Components

Alicia N. Rambaldi† Ryan R. J. McAllister†† and Cameron S. Fletcher††1

†The University of Queensland
††CSIRO

SEM Annual Conference - 22nd July 2015

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Introduction and Background

The Valuer’s Model
  Simple Behavioural Model

The Econometric Approach to the Decomposition
  Unobserved Components Approach

Price Indices

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  Model Estimation and Comparison to Valuer’s Estimates
  Bay Area - Monthly Data
  Brisbane Suburb - Annual Data

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Introduction

- A property is a bundled good composed of an *appreciating asset*, land, and a *depreciating asset*, structure.

- The importance of this distinction is increasingly recognised in the real estate literature (see Bostic et al. (2009), Malpezzi et al. (1987)) as well as in the price index construction literature (see European Comission et al. (2013), Chapter 13, Diewert et al. (2011), Diewert et al. (2015), Diewert and Shimizu (2013) and Färe et al. (2014)).
Introduction (cont.)

- Due to the mobility of materials and labor, construction costs are generally uniform within a housing market.
- Asymmetric appreciation across properties within a market arise from asymmetric exposure to common shocks to land values.
- At any point in time the value of the structure is its replacement cost less any accumulated depreciation.
- Sufficiently large depreciation can result in the structure declining in value over time.
  - Malpezzi et al. (1987), Knight and Sirmans (1996), Bostic et al. (2009), Diewert et al. (2011, 2015)
Contributions

- Propose an unobserved components based decomposition to separate the value of the land from that of the structure
  - Use dynamics of the components to identify them (Maravall and Aigner (1977), Harvey (2011), Komumjer and Ng (2014))
  - Diewert et al. (2015), Diewert and Shimizu (2013) and Färe et al. (2014) use exogenous information - *new dwelling construction price index* to aid at identifying the land component

- Compare the decomposition approach between the cases when the data available include
  - both property and vacant land sales transactions
  - only property sale transactions

- Compare price indices to those obtained using Diewert et al. (2015), Diewert and Shimizu (2013) and Färe et al. (2014)
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The state of QLD Valuer’s Statement

"When determining statutory land values, valuers from our department: examine trends and sales information for each land use category (e.g. residential, commercial, industrial and rural); inspect vacant or lightly improved properties that have recently been sold; consider the land’s present use and zoning under the relevant planning scheme; take into account physical attributes and constraints on use of the land" (http://www.dnrm.qld.gov.au/property/valuations/about/considerations).

The valuer’s task is to provide the tax authorities and the rate payers with a valuation of their property or land. We write a simple model for the expected value of the property,

\[ E_t(V_t) = E_t(L_t, S_t | \sum_{j=0}^{\tau} w_{t-j} \text{ [market sales: Property, Land]}_{t-j} ) \]  

(1)

where,

- \( V_t \) is the value of the property
- \( L_t \) is the land component of the value
- \( S_t \) is the structure component of the property value
- \( w_t \) is a weight such that \( w_{t-1} > w_{t-2} > w_{t-3} > \ldots \)
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Econometric Model

This follows previous studies (Bostic et al. (2009) and Diewert et al. (2011, 2015) where three orthogonal components are defined, land ($L$), structure ($S$) and noise.

$$y_t = L_t + S_t + \epsilon_t$$ (2)

where,

$y_t$ is a vector ($N_t \times 1$) with the sale price of each property (or vacant land) sold in period $t$.

$L_t$ is a vector ($N_t \times 1$) where each row is the value of the land component for the $i^{th}$ property sold in period $t$.

$S_t$ is a vector ($N_t \times 1$) where each row is the value of the structure component for the $i^{th}$ property sold in period $t$, and $S_{it} = 0$ if the sale is for vacant land.

$\epsilon_t \sim N(0, \sigma^2_\epsilon I)$
Econometric Model

- Let $X^L_t$ be an $N_t \times k_l$ matrix of hedonic characteristics intrinsic to the land component, e.g. size of the lot, location.

- Let $X^S_t$ be an $N_t \times k_s$ matrix of hedonic characteristics intrinsic to the structure component, e.g. age, size of the structure.

- Then we define,

$$L_t = f(X^L_t, \alpha^L_t)$$

$$S_t = g(X^S_t, \alpha^S_t)$$

where,

$\alpha^c_t$ are vectors of unknown parameters, $c = L, S$.

$E(L_tS_t) = 0$ for all $t$. 

The Econometric Approach to the Decomposition
Unobserved Components Approach

Econometric Model

- The simplest form of $f()$ and $g()$ is to use a linear combination

$$L_t = X_t^L \alpha_t^L$$

$$S_t = X_t^S \alpha_t^S$$

with law of motion given by,

$$\alpha_t^L = \alpha_{t-1}^L + \eta_t^L$$

$$\alpha_t^S = \alpha_{t-1}^S + \eta_t^S$$

where,

$$E[\eta_t\eta_t'] = Q_t = \begin{bmatrix} Q_t^L & 0 \\ 0 & Q_t^S \end{bmatrix}$$

A block diagonal covariance structure;

however, we do not directly specify it

$$\alpha_0 \sim N(a_0, P_0);$$

- The estimator of $\alpha_t$, $a_{t|t}$, has distribution $a_{t|t} \sim N(\alpha_t, P_{t|t})$
Modified Filter

- The two components (land, structure) are not correlated. Restriction on the covariance:
  - *Land component* bearing adjustments due to supply and demand pressures
  - *Structure component* value evolve due to construction costs (wages, CPI) and depreciate with Age.

- The dynamic discounting literature (see West and Harrison (1999), Koop and Korobilis (2013)) specifies $P_{t|t-1}$ is equal to $P_{t-1|t-1}$ discounted by a proportion.

- As our model has two components, we specify the problem with two discount factors, each associated with one of the components. The covariance is of the form:

$$P_{t|t} = blockdiag \left\{ \left( \delta_L^{-1} P_{[1:k_L,1:k_L]} \right), \left( \delta_S^{-1} P_{[(k_L+1):(k_L+k_S),(k_L+1):(k_L+k_S)]} \right) \right\}$$

(9)

- $0 \leq \delta_L < \delta_S \leq 1$, → this results in $Q_t$ being block diagonal as required

- Convergence of the estimator - see Triantafyllopoulos (2007)
Estimation of Parameters

- Covariance Parameters; \( \psi = [\sigma^2_\epsilon, \delta_L, \delta_S] \)
  - Grid Search for discount factors. Estimate model over a grid of \( \delta_L \) and \( \delta_S \)
    - 19 pairs covering \( d_L = 0.7 - 0.95 \) and \( d_S = 0.8 - 0.99 \).
  - Maximum likelihood estimation for \( \sigma^2_\epsilon \)
- See paper for details
- Matlab code - runs in seconds.
Estimation of $\alpha_t$

- Using the modified Kalman filter-smoother. The updating of $\alpha_t$ is standard. At time $t$ given all past information and up to and including the current period

$$a_{t|t} = a_{t|t-1} + K_t \nu_t$$  \hspace{1cm} (10)

- $\text{Var}(a_{t|t}) = P_{t|t}$ is the mean squared error variance
- where
  - $K_t$ is an adjustment factor (known as Kalman gain) - function of the $X_t$ data, $P_{t-1|t-1}$ and $F_t^{-1}$
  - $\nu_t = y_t - \hat{y}_{t|t-1}$ is prediction error with variance-covariance $F_t$

- Note that (10) can be written as

$$a_t = \sum_{j=1}^{t} w_j(a_{t|t}) y_j$$  \hspace{1cm} (11)

- where $w_j(a_{t|t})$ are weights that decrease with time and sum to one.
- See Rambaldi and Fletcher (2014) for review and discussion for the estimation of hedonic models.
Index for the land component

- The **Fisher Plutocratic index** is defined as:

\[
F^P_{(t-s),t} = \sqrt{L^P_{(t-s),t} \cdot P^P_{(t-s),t}}
\]  

(12)

where \(L^P_{t-s,t}\) and \(P^P_{t-s,t}\) are respectively the Laspeyres and Paasche index numbers,

\[
L^P_{(t-s),t} = \sum_{h=1}^{N_s} w^h_{(t-s)} \left( \frac{\hat{p}^L_{(t-s)}(x^L_{(t-s)})}{\hat{p}_{(t-s)}^L(x^L_{(t-s)})} \right); \quad P^P_{(t-s),t} = \left[ \sum_{h=1}^{N_t} w^h_t \left( \frac{\hat{p}^L_{(t-s)}(x^L_t)}{\hat{p}^L_t(x^L_t)} \right) \right]^{-1}
\]

where, \(\hat{p}^L_{(t-s)}(x^L_t)\) for \(s \geq 0\) is an *imputation* of the land component of \(h\), sold at time \(t\) with characteristics \(x^L_t\), using a vector of shadow prices for time period \(t - s\) and the value shares defined as in (13).

\(w^h_t\) is given by:

\[
w^h_t = \frac{P^h_t}{\sum_{n=1}^{N_t} P^n_t}
\]

(13)

where, \(P^h_t\) is the observed sale price of property/land \(h\) and \(N_t\) is the number of sales in period \(t\).

- The **Fisher Democratic index** is that where \(w^h_t = 1/N_t\)
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Empirical Evidence

1. Bay Area - Monthly Data, 1991-2010 (urban sprawling)
   - Homogeneous urban area north of Brisbane, $\approx 40$ KM from CBD
   - Large proportion of commuters to Brisbane
   - Close to ocean and other waterways

2. Brisbane Suburb (Neighbourhood) - Annual Data, 1970 - 2010
   - $\approx 5$ KM from CBD
   - Old, well established suburb
   - No close to the river to have "views"
   - Parts are close to waterways that lead to storm surge flooding
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## Data

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<tr>
<th></th>
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<th>Median</th>
<th>St.Dev</th>
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<td>191.77</td>
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<td>129.44</td>
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<td>13088</td>
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<td>Number of Months</td>
<td>233</td>
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<td>Number of Vacant Sales</td>
<td>3303</td>
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<tr>
<td>Sample period</td>
<td>1991:5</td>
<td>2010:9</td>
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</tbody>
</table>
Land Component Characteristics

\[ L_t = f(Land, Land^2, distances) \]

<table>
<thead>
<tr>
<th></th>
<th>Min</th>
<th>Max</th>
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</thead>
<tbody>
<tr>
<td>Land area (hectarea)</td>
<td>0.03</td>
<td>1.06</td>
<td>0.10</td>
<td>0.06</td>
<td>0.11</td>
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<tr>
<td>dist_coast (Km)</td>
<td>0.02</td>
<td>5.78</td>
<td>1.39</td>
<td>1.38</td>
<td>0.93</td>
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<tr>
<td>dist_waterway (Km)</td>
<td>0.01</td>
<td>0.86</td>
<td>0.27</td>
<td>0.25</td>
<td>0.16</td>
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<td>dist_OffenIndus (Km)</td>
<td>0.18</td>
<td>8.38</td>
<td>2.87</td>
<td>2.27</td>
<td>1.83</td>
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<td>dist_parks (Km)</td>
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<td>0.98</td>
<td>0.13</td>
<td>0.11</td>
<td>0.11</td>
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<tr>
<td>dist_busStop (Km)</td>
<td>0.02</td>
<td>4.35</td>
<td>0.47</td>
<td>0.22</td>
<td>0.80</td>
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<tr>
<td>dist_Schools (Km)</td>
<td>0.01</td>
<td>6.55</td>
<td>0.65</td>
<td>0.32</td>
<td>1.09</td>
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<tr>
<td>dist_Shops (Km)</td>
<td>0.01</td>
<td>4.80</td>
<td>0.53</td>
<td>0.40</td>
<td>0.49</td>
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<tr>
<td>dist_BoatRamp (Km)</td>
<td>0.06</td>
<td>6.29</td>
<td>1.97</td>
<td>1.60</td>
<td>1.46</td>
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</tbody>
</table>
Structure Component Characteristics

\[ S_t = f(Age, Age^2, Footprint, Footprint^2, Bath, Beds, Cars, Structure) \]

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<thead>
<tr>
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<tr>
<td>Structure=1</td>
<td>0.00</td>
<td>1.00</td>
<td>0.75</td>
<td>1.00</td>
<td>0.43</td>
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<tr>
<td>Age (years)</td>
<td>0.00</td>
<td>86.00</td>
<td>11.94</td>
<td>10.00</td>
<td>11.44</td>
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<tr>
<td>Structure Footprint (hectarea)</td>
<td>0.00</td>
<td>0.09</td>
<td>0.02</td>
<td>0.02</td>
<td>0.01</td>
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<tr>
<td>Number of Bathrooms</td>
<td>0.00</td>
<td>4.00</td>
<td>1.06</td>
<td>1.00</td>
<td>0.78</td>
</tr>
<tr>
<td>Number of Bedrooms</td>
<td>0.00</td>
<td>8.00</td>
<td>2.52</td>
<td>3.00</td>
<td>1.58</td>
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<tr>
<td>Number of Parking Spaces</td>
<td>0.00</td>
<td>5.00</td>
<td>1.39</td>
<td>1.00</td>
<td>1.12</td>
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</tbody>
</table>
Estimates $\psi = [\sigma^2_\epsilon, \delta_L, \delta_S]$

<table>
<thead>
<tr>
<th></th>
<th>$\sigma^2_\epsilon$</th>
<th>$\delta_L$</th>
<th>$\delta_S$</th>
<th>Highest Gen $R^2$</th>
<th>Highest Gen $R^2$</th>
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<tbody>
<tr>
<td><strong>Model: A</strong></td>
<td></td>
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<tr>
<td>Initial Estimates</td>
<td>2.61e+03</td>
<td>0.7</td>
<td>0.95</td>
<td>0.768$^b$</td>
<td>0.866$^c$</td>
</tr>
<tr>
<td>Final Estimates</td>
<td>46.734</td>
<td>0.7</td>
<td>0.95</td>
<td>0.768$^b$</td>
<td>0.866$^c$</td>
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<td>(MLE/Highest Gen $R^2$)</td>
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<tr>
<td><strong>Model: B</strong></td>
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<tr>
<td>Initial OLS/Highest $R^2$</td>
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<td>0.7</td>
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<tr>
<td>Final Estimates</td>
<td>233.17</td>
<td>0.7</td>
<td>0.90</td>
<td></td>
<td>0.857</td>
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<tr>
<td>(MLE/Generalised $R^2$)</td>
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</table>

$^a$Chosen using Gen $R^2$ from Land transactions;

$^b$this value is equal for $d_L, d_S = [0.7, 0.95]$ and $[0.7, 0.99]$;

$^c$this value is for $d_L, d_S = [0.7, 0.90]$
Use all transactions

MODEL A - PREDICTED LAND PROPORTION IN PROPERTY SALES

Proportion

Months, 1990:5 – 2010:9
Ignore Vacant Land Sales

MODEL B - PREDICTED LAND PROPORTION IN PROPERTY SALES
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<th>St. Dev</th>
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<tbody>
<tr>
<td>Sale Price (in 1000)</td>
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<td>1970</td>
<td>2010</td>
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## Land Component Characteristics

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<tbody>
<tr>
<td>Land area (hectareas)</td>
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<td>dist_shops (Km)</td>
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<td>3.97</td>
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<tr>
<td>Structure Component Characteristics</td>
<td>Min</td>
<td>Max</td>
<td>Mean</td>
<td>Median</td>
<td>St.Dev</td>
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<td>Pre-War</td>
<td>0.00</td>
<td>1.00</td>
<td>0.49</td>
<td>0.00</td>
<td>0.50</td>
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<tr>
<td>War/Post War</td>
<td>0.00</td>
<td>1.00</td>
<td>0.37</td>
<td>0.00</td>
<td>0.48</td>
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<tr>
<td>Late 20th C</td>
<td>0.00</td>
<td>1.00</td>
<td>0.07</td>
<td>0.00</td>
<td>0.26</td>
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<tr>
<td>Contemporaneous</td>
<td>0.00</td>
<td>1.00</td>
<td>0.04</td>
<td>0.00</td>
<td>0.20</td>
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<tr>
<td>Structure=1</td>
<td>0.00</td>
<td>1.00</td>
<td>0.98</td>
<td>1.00</td>
<td>0.15</td>
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<tr>
<td>Structure footprint</td>
<td>0.00</td>
<td>0.10</td>
<td>0.02</td>
<td>0.02</td>
<td>0.01</td>
</tr>
<tr>
<td>Number of Levels</td>
<td>0.00</td>
<td>4.00</td>
<td>1.10</td>
<td>1.00</td>
<td>0.36</td>
</tr>
<tr>
<td>Number of Bathrooms</td>
<td>0.00</td>
<td>6.00</td>
<td>1.37</td>
<td>1.00</td>
<td>0.67</td>
</tr>
<tr>
<td>Number of Bedrooms</td>
<td>0.00</td>
<td>8.00</td>
<td>3.04</td>
<td>3.00</td>
<td>0.91</td>
</tr>
<tr>
<td>Number of Parking Spaces</td>
<td>0.00</td>
<td>8.00</td>
<td>1.66</td>
<td>2.00</td>
<td>0.78</td>
</tr>
</tbody>
</table>
PREDICTED LAND PROPORTION IN PROPERTY SALES

(years, 1970–2010)

Proportion

0 0.1 0.2 0.3 0.4 0.5 0.6 0.7 0.8 0.9 1

0 5 10 15 20 25 30 35 40
Model vs Valuer - Properties sold in 2009

- \( VE_i = \text{valuer’s land valuation}_i / \text{property sale price}_i \)

<table>
<thead>
<tr>
<th>Month Sold</th>
<th>Median VE</th>
<th># Properties</th>
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<tbody>
<tr>
<td>Jan-09</td>
<td>0.721</td>
<td>13</td>
</tr>
<tr>
<td>Feb-09</td>
<td>0.704</td>
<td>11</td>
</tr>
<tr>
<td>Mar-09</td>
<td>0.762</td>
<td>16</td>
</tr>
<tr>
<td>Apr-09</td>
<td>0.741</td>
<td>17</td>
</tr>
<tr>
<td>May-09</td>
<td>0.746</td>
<td>16</td>
</tr>
<tr>
<td>Jun-09</td>
<td>0.675</td>
<td>9</td>
</tr>
<tr>
<td>Jul-09</td>
<td>0.738</td>
<td>11</td>
</tr>
<tr>
<td>Aug-09</td>
<td>0.673</td>
<td>13</td>
</tr>
<tr>
<td>Sep-09</td>
<td>0.734</td>
<td>14</td>
</tr>
<tr>
<td>Oct-09</td>
<td>0.617</td>
<td>19</td>
</tr>
<tr>
<td>Nov-09</td>
<td>0.683</td>
<td>12</td>
</tr>
<tr>
<td>Dec-09</td>
<td>0.716</td>
<td>15</td>
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<tr>
<td>Median 2009</td>
<td>(0.716)</td>
<td>166</td>
</tr>
</tbody>
</table>

- Model Median for the 166 properties sold in 2009 = 0.669
Outline

Introduction and Background

The Valuer’s Model
  Simple Behavioural Model

The Econometric Approach to the Decomposition
  Unobserved Components Approach

Price Indices

Decompositions - Empirical Estimates
  Model Estimation and Comparison to Valuer’s Estimates
  Bay Area - Monthly Data
  Brisbane Suburb - Annual Data

Price Indices - Empirical Evidence
  Town of A Data
  Town of A Indices

Discussion-Conclusions

References
Used in Diewert et al. (2015). A shorter and earlier version was used by Färe et al. (2014).

<table>
<thead>
<tr>
<th></th>
<th>min</th>
<th>max</th>
<th>mean</th>
<th>median</th>
<th>stdev</th>
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<tbody>
<tr>
<td>Price (000 Euros)</td>
<td>70</td>
<td>550</td>
<td>182.260</td>
<td>160</td>
<td>71.316</td>
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<tr>
<td>Land Characteristics</td>
<td></td>
<td></td>
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<td></td>
</tr>
<tr>
<td>Land (sq mts)</td>
<td>70</td>
<td>1344</td>
<td>258.060</td>
<td>217</td>
<td>152.310</td>
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<tr>
<td>Structure Characteristics</td>
<td></td>
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<td></td>
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</tr>
<tr>
<td>House (sq mts)</td>
<td>65</td>
<td>352</td>
<td>126.560</td>
<td>120</td>
<td>29.841</td>
</tr>
<tr>
<td>Age (years)</td>
<td>0</td>
<td>4</td>
<td>1.895</td>
<td>2</td>
<td>1.231</td>
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<td>floors</td>
<td>1</td>
<td>6</td>
<td>2.878</td>
<td>3</td>
<td>0.478</td>
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<tr>
<td>rooms</td>
<td>2</td>
<td>10</td>
<td>4.730</td>
<td>5</td>
<td>0.874</td>
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<td>Number of Transactions</td>
<td>3487</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Number of months</td>
<td>66</td>
<td></td>
<td>(2003:1)</td>
<td>2008:6</td>
<td></td>
</tr>
</tbody>
</table>

The data were cleaned following Diewert et al (2015). See footnotes 11,12,13.
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Price Indices - Empirical Evidence
  Town of A Data
    Town of A Indices

Discussion-Conclusions

References
<table>
<thead>
<tr>
<th>Model</th>
<th>Estimation</th>
<th>Label</th>
<th>Symbol</th>
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</thead>
<tbody>
<tr>
<td>Model 3: land, house, age</td>
<td>2003:Q1 - 2008:Q2 quarter-by-quarter</td>
<td>DdH_Pl3 (DdH_PS3)</td>
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<tr>
<td>Model 4: Model 3 + other hedonic</td>
<td>2003:Q1 - 2008:Q2 quarter-by-quarter</td>
<td>DdH_Pl4 (DdH_PS4)</td>
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<td>characteristics</td>
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<tr>
<td>Model 4</td>
<td></td>
<td>FGCS_DS2_L (FGCS_DS2_S)</td>
<td></td>
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<tr>
<td>Model 4</td>
<td></td>
<td>FGCS_SFA_L (FGCS_SFA_S)</td>
<td></td>
</tr>
</tbody>
</table>

- Model 3: Builder’s Model with linear splines (New Construction Index)
- Model 4: Model 3 + other hedonic characteristics
- Distance Function Approach - whole sample
Price Indices Compared (cont)

- **Our Model**
  
  \[ \text{Price} = f(\text{land}, \text{house}, \text{age}, \text{rooms}, \text{rooms}^2, \text{floors}, \text{floors}^2) \]

- Monthly 2003:1-2008:6. Estimation for time \( \tau \) uses \( t = 1, \ldots, \tau - 1, \tau \).

- **Indices labels**
  1. FP\(_L\) (FD\(_L\))
  2. FP\(_S\) (FD\(_S\))
Comparison of Land Price Indices. TownA- Aug03-Jun08, Feb05=1 / Q105=1
Comparison of Structure Price Indices. TownA- Aug03-Jun08, Feb05=1 / Q105=1
An econometric model of the valuer’s problem.

- Method combines
  - hedonic information on the land (including location) and structure
  - time-varying parameters model with a constrained covariance structure to maintain the uncorrelativeness of the components
- No other information is used
- The key parameters can be obtained through running a regression and the equations of the KF.
- The decompositions obtained are reasonable and comparable to those made by valuers from the QLD state government.
- Fisher indices for the prices of the land and structure components are computed.
  - Indices are less volatile than DhH, but are able to pick up the turns in market conditions
  - DhD estimates the underlying model at each period
  - FGCS estimates the underlying model over the full sample
  - Our estimates of the components are weighted sums of past and current information


