Age, Time, Depreciation and House Prices: A Hedonic Imputation Approach

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Age, Time, Vintage, and Hedonic Regressions of House Prices

Jan de Haan & Iqbal Syed

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The identification problem, and economic depreciation

- Age + cohort = time
- Each variable is important
  - ageing effect is interpreted as the measure of depreciation
  - time effect provides the measure of inflation
  - cohort effect is related to premium to particular construction periods
- Can we disentangle the age, cohort and time effects in house prices?
- Economic depreciation:
  - decline is asset prices due to the aging of asset prices (Hulten and Wykoff 1981)
  - its measurement involves establishing an empirical relationship between price and age (Jorgenson 1996)
  - combination of physical deterioration, functional obsolescence, external obsolescence (Knight and Sirmans 1996)
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Hedonic regressions and measures of housing depreciation

- Time-dummy hedonic model with non-linear age specification:

\[ \ln p_i = \sum_{t=1}^{T} \delta_t d_{t,i} + \sum_{c=1}^{C} \beta_c z_{c,i} + \gamma f(a_i) + \epsilon_i, \quad i = 1, \ldots, I; \quad (1) \]

where \( \ln(p_i) \) is the natural log of prices of house \( i \), \( d_{t,i} \) is the time-dummy, \( z_{c,i} \) refers to characteristic \( c \), \( f(a_i) \) is a non-linear function of age, \( \epsilon_i \) is the random error term.

- Specification of the age function
  - \( f(a) = \log(a) \) (Lee, Ching and Kim 2005; Harding, Rosenthal and Sirmans 2007)
  - \( f(a) = a^2 \) (Smith 2004; Wilhelmsson 2008)
  - \( f(a) = a^2 + a^3 \) (Malpezzi, Ozanne and Thibodeau 1987; Lee et al. 2005)
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Malpezzi, Ozanne and Thibodeau (1987):
- surveyed the empirical literature of housing depreciation and found a large variability in the estimates of depreciation rates, ranging from 0.5% to 2.5% per year
- "One shortcoming of...most hedonic studies...is that restrict functional form in a manner which arbitrarily imposes a particular depreciation pattern." (p. 373)

Coulson and McMillen (2008):
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Hedonic Imputation Approach: Regressions

- We estimate regressions separately for each age-cohort pair of houses, and include time-dummies as regressors.
- Consider two ages of houses, j and k; two cohorts, l and m; houses are sold in period, 1, ..., T.
  Four age-cohort pairs - (j,l), (k,l), (j,m) and (k,m).
- Hedonic regression for each age-cohort pair of houses:

\[
\ln p_{i}^{a,v} = \sum_{t=1}^{T} \delta_{t,v} d_{t,i}^{a,v} + \sum_{c=1}^{C} \beta_{c,v} z_{c,i}^{a,v} + u_{i}^{a,v},
\]

where \( \ln p_{i}^{a,v} \) is the price of house \( i \) belonging to age-cohort \((a, v)\)
\( d_{t,i}^{a,v} \) is 1 if house \( i \) is sold in period \( t \) and 0 otherwise
\( z_{c,i}^{a,v} \) is the value of characteristic \( c = 1, \ldots, C \)
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\( a = j, k; \; \; v = l, m; \; \; i = 1, \ldots, I^{a,v} \);

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\( u_{i}^{a,v} \) are i.i.d. error terms.
Hedonic Imputation Approach: Imputations

• Let \( h \) be a house in \((j, l)\). Imputed price of \( h \) as it reaches age \( k \):

\[
\hat{p}^k_{s,l}(x^j_{h,l}) = \exp \left( \sum_{t=1}^{T} \hat{\delta}_{t,l} d^j_{t,h} + \sum_{c=1}^{C} \hat{\beta}_{c,l} z^j_{c,h} \right)
\]

where \( x^j_{h,l} = (d^j_{1,h}, \ldots, d^j_{T,h}, z^j_{1,h}, \ldots, z^j_{C,h}) \).

• The price change as house \( h \) ages from \( j \) to \( k \):

\[
\wp_h^{(k,l)/(j,l)} (SI) = \frac{\hat{p}^k_{s,l}(x^j_{h,l})}{p^j_{s,l}}
\]

• An alternative method would be to replace the original price at age \( j \) with its imputed price:

\[
\wp_h^{(k,l)/(j,l)} (DI) = \frac{\hat{p}^k_{s,l}(x^j_{h,l})}{\hat{p}^j_{s,l}(x^j_{h,l})}
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where \( \hat{p}^j_{s,l}(x^j_{h,l}) = \exp \left( \sum_{t=1}^{T} \hat{\delta}_{t,l} d^j_{t,h} + \sum_{c=1}^{C} \hat{\beta}_{c,l} z^j_{c,h} \right) \)
Hedonic Imputation Approach: Imputations

Let $h$ be a house in $(j, l)$. Imputed price of $h$ as it reaches age $k$:

$$\hat{p}^{k, l}(x^{j, l}_h) = \exp \left( \sum_{t=1}^{T} \hat{\delta}^{k, l}_t d^{j, l}_{t,h} + \sum_{c=1}^{C} \hat{\beta}^{k, l}_c z^{j, l}_{c,h} \right)$$

where $x^{j, l}_h = (d^{j, l}_{1,h}, \ldots, d^{j, l}_{T,h}, z^{j, l}_{1,h}, \ldots, z^{j, l}_{C,h})$.

The price change as house $h$ ages from $j$ to $k$:

$$\phi^{(k, l)/(j, l)}_h (SI) = \frac{\hat{p}^{k, l}(x^{j, l}_h)}{p^{j, l}_h}$$

An alternative method would be to replace the original price at age $j$ with its imputed price:

$$\phi^{(k, l)/(j, l)}_h (DI) = \frac{\hat{p}^{k, l}(x^{j, l}_h)}{\hat{p}^{j, l}_h(x^{j, l}_h)}$$

where $\hat{p}^{j, l}_h(x^{j, l}_h) = \exp \left( \sum_{t=1}^{T} \hat{\delta}^{j, l}_t d^{j, l}_{t,h} + \sum_{c=1}^{C} \hat{\beta}^{j, l}_c z^{j, l}_{c,h} \right)$.
Hedonic Imputation Approach: Imputations

- Let $h$ be a house in $(j, l)$. Imputed price of $h$ as it reaches age $k$:
  $$\hat{p}_{s}^{k,l}(x_{h}^{j,l}) = \exp \left( \sum_{t=1}^{T} \hat{\delta}_{t}^{k,l} d_{t,h}^{j,l} + \sum_{c=1}^{C} \hat{\beta}_{c}^{k,l} z_{c,h}^{j,l} \right)$$

  where $x_{h}^{j,l} = (d_{1,h}^{j,l}, \ldots, d_{T,h}^{j,l}, z_{1,h}^{j,l}, \ldots, z_{C,h}^{j,l})$.

- The price change as house $h$ ages from $j$ to $k$:
  $$\varphi_{h}^{(k,l)/(j,l)}(SI) = \frac{\hat{p}_{h}^{k,l}(x_{h}^{j,l})}{p_{h}^{j,l}}$$

- An alternative method would be to replace the original price at age $j$ with its imputed price:
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$$

where $x^{j,l}_h = (d^{j,l}_{1,h}, \ldots, d^{j,l}_{T,h}, z^{j,l}_{1,h}, \ldots, z^{j,l}_{C,h})$.

- The price change as house $h$ ages from $j$ to $k$:

$$
\frac{\varphi_{(k,l)/(j,l)}(SI)}{\varphi_{(k,l)/(j,l)}(DI)} = \frac{\hat{p}^{k,l}_s(x^{j,l}_h)}{p^{j,l}_h(x^{j,l}_h)}
$$

- An alternative method would be to replace the original price at age $j$ with its imputed price:

$$
\frac{\varphi_{(k,l)/(j,l)}(DI)}{\varphi_{(k,l)/(j,l)}(SI)} = \frac{\hat{p}^{k,l}_s(x^{j,l}_h)}{\hat{p}^{j,l}_h(x^{j,l}_h)}
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where $\hat{p}^{j,l}_h(x^{j,l}_h) = \exp \left( \sum_{t=1}^{T} \hat{\delta}^{j,l}_t d^{j,l}_{t,h} + \sum_{c=1}^{C} \hat{\beta}^{j,l}_c z^{j,l}_{c,h} \right)$.
Hedonic Imputation Approach: Imputations (cont.)

Figure 1: Imputed Price of each house in our 4 age-cohort pair houses

(a) (j,l) pair houses

(b) (k,l) pair houses

(c) (j,m) pair houses

(d) (k,m) pair houses

The regular type of goods and services consumed by households. This is because each house is different and, therefore, irrespective of the price, only one house of a particular type is bought. This means that, in equation (10),

\[ q_{j,v}^{i} = 1 \quad \text{and} \quad w_{j,v}^{i} = p_{j,v}^{i} / \sum_{I} p_{j,v}^{i} = 1 \quad p_{j,v}^{i}. \]

This implies that \( w_{j,v}^{i} \) gives more weight to more expensive houses in the construction of price indexes, which is not the same as giving more weight to items which account for larger expenditure shares in household consumption. Since each house is somewhat different to other houses, it is more...
Hedonic Imputation Approach: Price indexes

- A Laspeyres index based on the houses in the \((j, v)\) pair with \((l, m) \in v\) and measuring the price changes as they age from \(j\) to \(k\):

  \[
P_{jL}^{k,v} = \sum_{i=1}^{l,j,v} w_{i}^{j,v} \left[ \frac{\hat{p}_{i}^{k,v}(x_{i}^{j,v})}{\hat{p}_{i}^{j,v}(x_{i}^{j,v})} \right], \text{ where } w_{i}^{j,v} = \frac{p_{i}^{j,v}q_{i}^{j,v}}{\sum_{i=1}^{l,j,v} p_{i}^{j,v}q_{i}^{j,v}}, (l, m) \in v
  \]

- In the housing context, the Laspeyres index can be simplified to:

  \[
P_{jL}^{k,v} = \frac{1}{l,j,v} \sum_{i=1}^{l,j,v} \left[ \frac{\hat{p}_{i}^{k,v}(x_{i}^{j,v})}{\hat{p}_{i}^{j,v}(x_{i}^{j,v})} \right], \quad (l, m) \in v,
  \]

- A Paasche index based on the houses in \((k, v)\) pair and measuring the price changes due to ageing from \(j\) to \(k\):

  \[
P_{jQ}^{k,v} = \left\{ \frac{1}{l,k,v} \sum_{i=1}^{l,k,v} \left[ \frac{\hat{p}_{i}^{k,v}(x_{i}^{k,v})}{\hat{p}_{i}^{j,v}(x_{i}^{k,v})} \right]^{-1} \right\}^{-1}, \quad (l, m) \in v
  \]
Hedonic Imputation Approach: Price indexes

- A Laspeyres index based on the houses in the \((j, v)\) pair with \((l, m) \in v\) and measuring the price changes as they age from \(j\) to \(k\):

\[
P^{j,k,v}_{Las} = \sum_{i=1}^{l_j,v} w^{j,v}_i \left[ \frac{p^{k,v}_i(x^{j,v}_i)}{p^{j,v}_i(x^{j,v}_i)} \right], \text{ where } w^{j,v}_i = \frac{p^{j,v}_i q^{j,v}_i}{\sum_{i=1}^{l_j,v} p^{j,v}_i q^{j,v}_i}, \quad (l, m) \in v
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- In the housing context, the Laspeyres index can be simplified to:

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\]

- A Paasche index based on the houses in \((k, v)\) pair and measuring the price changes due to ageing from \(j\) to \(k\):

\[
P^{j,k,v}_{Pas} = \left\{ \frac{1}{l_{k,v}} \sum_{i=1}^{l_{k,v}} \left[ \frac{p^{k,v}_i(x^{k,v}_i)}{p^{j,v}_i(x^{k,v}_i)} \right]^{-1} \right\}^{-1}, \quad (l, m) \in v
\]
Hedonic Imputation Approach: Price indexes

- A Laspeyres index based on the houses in the \((j, v)\) pair with \((l, m) \in v\) and measuring the price changes as they age from \(j\) to \(k\):

\[
P_{Las}^{jk,v} = \sum_{i=1}^{l_{j,v}} w_{i,v}^{j,v} \left[ \frac{\hat{p}_{i,v}^{k,j,v}(x_{i,v}^{j,v})}{\hat{p}_{i,v}^{j,v}(x_{i,v}^{j,v})} \right], \text{ where } w_{i,v}^{j,v} = \frac{p_{i,v}^{j,v} q_{i,v}^{j,v}}{\sum_{i=1}^{l_{j,v}} p_{i,v}^{j,v} q_{i,v}^{j,v}}, (l, m) \in v
\]

- In the housing context, the Laspeyres index can be simplified to:

\[
P_{Las}^{jk,v} = \frac{1}{l_{j,v}} \sum_{i=1}^{l_{j,v}} \left[ \frac{\hat{p}_{i,v}^{k,j,v}(x_{i,v}^{j,v})}{\hat{p}_{i,v}^{j,v}(x_{i,v}^{j,v})} \right], \quad (l, m) \in v,
\]

- A Paasche index based on the houses in \((k, v)\) pair and measuring the price changes due to ageing from \(j\) to \(k\):

\[
P_{Pas}^{jk,v} = \left\{ \frac{1}{l_{k,v}} \sum_{i=1}^{l_{k,v}} \left[ \frac{\hat{p}_{i,v}^{k,j,v}(x_{i,v}^{k,v})}{\hat{p}_{i,v}^{j,v}(x_{i,v}^{k,v})} \right]^{-1} \right\}^{-1}, \quad (l, m) \in v
\]
Hedonic Imputation Approach: Price indexes

- A Laspeyres index based on the houses in the \((j, v)\) pair with \((l, m) \in v\) and measuring the price changes as they age from \(j\) to \(k\):

  \[
  P_{Jak,v}^{L} = \sum_{i=1}^{Ij,v} w_i^{j,v} \left[ \frac{\hat{p}_{i}^{k,v}(x_i^{j,v})}{\hat{p}_{i}^{j,v}(x_i^{j,v})} \right], \text{ where } w_i^{j,v} = \frac{p_i^{j,v} q_i^{j,v}}{\sum_{i=1}^{Ij,v} p_i^{j,v} q_i^{j,v}}, (l, m) \in v
  \]

- In the housing context, the Laspeyres index can be simplified to:

  \[
  P_{Jak,v}^{L} = \frac{1}{Ij,v} \sum_{i=1}^{Ij,v} \left[ \frac{\hat{p}_{i}^{k,v}(x_i^{j,v})}{\hat{p}_{i}^{j,v}(x_i^{j,v})} \right], \text{ (l, m) } \in v
  \]

- A Paasche index based on the houses in \((k, v)\) pair and measuring the price changes due to ageing from \(j\) to \(k\):

  \[
  P_{Jak,v}^{P} = \left\{ \frac{1}{Ik,v} \sum_{i=1}^{Ik,v} \left[ \frac{\hat{p}_{i}^{k,v}(x_i^{k,v})}{\hat{p}_{i}^{j,v}(x_i^{k,v})} \right]^{-1} \right\}^{-1}, \text{ (l, m) } \in v
  \]
A Fisher index is as follows:

\[ P_{F}^{jk,v} = \sqrt{P_{Las}^{jk,v} \times P_{Pas}^{jk,v}}, \quad (l, m) \in v \]

Extensions: \( a = 1, \ldots, A; \ v = 1, \ldots, V \)

The chained index measuring the ageing effect between age 1 and \( \alpha \) for \( (l, m) \in v \):

\[ P_{FC}^{(1,\alpha),v} = P_{F}^{(1,2),v} \times P_{F}^{(2,3),v} \times \ldots \times P_{F}^{(\alpha-2,\alpha-1),v} \times P_{F}^{(\alpha-1,\alpha),v} \]

To obtain an overall measure of depreciation pattern, we aggregate \( P_{FC}^{(j,k),v} \) across all cohorts, \( v = 1, \ldots, V \), as follows:

\[ P_{FC}^{(j,k)} = \prod_{v=1}^{V} \left[ P_{FC}^{(j,k),v} \right]^{0.5(S_{j,v}^{i} + S_{k,v}^{k})} \]  

where \( S_{j,v}^{i} \) and \( S_{k,v}^{k} \) are the proportion of houses in \( (j, v) \) and \( (k, v) \) pairs among all houses in our sample.
A Fisher index is as follows:

\[ P^{j,k,v}_{F} = \sqrt{P^{j,k,v}_{Las} \times P^{j,k,v}_{Pas}}, \quad (l, m) \in v \]

Extensions: \( a = 1, \ldots, A; \quad v = 1, \ldots, V \)

The chained index measuring the ageing effect between age 1 and \( \alpha \) for \( (l, m) \in v \):

\[ P^{(1,\alpha),v}_{FC} = P^{(1,2),v}_{F} \times P^{(2,3),v}_{F} \times \ldots \times P^{(\alpha-2,\alpha-1),v}_{F} \times P^{(\alpha-1,\alpha),v}_{F} \]

To obtain an overall measure of depreciation pattern, we aggregate \( P^{(j,k),v}_{FC} \) across all cohorts, \( v = 1, \ldots, V \), as follows:

\[ P^{(j,k)}_{FC} = \prod_{v=1}^{V} \left[ P^{(j,k),v}_{FC} \right]^{0.5(S^{j,v}+S^{k,v})} \quad (3) \]

where \( S^{j,v} \) and \( S^{k,v} \) are the proportion of houses in \( (j, v) \) and \( (k, v) \) pairs among all houses in our sample.
A Fisher index is as follows:

\[ P_{F}^{jk,v} = \sqrt{P_{Las}^{jk,v} \times P_{Pas}^{jk,v}}, \quad (l, m) \in \nu \]

Extensions: \( a = 1, \ldots, A; \nu = 1, \ldots, V \)

The chained index measuring the ageing effect between age 1 and \( \alpha \) for \( (l, m) \in \nu \):

\[ P_{FC}^{(1,\alpha),\nu} = P_{F}^{(1,2),\nu} \times P_{F}^{(2,3),\nu} \times \ldots \times P_{F}^{(\alpha-2,\alpha-1),\nu} \times P_{F}^{(\alpha-1,\alpha),\nu} \]

To obtain an overall measure of depreciation pattern, we aggregate \( P_{F}^{(j,k),\nu} \) across all cohorts, \( \nu = 1, \ldots, V \), as follows:

\[ P_{FC}^{(j,k)} = \prod_{\nu=1}^{V} \left[ P_{FC}^{(j,k),\nu} \right]^{0.5(S_{j,\nu} + S_{k,\nu})} \tag{3} \]

where \( S_{j,\nu} \) and \( S_{k,\nu} \) are the proportion of houses in \( (j, \nu) \) and \( (k, \nu) \) pairs among all houses in our sample.
A Fisher index is as follows:

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Extensions: \( a = 1, \ldots, A; \nu = 1, \ldots, V \)

The chained index measuring the ageing effect between age 1 and \( \alpha \) for \((l, m) \in \nu\):

\[ P_{FC}^{(1,\alpha),v} = P_{F}^{(1,2),v} \times P_{F}^{(2,3),v} \times \ldots \times P_{F}^{(\alpha-2,\alpha-1),v} \times P_{F}^{(\alpha-1,\alpha),v} \]

To obtain an overall measure of depreciation pattern, we aggregate \( P_{FC}^{(j,k),v} \) across all cohorts, \( \nu = 1, \ldots, V \), as follows:

\[ P_{FC}^{(j,k)} = \prod_{\nu=1}^{V} \left[ P_{FC}^{(j,k),v} \right]^{0.5(S_{j,v} + S_{k,v})} \quad (3) \]

where \( S_{j,v} \) and \( S_{k,v} \) are the proportion of houses in \((j, v)\) and \((k, v)\) pairs among all houses in our sample.
Hedonic Imputation Approach: Price indexes (cont.)

- A Fisher index is as follows:
  \[ P_{F}^{jk,v} = \sqrt{P_{Las}^{jk,v} \times P_{Pas}^{jk,v}}, \quad (l, m) \in v \]

- Extensions: \( a = 1, \ldots, A; \) \( v = 1, \ldots, V \)

- The chained index measuring the ageing effect between age 1 and \( \alpha \) for \((l, m) \in v\):
  \[ P_{FC}^{(1,\alpha),v} = P_{F}^{(1,2),v} \times P_{F}^{(2,3),v} \times \ldots \times P_{F}^{(\alpha-2,\alpha-1),v} \times P_{F}^{(\alpha-1,\alpha),v} \]

- To obtain an overall measure of depreciation pattern, we aggregate \( P_{FC}^{(j,k),v} \) across all cohorts, \( v = 1, \ldots, V \), as follows:
  \[ P_{FC}^{(j,k)} = \prod_{v=1}^{V} \left[ P_{FC}^{(j,k),v} \right]^{0.5(S_{j,v} + S_{k,v})} \]  

where \( S_{j,v} \) and \( S_{k,v} \) are the proportion of houses in \((j, v)\) and \((k, v)\) pairs among all houses in our sample.
Measurement of inflation from time dummies

- Hedonic regression for each age-cohort pair of houses (equation 2):

\[
\ln p_{i}^{a,v} = \sum_{t=1}^{T} \delta_{t}^{a,v} d_{t,i}^{a,v} + \sum_{c=1}^{C} \beta_{c}^{a,v} z_{c,i}^{a,v} + u_{i}^{a,v},
\]

\[a = j, k; \quad v = l, m; \quad i = 1, \ldots, I^{a,v};\]

where \(d_{t,i}^{a,v}\) is 1 if house \(i\) is sold in period \(t\) and 0 otherwise.

\(\exp(\hat{\delta}_{t}^{a,v})\) provides a measure of price change between the base period and \(t\).

- Aggregating \(\hat{\delta}_{t}^{a,v}\) provides the overall measurement of housing inflation:

\[
P_{TD}^{t-1,t} = \prod_{a=1}^{A} \left[ \prod_{v=1}^{V} \left( \exp(\hat{\delta}_{t-1,t}^{a,v}) \right)^{0.5(S_{t-1}^{a,v} + S_{t}^{a,v})} \right]^{0.5(S_{t-1}^{a,v} + S_{t}^{a,v})}\]

where \(S_{t-1}^{a,v}\) and \(S_{t}^{a,v}\) are the shares of houses in \((a, v)\) in \(t - 1\) and \(t\);
\(S_{t-1}^{a}\) and \(S_{t}^{a}\) are the shares of houses sold at age \(a\) in \(t - 1\) and \(t\).
Measurement of inflation from time dummies

- Hedonic regression for each age-cohort pair of houses (equation 2):

\[
\ln p_i^{a,v} = \sum_{t=1}^{T} \delta_t^{a,v} d_{t,i}^{a,v} + \sum_{c=1}^{C} \beta_c^{a,v} z_c^{a,v} + u_i^{a,v},
\]

where \( d_{t,i}^{a,v} \) is 1 if house \( i \) is sold in period \( t \) and 0 otherwise.

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P_{t-1,t}^{TD} = \prod_{a=1}^{A} \left[ \prod_{v=1}^{V} \left( \exp(\hat{\delta}_{t-1,t}^{a,v}) \right)^{0.5(S_{t-1}^{a,v} + S_t^{a,v})} \right]^{0.5(S_t^{a,v} + S_t^{a,v})}
\]

(4)

where \( S_{t-1}^{a,v} \) and \( S_t^{a,v} \) are the shares of houses in \((a, v)\) in \( t - 1 \) and \( t \);

\( S_{t-1}^{a} \) and \( S_t^{a} \) are the shares of houses sold at age \( a \) in \( t - 1 \) and \( t \).
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\ln p_{i}^{a,v} = \sum_{t=1}^{T} \delta_{t}^{a,v} d_{t,i}^{a,v} + \sum_{c=1}^{C} \beta_{c}^{a,v} z_{c,i}^{a,v} + u_{i}^{a,v},
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where \( d_{t,i}^{a,v} \) is 1 if house \( i \) is sold in period \( t \) and 0 otherwise.

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where \( S_{t-1}^{a,v} \) and \( S_{t}^{a,v} \) are the shares of houses in \((a, v)\) in \( t-1 \) and \( t \); \( S_{t-1}^{a} \) and \( S_{t}^{a} \) are the shares of houses sold at age \( a \) in \( t-1 \) and \( t \).
The sales of detached houses for the city “Assen” in the Netherlands (small town with population of around 60,000)

- Data set is used in Eurostat (2013): “Handbook on Residential Property Prices Indices (RPPIs)"
- No. of observations: 6348 (after some deletions); Period: 1998:1 - 2008:2
- Available information: sale price, period of sale (in quarters), lot size, floor space, total number of rooms, constriction period, no. of toilets, balconies, garages, dormers
- Median sale price: 142,950 Euros (mean price is 159,440 Euros); Median lot size: 209.50 M²; Median floor space: 120 M²; Median no. of rooms: 5; Median no. of toilet-baths: 2
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Available information: sale price, period of sale (in quarters), lot size, floor space, total number of rooms, constriction period, no. of toilets, balconies, garages, dormers

Ages are determined as follows: houses built during 2001-2008 is assigned Age0, 1991-2000 Age1, 1981-1990 Age2, 1971-1980 Age3 and 1960-1970 Age4

Median sale price: 142,950 Euros (mean price is 159,440 Euros); Median lot size: 209.50 M²; Median floor space: 120 M²; Median no. of rooms: 5; Median no. of toilet-baths: 2
Empirical results: Estimated regressions based on houses sold at each age

<table>
<thead>
<tr>
<th>Variables†</th>
<th>Age0 Coefs</th>
<th>Std</th>
<th>Age1 Coefs</th>
<th>Std</th>
<th>Age2 Coefs</th>
<th>Std</th>
<th>Age3 Coefs</th>
<th>Std</th>
<th>Age4 Coefs</th>
<th>Std</th>
</tr>
</thead>
<tbody>
<tr>
<td>1998 dum</td>
<td>-</td>
<td>-</td>
<td>1.65</td>
<td>0.09</td>
<td>2.11</td>
<td>0.11</td>
<td>2.03</td>
<td>0.11</td>
<td>1.44</td>
<td>0.13</td>
</tr>
<tr>
<td>1999 dum.</td>
<td>-</td>
<td>-</td>
<td>1.82</td>
<td>0.08</td>
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<td>2.16</td>
<td>0.11</td>
<td>1.59</td>
<td>0.13</td>
</tr>
<tr>
<td>2000 dum.</td>
<td>-</td>
<td>-</td>
<td>1.93</td>
<td>0.08</td>
<td>2.40</td>
<td>0.12</td>
<td>2.32</td>
<td>0.11</td>
<td>1.66</td>
<td>0.13</td>
</tr>
<tr>
<td>2001 dum.</td>
<td>2.24</td>
<td>0.16</td>
<td>2.05</td>
<td>0.08</td>
<td>2.52</td>
<td>0.12</td>
<td>2.41</td>
<td>0.11</td>
<td>1.79</td>
<td>0.13</td>
</tr>
<tr>
<td>2002 dum.</td>
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<td>2.07</td>
<td>0.08</td>
<td>2.59</td>
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<td>0.11</td>
<td>1.89</td>
<td>0.13</td>
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<td>2003 dum.</td>
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<td>0.08</td>
<td>2.61</td>
<td>0.15</td>
<td>2.54</td>
<td>0.11</td>
<td>1.93</td>
<td>0.13</td>
</tr>
<tr>
<td>2004 dum.</td>
<td>2.33</td>
<td>0.15</td>
<td>2.16</td>
<td>0.08</td>
<td>2.66</td>
<td>0.12</td>
<td>2.55</td>
<td>0.11</td>
<td>1.95</td>
<td>0.13</td>
</tr>
<tr>
<td>2005 dum.</td>
<td>2.34</td>
<td>0.15</td>
<td>2.20</td>
<td>0.08</td>
<td>2.71</td>
<td>0.11</td>
<td>2.62</td>
<td>0.11</td>
<td>2.04</td>
<td>0.13</td>
</tr>
<tr>
<td>2006 dum.</td>
<td>2.40</td>
<td>0.15</td>
<td>2.24</td>
<td>0.08</td>
<td>2.73</td>
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<td>2.62</td>
<td>0.11</td>
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<tr>
<td>2007 dum.</td>
<td>2.43</td>
<td>0.15</td>
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<td>2.66</td>
<td>0.11</td>
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<td>0.08</td>
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<td>0.01</td>
<td>-0.09</td>
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<tr>
<td>region-new</td>
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<td>0.04</td>
<td>-0.01</td>
<td>0.01</td>
<td>0.10</td>
<td>0.01</td>
<td>-0.03</td>
<td>0.02</td>
<td>-0.02</td>
<td>0.03</td>
</tr>
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<td>0.02</td>
<td>0.03</td>
<td>0.02</td>
<td>0.10</td>
<td>0.01</td>
<td>0.23</td>
<td>0.06</td>
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<td>0.02</td>
<td>0.01</td>
<td>0.01</td>
<td>0.04</td>
<td>0.01</td>
<td>0.03</td>
<td>0.01</td>
<td>0.01</td>
<td>0.02</td>
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<td>0.02</td>
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<td>detached</td>
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<td>0.33</td>
<td>0.02</td>
<td>0.47</td>
<td>0.02</td>
<td>0.45</td>
<td>0.02</td>
<td>0.32</td>
<td>0.03</td>
</tr>
<tr>
<td>ln(lotsize)</td>
<td>0.22</td>
<td>0.02</td>
<td>0.26</td>
<td>0.01</td>
<td>0.16</td>
<td>0.01</td>
<td>0.22</td>
<td>0.01</td>
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<td>0.02</td>
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<tr>
<td>ln(flrspace)</td>
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<td>0.03</td>
<td>0.27</td>
<td>0.02</td>
<td>0.27</td>
<td>0.02</td>
<td>0.22</td>
<td>0.02</td>
<td>0.31</td>
<td>0.03</td>
</tr>
</tbody>
</table>

† The estimated coefficients are not shown for the variables: no. of rooms and toilets, whether the houses have a balcony, garage, dormer and roof terrace.

d Haan & Syed (SEM, 2015)

<table>
<thead>
<tr>
<th>Adjusted R²</th>
<th>0.94</th>
<th>0.93</th>
<th>0.91</th>
<th>0.90</th>
<th>0.91</th>
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<tbody>
<tr>
<td>d.f.</td>
<td>406</td>
<td>2139</td>
<td>1499</td>
<td>1388</td>
<td>770</td>
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Empirical results: Price Indexes measuring depreciation of houses

<table>
<thead>
<tr>
<th>Age</th>
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<th>Törnqvist Index</th>
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<tbody>
<tr>
<td>Age0</td>
<td>100.00</td>
<td>100.00</td>
<td>100.00</td>
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<tr>
<td>Age1</td>
<td>69.21</td>
<td>94.52</td>
<td>94.38</td>
</tr>
<tr>
<td>Age2</td>
<td>55.21</td>
<td>85.43</td>
<td>85.33</td>
</tr>
<tr>
<td>Age3</td>
<td>56.49</td>
<td>82.02</td>
<td>82.95</td>
</tr>
<tr>
<td>Age4</td>
<td>53.02</td>
<td>80.35</td>
<td>80.86</td>
</tr>
</tbody>
</table>

Annual average depreciation (%)\(^\dagger\) 1.17 0.49 0.48

\(^\dagger\) Calculated by dividing the cumulative depreciation by 40.

Malpezzi et al. (1987): 0.43-0.93% annual depreciation rate in 59 metropolitan areas in the U.S.
Cannaday and Sunderman (1986): 0.38-0.75% per year, Champaign, Illinois
Wilhelmsson (2008): 0.77% per year in Stockholm, Sweden (for well maintained properties)

See also Chinloy 1979; Fletcher et al. 2000; Smith 2004; and Chau et al. 2005
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<tr>
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| Annual average depreciation (%)† | 1.17 | 0.49 | 0.48 |

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<tr>
<td>Age4</td>
<td>53.02</td>
<td>80.35</td>
<td>80.86</td>
</tr>
</tbody>
</table>

Annual average depreciation (%)† 1.17 0.49 0.48

† Calculated by dividing the cumulative depreciation by 40.

- Malpezzi et al. (1987): 0.43-0.93% annual depreciation rate in 59 metropolitan areas in the U.S.
- Cannaday and Sunderman (1986): 0.38-0.75% per year, Champaign, Illinois
- Wilhelmsson (2008): 0.77% per year in Stockholm, Sweden (for well maintained properties)
- See also Chinloy 1979; Fletcher et al. 2000; Smith 2004; and Chau et al. 2005
Empirical results: Non-linear age specification in hedonic regressions

\[ \log(\text{price}) = \text{function}(\text{time-dummies, physical attributes, region dummies(yes, no), } f(\text{age})) + \text{error} \]

<table>
<thead>
<tr>
<th>Regional dummies†</th>
<th>( f(\text{age}) = \log(\text{age}) )</th>
<th>( f(\text{age}) = \text{age}^2 )</th>
<th>( f(\text{age}) = \text{age}^2, \text{age}^3^* )</th>
<th>( f(\text{age}) = e^{-\text{age}} )</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Coefs</td>
<td>Std</td>
<td>Coefs</td>
<td>Std</td>
</tr>
<tr>
<td>No region dummies</td>
<td>-0.187</td>
<td>0.004</td>
<td>-0.010</td>
<td>0.001</td>
</tr>
<tr>
<td></td>
<td>[0.917]</td>
<td></td>
<td>[0.915]</td>
<td></td>
</tr>
<tr>
<td>Postcode specific dummies</td>
<td>-0.162</td>
<td>0.005</td>
<td>-0.011</td>
<td>0.001</td>
</tr>
<tr>
<td></td>
<td>[0.919]</td>
<td></td>
<td>[0.919]</td>
<td></td>
</tr>
<tr>
<td>Construction period specific dummies</td>
<td>-0.123</td>
<td>0.005</td>
<td>-0.007</td>
<td>0.001</td>
</tr>
<tr>
<td></td>
<td>[0.921]</td>
<td></td>
<td>[0.919]</td>
<td></td>
</tr>
</tbody>
</table>

Note: Dependent variable is the natural log of prices. No. of observations: 6348
* The numbers corresponding to first row are for \( \text{age}^2 \), and the row below are for \( \text{age}^3 \).
Empirical results: Depreciation patterns obtained from different age specifications

![Depreciation patterns graph](image)

- Fisher index
- \( \ln(\text{age}) \)
- squared-\( \text{age} \)
- squared- & cubic-\( \text{age} \)
- \( 1/\exp(\text{age}) \)
- spline(Fisher index)

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de Haan & Syed (SEM, 2015)
Depreciation patterns obtained with and without cohort in hedonic regressions

de Haan & Syed (SEM, 2015)
Time dummy indexes, with different age and region specifications in hedonic regression
Conclusion

- Pre-specification of functional form of age (such as log(age)) in hedonic regressions may introduce bias in the estimates of depreciation rates.
- We propose a method following hedonic imputation approach, where regression models are parsimonious, and age, cohort and time effects can be estimated in a flexible manner.
- Provides estimates of depreciation rates across different sections of the market and between periods only through compilation of the estimated price relatives.
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