

# An Evaluation of the Methods Used by European Countries to Compute their Official House Price Indices

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## Abstract

Since 2012 Eurostat requires the national statistical institutes (NSIs) in all European Union (EU) countries to compute official House Price Indices (HPIs) at a quarterly frequency. Eurostat recommends computing the HPI using a hedonic method. Most NSIs have followed this advice, although they differ in their choice of method. Some NSIs use stratified medians instead of hedonic methods. We evaluate the theoretical and empirical properties of these methods. Of particular concern is the comparability of the HPIs across countries when computed using different methods. Our empirical comparisons use detailed micro-level data sets for Sydney and Tokyo, containing about 867 000 actual housing transactions. All the hedonic methods perform better than stratified medians. The hedonic methods generate quite similar results, except when applied to new dwellings in Tokyo. This finding shows that the choice of hedonic method can become important for smaller data sets. Also, the widely used hedonic repricing method becomes unreliable when the reference shadow prices are not updated frequently. (JEL: C43, E31, R31)

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# 1 Introduction

The fundamental role played by housing in the broader economy has been demonstrated by the global financial crisis of 2007-2011, which began in the US housing market. It is essential therefore that governments, central banks and market participants are kept well informed of trends in house prices.

In Europe, Eurostat – the statistical institute of the European Union (EU)– has required since 2012 (see Eurostat 2016) that the national statistical institutes (NSIs) in all EU member countries compute official house price indices (HPIs).

HPIs, however, can be highly sensitive to the method of construction, and this sensitivity can be a source of confusion amongst users (see Silver 2011). In a European context it is also important that the HPIs of different countries are reasonably comparable, especially in the Eurozone where the HPIs are needed by the European Central Bank for its decisions on monetary policy, financial regulation, and the monitoring of financial stability.

The difficulty in measuring house price developments is that every house is different both in terms of its physical characteristics and its location. HPIs need to take account of these quality differences. Otherwise the price index will confound price changes and quality differences. The importance of these measurement problems has been recently recognized by the international community and the European Commission, Eurostat, the UN, ILO, OECD, World Bank and IMF together commissioned a Handbook on Residential Property Price Indices that was completed in 2013 (see European Commission et al., 2013).

Hedonic methods – which express house prices as a function of a vector of characteristics – are ideally suited for constructing quality-adjusted HPIs (see Diewert 2011 and Hill 2013). Eurostat recommends that the HPI should be computed using a hedonic approach, but has not provided guidance to NSIs as to which hedonic method should be used. As a result, different countries have adopted different methods. In total six different methods are being used:

(i) Repricing: used by Austria, Belgium, Finland, Hungary, Italy, Latvia, Luxembourg, Norway, Slovenia;

- (ii) Average characteristics: used by Romania, Spain;
- (iii) Hedonic imputation: used by Germany, UK;
- (iv) Rolling time dummy (RTD): used by Croatia, Cyprus, France, Ireland, Portugal;
- (v) Stratified median (or mix-adjusted median): used by Bulgaria, Czech Republic, Estonia, Iceland, Lithuania, Poland, Slovakia;
- (vi) Sales Price Appraisal Ratio (SPAR): used by Denmark, the Netherlands, and Sweden.

The sources for the methods used by each country are listed in Appendix A. The first four methods are hedonic. Method (v) by averaging medians across strata provides some partial quality adjustment, although not to the same extent as a hedonic method. Method (vi) combines actual prices with expert valuations (see de Haan, Wal, Steege, and Vries 2006).

For each method, the taxonomy can be further refined, in that two countries using the same basic method in some cases differ slightly in the way it is formulated. For example, with regard to the RTD method, some countries use a two quarter rolling window while others use a four or five quarter window.

Our objective here is to evaluate the theoretical and empirical properties of the methods (i), (ii), (iii), (iv) and (v) used by NSIs in Europe to compute their HPIs. We do not consider method (vi) – the SPAR method – since for our data sets we do not have access to any expert valuations. Of particular concern is the comparability of the HPIs across countries when computed using different methods.

We show that the underlying structures of the repricing, average characteristics, and hedonic imputation methods share some common features. The RTD method is somewhat different in its approach.

Empirically we compare the hedonic methods and stratified medians using detailed micro-level data for Sydney and Tokyo. These data sets were chosen since together they contain about 867 000 actual housing transactions, and cover quite long time spans. The Sydney data covers 11 years, while the Tokyo data covers 30 years. When comparing hedonic methods, it is important to have a sufficiently long time series, since problems of drift or bias may only emerge over these kinds of time horizons. To understand how these hedonic methods perform in practice it is important that they are compared

using real housing data sets, rather than just simulated data. Also, by evaluating EU methods using non-EU data we provide an independent check on method selection.

The empirical comparisons have two main objectives. The first is to establish how sensitive the HPI is to the choice of hedonic method. The second is to see whether any of the hedonic methods (computed on a quarterly basis) behave in anomalous ways, particularly over longer time horizons (e.g., 10+ years). This is potentially a concern especially for the widely used repricing method, which extrapolates to later periods using the estimated characteristic shadow prices of the base period.

Eurostat recommends that each NSI compute separate hedonic indices for houses and apartments. We are able to do this for Sydney, but not for Tokyo, since almost all the transactions in the latter are for apartments. Furthermore, indices specifically for new housing are needed for the owner occupied housing price index (OOHI) which is being used on an experimental basis in the Harmonized Index of Consumer Prices (HICP) (see Eurostat 2016). The age of dwellings is included as a characteristic in the Tokyo data set but not in the Sydney data set. Hence we are able to compute a new dwellings HPI for Tokyo, but not for Sydney. Our findings for Tokyo in this regard have important implications for HPIs, OOHI, and the HICP in Europe.

The remainder of the paper is structured as follows. Section 2 explains the theoretical properties of the hedonic methods used by NSIs in Europe to compute their HPIs. The hedonic methods are compared empirically using data for Sydney in section 3, and using data for Tokyo in section 4. Our main findings are then summarized in the conclusion in section 5.

## **2 Some Alternative Methods for Constructing Hedonic House Price Indices (HPIs)**

All the methods considered here are formulated to be compatible with Eurostat guidelines. In other contexts, these methods could be structured in slightly different ways.

## 2.1 Repricing method

The repricing method is currently the most widely used hedonic method for computing the HPI in Europe. It is used by the NSIs of Austria, Finland, Hungary, Italy, Latvia, Luxembourg, Norway, and Slovenia.

The repricing method begins by estimating a semilog hedonic model using only the data of year 1. The hedonic model can be written as follows:

$$\ln p_{(1,q),h} = \sum_{c=1}^C \beta_{1,c} z_{(1,q),h,c} + \varepsilon_{(1,q),h}, \quad (1)$$

where  $h$  denotes a dwelling sold in year 1,  $(1, q)$  is the quarter in year 1 in which the dwelling was sold,  $c = 1, \dots, C$  indexes the characteristics of dwellings available in the data set (such as number of bedrooms, and land area), and  $\varepsilon$  is a random error term.

The objective of estimating the hedonic model in (1) is to compute the shadow prices  $\beta_{1,c}$  on the characteristics. These shadow prices are computed using the whole year's data.

As it is typically applied in the HPI, the repricing method compares one quarter  $(t, q - 1)$  with the next quarter  $(t, q)$  using the base year's shadow price vector  $\hat{\beta}_1$ .

The repricing price index formula consists of two components: a quality unadjusted price index (QUPI) and a quality adjustment factor (QAF). The QUPI is the ratio of the geometric mean prices in both periods  $(t, q - 1)$  and  $(t, q)$ , computed as follows:

$$QUPI_{(t,q),(t,q-1)} = \frac{\tilde{p}_{(t,q)}}{\tilde{p}_{(t,q-1)}},$$

where  $\tilde{p}_{(t,q-1)}$  and  $\tilde{p}_{(t,q)}$  denote, respectively, the geometric mean price of dwellings sold in year-quarter  $(t, q - 1)$  and year-quarter  $(t, q)$ .

$$\tilde{p}_{(t,q-1)} = \prod_h^{H(t,q-1)} (p_{(t,q-1),h})^{1/H(t,q-1)}, \quad \tilde{p}_{(t,q)} = \prod_h^{H(t,q)} (p_{(t,q),h})^{1/H(t,q)},$$

where  $H_{(t,q-1)}$  and  $H_{(t,q)}$  denote the number of properties sold in  $(t, q - 1)$  and  $(t, q)$  respectively. Arithmetic means could be used instead. However, geometric means have the advantage of being less sensitive to outliers, which is important since the house price distribution is typically highly right skewed.

The next step is to compute a quality adjustment factor (QAF). This is done by using shadow prices of year 1 as a point of reference to compare quality of the average

dwelling sold in periods  $(t, q - 1)$ , and  $(t, q)$ . The formula of the quality adjustment factor is as follows:

$$QAF_{(t,q-1),(t,q)} = \frac{\exp(\sum_{c=1}^C \hat{\beta}_{1,c} \bar{z}_{(t,q),c})}{\exp(\sum_{c=1}^C \hat{\beta}_{1,c} \bar{z}_{(t,q-1),c})},$$

where

$$\bar{z}_{(t,q-1),c} = \frac{1}{H_{(t,q-1)}} \sum_{h=1}^{H_{(t,q-1)}} z_{(t,q-1),h,c}, \quad \bar{z}_{(t,q),c} = \frac{1}{H_{(t,q)}} \sum_{h=1}^{H_{(t,q)}} z_{(t,q),h,c},$$

denote the average basket of characteristics of periods  $(t, q - 1)$  and  $(t, q)$ , respectively, computed using the arithmetic mean formula. In the case of dummy variables, such as postcodes, the average measures the proportion of transactions that feature that postcode. For example, if 1 percent of the transactions occur in postcode 1, then the average basket for postcode 1 equals 0.01.

The quality adjustment factor can be rewritten as follows:

$$QAF_{(t,q-1),(t,q)} = \frac{\exp(\sum_{c=1}^C \hat{\beta}_{1,c} \bar{z}_{(t,q),c})}{\exp(\sum_{c=1}^C \hat{\beta}_{1,c} \bar{z}_{1,c})} \bigg/ \frac{\exp(\sum_{c=1}^C \hat{\beta}_{1,c} \bar{z}_{(t,q-1),c})}{\exp(\sum_{c=1}^C \hat{\beta}_{1,c} \bar{z}_{1,c})} = \frac{Q_{1,(t,q)}^L}{Q_{1,(t,q-1)}^L},$$

where  $Q_{j,k}^L$  denotes a Laspeyres quantity index between periods  $j$  and  $k$ . Hence the quality adjustment factor is the ratio of two Laspeyres quantity indices.

The repricing price index is now obtained by dividing the quality-unadjusted index (QUPI) by the quality adjustment factor (QAF) as follows:

$$\frac{P_{(t,q)}}{P_{(t,q-1)}} = \frac{QUPI_{(t,q),(t,q-1)}}{QAF_{(t,q-1),(t,q)}} = \frac{\tilde{p}_{(t,q)}}{\tilde{p}_{(t,q-1)}} \bigg/ \frac{\exp(\sum_{c=1}^C \hat{\beta}_{1,c} \bar{z}_{(t,q),c})}{\exp(\sum_{c=1}^C \hat{\beta}_{1,c} \bar{z}_{(t,q-1),c})} = \frac{\tilde{p}_{(t,q)}}{\tilde{p}_{(t,q-1)}} \bigg/ \frac{Q_{1,(t,q)}^L}{Q_{1,(t,q-1)}^L}. \quad (2)$$

More generally, relative to the first quarter in the data set  $(1,1)$ , the price index for period  $(t, q)$  is calculated as follows:

$$\frac{P_{(t,q)}}{P_{(1,1)}} = \frac{\tilde{p}_{(t,q)}}{\tilde{p}_{(1,1)}} \bigg/ \frac{\exp(\sum_{c=1}^C \hat{\beta}_{1,c} \bar{z}_{(t,q),c})}{\exp(\sum_{c=1}^C \hat{\beta}_{1,c} \bar{z}_{(1,1),c})} = \frac{\tilde{p}_{(t,q)}}{\tilde{p}_{(1,1)}} \bigg/ \frac{Q_{1,(t,q)}^L}{Q_{1,(1,1)}^L}. \quad (3)$$

An interesting feature of the repricing method is that it only requires the hedonic model to be estimated once (in the base year). This is perhaps one reason why it has proved popular with NSIs.

The base year under the repricing method should be updated at regular time intervals. For example, Italy and Luxembourg update the base year every year. However,

not all the NSIs using the repricing method update this frequently. Indeed this is the key problem with the repricing method. It provides a temptation to get lazy and not update the base year. In the empirical comparisons in sections 3 and 4, we consider two versions of the repricing method. The first never updates the base year, while the second updates it every five years. Our empirical results show that failure to update the base year can lead to drift in the index.

## 2.2 Average characteristics method

The average characteristics method and the hedonic imputation method both begin by estimating the following semilog hedonic model separately for each period  $(t, q)$ :

$$\ln p_{(t,q),h} = \sum_{c=1}^C \beta_{(t,q),c} z_{(t,q),h,c} + \varepsilon_{(t,q),h}, \quad (4)$$

where  $h$  indexes the dwelling transactions in period  $(t, q)$ ,  $p_{(t,q),h}$  the transaction price, and  $z_{(t,q),h,c}$  is the level of characteristic  $c$  in dwelling  $h$ . Unlike under the repricing method, the estimated shadow prices on the characteristics,  $\beta_{(t,q),c}$ , are specific to period  $(t, q)$  and are updated every period.

The next step is to construct an average basket of characteristics. The hedonic method then measures the change in the imputed price of the average dwelling over time. The version used by European NSIs computes an average basket  $\bar{z}_{t,c}$  based on a whole year's data calculated using the arithmetic mean formula. The price index between two adjacent quarters in the same year therefore is now calculated as follows:

$$\begin{aligned} \frac{P_{(t,q)}}{P_{(t,q-1)}} &= \frac{\exp(\sum_{c=1}^C \hat{\beta}_{(t,q),c} \bar{z}_{t-1,c})}{\exp(\sum_{c=1}^C \hat{\beta}_{(t,q-1),c} \bar{z}_{t-1,c})} \\ &= \frac{\exp(\sum_{c=1}^C \hat{\beta}_{(t,q),c} \bar{z}_{t-1,c})}{\exp(\sum_{c=1}^C \hat{\beta}_{t-1,c} \bar{z}_{t-1,c})} \bigg/ \frac{\exp(\sum_{c=1}^C \hat{\beta}_{(t,q-1),c} \bar{z}_{t-1,c})}{\exp(\sum_{c=1}^C \hat{\beta}_{t-1,c} \bar{z}_{t-1,c})} = \frac{P_{t-1,(t,q)}^L}{P_{t-1,(t,q-1)}^L}, \end{aligned}$$

where  $P_{j,k}^L$  denotes a Laspeyres price index between periods  $j$  and  $k$ . Hence the quality adjustment factor is the ratio of two Laspeyres price indices.

Once a year, the average characteristic basket is updated. This can be done at the end of the year, once all the data for that year are available. The price index between the fourth quarter in one year and the first quarter in the next year therefore

is calculated as follows:

$$\begin{aligned} \frac{P_{(t+1,1)}}{P_{(t,4)}} &= \frac{\exp(\sum_{c=1}^C \hat{\beta}_{(t+1,1),c} \bar{z}_{t,c})}{\exp(\sum_{c=1}^C \hat{\beta}_{(t,4),c} \bar{z}_{t,c})} \\ &= \frac{\exp(\sum_{c=1}^C \hat{\beta}_{(t+1,1),c} \bar{z}_{t,c})}{\exp(\sum_{c=1}^C \hat{\beta}_{t,c} \bar{z}_{t,c})} \bigg/ \frac{\exp(\sum_{c=1}^C \hat{\beta}_{(t,4),c} \bar{z}_{t,c})}{\exp(\sum_{c=1}^C \hat{\beta}_{t,c} \bar{z}_{t,c})} = \frac{P_{t,(t+1,1)}^L}{P_{t,(t,4)}^L}. \end{aligned}$$

Again the quality adjustment factor is the ratio of two Laspeyres price indices.

Relative to the first quarter in the data set (1,1), the price index for period  $(t+1, 1)$  is calculated as follows:

$$\frac{P_{(t+1,1)}}{P_{(1,1)}} = \frac{P_{0,(1,2)}^L}{P_{0,(1,1)}^L} \times \frac{P_{0,(1,3)}^L}{P_{0,(1,2)}^L} \times \frac{P_{0,(1,4)}^L}{P_{0,(1,3)}^L} \times \frac{P_{1,(2,1)}^L}{P_{1,(1,4)}^L} \times \dots \times \frac{P_{t-1,(t,4)}^L}{P_{t-1,(t,3)}^L} \times \frac{P_{t,(t+1,1)}^L}{P_{t,(t,4)}^L}.$$

It turns out that the repricing method (see section 2.1) can be represented as a fixed base average characteristics method. Suppose, as with the average characteristics and hedonic imputation methods, the hedonic model is estimated for a single quarter. The imputed errors from the semilog hedonic model for quarter  $s$  can then be written as follows:

$$\hat{\varepsilon}_{sh} = \ln p_{sh} - \sum_{c=1}^C \hat{\beta}_{s,c} z_{shc}.$$

By construction under OLS,  $\sum_{h=1}^{H_1} \hat{\varepsilon}_{sh} = 0$ . Hence,

$$\sum_{h=1}^{H_s} [\ln p_{sh} - \sum_{c=1}^C \hat{\beta}_{s,c} z_{shc}] = 0,$$

which in turn implies that the geometric mean price takes the following form:

$$\tilde{p}_s = \exp\left(\sum_{c=1}^C \hat{\beta}_{s,c} \bar{z}_{sc}\right).$$

Substituting this expression into the repricing formula (with shadow prices estimated using only the first quarter not the first year) yields the following:

$$\begin{aligned} \frac{\bar{p}_{(t,q)}}{\bar{p}_{(t,q-1)}} &\bigg/ \frac{\exp(\sum_{c=1}^C \hat{\beta}_{(1,1),c} \bar{z}_{(t,q),c})}{\exp(\sum_{c=1}^C \hat{\beta}_{(1,1),c} \bar{z}_{(t,q-1),c})} = \frac{\exp(\sum_{c=1}^C \hat{\beta}_{(t,q),c} \bar{z}_{(t,q),c})}{\exp(\sum_{c=1}^C \hat{\beta}_{(t,q-1),c} \bar{z}_{(t,q-1),c})} \bigg/ \frac{\exp(\sum_{c=1}^C \hat{\beta}_{(1,1),c} \bar{z}_{(t,q),c})}{\exp(\sum_{c=1}^C \hat{\beta}_{(1,1),c} \bar{z}_{(t,q-1),c})} \\ &= \frac{\exp(\sum_{c=1}^C \hat{\beta}_{(t,q),c} \bar{z}_{(t,q),c})}{\exp(\sum_{c=1}^C \hat{\beta}_{1,1,c} \bar{z}_{t,q,c})} \bigg/ \frac{\exp(\sum_{c=1}^C \hat{\beta}_{(1,1),c} \bar{z}_{(t,q-1),c})}{\exp(\sum_{c=1}^C \hat{\beta}_{(t,q-1),c} \bar{z}_{(t,q-1),c})} = \frac{P_{(1,1),(t,q)}^P}{P_{(1,1),(t,q-1)}^P}, \end{aligned}$$

where  $P_{j,k}^P$  denotes a Paasche price index between periods  $j$  and  $k$ . Hence the repricing method can also be interpreted as an average characteristics method that uses the Paasche price index formula.



## 2.3 Hedonic imputation method

The underlying rationale of the hedonic imputation method is to use the hedonic model to ask counterfactual questions regarding what a particular dwelling would have sold for if it had sold in a different period from the one it actually sold in. In this way it is possible to construct price relatives measuring how the price of each dwelling has changed over time. These price relatives can then be averaged across dwellings to obtain the overall price index.

Here we will present two slightly different variants of the hedonic imputation method. The first is used by the UK NSI and the second by the German NSI. Both versions use the same estimated hedonic model as the average characteristics method in (4) to impute prices for each dwelling. For example, let  $\hat{p}_{(t,q),h}(z_{t-1,h})$  denote an imputed price in period  $(t, q)$  for dwelling  $h$  which was actually sold one year earlier in period  $(t-1, q)$ .

The UK version is a chained Lowe index where the reference basket is all the dwellings sold in the previous year. When comparing two quarters in the same year (here  $t$ ), the formula is as follows:

$$\frac{P_{(t,q)}}{P_{(t,q-1)}} = \prod_{h=1}^{H_{t-1}} \left[ \frac{\hat{p}_{(t,q),h}(z_{t-1,h})}{\hat{p}_{(t,q-1),h}(z_{t-1,h})} \right]^{1/H_{t-1}},$$

where  $H_{t-1}$  denotes the number of properties sold in year  $t-1$ . When the 4th quarter is compared with the 1st quarter of the next year the reference basket is updated as follows:

$$\frac{P_{(t+1,1)}}{P_{(t,4)}} = \prod_{h=1}^{H_t} \left[ \frac{\hat{p}_{(t+1,1),h}(z_{t,h})}{\hat{p}_{(t,4),h}(z_{t,h})} \right]^{1/H_t}.$$

When the underlying hedonic model has a semilog functional form, the UK method is in fact identical to the average characteristics method described above. This duality between the average characteristics method and the hedonic imputation method is explored in more detail in Hill and Melsor (2008). In the case of the UK method, the duality can be demonstrated as follows:

$$\frac{P_{(t,q)}}{P_{(t,q-1)}} = \prod_{h=1}^{H_{t-1}} \left[ \frac{\hat{p}_{(t,q),h}(z_{t-1,h})}{\hat{p}_{(t,q-1),h}(z_{t-1,h})} \right]^{1/H_{t-1}} = \prod_{h=1}^{H_{t-1}} \left[ \frac{\sum_{c=1}^C \exp(\hat{\beta}_{(t,q)} z_{t-1,h})}{\sum_{c=1}^C \exp(\hat{\beta}_{(t,q-1)} z_{t-1,h})} \right]^{1/H_{t-1}}$$

$$= \frac{\frac{1}{H_{t-1}} \sum_{c=1}^C \sum_{h=1}^{H_{t-1}} \exp(\hat{\beta}_{(t,q)} z_{t-1,h})}{\frac{1}{H_{t-1}} \sum_{c=1}^C \sum_{h=1}^{H_{t-1}} \exp(\hat{\beta}_{(t,q-1)} z_{t-1,h})} = \frac{\exp(\sum_{c=1}^C \hat{\beta}_{(t,q),c} \bar{z}_{t-1,c})}{\exp(\sum_{c=1}^C \hat{\beta}_{(t,q-1),c} \bar{z}_{t-1,c})} = \frac{P_{t-1,(t,q)}^L}{P_{t-1,(t,q-1)}^L}.$$

In an analogous way it can be shown that

$$\frac{P_{(t+1,1)}}{P_{(t,4)}} = \prod_{h=1}^{H_t} \left[ \frac{\hat{p}_{(t+1,1),h}(z_{t,h})}{\hat{p}_{(t,4),h}(z_{t,h})} \right]^{1/H_t} = \frac{\exp(\sum_{c=1}^C \hat{\beta}_{(t+1,1),c} \bar{z}_{t,c})}{\exp(\sum_{c=1}^C \hat{\beta}_{(t,4),c} \bar{z}_{t,c})} = \frac{P_{t,(t+1,1)}^L}{P_{t,(t,4)}^L}.$$

The German version by contrast uses a Törnqvist-type formula (i.e., the geometric mean of geometric-Laspeyres and geometric-Paasche-type formulas) defined as follows:

$$\text{Geometric Laspeyres (GL)} : \frac{P_{(t,q)}}{P_{(t,q-1)}} = \left[ \prod_{h=1}^{H_{(t,q-1)}} \frac{\hat{p}_{(t,q),h}(z_{(t,q-1),h})}{\hat{p}_{(t,q-1),h}(z_{(t,q-1),h})} \right]^{1/H_{(t,q-1)}} ;$$

$$\text{Geometric Paasche (GP)} : \frac{P_{(t,q)}}{P_{(t,q-1)}} = \left[ \prod_{h=1}^{H_{(t,q)}} \frac{\hat{p}_{(t,q),h}(z_{(t,q),h})}{\hat{p}_{(t,q-1),h}(z_{(t,q),h})} \right]^{1/H_{(t,q)}}$$

$$\text{Törnqvist} : \frac{P_{(t,q)}}{P_{(t,q-1)}} = \left\{ \left[ \prod_{h=1}^{H_{(t,q-1)}} \frac{\hat{p}_{(t,q),h}(z_{(t,q-1),h})}{\hat{p}_{(t,q-1),h}(z_{(t,q-1),h})} \right]^{1/H_{(t,q-1)}} \left[ \prod_{h=1}^{H_{(t,q)}} \frac{\hat{p}_{(t,q),h}(z_{(t,q),h})}{\hat{p}_{(t,q-1),h}(z_{(t,q),h})} \right]^{1/H_{(t,q)}} \right\}^{1/2}.$$

Here it makes no difference whether we are comparing two quarters in the same year or the last quarter in one year with the first quarter in the next.

When the underlying hedonic model is semilog, the geometric-Laspeyres (GL), geometric-Paasche (GP), and Törnqvist hedonic imputation indices can be represented as average characteristic methods as follows:

$$\text{GL} : \left[ \prod_{h=1}^{H_{(t,q-1)}} \frac{\hat{p}_{(t,q),h}(z_{(t,q-1),h})}{\hat{p}_{(t,q-1),h}(z_{(t,q-1),h})} \right]^{1/H_{(t,q-1)}} = \frac{\exp(\sum_{c=1}^C \hat{\beta}_{(t,q),c} \bar{z}_{(t,q-1),c})}{\exp(\sum_{c=1}^C \hat{\beta}_{(t,q-1),c} \bar{z}_{(t,q-1),c})} = P_{(t,q-1),(t,q)}^L ;$$

$$\text{GP} : \frac{P_{(t,q)}}{P_{(t,q-1)}} = \left[ \prod_{h=1}^{H_{(t,q)}} \frac{\hat{p}_{(t,q),h}(z_{(t,q),h})}{\hat{p}_{(t,q-1),h}(z_{(t,q),h})} \right]^{1/H_{(t,q)}} = \frac{\exp(\sum_{c=1}^C \hat{\beta}_{(t,q),c} \bar{z}_{(t,q),c})}{\exp(\sum_{c=1}^C \hat{\beta}_{(t,q-1),c} \bar{z}_{(t,q),c})} = P_{(t,q-1),(t,q)}^P ;$$

$$\begin{aligned} \text{Törnqvist} : & \left\{ \left[ \prod_{h=1}^{H_{(t,q-1)}} \frac{\hat{p}_{(t,q),h}(z_{(t,q-1),h})}{\hat{p}_{(t,q-1),h}(z_{(t,q-1),h})} \right]^{1/H_{(t,q-1)}} \left[ \prod_{h=1}^{H_{(t,q)}} \frac{\hat{p}_{(t,q),h}(z_{(t,q),h})}{\hat{p}_{(t,q-1),h}(z_{(t,q),h})} \right]^{1/H_{(t,q)}} \right\}^{1/2} \\ & = \left\{ \frac{\exp[\sum_{c=1}^C \hat{\beta}_{(t,q),c} (\bar{z}_{(t,q-1),c} + \bar{z}_{(t,q),c})]}{\exp[\sum_{c=1}^C \hat{\beta}_{(t,q-1),c} (\bar{z}_{(t,q-1),c} + \bar{z}_{(t,q),c})]} \right\}^{1/2} = (P_{(t,q-1),(t,q)}^L \times P_{(t,q-1),(t,q)}^P)^{1/2} = P_{(t,q-1),(t,q)}^F, \end{aligned}$$

where  $P_{j,k}^F$  denotes a Fisher price index comparison between periods  $j$  and  $k$ .

Relative to the first quarter in the data set (1,1), the price index for period  $(t+1, 1)$  is calculated as follows:

$$\frac{P_{(t+1,1)}}{P_{(1,1)}} = P_{(1,1),(1,2)}^F \times P_{(1,2),(1,3)}^F \times \cdots \times P_{(t+1,1),(t,4)}^F.$$

In practice this means that the UK method is essentially equivalent to the average characteristic method used by Romania and Spain. While Germany's method can also be represented as an average characteristics method, it is the only country in the EU that uses the Törnqvist formula to construct its HPI.

## 2.4 Rolling time dummy (RTD) method

The Rolling Time Dummy (RTD) method, as proposed by Shimizu, Takatsuji, Ono and Nishimura (2010) (see also O'Hanlon 2011), is used by a number of NSIs in Europe. RTD is a variant on the widely used time-dummy hedonic method. The relationship between time-dummy and hedonic imputations methods is explored by Diewert, Heravi, and Silver (2009) and de Haan (2010).

When discussing the RTD method we use a slightly different notation than we have used thus far in this paper. We refer simply to periods denoted by  $s$  and  $t$ , without distinguishing which year and quarter they are in.

The RTD method begins by estimating the following hedonic model over a time window of  $k + 1$  periods starting with period  $s$ :

$$\ln p_{uh} = \sum_{c=1}^C \beta_{(s,s+k),c} z_{uhc} + \sum_{i=s+1}^{s+k} \delta_i D_{ih} + \varepsilon_{uh}, \quad (5)$$

where  $h$  now indices the dwelling transactions in periods  $s, \dots, s + k$ , and  $D_{ih}$  is a dummy variable that equals 1 when  $u = i$  is the period in which the dwelling sold, and zero otherwise. Now the characteristic shadow prices  $\beta_{(s,s+k),c}$  are common to periods  $s, \dots, s + k$ . The RTD method then moves the window forward one period, and re-estimates the model.

The RTD method derives the price index comparing period  $t + k - 1$  to period  $t + k$  as follows:

$$\frac{P_{t+k}}{P_{t+k-1}} = \frac{\exp(\hat{\delta}_{t+k}^t)}{\exp(\hat{\delta}_{t+k-1}^t)}. \quad (6)$$

A superscript  $t$  is included on the estimated  $\delta$  coefficients to indicate that they obtained from the hedonic model with period  $t$  as the base. The hedonic model with period  $t$  as the base is only used to compute the change in house prices from period  $t + k - 1$  to period  $t + k$ . The window is then rolled forward one period and the hedonic model is re-estimated. The change in house prices from period  $t + k$  to period  $t + k + 1$  is now computed as follows:

$$\frac{P_{t+k+1}}{P_{t+k}} = \frac{\exp(\hat{\delta}_{t+k+1}^{t+1})}{\exp(\hat{\delta}_{t+k}^{t+1})}, \quad (7)$$

where now the base period in the hedonic model is period  $t + 1$ . The price index over multiple periods is computed by chaining these bilateral comparisons together as follows:

$$\frac{P_{t+k+1}}{P_t} = \left( \frac{\exp(\hat{\delta}_{t+1}^{t-k})}{\exp(\hat{\delta}_t^{t-k})} \right) \left( \frac{\exp(\hat{\delta}_{t+2}^{t-k+1})}{\exp(\hat{\delta}_{t+1}^{t-k+1})} \right) \cdots \left( \frac{\exp(\hat{\delta}_{t+k+1}^{t+1})}{\exp(\hat{\delta}_{t+k}^{t+1})} \right). \quad (8)$$

A trade-off exists when choosing the window length. A shorter window makes the price index more current, but less robust. When data points are scarce, RTD4Q and RTD5Q (i.e., 4 or 5 quarter windows) are recommended over RTD2Q (i.e., a 2 quarter window). The size of a country's housing market will therefore influence the choice of window length. NSIs in Europe using the RTD method have selected the following window lengths:

France=2,Cyprus=4,Ireland=5, Portugal=2, Croatia=4.

An important feature of the RTD method is that once a price change  $P_{t+k}t + k - 1$  has been computed, it is never revised. Hence when data for a new period  $t + k + 1$  becomes available, the price indices  $P_t, P_{t+1}, \dots, P_{t+k}$  are already fixed. The sole objective when estimating the hedonic model inclusive of data from period  $t + k + 1$  is to compute  $P_{t+k+1}$ , irrespective of how many periods are included in the hedonic model. More generally, this property of never being revised is shared by all the hedonic price indices considered here. This is a useful property for an HPI.

## 2.5 Stratified medians

A stratified median is not a hedonic method. The first step in computing a stratified (or mix-adjusted) median index is to split the data set into strata. As with hedonic methods, the first split should be between houses and apartments. Each stratum should

be further subdivided based on location, for example by province, county, district or postcode. When information on the physical characteristics of dwelling are available, splits can also be done based say on size (for example floor area less than 80 square meters and greater than 80 square meters), or age (e.g., new and existing). In the empirical application in sections 3 and 4, after splitting houses and apartments, we focus on locational stratification based on postcodes and Residex regions for Sydney, and wards in Tokyo.

Once the strata have been constructed, the median price for each stratum is computed. These medians are then averaged separately for houses and apartments, typically using the arithmetic mean formula. One issue that arises is whether the arithmetic mean formula should be weighted by the number of transactions in each stratum.

With regard to computational complexity, a stratified median method lies somewhere in between a simple median method and a quality-adjusted hedonic method. Averaging medians across strata reduces the noise in the index resulting from compositional changes in the median dwelling over time. While in principle more strata should imply better quality adjustment, this approach soon runs into the problem when the classification becomes finer that some of the strata may be empty in some periods (i.e., there are no transactions with that particular mix of characteristics). This imposes limits on how far stratified median methods can take the quality-adjustment process.

## **3 Results for Sydney (2003-2014)**

### **3.1 The Sydney data set**

We use a data set obtained from Australian Property Monitors that consists of prices and characteristics of houses and apartments sold in Sydney (Australia) for the years 2002–2014. Results are presented for the years 2003-2014. For some methods, data for 2002 are needed to compute the reference baskets used in 2003.

For each house we have the following characteristics:

- the actual sale price,
- time of sale, postcode,

- property type (i.e., detached or semi),
- number of bedrooms,
- number of bathrooms,
- land area,
- postcode (there are 202 postcodes in the data set).

For apartments we have the same set of characteristics. However, we drop the land area characteristic for apartments in our hedonic analysis since it refers to the whole strata, and we do not have any information on the number of apartments in the building.

For a robust analysis it was necessary to remove some outliers. This is because there is a concentration of data entry errors in the tails, caused for example by the inclusion of erroneous extra zeroes. These extreme observations can distort the results. The exclusion criteria we applied are shown in Table 1. Complete data on all our hedonic characteristics are available for 380 414 house transactions. For apartments the corresponding figure is 250 005.

### **3.2 Summary of methods to be considered**

The methods that will be compared (of which the first nine are hedonic) are listed below:

1. Repricing (no updating of base year)
2. Repricing (base year updated every five years)
3. Average characteristics
4. Double imputation Geometric-Laspeyres
5. Double imputation Geometric-Paasche
6. Double imputation Törnqvist
7. RTD (2 quarters)
8. RTD (4 quarters)
9. RTD (5 quarters)
10. Stratified median

In the case of Sydney, price indices will be computed separately for houses and

apartments. An overall HPI for Sydney could then be computed using the standard method for aggregating strata recommended in chapter 9 of the CPI Manual – (see ILO/IMF/OECD/UNECE/Eurostat/The World Bank 2004). For Tokyo only data for apartments are available. The age of dwellings is available for Tokyo but not for Sydney. So for Tokyo we compute price indices for all apartments and for new apartments.

It is particularly important to determine how well the methods used by NSIs perform on a data set for new dwellings, since a price index for new dwellings is a key input into the experimental owner-occupied housing price index (OOHI) in Europe. The OOHI is in turn being considered for inclusion in the harmonized index of consumer prices (HICP).

### 3.3 House and apartment price indices for Sydney

The house price indices (HPIs) for Sydney generated by the various methods discussed above are shown in Table 2. Five of the series are graphed in Figure 1. As is clear from Table 2 and Figure 1 that the HPI is quite robust to the choice of method. Over the whole sample period, depending on the choice of hedonic method, house prices rose by between 73.7 and 78.1 percent. The two repricing methods – RP1 (which uses shadow prices from 2003) and RP2 (which updates the shadow prices every five years) – generate the lowest increase in house prices.<sup>1</sup>

Also shown in Table 2 are stratified median results computed in two different ways. MIX-PC stratifies houses by postcodes of which there are 202. MIX-RX stratifies by Residex region of which there are 16.<sup>2</sup> The MIX-PC stratification is hence much finer

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<sup>1</sup>Examples of the estimated characteristic shadow prices from the hedonic models are provided for Sydney in 2003 and for Tokyo in 2002 in Appendix B. It can be seen that most of the shadow prices are significantly different from zero at the 5 percent significance level, and the adjusted R-squared for are about 0.85.

<sup>2</sup>The Residex regions (with their constituent postcodes listed in brackets) are as follows: Inner Sydney (2000 to 2020), Eastern Suburbs (2021 to 2036), Inner West (2037 to 2059), Lower North Shore (2060 to 2069), Upper North Shore (2070 to 2087), Mosman-Cremorne (2088 to 2091), Manly-Warringah (2092 to 2109), North Western (2110 to 2126), Western Suburbs (2127 to 2145), Parramatta Hills (2146 to 2159), Fairfield-Liverpool (2160 to 2189), Canterbury-Bankstown (2190 to 2200), St George (2201 to 2223), Cronulla-Sutherland (2224 to 2249), Campbelltown (2552 to 2570), Penrith-

than its MIX-RX counterpart. It is not surprising therefore that the MIX-PC index is less erratic and closer to the hedonic indices. The MIX-PC index rises by 82 percent while MIX-RX rises by 87 percent. The concern is not just that it rises faster than the hedonic indices, but also that it is more volatile, as can be seen from Figure 1.

The results for apartments in Sydney shown in Figure 2 are also reasonably robust to the choice of method, when we restrict the comparison to the hedonic methods actually used by NSIs to compute the HPI. The measured cumulative rise in apartment prices for the hedonic methods ranges between 68.1 and 72.6 percent. The stratified median index MIX-RX, by contrast, rises by 80 percent.

The double imputation Paasche (DIP) and Laspeyres (DIL) indices – shown in Table 3 but excluded from Figure 2 – exhibit clear evidence of drift. According to DIP, prices rise by only 65.3 percent while according to DIL prices rise by 78.1 percent. It is fortunate therefore that none of the NSIs are using either DIP or DIL. The German NSI uses the double imputation Törnqvist (DIT) method, which is the geometric mean of DIP and DIL. The results indicate that the drift in DIP and DIL is offsetting, and hence DIT should be unaffected by any drift problems.

Given the duality between average characteristic and hedonic imputation methods, we should also consider the implications of this finding for the former. The average characteristics method, which uses a Laspeyres type formula, is potentially also at risk of drift. However, the drift arises here when the average dwelling is updated each quarter based on the previous quarter’s data. The average characteristics method used by NSIs only updates the average dwelling annually and computes it based on a whole year’s data. This seems to be enough to prevent drift.

It is also noticeable that RP2 (repricing where the base period is updated every five years) generates very similar results to the average characteristics (AC) method. Given the duality that exists between the repricing and average characteristics methods this result is not so surprising. However, such similarity in the RP2 and AC results was not observed for houses in Table 2.

The results for the stratified median methods are similar to those obtained for houses. The stratified median indices rise more than the hedonic indices, and are more

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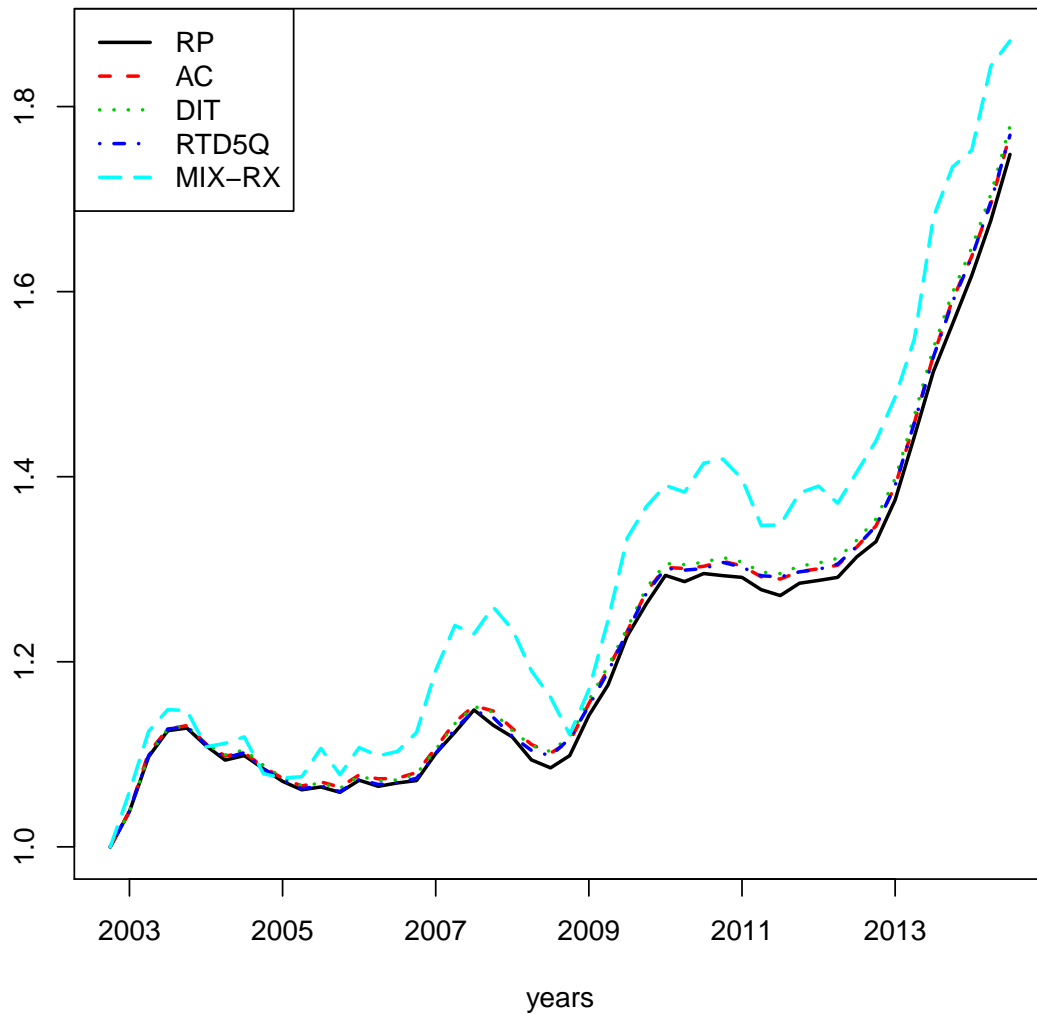
Windsor (2740 to 2777).



Table 1: Criteria for removing outliers

	PRICE	BED	BATH	AREA
Minimum Allowed	\$100 000	1.000	1.000	100.0
Maximum Allowed	\$4 000 000	6.000	6.000	10 000.0

Figure 1: Price Indices for Houses in Sydney (2003Q1=1)



Note: RP = Repricing; AC = Average characteristics; DIT = Double imputation Törnqvist; RTD5Q = Rolling time dummy with five quarter window; MIX-RX = Mix adjusted stratified by Residex region.

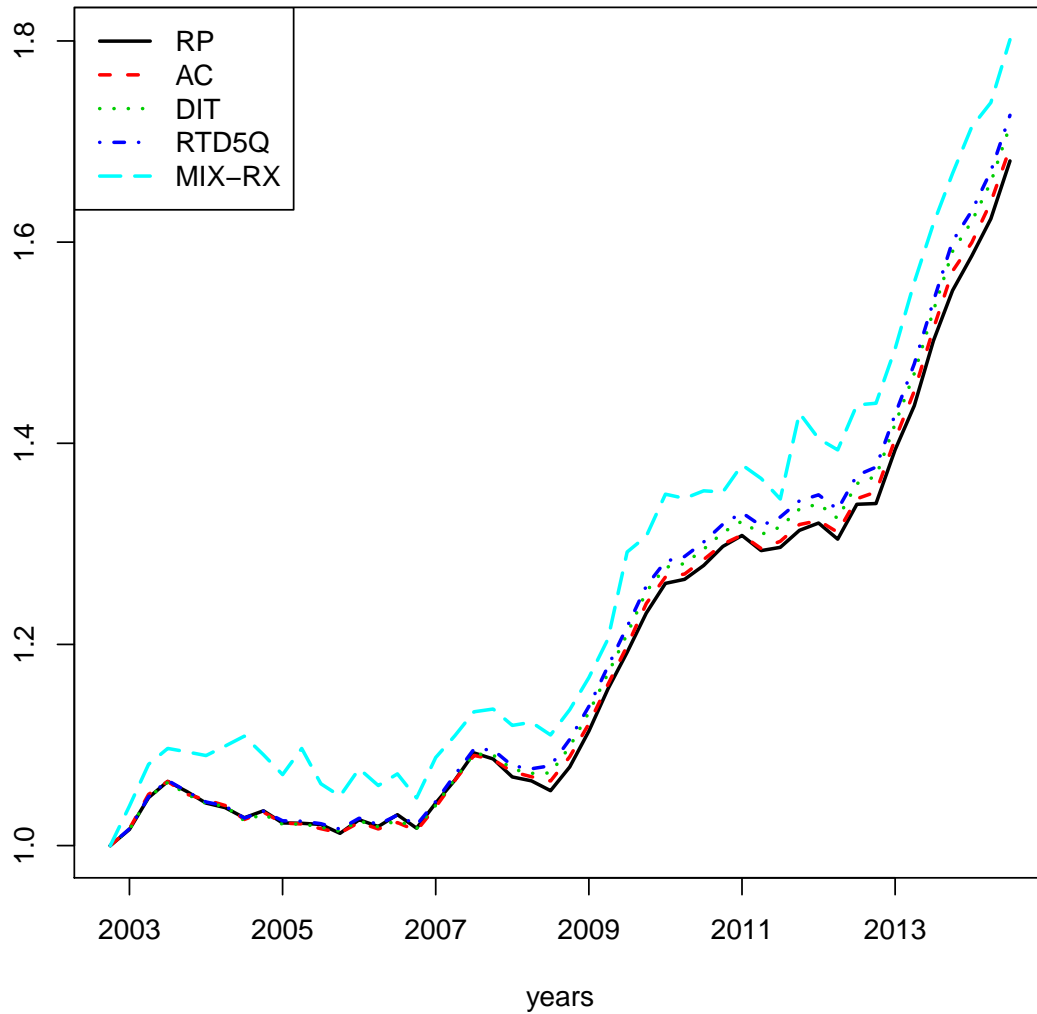
Table 2: Price Indices for Houses in Sydney (2003Q1=1)

	RP1	RP2	AC	DIL	DIP	DIT	RTD2Q	RTD4Q	RTD5Q	MIX-PC	MIX-RX
2003Q1	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
2003Q2	1.038	1.038	1.039	1.038	1.038	1.038	1.038	1.039	1.039	1.033	1.059
2003Q3	1.097	1.097	1.102	1.098	1.099	1.099	1.099	1.098	1.098	1.111	1.125
2003Q4	1.126	1.126	1.127	1.128	1.127	1.127	1.127	1.127	1.127	1.129	1.148
2004Q1	1.128	1.128	1.131	1.131	1.129	1.130	1.131	1.129	1.130	1.146	1.147
2004Q2	1.109	1.109	1.111	1.113	1.110	1.111	1.112	1.110	1.110	1.091	1.108
2004Q3	1.094	1.094	1.098	1.100	1.099	1.099	1.099	1.096	1.096	1.083	1.112
2004Q4	1.099	1.099	1.102	1.106	1.104	1.105	1.105	1.102	1.102	1.097	1.119
2005Q1	1.084	1.084	1.086	1.090	1.087	1.088	1.088	1.085	1.084	1.074	1.079
2005Q2	1.071	1.071	1.074	1.076	1.074	1.075	1.075	1.072	1.072	1.044	1.074
2005Q3	1.062	1.062	1.066	1.068	1.065	1.066	1.066	1.063	1.063	1.047	1.076
2005Q4	1.065	1.065	1.070	1.070	1.067	1.069	1.069	1.067	1.066	1.072	1.106
2006Q1	1.059	1.059	1.065	1.065	1.062	1.063	1.064	1.060	1.060	1.057	1.078
2006Q2	1.072	1.072	1.078	1.077	1.075	1.076	1.077	1.074	1.073	1.078	1.107
2006Q3	1.065	1.065	1.073	1.073	1.070	1.071	1.072	1.068	1.067	1.092	1.098
2006Q4	1.069	1.069	1.074	1.073	1.071	1.072	1.072	1.070	1.069	1.094	1.103
2007Q1	1.072	1.072	1.080	1.079	1.078	1.079	1.079	1.075	1.074	1.109	1.124
2007Q2	1.101	1.101	1.107	1.105	1.105	1.105	1.105	1.102	1.101	1.139	1.191
2007Q3	1.124	1.124	1.135	1.133	1.133	1.133	1.133	1.129	1.127	1.204	1.239
2007Q4	1.148	1.148	1.153	1.152	1.152	1.152	1.152	1.148	1.147	1.205	1.230
2008Q1	1.131	1.131	1.147	1.144	1.147	1.146	1.146	1.142	1.140	1.211	1.259
2008Q2	1.119	1.112	1.128	1.124	1.127	1.126	1.126	1.121	1.120	1.203	1.235
2008Q3	1.094	1.096	1.111	1.108	1.111	1.109	1.109	1.106	1.104	1.160	1.190
2008Q4	1.085	1.090	1.101	1.101	1.105	1.103	1.103	1.100	1.098	1.137	1.162
2009Q1	1.099	1.110	1.114	1.114	1.124	1.119	1.119	1.118	1.117	1.137	1.121
2009Q2	1.142	1.142	1.155	1.153	1.164	1.158	1.159	1.155	1.152	1.180	1.170
2009Q3	1.175	1.179	1.192	1.190	1.200	1.195	1.196	1.191	1.189	1.241	1.245
2009Q4	1.228	1.217	1.233	1.230	1.242	1.236	1.236	1.235	1.232	1.302	1.334
2010Q1	1.263	1.258	1.276	1.274	1.285	1.280	1.280	1.277	1.274	1.366	1.368
2010Q2	1.293	1.287	1.302	1.301	1.311	1.306	1.307	1.304	1.301	1.399	1.391
2010Q3	1.287	1.285	1.301	1.300	1.310	1.305	1.306	1.302	1.299	1.373	1.383
2010Q4	1.295	1.285	1.303	1.303	1.311	1.307	1.308	1.304	1.301	1.365	1.415
2011Q1	1.293	1.290	1.309	1.309	1.317	1.313	1.313	1.310	1.307	1.389	1.419
2011Q2	1.291	1.287	1.304	1.305	1.311	1.308	1.309	1.305	1.302	1.359	1.398
2011Q3	1.278	1.280	1.292	1.293	1.301	1.297	1.298	1.296	1.293	1.321	1.347
2011Q4	1.272	1.279	1.289	1.291	1.300	1.295	1.296	1.294	1.292	1.339	1.348
2012Q1	1.285	1.277	1.297	1.300	1.307	1.303	1.304	1.300	1.297	1.343	1.382
2012Q2	1.288	1.279	1.301	1.303	1.310	1.307	1.307	1.303	1.300	1.347	1.390
2012Q3	1.291	1.289	1.304	1.309	1.315	1.312	1.313	1.308	1.306	1.342	1.371
2012Q4	1.313	1.301	1.324	1.327	1.335	1.331	1.332	1.328	1.325	1.377	1.405
2013Q1	1.330	1.324	1.347	1.352	1.357	1.354	1.355	1.350	1.347	1.408	1.439
2013Q2	1.375	1.366	1.390	1.395	1.400	1.398	1.398	1.394	1.390	1.453	1.486
2013Q3	1.443	1.433	1.458	1.463	1.469	1.466	1.466	1.462	1.458	1.530	1.549
2013Q4	1.514	1.502	1.531	1.536	1.542	1.539	1.540	1.534	1.530	1.613	1.681
2014Q1	1.565	1.562	1.591	1.597	1.602	1.599	1.599	1.593	1.589	1.676	1.735
2014Q2	1.617	1.609	1.638	1.646	1.649	1.647	1.648	1.642	1.637	1.704	1.753
2014Q3	1.677	1.668	1.695	1.702	1.708	1.705	1.706	1.702	1.697	1.752	1.844
2014Q4	1.748	1.737	1.770	1.777	1.781	1.779	1.780	1.774	1.769	1.819	1.871

Note: The hedonic methods are as follows: RP1 = Repricing; RP2 = Repricing where the base period is updated every five years; AC = Average characteristics; Double imputation Laspeyres = DIL; Double imputation Paasche = DIP; Double imputation Törnqvist = DIT; RTD2Q = Rolling time dummy with a 2 quarter rolling window; RTD4Q and RTD5Q have 4 and 5 quarter rolling windows; MIX-PC = Mix adjusted stratified by postcode; MIX-RX = Mix adjusted stratified by Residex region.

volatile. Again, as expected, of the two stratified median indices, MIX-PC is less erratic and approximates better the hedonic indices.

Figure 2: Price Indices for Apartments in Sydney (2003Q1=1)



Note: Note: RP = Repricing; AC = Average characteristics; DIT = Double imputation Törnqvist; RTD5Q = Rolling time dummy with five quarter window; MIX-RX = Mix adjusted stratified by Residex region.

Table 3: Price Indices for Apartments in Sydney (2003Q1=1)

	RP1	RP2	AC	HIL	HIP	HIT	RTD2Q	RTD4Q	RTD5Q	MIX-PC	MIX-RX
2003Q1	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
2003Q2	1.016	1.016	1.017	1.018	1.015	1.016	1.016	1.016	1.017	1.019	1.039
2003Q3	1.048	1.048	1.051	1.046	1.050	1.048	1.048	1.049	1.049	1.050	1.081
2003Q4	1.064	1.064	1.064	1.060	1.066	1.063	1.063	1.065	1.065	1.078	1.097
2004Q1	1.054	1.054	1.051	1.047	1.056	1.051	1.051	1.054	1.054	1.061	1.093
2004Q2	1.042	1.042	1.045	1.037	1.047	1.042	1.042	1.044	1.043	1.075	1.089
2004Q3	1.038	1.038	1.040	1.032	1.046	1.039	1.039	1.040	1.039	1.072	1.099
2004Q4	1.028	1.028	1.026	1.017	1.033	1.025	1.026	1.028	1.027	1.065	1.109
2005Q1	1.035	1.035	1.033	1.023	1.040	1.031	1.031	1.034	1.034	1.067	1.090
2005Q2	1.022	1.022	1.022	1.013	1.029	1.021	1.021	1.025	1.025	1.041	1.071
2005Q3	1.022	1.022	1.021	1.013	1.030	1.022	1.022	1.025	1.024	1.054	1.097
2005Q4	1.021	1.021	1.017	1.009	1.027	1.018	1.018	1.022	1.022	1.040	1.061
2006Q1	1.012	1.012	1.013	1.004	1.024	1.014	1.014	1.018	1.016	1.064	1.049
2006Q2	1.026	1.026	1.023	1.015	1.034	1.025	1.024	1.028	1.027	1.049	1.076
2006Q3	1.019	1.019	1.017	1.008	1.029	1.019	1.019	1.022	1.021	1.034	1.060
2006Q4	1.031	1.031	1.023	1.012	1.038	1.025	1.025	1.031	1.030	1.054	1.071
2007Q1	1.017	1.017	1.015	1.002	1.032	1.017	1.017	1.022	1.020	1.026	1.047
2007Q2	1.042	1.042	1.038	1.025	1.055	1.040	1.040	1.045	1.044	1.063	1.088
2007Q3	1.065	1.065	1.065	1.050	1.083	1.066	1.066	1.071	1.070	1.098	1.109
2007Q4	1.092	1.092	1.090	1.073	1.109	1.091	1.091	1.097	1.096	1.132	1.133
2008Q1	1.086	1.086	1.086	1.070	1.110	1.090	1.090	1.096	1.095	1.109	1.136
2008Q2	1.068	1.070	1.073	1.054	1.098	1.076	1.076	1.080	1.079	1.084	1.119
2008Q3	1.064	1.066	1.068	1.050	1.094	1.072	1.072	1.076	1.076	1.072	1.123
2008Q4	1.055	1.068	1.064	1.048	1.097	1.072	1.072	1.079	1.079	1.088	1.110
2009Q1	1.078	1.095	1.088	1.073	1.125	1.098	1.098	1.105	1.106	1.106	1.135
2009Q2	1.114	1.126	1.121	1.105	1.161	1.132	1.132	1.138	1.138	1.133	1.167
2009Q3	1.156	1.166	1.160	1.142	1.202	1.171	1.170	1.178	1.178	1.170	1.205
2009Q4	1.192	1.198	1.199	1.177	1.245	1.210	1.210	1.218	1.218	1.239	1.292
2010Q1	1.231	1.242	1.241	1.218	1.289	1.253	1.252	1.259	1.258	1.271	1.308
2010Q2	1.261	1.265	1.267	1.241	1.313	1.277	1.275	1.283	1.283	1.296	1.349
2010Q3	1.265	1.269	1.270	1.244	1.318	1.280	1.279	1.287	1.287	1.296	1.345
2010Q4	1.279	1.282	1.284	1.259	1.332	1.295	1.294	1.302	1.302	1.311	1.353
2011Q1	1.297	1.300	1.300	1.274	1.349	1.311	1.310	1.319	1.319	1.324	1.351
2011Q2	1.308	1.315	1.309	1.283	1.363	1.323	1.321	1.330	1.331	1.316	1.379
2011Q3	1.293	1.300	1.295	1.268	1.352	1.309	1.308	1.317	1.318	1.320	1.365
2011Q4	1.297	1.313	1.303	1.274	1.361	1.317	1.315	1.325	1.327	1.307	1.345
2012Q1	1.313	1.316	1.319	1.289	1.382	1.335	1.333	1.342	1.343	1.358	1.430
2012Q2	1.321	1.325	1.323	1.293	1.388	1.340	1.339	1.348	1.349	1.361	1.405
2012Q3	1.305	1.314	1.311	1.277	1.375	1.325	1.324	1.333	1.334	1.346	1.393
2012Q4	1.339	1.341	1.345	1.311	1.411	1.360	1.359	1.367	1.368	1.388	1.438
2013Q1	1.340	1.353	1.352	1.317	1.420	1.367	1.366	1.375	1.376	1.412	1.440
2013Q2	1.394	1.404	1.404	1.367	1.474	1.419	1.418	1.427	1.429	1.462	1.494
2013Q3	1.437	1.453	1.452	1.415	1.526	1.469	1.469	1.478	1.479	1.500	1.560
2013Q4	1.502	1.513	1.514	1.476	1.589	1.532	1.531	1.540	1.541	1.584	1.618
2014Q1	1.552	1.573	1.571	1.533	1.651	1.591	1.590	1.600	1.601	1.627	1.668
2014Q2	1.586	1.603	1.599	1.561	1.682	1.621	1.620	1.630	1.631	1.669	1.714
2014Q3	1.623	1.641	1.640	1.598	1.723	1.660	1.659	1.670	1.671	1.675	1.739
2014Q4	1.681	1.693	1.694	1.653	1.781	1.716	1.715	1.726	1.726	1.767	1.801

Note: The hedonic methods are again as follows: RP1 = Repricing; RP2 = Repricing where the base period is updated every five years; AC = Average characteristics; Double imputation Laspeyres = DIL; Double imputation Paasche = DIP; Double imputation Törnqvist = DIT; RTD2Q = Rolling time dummy with a 2 quarter rolling window; RTD4Q and RTD5Q have 4 and 5 quarter rolling windows; MIX-PC = Mix adjusted stratified by postcode; MIX-RX = Mix adjusted stratified by Residex region.

Overall, the results in Tables 2 and 3 should be reassuring to Eurostat. They indicate that the HPIs of different countries should be broadly comparable even when computed using different hedonic methods. For those countries using stratified medians, it is important that the strata are sufficiently finely defined. Otherwise, like MIX-RX, the index will behave erratically.

## 4 Results for Tokyo (1986-2016)

### 4.1 The Tokyo data set

The Tokyo data set consists of 23 wards of the Tokyo metropolitan area (621 square kilometers), and the analysis period is approximately 30 years between January 1986 and June 2016. The data set covers previously-owned condominiums (apartments) published in Residential Information Weekly (or *Shukan Jyutaku Joho* in Japanese) published by RECRUIT, Co. This magazine provides information on the characteristics and asking prices of listed properties on a weekly basis. Moreover, *Shukan Jutaku Joho* provides time-series data on housing prices from the week they were first posted until the week they were removed as a result of successful transactions. We only use the price in the final week because this can be safely regarded as sufficiently close to the contract price.

The available housing characteristics are: floor area, age of building, travel time to nearest station, travel time to Tokyo central station, and the 23 wards (i.e., city codes). The hedonic model for Tokyo is estimated over 237 190 observations. A few observations were deleted since they were incomplete, or contained clear errors. The total number of deletions was less than 1 percent.

The functional form for our hedonic models is again semilog. The explanatory variables used are:

- log of floor area,
- age (included as a quadratic),
- time to nearest station,
- time to Tokyo central station (included as a quadratic),
- ward dummy.

The hedonic methods considered are the same as in section 4.2. The reason for including quadratics for *age* and *time to Tokyo central station* is that the impact of these variables on  $\log(\text{price})$  may be nonlinear and even possibly nonmonotonic. For example, there may be an optimal time to Tokyo central station (i.e., one may not want to live too near and not too far away either). This quadratic specification, however, can create problems with the repricing method, as is explained below.

## 4.2 Price indices for all apartments in Tokyo

The results for Tokyo for the years 1986 to 2016 for all apartments are shown in Table 6 and Figure 3. The general pattern that emerges is similar to that observed for Sydney, although there are some important differences.

Focusing first on the differences, two versions of the repricing method without rebasing – RP1 and RP1 (lin) – are presented in Table 6. RP1 (lin) is much closer to the other methods than RP1. RP1 and RP1 (lin) differ in that the former uses the functional form discussed above that includes *age* and *time to Tokyo central station* as quadratics. RP1 (lin) includes these variables as linear functions. The problem with RP1 is that while the quadratics by construction fit the data well in 1987 – the first full year of the data set – this specification does not perform so well when it is applied to data in other years. The squared term in the quadratics can distort the results for later years. The implication is that there is a trade off between model fit in the base period and overall performance of the HPI. When the repricing method is used, quadratic terms in the hedonic model should be avoided. It is better to stick with a simpler more linear model. This problem was not observed for the Sydney data set because these variables were not included in the hedonic model.

A second difference is that there is no clear evidence of drift in the DIL and DIP results in Table 6, as compared with what was observed for Sydney apartments.

Over the whole sample period, the rise in house prices for all hedonic methods, excluding repricing without updating, ranges between 8.5 and 13.8 percent. The average masks a rollercoaster ride where prices first went way up and then way down before gradually returning to near their starting point.

Turning now to the similarities between the results for Sydney and Tokyo, the drift

in the repricing results is again downward. although smaller for RP1 (lin) than RP1. According to RP1 (lin) prices rose by about 7 percent, as opposed to a 6 percent fall when RP1 is used.

It is noticeable that, as with Sydney apartments, RP2 (repricing where the base period is updated every five years) generates very similar results to the average characteristics (AC) method. Given the duality that exists between the repricing and average characteristics methods this result is not so surprising. However, such similarity in the RP2 and AC results was not observed for houses in Sydney in Table 2.

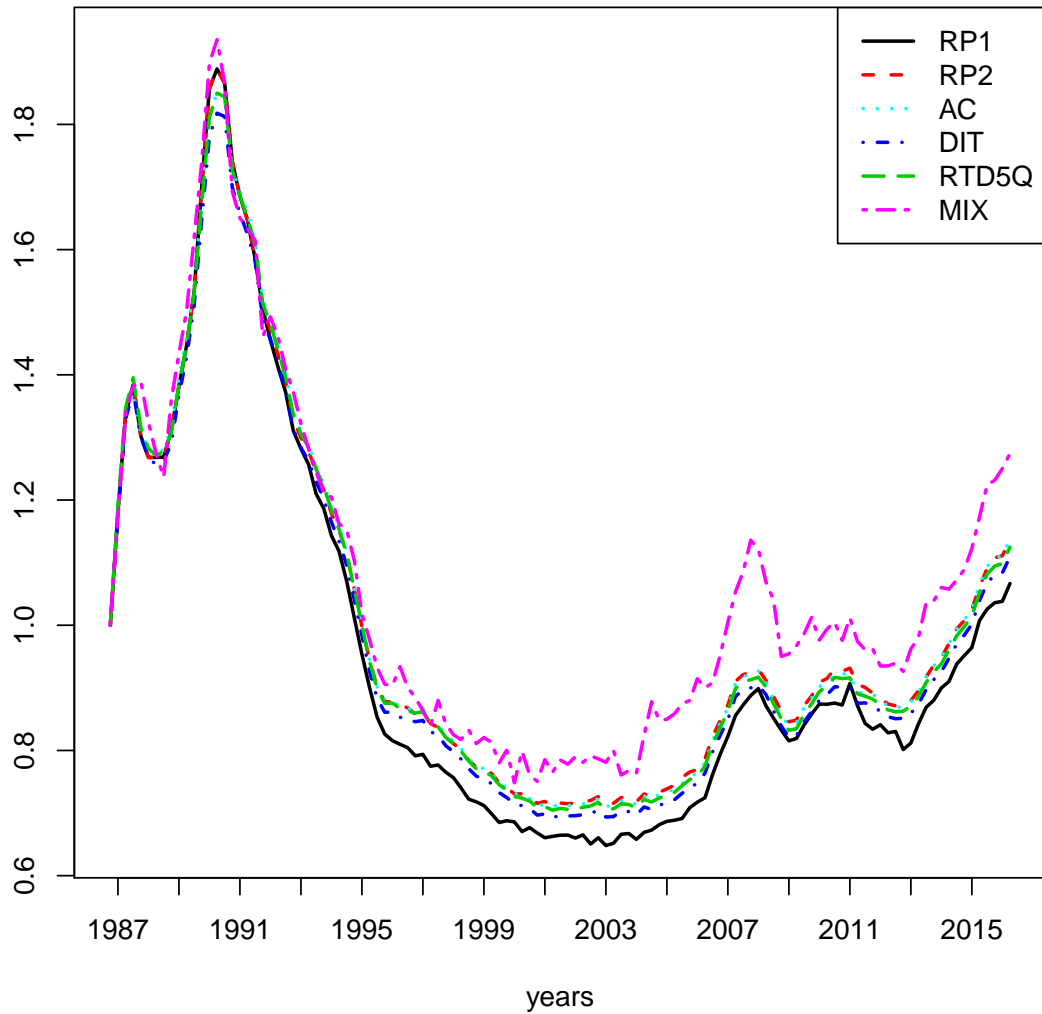
The stratified median index differs quite significantly from the hedonic indices. It rises by 27.4 percent, as compared with the hedonic range of 8.5 and 13.8 percent. It is worth noting that the stratified median indices in all three Figures rise faster than their hedonic counterparts. One possible explanation for this finding is that the average quality of dwellings sold has increased over time.

### 4.3 Price indices for new apartments in Tokyo

Estimating a price index for new apartments is difficult for the Tokyo data set due to the small sample size. We define a new build as any apartment that is less than three years old. We would have preferred less than two years old, but this is hardly feasible. The main problem here is to estimate shadow prices for the locational ward dummy variables. For some wards, no transactions on new dwellings are observed in some quarters. This is a problem particularly for the average characteristics and hedonic imputation methods that begin by estimating a separate hedonic model for each quarter as stated in (4). One way of dealing with missing wards is to restrict a comparison between adjacent quarters to the apartments sold in wards that are observed in both quarters. This means that two different hedonic models need to be estimated for each quarter  $q$ . The first includes the apartments sold in wards that are observed in both  $q - 1$  and  $q$ , while the second includes the apartments sold in wards observed in both  $q$  and  $q + 1$ . If the characteristics vectors  $z$  being priced include any wards not included in the estimated hedonic model, then these wards are dropped and the weights on the remaining wards are adjusted so that they still sum to one.

This problem is not as severe for the repricing method since it estimates the hedonic

Figure 3: Price Indices for Apartments in Tokyo (1986Q1=1)



Note: Note: RP1 = Repricing; RP2 = Repricing where the base period is updated every five years; AC = Average characteristics; DIT = Double imputation Törnqvist; RTD5Q = Rolling time dummy with five quarter window.



model based on a whole year's data, as stated in (1). Again, though, if a ward is not observed in the base year, then all apartments sold in that ward in future periods are excluded from the comparison. An alternative approach would be to substitute an adjacent ward for these apartments.

By contrast, the problem of missing wards does not arise for the RTD method. Any wards that are observed in any quarter can be included in the RTD hedonic model, as stated in (5). This example illustrates an important advantage of the RTD method, in that it performs well on smaller data sets.

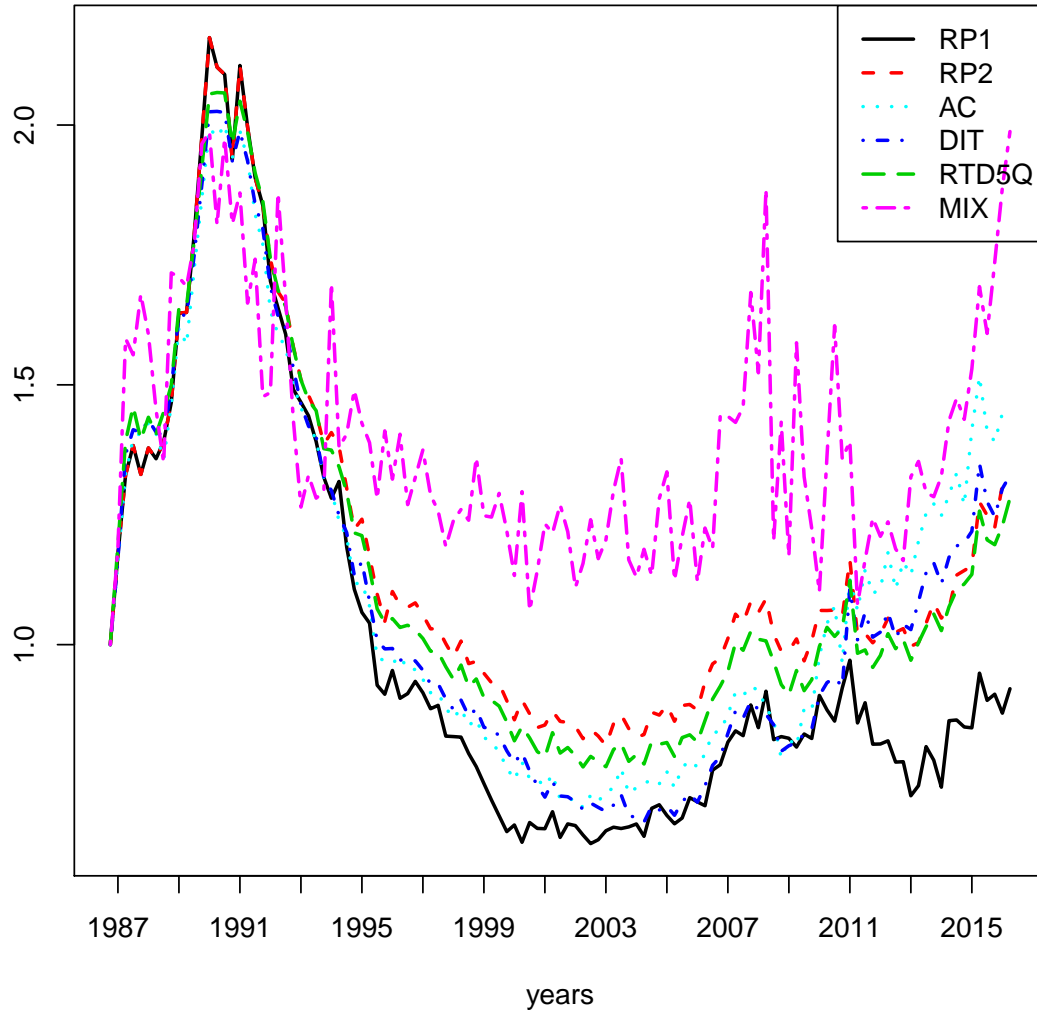
The new apartment price indices are shown in Figure 4. It can be seen that the index is much more sensitive to the choice of method than in Figures 1, 2, and 3. The stratified median index is particularly badly affected by the small sample size. Faced with a small sample problem, we have greatest confidence in the RTD method with a relatively long window (e.g., RTD5Q). Using RTD5Q as our benchmark, the downward drift in the repricing index (RP1) is much more pronounced than in the previous figures. Updating the reference shadow prices every five years (RP2) solves this problem. Indeed RP2 approximates RTD5Q quite closely. The average characteristics and hedonic imputation methods in this case are somewhat erratic. This is presumably because there are not enough data points to justify estimating a separate hedonic model each quarter.

The results for new builds in Tokyo have important implications for the HPI in smaller EU countries. In cases where there are less data, as Figure 4 clearly illustrates, the choice of method for constructing the HPI becomes much more important. The number of new built apartments in Tokyo each quarter may well be higher than the total number of house or apartment transactions in countries such as Slovenia, Malta and Cyprus.

Figure 4 also illustrates one of the problems with the acquisitions method for including owner-occupied housing (OOH) in the HICP. The acquisitions method as recommended by Eurostat requires, where possible, a price index specifically for new builds. It is much harder, however, to construct a reliable quality-adjusted HPI for new builds than it is to construct an index covering all housing transactions.

While a price index for new builds may be needed in Europe for the HICP (when

Figure 4: Price Indices for New Apartments in Tokyo (1986Q1=1)



Note: Note: RP1 = Repricing; RP2 = Repricing where the base period is updated every five years; AC = Average characteristics; DIT = Double imputation Törnqvist; RTD5Q = Rolling time dummy with five quarter window.

OOH is included using the acquisitions method), in the context of the HPI it does not make sense to compute separate HPIs for new builds and existing dwellings and then combine them. Rather, when available, age (or a dummy variable for new builds) should be included directly as a characteristic in a single hedonic model that encompasses both new and existing dwellings. Separate hedonic models, however, should be estimated for houses and apartments since the list of available characteristics for each may differ, and even when they do coincide, shadow prices that are representative for one may not be for the other. The methods outlined in chapter 9 of the CPI Manual can then be used to construct an overall HPI that combines both houses and apartments – see ILO/IMF/OECD/UNECE/Eurostat/The World Bank (2004).

## 5 Conclusion

Our main findings are as follows:

- The price indices seem to be quite robust over the range of hedonic methods used by NSIs in Europe to compute their HPIs.
- In smaller data sets (e.g., new builds in Tokyo) the HPI becomes more sensitive to the choice of method. Hence smaller countries in the EU need to be more careful when choosing a method. We recommend RTD5Q for smaller countries.
- The double imputation Paasche and Laspeyres (DIP and DIL) indices for apartments in Sydney are subject to drift. Evidence of a small amount of drift is also apparent in the Tokyo data. The results for Sydney apartments indicate that DIP and DIL should not be used. Fortunately, no NSIs are using either of these methods.
- The repricing method does not perform that badly (except for new apartments in Tokyo), even when the same reference shadow prices are used for many years. Nevertheless, in both our data sets it has a downward bias.
- With the repricing method, a hedonic model that performs well in the base period may not provide a good fit later periods. In the case of Tokyo, the quadratic terms

for *age* and *time to Tokyo central station* cause problems. In this sense there is a greater risk of problems with the repricing method. Hence we recommend keeping the functional form of the hedonic model quite simple (e.g., with no quadratic terms) when the repricing method is used.

- We recommend that NSIs using the repricing method update the reference shadow prices frequently (preferably every year, and at least every five years).
- Where possible stratified median indices should be avoided. In both our data sets, the stratified median indices are somewhat erratic and rise faster than the hedonic indices. This suggests that average quality of transacted dwellings rose over time in both data sets.
- It is more difficult to construct a quality-adjusted price index for new builds. Again, RTD5Q is recommended for computing an HPI for new dwellings when there is a shortage of data points.
- For the HPI we recommend not splitting new and existing dwellings. It is better to combine them in the same hedonic model, with age as one of the explanatory characteristics.
- Houses and apartments should be estimated using separate hedonic models, and then combined using the standard Eurostat method for combining strata (see Eurostat 2013, chapter X).
- Finally, it should be noted that computing an HPI for a large city is easier than for a whole country, particularly if that country is small. Hence our empirical comparisons may err on underestimating the sensitivity of an HPI to the choice of method used for constructing it.

Table 6: Price Indices for Apartments in Tokyo (1986Q4=1)

	RP1	RP1 (lin)	RP2	AC	DIL	DIP	DIT	RTD2Q	RTD4Q	RTD5Q	MIX
1986Q4	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
1987Q1	1.181	1.180	1.180	1.175	1.179	1.169	1.174	1.173	1.185	1.190	1.175
1987Q2	1.336	1.336	1.336	1.338	1.326	1.332	1.329	1.329	1.346	1.347	1.339
1987Q3	1.383	1.384	1.384	1.372	1.366	1.382	1.374	1.374	1.397	1.395	1.382
1987Q4	1.302	1.302	1.302	1.304	1.295	1.306	1.301	1.300	1.318	1.316	1.390
1988Q1	1.267	1.268	1.268	1.284	1.265	1.272	1.268	1.267	1.285	1.282	1.324
1988Q2	1.269	1.268	1.268	1.268	1.252	1.260	1.256	1.256	1.272	1.272	1.275
1988Q3	1.272	1.269	1.269	1.283	1.259	1.265	1.262	1.262	1.279	1.278	1.236
1988Q4	1.310	1.311	1.311	1.313	1.289	1.292	1.291	1.291	1.309	1.307	1.360
1989Q1	1.377	1.382	1.382	1.394	1.367	1.368	1.367	1.368	1.387	1.384	1.434
1989Q2	1.438	1.446	1.446	1.460	1.427	1.429	1.428	1.429	1.449	1.446	1.501
1989Q3	1.522	1.533	1.533	1.541	1.510	1.513	1.511	1.512	1.534	1.531	1.620
1989Q4	1.690	1.703	1.703	1.683	1.647	1.652	1.650	1.650	1.676	1.674	1.741
1990Q1	1.844	1.858	1.858	1.815	1.778	1.784	1.781	1.782	1.812	1.811	1.898
1990Q2	1.875	1.889	1.889	1.852	1.814	1.821	1.818	1.819	1.851	1.850	1.935
1990Q3	1.847	1.866	1.866	1.846	1.809	1.816	1.813	1.814	1.846	1.844	1.866
1990Q4	1.729	1.740	1.740	1.730	1.697	1.702	1.699	1.700	1.729	1.727	1.693
1991Q1	1.670	1.685	1.685	1.693	1.656	1.660	1.658	1.659	1.688	1.686	1.650
1991Q2	1.632	1.647	1.647	1.657	1.622	1.627	1.624	1.625	1.653	1.651	1.633
1991Q3	1.571	1.585	1.585	1.614	1.580	1.584	1.582	1.583	1.609	1.608	1.615
1991Q4	1.491	1.505	1.505	1.520	1.486	1.491	1.489	1.490	1.516	1.514	1.461
1992Q1	1.441	1.455	1.471	1.487	1.454	1.460	1.457	1.458	1.483	1.481	1.493
1992Q2	1.396	1.412	1.432	1.446	1.416	1.419	1.418	1.418	1.442	1.440	1.461
1992Q3	1.357	1.372	1.388	1.402	1.372	1.376	1.374	1.374	1.398	1.396	1.409
1992Q4	1.297	1.311	1.329	1.340	1.311	1.316	1.314	1.314	1.338	1.336	1.373
1993Q1	1.264	1.282	1.299	1.308	1.281	1.286	1.284	1.284	1.307	1.306	1.322
1993Q2	1.238	1.257	1.279	1.287	1.260	1.266	1.263	1.263	1.285	1.284	1.282
1993Q3	1.185	1.210	1.244	1.254	1.227	1.232	1.230	1.230	1.251	1.249	1.246
1993Q4	1.168	1.186	1.216	1.225	1.199	1.204	1.202	1.202	1.223	1.221	1.211
1994Q1	1.123	1.143	1.179	1.188	1.162	1.168	1.165	1.165	1.186	1.184	1.205
1994Q2	1.098	1.118	1.152	1.157	1.132	1.136	1.134	1.134	1.154	1.153	1.162
1994Q3	1.047	1.071	1.114	1.117	1.094	1.098	1.096	1.096	1.115	1.114	1.152
1994Q4	0.988	1.012	1.058	1.061	1.038	1.043	1.041	1.041	1.059	1.058	1.103
1995Q1	0.931	0.954	0.998	1.004	0.981	0.987	0.984	0.984	1.002	1.000	1.019
1995Q2	0.875	0.901	0.945	0.945	0.924	0.929	0.927	0.927	0.943	0.942	0.977
1995Q3	0.828	0.853	0.901	0.901	0.881	0.885	0.883	0.883	0.899	0.898	0.932
1995Q4	0.798	0.826	0.878	0.879	0.860	0.862	0.861	0.861	0.876	0.875	0.906
1996Q1	0.786	0.816	0.877	0.879	0.860	0.862	0.861	0.861	0.876	0.876	0.904
1996Q2	0.776	0.810	0.871	0.870	0.853	0.854	0.853	0.853	0.868	0.867	0.934
1996Q3	0.771	0.804	0.868	0.867	0.849	0.849	0.849	0.849	0.864	0.863	0.900
1996Q4	0.754	0.791	0.858	0.864	0.846	0.846	0.846	0.846	0.860	0.860	0.884
1997Q1	0.753	0.794	0.861	0.867	0.848	0.848	0.848	0.848	0.862	0.862	0.864
1997Q2	0.734	0.775	0.843	0.847	0.829	0.831	0.830	0.830	0.844	0.844	0.839
1997Q3	0.737	0.777	0.836	0.842	0.823	0.825	0.824	0.824	0.838	0.838	0.880
1997Q4	0.722	0.765	0.821	0.825	0.807	0.808	0.808	0.808	0.821	0.821	0.843
1998Q1	0.716	0.757	0.811	0.815	0.797	0.799	0.798	0.798	0.811	0.811	0.825
1998Q2	0.693	0.740	0.801	0.803	0.785	0.787	0.786	0.786	0.799	0.799	0.817
1998Q3	0.680	0.722	0.784	0.787	0.769	0.772	0.771	0.771	0.784	0.783	0.833
1998Q4	0.676	0.718	0.773	0.775	0.757	0.761	0.759	0.759	0.771	0.771	0.811
1999Q1	0.667	0.712	0.770	0.771	0.753	0.756	0.754	0.754	0.767	0.766	0.821
1999Q2	0.651	0.699	0.763	0.764	0.745	0.749	0.747	0.747	0.760	0.760	0.813
1999Q3	0.637	0.685	0.748	0.748	0.731	0.735	0.733	0.733	0.746	0.745	0.780
1999Q4	0.641	0.688	0.741	0.740	0.723	0.727	0.725	0.725	0.737	0.736	0.800
2000Q1	0.639	0.686	0.731	0.732	0.713	0.716	0.715	0.715	0.727	0.726	0.748
2000Q2	0.617	0.670	0.731	0.727	0.711	0.712	0.712	0.712	0.724	0.724	0.799
2000Q3	0.628	0.677	0.724	0.723	0.706	0.709	0.707	0.707	0.720	0.719	0.761
2000Q4	0.616	0.668	0.715	0.712	0.695	0.699	0.697	0.696	0.709	0.709	0.751
2001Q1	0.605	0.661	0.719	0.714	0.696	0.701	0.699	0.698	0.711	0.710	0.785
2001Q2	0.609	0.663	0.710	0.710	0.690	0.696	0.693	0.693	0.705	0.705	0.765
2001Q3	0.605	0.665	0.716	0.714	0.693	0.699	0.696	0.696	0.709	0.708	0.785

Table 6: Price Indices for Apartments in Tokyo (1986Q4=1) (continued)

	RP1	RP1 (lin)	RP2	AC	DIL	DIP	DIT	RTD2Q	RTD4Q	RTD5Q	MIX
2001Q4	0.607	0.665	0.715	0.712	0.692	0.698	0.695	0.695	0.707	0.706	0.778
2002Q1	0.599	0.660	0.716	0.713	0.693	0.699	0.696	0.696	0.709	0.708	0.790
2002Q2	0.603	0.665	0.718	0.715	0.694	0.700	0.697	0.697	0.710	0.709	0.781
2002Q3	0.588	0.651	0.720	0.718	0.696	0.703	0.699	0.699	0.713	0.712	0.791
2002Q4	0.594	0.661	0.726	0.723	0.701	0.708	0.705	0.704	0.718	0.717	0.787
2003Q1	0.583	0.648	0.715	0.711	0.689	0.698	0.694	0.693	0.706	0.706	0.781
2003Q2	0.591	0.652	0.716	0.712	0.689	0.700	0.694	0.694	0.708	0.707	0.800
2003Q3	0.594	0.666	0.725	0.719	0.697	0.709	0.703	0.703	0.716	0.715	0.761
2003Q4	0.600	0.667	0.723	0.720	0.698	0.707	0.702	0.702	0.715	0.714	0.768
2004Q1	0.587	0.658	0.718	0.713	0.693	0.701	0.697	0.697	0.709	0.708	0.763
2004Q2	0.608	0.669	0.730	0.727	0.706	0.714	0.710	0.710	0.723	0.722	0.824
2004Q3	0.608	0.673	0.728	0.722	0.701	0.711	0.706	0.706	0.719	0.718	0.878
2004Q4	0.617	0.681	0.734	0.729	0.707	0.717	0.712	0.712	0.725	0.724	0.848
2005Q1	0.622	0.687	0.738	0.734	0.712	0.721	0.717	0.717	0.729	0.728	0.850
2005Q2	0.624	0.689	0.744	0.737	0.717	0.726	0.721	0.721	0.734	0.733	0.859
2005Q3	0.623	0.691	0.757	0.747	0.726	0.737	0.732	0.731	0.745	0.744	0.874
2005Q4	0.638	0.709	0.766	0.757	0.734	0.748	0.741	0.741	0.754	0.753	0.880
2006Q1	0.646	0.717	0.769	0.764	0.741	0.754	0.747	0.747	0.760	0.759	0.915
2006Q2	0.645	0.724	0.787	0.780	0.757	0.771	0.764	0.764	0.776	0.775	0.900
2006Q3	0.683	0.762	0.822	0.816	0.791	0.805	0.798	0.798	0.811	0.810	0.908
2006Q4	0.708	0.794	0.848	0.844	0.818	0.831	0.825	0.824	0.838	0.837	0.952
2007Q1	0.744	0.823	0.873	0.868	0.842	0.857	0.850	0.849	0.864	0.862	1.005
2007Q2	0.776	0.856	0.910	0.908	0.878	0.895	0.887	0.886	0.901	0.899	1.053
2007Q3	0.791	0.873	0.921	0.918	0.887	0.906	0.897	0.896	0.911	0.910	1.085
2007Q4	0.810	0.888	0.925	0.922	0.891	0.909	0.900	0.899	0.914	0.913	1.136
2008Q1	0.826	0.899	0.929	0.927	0.895	0.913	0.904	0.903	0.918	0.917	1.121
2008Q2	0.797	0.871	0.912	0.910	0.881	0.898	0.889	0.889	0.903	0.901	1.069
2008Q3	0.765	0.851	0.886	0.880	0.852	0.874	0.863	0.862	0.875	0.874	1.040
2008Q4	0.749	0.832	0.863	0.856	0.827	0.852	0.839	0.839	0.852	0.851	0.950
2009Q1	0.734	0.815	0.846	0.840	0.806	0.837	0.821	0.821	0.833	0.832	0.954
2009Q2	0.738	0.819	0.849	0.845	0.808	0.840	0.824	0.824	0.835	0.835	0.967
2009Q3	0.754	0.841	0.872	0.869	0.830	0.862	0.846	0.846	0.858	0.858	0.986
2009Q4	0.778	0.858	0.887	0.884	0.847	0.878	0.862	0.862	0.875	0.875	1.013
2010Q1	0.782	0.874	0.909	0.902	0.865	0.896	0.880	0.881	0.894	0.894	0.976
2010Q2	0.778	0.874	0.915	0.909	0.874	0.904	0.889	0.889	0.903	0.903	0.994
2010Q3	0.767	0.876	0.930	0.922	0.885	0.919	0.902	0.902	0.917	0.917	1.005
2010Q4	0.774	0.873	0.927	0.923	0.883	0.918	0.901	0.901	0.915	0.915	0.976
2011Q1	0.809	0.907	0.931	0.921	0.884	0.918	0.901	0.902	0.916	0.916	1.012
2011Q2	0.771	0.871	0.906	0.892	0.856	0.895	0.875	0.878	0.891	0.890	0.974
2011Q3	0.732	0.843	0.901	0.893	0.853	0.899	0.876	0.876	0.888	0.887	0.961
2011Q4	0.733	0.834	0.891	0.890	0.850	0.894	0.871	0.871	0.883	0.882	0.962
2012Q1	0.739	0.841	0.882	0.881	0.842	0.883	0.862	0.862	0.874	0.873	0.935
2012Q2	0.720	0.828	0.874	0.871	0.834	0.874	0.854	0.854	0.865	0.865	0.935
2012Q3	0.723	0.830	0.871	0.868	0.830	0.872	0.851	0.850	0.862	0.862	0.939
2012Q4	0.693	0.801	0.872	0.870	0.831	0.873	0.851	0.851	0.863	0.863	0.926
2013Q1	0.708	0.812	0.880	0.878	0.838	0.880	0.859	0.859	0.871	0.871	0.962
2013Q2	0.735	0.843	0.895	0.893	0.852	0.897	0.874	0.874	0.887	0.886	0.981
2013Q3	0.758	0.869	0.917	0.918	0.875	0.920	0.897	0.897	0.910	0.909	1.035
2013Q4	0.777	0.880	0.936	0.935	0.892	0.935	0.913	0.913	0.927	0.926	1.039
2014Q1	0.791	0.900	0.948	0.949	0.905	0.948	0.926	0.926	0.940	0.938	1.060
2014Q2	0.795	0.910	0.971	0.970	0.926	0.969	0.947	0.947	0.961	0.960	1.058
2014Q3	0.815	0.938	0.994	0.993	0.949	0.991	0.970	0.970	0.984	0.983	1.072
2014Q4	0.840	0.951	1.007	1.008	0.962	1.007	0.984	0.984	0.999	0.998	1.089

Table 6: Price Indices for Apartments in Tokyo (1986Q4=1) (continued)

	RP1	RP1 (lin)	RP2	AC	DIL	DIP	DIT	RTD2Q	RTD4Q	RTD5Q	MIX
2015Q1	0.850	0.964	1.026	1.027	0.980	1.024	1.002	1.002	1.016	1.014	1.122
2015Q2	0.895	1.007	1.061	1.065	1.017	1.062	1.039	1.039	1.054	1.053	1.173
2015Q3	0.908	1.026	1.091	1.094	1.044	1.092	1.068	1.068	1.083	1.082	1.224
2015Q4	0.918	1.036	1.108	1.107	1.057	1.104	1.080	1.081	1.096	1.094	1.232
2016Q1	0.924	1.038	1.111	1.111	1.060	1.108	1.084	1.084	1.100	1.099	1.250
2016Q2	0.947	1.067	1.136	1.138	1.085	1.134	1.109	1.110	1.125	1.125	1.274

Note: The hedonic methods are again as follows: RP1 = Repricing; RP1 (lin) = Repricing using a simplified functional form where the quadratics in age and time to Tokyo central station are replaced with linear functions; RP2 = Repricing where the base period is updated every five years; AC = Average characteristics; Double imputation Laspeyres = DIL; Double imputation Paasche = DIP; Double imputation Törnqvist = DIT; RTD2Q = Rolling time dummy with a 2 quarter rolling window; RTD4Q and RTD5Q have 4 and 5 quarter rolling windows; MIX = Mix adjusted stratified by ward.

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## Appendix A: Methods used in EU Countries to calculate the HPI or OOHl

EUROSTAT provides information on the methodologies used by EU countries to compute their official House Price Indices (HPIs) at [http://ec.europa.eu/eurostat/cache/metadata/en/prc\\_hoi\\_inx\\_esms.htm](http://ec.europa.eu/eurostat/cache/metadata/en/prc_hoi_inx_esms.htm). For information on how EU countries construct their OOHIs (Owner Occupied Housing Indices for inclusion in the HICP) EUROSTAT provides the following link: <http://ec.europa.eu/eurostat/web/hicp/methodology/metadata-and-national-practices>. In addition to these EUROSTAT links, the following information can be found on the EUROSTAT or individual NSI websites.

Country	Method for HPI	Information on method
Austria	Repricing	From EUROSTAT webpage: <a href="http://ec.europa.eu/eurostat/cache/metadata/EN/prc_hoi_inx_esms_at.htm#comment_dset1488192033587">http://ec.europa.eu/eurostat/cache/metadata/EN/prc_hoi_inx_esms_at.htm#comment_dset1488192033587</a>
Belgium	Repricing	From EUROSTAT webpage: <a href="http://ec.europa.eu/eurostat/cache/metadata/EN/prc_hoi_inx_esms_be.htm">http://ec.europa.eu/eurostat/cache/metadata/EN/prc_hoi_inx_esms_be.htm</a>
Bulgaria	Stratified median	From EUROSTAT webpage: <a href="http://ec.europa.eu/eurostat/cache/metadata/EN/prc_hoi_inx_esms_bg.htm#stat_pres1488192082348">http://ec.europa.eu/eurostat/cache/metadata/EN/prc_hoi_inx_esms_bg.htm#stat_pres1488192082348</a> Bulgarian NSI: <a href="http://www.nsi.bg/en/content/14379/%D0%BC%D0%B5%D1%82%D0%80%D0%B4%D0%BD%D0%BD%D0%B8/house-price-index-hpi">http://www.nsi.bg/en/content/14379/%D0%BC%D0%B5%D1%82%D0%80%D0%B4%D0%BD%D0%BD%D0%B8/house-price-index-hpi</a>
Croatia	RTD	From EUROSTAT webpage: <a href="http://ec.europa.eu/eurostat/cache/metadata/EN/prc_hoi_inx_esms_hr.htm#contact1488192095079">http://ec.europa.eu/eurostat/cache/metadata/EN/prc_hoi_inx_esms_hr.htm#contact1488192095079</a>
Cyprus	RTD	From EUROSTAT webpage: <a href="http://ec.europa.eu/eurostat/cache/metadata/EN/prc_hoi_inx_esms_cy.htm#accessibility_clarity1470212625558">http://ec.europa.eu/eurostat/cache/metadata/EN/prc_hoi_inx_esms_cy.htm#accessibility_clarity1470212625558</a> Cystat.gov.cy also provides data based on OOH pilot study (complemented with estimates). Link to Construction and Housing Statistics publications (for quarterly output prices index in construction – primarily used for self builders – and methodology).
Czech Republic	Stratified median	From EUROSTAT webpage: <a href="http://ec.europa.eu/eurostat/cache/metadata/EN/prc_hoi_inx_esms_cz.htm#stat_pres1488192085615">http://ec.europa.eu/eurostat/cache/metadata/EN/prc_hoi_inx_esms_cz.htm#stat_pres1488192085615</a> There are some statistics in English (including description and methodology) available through these links: [1] and [2].
Denmark	SPAR	From EUROSTAT webpage: <a href="http://ec.europa.eu/eurostat/cache/metadata/EN/prc_hoi_inx_esms_dk.htm#accessibility_clarity1470212636238">http://ec.europa.eu/eurostat/cache/metadata/EN/prc_hoi_inx_esms_dk.htm#accessibility_clarity1470212636238</a> Also, follow this link to the documentation of Statistics Denmark 'sales of real property' statistics
Estonia	Stratified median	From EUROSTAT webpage: <a href="http://ec.europa.eu/eurostat/cache/metadata/en/prc_hicp_esms_ee.htm#meta_update1470212521107">http://ec.europa.eu/eurostat/cache/metadata/en/prc_hicp_esms_ee.htm#meta_update1470212521107</a> More information via the Estonian NSI webpage: <a href="http://pub.stat.ee/px-web.2001/..Databases/Economy/24Prices/XO_027.htm">http://pub.stat.ee/px-web.2001/..Databases/Economy/24Prices/XO_027.htm</a> and <a href="http://ec.europa.eu/eurostat/cache/metadata/EN/prc_hoi_inx_esms_fi.htm#stat_pres1488192063623">http://ec.europa.eu/eurostat/cache/metadata/EN/prc_hoi_inx_esms_fi.htm#stat_pres1488192063623</a> ;
Finland	Repricing	From EUROSTAT webpage: <a href="http://ec.europa.eu/eurostat/cache/metadata/EN/prc_hoi_inx_esms_fi.htm">http://ec.europa.eu/eurostat/cache/metadata/EN/prc_hoi_inx_esms_fi.htm</a> The Finnish method is based on the doctoral thesis by Eugen Koev (2003): <a href="http://www.ottawagroup.org/Ottawa/Ottawagroup.nsf/4a256353001af3aed42562bb00121564/3f17c6b9377ce63eca25727a00088293/\$FILE/2004%208th%20Meeting%20-%20Koev%20Eugen%20-%20Combining%20Classification%20and%20Hedonic%20Quality%20Adjustment%20in%20Constructing%20a%20House%20Price%20Index.pdf">http://www.ottawagroup.org/Ottawa/Ottawagroup.nsf/4a256353001af3aed42562bb00121564/3f17c6b9377ce63eca25727a00088293/\$FILE/2004%208th%20Meeting%20-%20Koev%20Eugen%20-%20Combining%20Classification%20and%20Hedonic%20Quality%20Adjustment%20in%20Constructing%20a%20House%20Price%20Index.pdf</a>
France	RTD	From EUROSTAT webpage: <a href="http://ec.europa.eu/eurostat/cache/metadata/EN/prc_hoi_inx_esms_fr.htm">http://ec.europa.eu/eurostat/cache/metadata/EN/prc_hoi_inx_esms_fr.htm</a> INSEE provides more information on their website. In particular, explanations on their HPI method can be found via: <a href="https://www.insee.fr/fr/statistiques/2829290#documentation">https://www.insee.fr/fr/statistiques/2829290#documentation</a> (in French) and <a href="http://www.insee.fr/en/ppp/sommaire/jmet128-ex">http://www.insee.fr/en/ppp/sommaire/jmet128-ex</a>

		<a href="#">calculation-procedures-applied.pdf</a> (English summary)
<b>Germany</b>	Hedonic Imputation	From EUROSTAT webpage: <a href="http://ec.europa.eu/eurostat/cache/metadata/EN/prc_hpi_inx_esms_de.htm#stat_process1488192007811">http://ec.europa.eu/eurostat/cache/metadata/EN/prc_hpi_inx_esms_de.htm#stat_process1488192007811</a> Also, tables on house price indices are available in the GENESIS-Online data base under 'statistics by theme' at code number 61262.
<b>Hungary</b>	At the moment Repricing, but planning to switch to RTD	From EUROSTAT webpage: <a href="http://ec.europa.eu/eurostat/cache/metadata/EN/prc_hpi_inx_esms_hu.htm">http://ec.europa.eu/eurostat/cache/metadata/EN/prc_hpi_inx_esms_hu.htm</a> From Statistics Hungary webpage: <a href="http://www.ksh.hu/apps/meta.objektum?lang=EN&amp;p_menu_id=120&amp;p_almenu_id=104&amp;p_ot_id=100&amp;p_obj_id=OSLA&amp;p_session_id=42138786">http://www.ksh.hu/apps/meta.objektum?lang=EN&amp;p_menu_id=120&amp;p_almenu_id=104&amp;p_ot_id=100&amp;p_obj_id=OSLA&amp;p_session_id=42138786</a>
<b>Iceland</b>	Stratification method	From Eurostat webpage: <a href="http://ec.europa.eu/eurostat/cache/metadata/EN/prc_hpi_inx_esms_is.htm#stat_process1488192036854">http://ec.europa.eu/eurostat/cache/metadata/EN/prc_hpi_inx_esms_is.htm#stat_process1488192036854</a>
<b>Ireland</b>	RTD	From EUROSTAT webpage: <a href="http://ec.europa.eu/eurostat/cache/metadata/EN/prc_hpi_inx_esms_ie.htm#comment_desc1488192017208">http://ec.europa.eu/eurostat/cache/metadata/EN/prc_hpi_inx_esms_ie.htm#comment_desc1488192017208</a> The Irish method is also explained in: O'Hanlon, N. (2011). Constructing a national house price index for Ireland. Statistical and Social Inquiry Society of Ireland, 40, 167-196 ( <a href="http://www.tara.tcd.ie/xmlui/bitstream/handle/2262/62349/o'hanlon%20.pdf">http://www.tara.tcd.ie/xmlui/bitstream/handle/2262/62349/o'hanlon%20.pdf</a> ; pdfjsessionid=9154965E69A20A0C9587D7985D4FE6DE?sequence=1)
<b>Italy</b>	Repricing	From EUROSTAT webpage: <a href="http://ec.europa.eu/eurostat/cache/metadata/EN/prc_hpi_inx_esms_it.htm">http://ec.europa.eu/eurostat/cache/metadata/EN/prc_hpi_inx_esms_it.htm</a> ISTAT website description: <a href="http://www.istat.it/en/files/2015/07/Methodological-note2015.pdf?title=House+prices+-+2+in+2015+-+Note+methodological.pdf">http://www.istat.it/en/files/2015/07/Methodological-note2015.pdf?title=House+prices+-+2+in+2015+-+Note+methodological.pdf</a>
<b>Latvia</b>	Repricing	From EUROSTAT webpage: <a href="http://ec.europa.eu/eurostat/cache/metadata/EN/prc_hpi_inx_esms_lv.htm#stat_process1488192088860">http://ec.europa.eu/eurostat/cache/metadata/EN/prc_hpi_inx_esms_lv.htm#stat_process1488192088860</a> Additional information can be found via: <a href="http://www.csb.gov.lv/en/statistikas-temas/metodologia/house-price-index-36211.html">http://www.csb.gov.lv/en/statistikas-temas/metodologia/house-price-index-36211.html</a>
<b>Lithuania</b>	Stratified median	From EUROSTAT webpage: <a href="http://ec.europa.eu/eurostat/cache/metadata/EN/prc_hpi_inx_esms_lt.htm#stat_process1488192091950">http://ec.europa.eu/eurostat/cache/metadata/EN/prc_hpi_inx_esms_lt.htm#stat_process1488192091950</a> method description (in Lithuanian) via: <a href="http://osp.stat.gov.lt/documents/10180/586325/HPI_methodology_2013.pdf/76adae82-f64f-4aad-a051-313776180103">http://osp.stat.gov.lt/documents/10180/586325/HPI_methodology_2013.pdf/76adae82-f64f-4aad-a051-313776180103</a>
<b>Luxembourg</b>	Repricing	from EUROSTAT webpage : <a href="http://ec.europa.eu/eurostat/cache/metadata/EN/prc_hpi_inx_esms_lu.htm">http://ec.europa.eu/eurostat/cache/metadata/EN/prc_hpi_inx_esms_lu.htm</a> More information on the Luxembourg HPI method (in French): <a href="http://www.statistiques.public.lu/catalogue-publications/economie-statistiques/2010/44-2010.pdf">http://www.statistiques.public.lu/catalogue-publications/economie-statistiques/2010/44-2010.pdf</a>
<b>Malta</b>	Planning to use RTD	Eurostat weblink: <a href="http://ec.europa.eu/eurostat/cache/metadata/EN/prc_hpi_inx_esms_mt.htm#stat_process1488192020655">http://ec.europa.eu/eurostat/cache/metadata/EN/prc_hpi_inx_esms_mt.htm#stat_process1488192020655</a>
<b>Netherlands</b>	SPAR	From EUROSTAT webpage: <a href="http://ec.europa.eu/eurostat/cache/metadata/EN/prc_hpi_inx_esms_nl.htm#accessibility_clarity1477561095670">http://ec.europa.eu/eurostat/cache/metadata/EN/prc_hpi_inx_esms_nl.htm#accessibility_clarity1477561095670</a> Additional information by Statistics Netherlands can be found via: <a href="http://statline.cbs.nl/StatWeb/publication/?DM=SL&amp;PA=71533&amp;ENG">http://statline.cbs.nl/StatWeb/publication/?DM=SL&amp;PA=71533&amp;ENG</a>
<b>Norway</b>	Repricing	From EUROSTAT webpage: <a href="http://ec.europa.eu/eurostat/cache/metadata/EN/prc_hpi_inx_esms_no.htm">http://ec.europa.eu/eurostat/cache/metadata/EN/prc_hpi_inx_esms_no.htm</a> A description of the method (in Norwegian) is available via: <a href="http://www.ssb.no/a/publikasjoner/pdf/notat_201210/notat_201210.pdf">http://www.ssb.no/a/publikasjoner/pdf/notat_201210/notat_201210.pdf</a> (for formula see page 28)
<b>Poland</b>	Stratified median	From EUROSTAT webpage: <a href="http://ec.europa.eu/eurostat/cache/metadata/EN/prc_hpi_inx_esms_pl.htm#contact1488192047334">http://ec.europa.eu/eurostat/cache/metadata/EN/prc_hpi_inx_esms_pl.htm#contact1488192047334</a>
<b>Portugal</b>	RTD	From EUROSTAT webpage: <a href="http://ec.europa.eu/eurostat/cache/metadata/EN/prc_hpi_inx_esms_pt.htm#stat_process1488192060402">http://ec.europa.eu/eurostat/cache/metadata/EN/prc_hpi_inx_esms_pt.htm#stat_process1488192060402</a> The compilation methodology of the HPI is available on the website of Statistics Portugal: <a href="http://www.ine.pt">www.ine.pt</a> (in Portuguese only). The Portuguese HPI method is based on the following paper: R. Evangelista and A. Teixeira, "Using Different Administrative Data Sources to Develop House Price Indexes for Portugal", March 2014
<b>Romania</b>	Average characteristics	Description of method in: <a href="http://www.insse.ro/cms/files/arhiva_buletine2015/bsp_12.pdf">http://www.insse.ro/cms/files/arhiva_buletine2015/bsp_12.pdf</a>
<b>Slovakia</b>	Stratified median	From EUROSTAT webpage

		<a href="http://ec.europa.eu/eurostat/cache/metadata/EN/prc_hpi_inx_esms_sk.htm#stat_process148819203045">http://ec.europa.eu/eurostat/cache/metadata/EN/prc_hpi_inx_esms_sk.htm#stat_process148819203045</a>
<b>Slovenia</b>	Repricing	From EUROSTAT webpage: <a href="http://ec.europa.eu/eurostat/cache/metadata/EN/prc_hpi_inx_esms_si.htm#stat_process1488192067083">http://ec.europa.eu/eurostat/cache/metadata/EN/prc_hpi_inx_esms_si.htm#stat_process1488192067083</a> A description of the methodology that is used for the compilation of the HPI is available via: <a href="http://www.stat.si/StatWeb/Common/Priказidokument.aspx?iddatoteke=8346">http://www.stat.si/StatWeb/Common/Priказidokument.aspx?iddatoteke=8346</a>
<b>Spain</b>	Average characteristics	From EUROSTAT webpage: <a href="http://ec.europa.eu/eurostat/cache/metadata/EN/prc_hpi_inx_esms_es.htm">http://ec.europa.eu/eurostat/cache/metadata/EN/prc_hpi_inx_esms_es.htm</a> A description of the Spanish HPI method can also be found via: <a href="http://www.ine.es/buscar/searchResults.do?searchType=DEF_SEARCH&amp;tipodocumento=&amp;searchString=hpi+method&amp;SearchButton=Search">http://www.ine.es/buscar/searchResults.do?searchType=DEF_SEARCH&amp;tipodocumento=&amp;searchString=hpi+method&amp;SearchButton=Search</a> (in Spanish) and <a href="http://www.ine.es/daco/daco42/jqv/metodologia.pdf">http://www.ine.es/daco/daco42/jqv/metodologia.pdf</a> (in Spanish)
<b>Sweden</b>	SPAR	From Eurostat webpage: <a href="http://ec.europa.eu/eurostat/cache/metadata/EN/prc_hpi_inx_esms_se.htm#stat_process1488192050466">http://ec.europa.eu/eurostat/cache/metadata/EN/prc_hpi_inx_esms_se.htm#stat_process1488192050466</a> Information on the "Swedish Real Estate Price Index", a closely related index to HPI, can be found via: <a href="http://www.scb.se/en/finding-statistics/search/?query=real+estate+price+index">http://www.scb.se/en/finding-statistics/search/?query=real+estate+price+index</a>
<b>UK</b>	Hedonic imputation	From EUROSTAT webpage: <a href="http://ec.europa.eu/eurostat/cache/metadata/EN/prc_hpi_inx_esms_uk.htm">http://ec.europa.eu/eurostat/cache/metadata/EN/prc_hpi_inx_esms_uk.htm</a> The summary definition of the model and index formula can be found in Annex A to F of the following link: <a href="http://www.ons.gov.uk/ons/guide-method/user-guidance/prices/hpi/official-house-price-statistics-explained.pdf">http://www.ons.gov.uk/ons/guide-method/user-guidance/prices/hpi/official-house-price-statistics-explained.pdf</a> Further description of model also available via: <a href="http://www.ons.gov.uk/ons/guide-method/user-guidance/prices/hpi/hedonic-model.pdf">http://www.ons.gov.uk/ons/guide-method/user-guidance/prices/hpi/hedonic-model.pdf</a>

## Appendix B - Sydney - Estimated shadow prices - 2003

Residuals:

	Min	1Q	Median	3Q	Max
	-2.207	-0.11789	-0.00379	0.10745	2.47241

Coefficients:

	Estimate	Std. Error	t	value	Pr(> t )
(Intercept)	1.30E+01	5.06E-02	257.57 <	2.00E-16	***
as.factor(BED)2	1.06E-01	2.35E-02	4.511	6.47E-06	***
as.factor(BED)3	2.21E-01	2.33E-02	9.516 <	2.00E-16	***
as.factor(BED)4	3.28E-01	2.35E-02	13.984 <	2.00E-16	***
as.factor(BED)5	3.68E-01	2.41E-02	15.277 <	2.00E-16	***
as.factor(BED)6	3.94E-01	2.72E-02	14.492 <	2.00E-16	***
as.factor(BATH)2	9.12E-02	3.70E-03	24.607 <	2.00E-16	***
as.factor(BATH)3	2.31E-01	5.76E-03	40.094 <	2.00E-16	***
as.factor(BATH)4	3.78E-01	1.21E-02	31.359 <	2.00E-16	***
as.factor(BATH)5	6.51E-01	2.53E-02	25.76 <	2.00E-16	***
as.factor(BATH)6	6.06E-01	5.73E-02	10.566 <	2.00E-16	***
AREA	3.14E-04	5.58E-06	56.18 <	2.00E-16	***
as.factor(POSTCODE)4	2.43E-01	5.57E-02	4.354	1.34E-05	***
as.factor(POSTCODE)6	6.67E-02	5.45E-02	1.225	0.22075	
as.factor(POSTCODE)7	5.55E-02	5.55E-02	0.999	0.317817	
as.factor(POSTCODE)9	3.79E-02	5.69E-02	0.666	0.505487	
as.factor(POSTCODE)10	-5.30E-02	5.64E-02	-0.939	0.347653	
as.factor(POSTCODE)11	-8.86E-02	5.41E-02	-1.635	0.101959	
as.factor(POSTCODE)12	6.64E-01	4.86E-02	13.684 <	2.00E-16	***
as.factor(POSTCODE)13	4.61E-01	4.99E-02	9.247 <	2.00E-16	***
as.factor(POSTCODE)14	8.84E-01	5.37E-02	16.481 <	2.00E-16	***
as.factor(POSTCODE)15	6.20E-01	5.14E-02	12.066 <	2.00E-16	***
as.factor(POSTCODE)16	8.42E-01	5.12E-02	16.435 <	2.00E-16	***
as.factor(POSTCODE)17	5.20E-01	4.92E-02	10.573 <	2.00E-16	***
as.factor(POSTCODE)19	1.04E+00	6.50E-02	15.953 <	2.00E-16	***
as.factor(POSTCODE)20	8.05E-01	5.64E-02	14.258 <	2.00E-16	***
as.factor(POSTCODE)21	8.89E-01	5.00E-02	17.781 <	2.00E-16	***
as.factor(POSTCODE)22	5.17E-01	4.82E-02	10.736 <	2.00E-16	***
as.factor(POSTCODE)23	2.84E-01	5.35E-02	5.32	1.05E-07	***
as.factor(POSTCODE)24	3.82E-01	5.46E-02	6.994	2.74E-12	***
as.factor(POSTCODE)25	6.01E-01	5.13E-02	11.724 <	2.00E-16	***
as.factor(POSTCODE)26	2.87E-01	4.81E-02	5.975	2.33E-09	***
as.factor(POSTCODE)27	1.20E-01	5.00E-02	2.397	0.016529	*
as.factor(POSTCODE)28	2.07E-01	5.09E-02	4.06	4.92E-05	***
as.factor(POSTCODE)29	1.75E-01	4.91E-02	3.572	0.000354	***
as.factor(POSTCODE)30	1.59E-01	5.12E-02	3.114	0.001846	**
as.factor(POSTCODE)31	8.26E-02	4.70E-02	1.758	0.078739	.
as.factor(POSTCODE)32	4.05E-01	4.82E-02	8.403 <	2.00E-16	***
as.factor(POSTCODE)33	2.91E-02	4.81E-02	0.605	0.545361	
as.factor(POSTCODE)34	3.08E-02	5.52E-02	0.559	0.576446	
as.factor(POSTCODE)35	-2.19E-01	5.06E-02	-4.334	1.47E-05	***
as.factor(POSTCODE)36	1.62E-01	6.37E-02	2.536	0.011211	*

as.factor(POSTCODE)37	2.53E-01	4.84E-02	5.22	1.80E-07	***
as.factor(POSTCODE)38	3.27E-01	5.09E-02	6.433	1.27E-10	***
as.factor(POSTCODE)39	6.89E-02	5.09E-02	1.352	0.176471	
as.factor(POSTCODE)40	1.15E-02	5.02E-02	0.228	0.819314	
as.factor(POSTCODE)42	5.45E-01	5.53E-02	9.847 <	2.00E-16	***
as.factor(POSTCODE)44	4.24E-01	5.77E-02	7.351	2.03E-13	***
as.factor(POSTCODE)45	5.59E-01	5.25E-02	10.65 <	2.00E-16	***
as.factor(POSTCODE)46	3.09E-01	6.37E-02	4.847	1.26E-06	***
as.factor(POSTCODE)47	3.26E-01	4.83E-02	6.745	1.56E-11	***
as.factor(POSTCODE)48	2.63E-01	4.77E-02	5.518	3.46E-08	***
as.factor(POSTCODE)49	1.18E-01	4.97E-02	2.365	0.018016	*
as.factor(POSTCODE)50	2.86E-01	4.82E-02	5.937	2.93E-09	***
as.factor(POSTCODE)51	2.38E-01	4.92E-02	4.846	1.27E-06	***
as.factor(POSTCODE)52	1.23E-01	4.97E-02	2.472	0.013428	*
as.factor(POSTCODE)53	1.60E-01	5.00E-02	3.193	0.001412	**
as.factor(POSTCODE)54	1.03E-01	5.51E-02	1.873	0.061058	.
as.factor(POSTCODE)55	-1.91E-02	4.84E-02	-0.394	0.693711	
as.factor(POSTCODE)56	-1.11E-01	4.76E-02	-2.336	0.019483	*
as.factor(POSTCODE)57	-1.52E-01	4.75E-02	-3.196	0.001397	**
as.factor(POSTCODE)58	-1.76E-01	4.76E-02	-3.699	0.000217	***
as.factor(POSTCODE)59	-4.16E-01	4.84E-02	-8.596 <	2.00E-16	***
as.factor(POSTCODE)60	-4.65E-01	5.31E-02	-8.749 <	2.00E-16	***
as.factor(POSTCODE)62	-5.27E-01	5.98E-02	-8.82 <	2.00E-16	***
as.factor(POSTCODE)63	-5.26E-01	6.06E-02	-8.673 <	2.00E-16	***
as.factor(POSTCODE)65	-2.01E-01	6.44E-02	-3.116	0.001838	**
as.factor(POSTCODE)66	-1.73E-01	5.02E-02	-3.458	0.000545	***
as.factor(POSTCODE)67	-1.69E-01	4.89E-02	-3.446	0.000569	***
as.factor(POSTCODE)68	-1.22E-01	4.92E-02	-2.49	0.012796	*
as.factor(POSTCODE)69	8.05E-01	4.73E-02	17.025 <	2.00E-16	***
as.factor(POSTCODE)70	5.36E-01	5.55E-02	9.643 <	2.00E-16	***
as.factor(POSTCODE)71	6.22E-01	5.35E-02	11.635 <	2.00E-16	***
as.factor(POSTCODE)72	3.41E-01	5.12E-02	6.651	2.96E-11	***
as.factor(POSTCODE)73	3.17E-01	4.82E-02	6.572	5.07E-11	***
as.factor(POSTCODE)74	4.41E-01	5.83E-02	7.558	4.22E-14	***
as.factor(POSTCODE)75	5.48E-01	5.45E-02	10.058 <	2.00E-16	***
as.factor(POSTCODE)76	2.56E-01	5.09E-02	5.042	4.63E-07	***
as.factor(POSTCODE)77	6.69E-02	5.09E-02	1.315	0.188396	
as.factor(POSTCODE)78	-1.53E-02	4.79E-02	-0.319	0.750064	
as.factor(POSTCODE)79	-1.00E-01	4.94E-02	-2.027	0.04268	*
as.factor(POSTCODE)80	-1.09E-02	5.00E-02	-0.218	0.827783	
as.factor(POSTCODE)81	-1.04E-01	5.74E-02	-1.817	0.069215	.
as.factor(POSTCODE)82	6.81E-02	5.33E-02	1.276	0.201813	
as.factor(POSTCODE)83	3.74E-02	6.68E-02	0.56	0.575417	
as.factor(POSTCODE)85	1.27E-01	5.12E-02	2.487	0.01288	*
as.factor(POSTCODE)86	4.59E-02	4.87E-02	0.944	0.345424	
as.factor(POSTCODE)87	5.12E-01	5.91E-02	8.669 <	2.00E-16	***
as.factor(POSTCODE)88	4.88E-01	5.08E-02	9.615 <	2.00E-16	***
as.factor(POSTCODE)89	1.26E-01	5.17E-02	2.44	0.01471	*
as.factor(POSTCODE)90	-7.82E-02	4.84E-02	-1.616	0.106	
as.factor(POSTCODE)91	-1.73E-01	5.09E-02	-3.397	0.000683	***

as.factor(POSTCODE)92	-1.92E-01	5.05E-02	-3.791	0.00015	***
as.factor(POSTCODE)93	-3.64E-01	5.34E-02	-6.816	9.56E-12	***
as.factor(POSTCODE)94	-4.35E-01	5.62E-02	-7.737	1.05E-14	***
as.factor(POSTCODE)95	-3.50E-01	4.98E-02	-7.03	2.12E-12	***
as.factor(POSTCODE)96	-3.49E-01	4.91E-02	-7.101	1.27E-12	***
as.factor(POSTCODE)97	-1.92E-01	5.09E-02	-3.772	0.000162	***
as.factor(POSTCODE)98	-3.23E-01	4.80E-02	-6.736	1.66E-11	***
as.factor(POSTCODE)99	-1.93E-01	4.85E-02	-3.985	6.78E-05	***
as.factor(POSTCODE)100	-1.52E-01	4.99E-02	-3.049	0.002298	**
as.factor(POSTCODE)101	-3.29E-01	4.95E-02	-6.64	3.21E-11	***
as.factor(POSTCODE)102	-3.92E-01	4.95E-02	-7.915	2.57E-15	***
as.factor(POSTCODE)103	-1.50E-01	5.20E-02	-2.879	0.003997	**
as.factor(POSTCODE)105	2.99E-02	6.37E-02	0.469	0.639216	
as.factor(POSTCODE)106	-2.67E-02	5.50E-02	-0.486	0.626732	
as.factor(POSTCODE)107	1.01E-02	5.45E-02	0.185	0.853572	
as.factor(POSTCODE)108	-1.57E-01	5.31E-02	-2.96	0.003082	**
as.factor(POSTCODE)109	1.29E-01	5.64E-02	2.293	0.021877	*
as.factor(POSTCODE)110	3.04E-01	4.86E-02	6.25	4.18E-10	***
as.factor(POSTCODE)111	-9.25E-02	5.55E-02	-1.666	0.095685	.
as.factor(POSTCODE)112	1.94E-01	4.92E-02	3.933	8.41E-05	***
as.factor(POSTCODE)113	-2.60E-02	5.52E-02	-0.471	0.637658	
as.factor(POSTCODE)115	-4.68E-01	5.11E-02	-9.167	<	2.00E-16 ***
as.factor(POSTCODE)116	-6.25E-01	5.12E-02	-12.215	<	2.00E-16 ***
as.factor(POSTCODE)117	-5.18E-01	6.25E-02	-8.287	<	2.00E-16 ***
as.factor(POSTCODE)118	-5.12E-01	5.05E-02	-10.143	<	2.00E-16 ***
as.factor(POSTCODE)119	-5.67E-01	4.65E-02	-12.18	<	2.00E-16 ***
as.factor(POSTCODE)120	-6.47E-01	5.01E-02	-12.926	<	2.00E-16 ***
as.factor(POSTCODE)121	-7.29E-01	4.69E-02	-15.544	<	2.00E-16 ***
as.factor(POSTCODE)122	-7.68E-01	4.63E-02	-16.572	<	2.00E-16 ***
as.factor(POSTCODE)123	-3.80E-01	5.90E-02	-6.451	1.13E-10	***
as.factor(POSTCODE)124	-3.80E-01	5.15E-02	-7.379	1.64E-13	***
as.factor(POSTCODE)125	-4.94E-01	5.35E-02	-9.234	<	2.00E-16 ***
as.factor(POSTCODE)126	-4.69E-01	4.65E-02	-10.087	<	2.00E-16 ***
as.factor(POSTCODE)127	-4.05E-01	4.69E-02	-8.63	<	2.00E-16 ***
as.factor(POSTCODE)128	-4.73E-01	4.63E-02	-10.236	<	2.00E-16 ***
as.factor(POSTCODE)129	-4.50E-01	5.47E-02	-8.234	<	2.00E-16 ***
as.factor(POSTCODE)131	-3.78E-01	5.87E-02	-6.445	1.18E-10	***
as.factor(POSTCODE)133	-4.99E-01	4.82E-02	-10.371	<	2.00E-16 ***
as.factor(POSTCODE)134	-5.91E-01	4.89E-02	-12.08	<	2.00E-16 ***
as.factor(POSTCODE)135	-5.77E-01	5.04E-02	-11.437	<	2.00E-16 ***
as.factor(POSTCODE)137	-7.07E-01	4.96E-02	-14.26	<	2.00E-16 ***
as.factor(POSTCODE)138	-6.80E-01	4.83E-02	-14.089	<	2.00E-16 ***
as.factor(POSTCODE)139	-7.18E-01	4.79E-02	-15.001	<	2.00E-16 ***
as.factor(POSTCODE)140	-7.96E-01	6.15E-02	-12.947	<	2.00E-16 ***
as.factor(POSTCODE)141	-7.47E-01	4.67E-02	-15.994	<	2.00E-16 ***
as.factor(POSTCODE)142	-6.82E-01	4.61E-02	-14.791	<	2.00E-16 ***
as.factor(POSTCODE)143	-5.61E-01	4.78E-02	-11.745	<	2.00E-16 ***
as.factor(POSTCODE)144	-3.99E-01	6.86E-02	-5.818	6.01E-09	***
as.factor(POSTCODE)145	-5.65E-01	4.83E-02	-11.697	<	2.00E-16 ***
as.factor(POSTCODE)148	-6.14E-01	4.74E-02	-12.945	<	2.00E-16 ***

as.factor(POSTCODE)149	-6.92E-01	5.19E-02	-13.333 <	2.00E-16 ***
as.factor(POSTCODE)151	-4.65E-01	4.90E-02	-9.489 <	2.00E-16 ***
as.factor(POSTCODE)152	-2.93E-01	5.69E-02	-5.144 2.71E-07 ***	
as.factor(POSTCODE)153	-3.23E-01	5.43E-02	-5.946 2.78E-09 ***	
as.factor(POSTCODE)154	-1.61E-01	5.26E-02	-3.056 0.002247 **	
as.factor(POSTCODE)155	-2.65E-01	5.55E-02	-4.764 1.91E-06 ***	
as.factor(POSTCODE)156	-5.03E-01	5.52E-02	-9.125 <	2.00E-16 ***
as.factor(POSTCODE)157	-4.48E-01	4.94E-02	-9.073 <	2.00E-16 ***
as.factor(POSTCODE)158	-5.50E-01	5.67E-02	-9.709 <	2.00E-16 ***
as.factor(POSTCODE)159	-5.26E-01	5.40E-02	-9.734 <	2.00E-16 ***
as.factor(POSTCODE)160	-5.41E-01	5.17E-02	-10.472 <	2.00E-16 ***
as.factor(POSTCODE)161	-4.67E-01	4.93E-02	-9.484 <	2.00E-16 ***
as.factor(POSTCODE)162	-3.89E-02	5.57E-02	-0.699 0.484867	
as.factor(POSTCODE)163	-9.80E-02	4.87E-02	-2.012 0.044223 *	
as.factor(POSTCODE)164	-2.79E-01	5.50E-02	-5.072 3.97E-07 ***	
as.factor(POSTCODE)165	-1.13E-01	5.03E-02	-2.251 0.024399 *	
as.factor(POSTCODE)166	-2.06E-01	4.88E-02	-4.21 2.56E-05 ***	
as.factor(POSTCODE)167	-1.68E-01	5.31E-02	-3.155 0.001609 **	
as.factor(POSTCODE)168	-2.51E-01	5.20E-02	-4.831 1.36E-06 ***	
as.factor(POSTCODE)169	-3.11E-01	4.86E-02	-6.383 1.77E-10 ***	
as.factor(POSTCODE)170	-4.35E-01	5.03E-02	-8.632 <	2.00E-16 ***
as.factor(POSTCODE)171	-5.38E-01	5.19E-02	-10.378 <	2.00E-16 ***
as.factor(POSTCODE)172	-3.93E-01	5.05E-02	-7.781 7.47E-15 ***	
as.factor(POSTCODE)173	-4.33E-01	6.96E-02	-6.217 5.15E-10 ***	
as.factor(POSTCODE)174	-1.29E-01	5.12E-02	-2.524 0.011605 *	
as.factor(POSTCODE)175	-1.64E-02	5.05E-02	-0.325 0.744995	
as.factor(POSTCODE)176	-1.70E-01	5.30E-02	-3.202 0.001367 **	
as.factor(POSTCODE)177	1.21E-01	5.30E-02	2.282 0.022523 *	
as.factor(POSTCODE)178	-1.75E-01	5.04E-02	-3.475 0.000512 ***	
as.factor(POSTCODE)179	9.90E-02	4.93E-02	2.009 0.044595 *	
as.factor(POSTCODE)180	-2.02E-01	5.69E-02	-3.543 0.000396 ***	
as.factor(POSTCODE)181	-8.42E-02	4.97E-02	-1.695 0.090141 .	
as.factor(POSTCODE)182	1.34E-01	5.06E-02	2.643 0.008213 **	
as.factor(POSTCODE)183	-8.31E-02	5.70E-02	-1.459 0.144643	
as.factor(POSTCODE)184	-2.60E-01	5.17E-02	-5.031 4.92E-07 ***	
as.factor(POSTCODE)185	-1.57E-01	5.20E-02	-3.021 0.002524 **	
as.factor(POSTCODE)186	-1.68E-01	5.10E-02	-3.288 0.001011 **	
as.factor(POSTCODE)187	3.20E-02	4.83E-02	0.663 0.507386	
as.factor(POSTCODE)188	1.22E-01	4.87E-02	2.497 0.012529 *	
as.factor(POSTCODE)190	-3.04E-01	4.84E-02	-6.285 3.32E-10 ***	
as.factor(POSTCODE)191	-4.24E-01	4.77E-02	-8.877 <	2.00E-16 ***
as.factor(POSTCODE)192	-3.29E-01	4.76E-02	-6.917 4.72E-12 ***	
as.factor(POSTCODE)195	-9.15E-01	5.02E-02	-18.252 <	2.00E-16 ***
as.factor(POSTCODE)197	-9.20E-01	4.59E-02	-20.073 <	2.00E-16 ***
as.factor(POSTCODE)198	-9.09E-01	5.07E-02	-17.935 <	2.00E-16 ***
as.factor(POSTCODE)199	-8.13E-01	4.93E-02	-16.483 <	2.00E-16 ***
as.factor(POSTCODE)200	-8.98E-01	4.76E-02	-18.866 <	2.00E-16 ***
as.factor(POSTCODE)201	-7.22E-01	4.63E-02	-15.596 <	2.00E-16 ***
as.factor(POSTCODE)204	-7.70E-01	4.91E-02	-15.674 <	2.00E-16 ***
as.factor(POSTCODE)205	-7.30E-01	4.71E-02	-15.507 <	2.00E-16 ***



as.factor(POSTCODE)206	-9.06E-01	4.71E-02	-19.24 <	2.00E-16 ***
as.factor(POSTCODE)208	-8.66E-01	4.85E-02	-17.842 <	2.00E-16 ***
as.factor(POSTCODE)209	-8.31E-01	4.69E-02	-17.709 <	2.00E-16 ***
as.factor(POSTCODE)210	-1.01E+00	6.15E-02	-16.345 <	2.00E-16 ***
as.factor(POSTCODE)211	-8.01E-01	5.17E-02	-15.482 <	2.00E-16 ***
as.factor(POSTCODE)212	-7.92E-01	5.87E-02	-13.5 <	2.00E-16 ***
as.factor(POSTCODE)213	-8.07E-01	4.71E-02	-17.11 <	2.00E-16 ***
as.factor(POSTCODE)215	-8.06E-01	6.60E-02	-12.218 <	2.00E-16 ***
as.factor(POSTCODE)216	-8.29E-01	4.73E-02	-17.516 <	2.00E-16 ***
as.factor(POSTCODE)217	-9.45E-01	4.72E-02	-20.04 <	2.00E-16 ***
as.factor(POSTCODE)218	-7.93E-01	4.69E-02	-16.888 <	2.00E-16 ***
as.factor(POSTCODE)219	-7.02E-01	6.05E-02	-11.589 <	2.00E-16 ***
as.factor(POSTCODE)220	-7.09E-01	4.71E-02	-15.045 <	2.00E-16 ***
as.factor(POSTCODE)221	-7.77E-01	5.51E-02	-14.119 <	2.00E-16 ***
as.factor(POSTCODE)222	-8.05E-01	5.05E-02	-15.942 <	2.00E-16 ***
as.factor(POSTCODE)223	-8.12E-01	4.95E-02	-16.398 <	2.00E-16 ***
as.factor(POSTCODE)224	-5.66E-01	4.68E-02	-12.099 <	2.00E-16 ***
as.factor(POSTCODE)226	-1.07E+00	4.61E-02	-23.091 <	2.00E-16 ***
as.factor(POSTCODE)227	-6.71E-01	5.53E-02	-12.126 <	2.00E-16 ***
as.factor(POSTCODE)228	-8.27E-01	5.11E-02	-16.201 <	2.00E-16 ***
as.factor(POSTCODE)230	-8.64E-01	5.59E-02	-15.469 <	2.00E-16 ***

Residual standard error: 0.225  
on 25312 degrees of freedom

Multiple R-squared: 0.8362 Adjusted R-squared: 0.8348

F-statistic: 609.5 on 212 and 25312 DF  
p-value: < 2.20E-16

## Appendix B - Tokyo - Estimated shadow prices - 2002

Residuals:

Min	1Q	Media	n	3Q	Max
			9	0.07784	0.60209

Coefficients:

	Estimate	Std. Error	t value	Pr(> t )	
(Intercept)	4.413798	0.140363	31.446	< 2e-16	***
l(log(S))	1.05579	0.029926	35.28	< 2e-16	***
ts	-0.0118	0.00223	-5.29	2.28E-07	***
tt	-0.00303	0.001654	-1.83	0.068153	.
as.factor(City.Code)13102	-0.35623	0.079633	-4.473	1.07E-05	***
as.factor(City.Code)13103	-0.07491	0.077853	-0.962	0.336649	
as.factor(City.Code)13104	-0.25781	0.081973	-3.145	0.001817	**
as.factor(City.Code)13105	-0.27628	0.084002	-3.289	0.001118	**
as.factor(City.Code)13106	-0.64729	0.081276	-7.964	2.96E-14	***
as.factor(City.Code)13107	-0.70919	0.091356	-7.763	1.14E-13	***
as.factor(City.Code)13108	-0.64804	0.077933	-8.315	2.68E-15	***
as.factor(City.Code)13109	-0.36827	0.082746	-4.451	1.18E-05	***
as.factor(City.Code)13110	-0.11086	0.082259	-1.348	0.178698	
as.factor(City.Code)13111	-0.30546	0.084348	-3.621	0.000341	***
as.factor(City.Code)13112	-0.16009	0.082705	-1.936	0.053787	.
as.factor(City.Code)13113	0.037748	0.089476	0.422	0.673399	
as.factor(City.Code)13114	-0.37918	0.098057	-3.867	0.000134	***
as.factor(City.Code)13115	-0.25545	0.084281	-3.031	0.002638	**
as.factor(City.Code)13116	-0.3731	0.083629	-4.461	1.13E-05	***
as.factor(City.Code)13117	-0.51581	0.093251	-5.531	6.63E-08	***
as.factor(City.Code)13118	-0.49937	0.087168	-5.729	2.34E-08	***
as.factor(City.Code)13119	-0.61115	0.087097	-7.017	1.37E-11	***
as.factor(City.Code)13120	-0.47517	0.101058	-4.702	3.84E-06	***
as.factor(City.Code)13121	-0.73563	0.083	-8.863	< 2e-16	***
as.factor(City.Code)13122	-0.77603	0.100203	-7.745	1.28E-13	***
as.factor(City.Code)13123	-0.58514	0.087869	-6.659	1.20E-10	***

Residual standard error: 0.145 on 319 degrees of freedom

Multiple R-squared: 0.8733 Adjusted R-squared: 0.8633

F-statistic: 87.92 on 25 and 319 DF

p-value: < 2.2e-16