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**Australian House
Prices: A Comparison
of Hedonic and
Repeat-sales Measures**

James Hansen

RDP 2006-03

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Abstract

House prices are intrinsically difficult to measure due to changes in the composition of properties sold through time and changes in the quality of housing. I provide an overview of the theoretical nature of these issues and consider how regression-based measures of house prices – hedonic and repeat-sales measures – can control for compositional and quality change. I then explore whether these regression-based alternatives can provide accurate estimates of pure house price changes in the Australian context.

Using unit record data for Australia's three largest cities – Sydney, Melbourne and Brisbane – between 1993 and 2005, the results suggest that the two regression-based approaches provide similar estimates of the pure price change in housing. The measures are comparable in terms of statistical fit, with around half of the variation in prices growth (for those houses sold more than once) explained. The regression-based measures also produce similar estimates of pure price changes to those obtained by a mix-adjusted measure. However, all three measures behave quite differently from a simple median, implying that compositional change matters empirically. These results confirm that regression-based measures are likely to be a useful analytical tool when measuring pure house price changes in Australia.

JEL Classification Numbers: G12, R21, R31

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James Hansen

1. Introduction

Movements in house prices can have important consequences for the Australian economy. Housing constitutes around 60 per cent of all household assets, and house prices can be prone to large swings or ‘boom-bust’ cycles. These swings can influence economic activity through both dwelling investment and consumption, with wealth effects influencing borrowing and spending decisions.

Since house prices are important for economic and financial developments, measuring their level and growth rate accurately is desirable. There are two key concerns which complicate this task: the prices of non-transacted houses, which are unobservable; and the difficulty in measuring the quality of houses that are heterogenous, especially if housing characteristics change through time. With only a subset of the population of houses sold in any given period and considerable heterogeneity across houses, the composition of houses sold can differ between periods. Differences in quality across houses at a given point in time can be difficult to control for, in part because of practical considerations regarding the available data, but also because housing is inherently heterogenous since the location of each house is unique. Quality also varies through time with changes to existing dwellings and the construction of new, typically higher-quality, housing. Hence, movements in house prices can reflect pure price changes, changes in the mix of houses sold and changes in the quality of houses.

Compositional and quality change can affect simple measures of house prices such as a median and, to a lesser extent, mix-adjusted measures (that adjust only for specific types of compositional change). To overcome the limitations of these measures, several regression-based approaches have been proposed in the literature.¹ These include: hedonic measures, which regress the log-level of prices

¹ See Cho (1996) and Conniffe and Duffy (1999), for extensive reviews of this literature.

against house attributes over time;² repeat-sales measures, which regress price changes of the same house over time (Bailey, Muth and Nourse 1963; Case and Shiller 1987); and hybrid measures, which combine the hedonic and repeat-sales approaches (Case and Quigley 1991; Quigley 1995).

Notwithstanding the extensive research on regression-based measures and other measures, there is still little consensus as to whether there is a superior approach to measuring house prices either on theoretical grounds or according to empirical comparisons, with many results conditional on the data used. One area that the literature has not focused on extensively is the volatility of alternative house price measures, particularly over a short-term horizon. Yet for researchers and policy-makers concerned with near-term movements in house prices, it is desirable to be able to distinguish between pure price changes, compositional changes, quality changes, and statistical noise associated with reporting error. This is particularly so around turning points in the data, where house price readings can be important in forming assessments of the housing market and the broader economy.

This paper makes two contributions. First, I compare two regression-based measures of house prices – specifically, hedonic and repeat-sales measures – to develop a regression-based approach to measuring house prices that controls for compositional change and, to some extent, quality change. This extends previous Australian research in this area, including Rossini, Kooymans and Kershaw (1995), Costello (1997) and Flaherty (2004), by using a wider range of measures and a larger sample of data, as well as placing more emphasis on the theoretical properties of alternative measures. Second, I gauge the performance of the regression-based measures by comparing them to some simpler measures of house prices, including a median and a mix-adjusted approach developed by Prasad and Richards (2006). This provides more general information about suitable measures in the Australian context, and whether the regression-based measures provide a better control for compositional and quality change. This work is complementary to Prasad and Richards, who investigate some of the key practical issues in house price measurement such as timeliness, seasonality, data availability, and the extent to which a mix-adjusted measure can help to control for compositional effects.

² These were initially developed by Waugh (1928), Court (1939), and Griliches (1971) and concerned the pricing of heterogenous goods more generally.

Estimates are based on unit record data on house sales for Australia's three largest cities – Sydney, Melbourne and Brisbane – from the March quarter 1993 to the September quarter 2005. The data are supplied by Australian Property Monitors (APM) (Sydney, Melbourne and Brisbane) and the Real Estate Institute of Victoria (REIV) (Melbourne). Data from APM are originally sourced from state land titles offices, while REIV data are a mixture of data from the land titles office and real estate agents. The data are comparable to that used by the Australian Bureau of Statistics (ABS) in producing its quarterly index on house prices, and cover around half of all house sales that occur in the Australian market.

The results suggest that regression-based methods can provide a useful control for compositional effects. In particular, hedonic and repeat-sales measures provide similar estimates of pure prices growth, suggesting that theoretical issues associated with choosing an appropriate specification may be less important for price measurement in practice. Estimates from these measures are also comparable to a simple mix-adjusted measure. In contrast, the median – which makes no adjustment for compositional change – displays considerable volatility and lower average price growth over the sample period. This implies that compositional change has mattered empirically.

The similarity between the hedonic, repeat-sales and mix-adjusted measures is somewhat surprising though, since the hedonic can, in principle, control for quality while the latter two cannot. This suggests that either the data available are not able to definitively capture quality change, or that quality change has been quite limited. In contrast, a repeat-sales regression with a constant (an alternative control for quality change) implied modest quality-related price increases over the sample period.

The remainder of the paper is organised as follows. Section 2 provides an overview of the concepts and definitions relevant to measuring house prices and discusses some of the theoretical difficulties involved. Alternative measures of house prices, both regression-based and non-regression-based, are examined in Section 3. Section 4 evaluates the various measures empirically. Conclusions are drawn in Section 5.

2. House Price Concepts and Definitions

When discussing house prices it is important to clarify whether we are interested in a price measure relating only to those houses sold in a period or a measure of prices relevant to all houses in the economy. If it is the former which is of interest, then concerns regarding compositional and quality change are not relevant. However, in the latter case, these issues need to be given careful consideration.

Specifically, a researcher is often concerned with how the price of a representative house (or the stock of housing) in the economy changes over time, assuming constant quality. This amounts to measuring the pure price change in housing, and is central to understanding the dynamics of housing markets for several reasons: it is the concept that is relevant for household consumption, borrowing and investment decisions, and for analysis of changes in household welfare; it provides information on past returns from a constant-quality investment in housing, which matters for the portfolio decisions of households and firms; and it can be useful in assessing whether house prices reflect fundamentals or are over- or under-valued as an asset (and, more generally, the efficiency of housing markets).

When measuring pure price changes, there are various weighting approaches. If the researcher is interested in the change in the value of the housing stock (or a representative portfolio), then a higher weight should be given to price changes in higher-value houses because of their greater share in the total value of the housing stock (Shiller 1991). On the other hand, if the researcher wishes to measure price changes in the representative house, then an equal weighting of observed house price inflation rates would be appropriate.³ For the remainder of this paper, the discussion centres on the pure price changes for a representative house, assuming an equal weighting.

When measuring pure price changes, this should ideally be imputed from the prices of all houses in the economy. However, since houses are heterogenous and traded infrequently,⁴ changes in the composition of properties sold can influence a simple transaction-based measure, such as a median. For instance, if the share

³ Alternatively, when combining observed prices levels of housing sub-markets, for example in the construction of a mix-adjusted measure, turnover weights or (ideally) housing stock weights can be used across market segments.

⁴ On average, approximately 6 per cent of the dwelling stock is turned over in any given year.

of higher quality (and hence more expensive) houses sold rises, a median measure will show an increase in price even if the prices of all houses in the economy did not change. More generally, a transaction-based measure of prices, which does not adjust for compositional change, may not be representative of the price movements relevant to all houses in the economy.

Adjusting for changes in the quality of the housing stock is also required for measuring pure price changes. New house construction and renovations to existing houses tend to improve the quality of the housing stock over time, contributing to higher prices, while depreciation of existing non-renovated houses tends to reduce quality. If the former effect dominates, then a simple transaction-based measure will over-estimate prices over time, reflecting quality improvements as well as pure price changes.

It is difficult to disentangle observed price movements into their respective price- and quality-driven components. Because location is unique, even with identical housing structures, an inherent difference exists in the quality of properties. This can be problematic when measuring price changes over time if, for example, the relative value of any particular location changes. From a practical perspective, it is difficult to obtain comprehensive data on all aspects of quality that influence the price of a property, and to measure changes in quality precisely over time. However, to the extent that data on quality are available, there is scope to come up with better estimates of pure price changes using this information.

3. Alternative Measures of House Prices

3.1 Hedonic Measures

Hedonic measures have a strong theoretical grounding (see, for example, Griliches 1971 and Rosen 1974) and use regression techniques to control for compositional and quality change. Meese and Wallace (1997) show that a general form of a hedonic specification can be written as follows:

$$p_{it} = \sum_{t=1}^T [D1_{it} \alpha_t + X_{it} \beta_t + D2_{it} X_{it} \gamma_t] + \varepsilon_{it} \quad (1)$$

where p_{it} is the log of the price of house i when sold at time t , $D1_{it}$ is a time dummy equal to 1 for the i^{th} house if sold at time t and 0 otherwise, X_{it} is a vector of house

characteristics for house i when sold at time t , $D2_{it}$ is a vector of dummy variables with 1's for repeat-sales observations and 0's otherwise, and ε_{it} is white noise. In this model the exponential of $(\alpha_t - \alpha_1)$ provides an estimate of the rate of growth in the mean price with respect to the mean price at the start of the sample period.⁵ Further, β_t provides estimates of the implicit value of the house characteristics at time t . It should be noted that this is a pooled rather than panel data regression, as the number of observations varies with each time period t . The key advantage of the general hedonic formulation is that it provides direct estimates of pure price changes and can, in principle, control for changes in the composition and quality of houses sold.

Nonetheless, hedonic measures are not without their limitations. In particular, the use of regression techniques implies that hedonic models are only as good as the specifications used to derive them, and often depend on the quality of the data available. If hedonic regressions omit variables that have a significant impact on house prices, this can result in biased estimates of pure price changes.⁶ Analogously, if the relationships between the attributes of houses and their effect on prices are incorrectly specified, for instance through an incorrect functional form, this could also result in biased estimates. For example, Equation (1) could have been formulated with additional second-order terms capturing squared terms of the characteristics vector and allowing for interaction terms between characteristics.

A related question is whether to use an unrestricted hedonic regression, as in Equation (1), where estimates of the implicit price relativities of housing characteristics are allowed to vary between single and repeat sales and over time, or a restricted hedonic regression that assumes the implicit price relativities are the same for both single and repeat sales ($\gamma_t = 0$ for all t) and are constant over time ($\beta_t = \beta$, conditional on $\gamma_t = 0$ for all t):

$$p_{it} = \sum_{t=1}^T D1_{it} \alpha_t + X_{it} \beta + \varepsilon_{it} \quad (2)$$

⁵ More precisely, the exponential of $\hat{\alpha}_t - \text{var}(\hat{\alpha}_t)/2 - \alpha_1$ provides the estimated rate of change. In practice, $\text{var}(\hat{\alpha}_t)/2$ is negligible for large samples (Hill and Melsers 2005).

⁶ For instance, this can occur where there is a change in an unobserved quality variable over time that leads to a change in prices.

In principle, whether Equation (2) is appropriate can be tested by estimating Equation (1) and testing whether the assumptions hold. While these tests provide information about the most appropriate specification, they may be less important in an economic sense if the estimates of pure price changes (the exponential of $\alpha_t - \alpha_1$) are similar, regardless of whether the unrestricted or restricted specification is chosen.

The results of several empirical studies lend support to the hedonic approach when compared with alternatives. For example, Mark and Goldberg (1984) compare mean, median, hedonic and repeat-sales measures for two Vancouver neighbourhoods and find that hedonic measures (as well as simple measures, such as a median) perform relatively well when compared with their repeat-sales counterparts that appear to underestimate pure prices growth. More recently, Meese and Wallace (1997) use US data and advocate the hedonic approach on the grounds that it is less affected by sample-selection bias (associated with the use of repeat-sales data) and non-constant implicit prices of housing attributes than a repeat-sales measure; similarly, Clapham *et al* (2004) find that hedonic indices constructed using Swedish data are less prone to revisions than repeat-sales. Comparing hedonic measures with mix-adjusted measures using data from the Netherlands, Francke, Vos and Janssen (2000) suggest that hedonic measures tend to be less sensitive to small market segments. In the Australian context, Rossini *et al* (1995), Costello (1997) and Flaherty (2004) argue in favour of the hedonic approach when compared with a median on the basis that it is less volatile, and provides some control for changes in the composition and quality of properties sold.

3.2 Repeat-sales Measures

While hedonic measures can, in principle, capture the pure price change in housing, their reliance on a large and high-quality information set regarding house characteristics has led researchers to investigate less data-intensive regression-based methods. Repeat-sales measures, initially proposed by Bailey *et al* (1963), provide an alternative estimation method based on price changes of houses sold more than once. In particular, if the restricted hedonic model in Equation (2) is differenced with respect to consecutive sales of houses that have sold more than

once in the sample period, it follows that:

$$p_{it} - p_{i\tau} = \sum_{t=1}^T D1_{it} \alpha_t - \sum_{\tau=1}^T D1_{i\tau} \alpha_\tau + (X_{it} - X_{i\tau})\beta + (\varepsilon_{it} - \varepsilon_{i\tau}) \quad (3)$$

where for each observation the log resale price is denoted by p_{it} at time t and the previous log sale price is denoted by $p_{i\tau}$ at time τ ($t > \tau$). Assuming that the characteristics of the i^{th} house do not change between sales ($X_{it} = X_{i\tau}$), Equation (3) can be estimated through:

$$p_{it} - p_{i\tau} = \sum_{t=1}^T G_{it} \alpha_t + \eta_{it} \quad (4)$$

where G_{it} is a time dummy equal to 1 in the period that the resale occurs, -1 in the period that the previous sale occurs and 0 otherwise, and η_{it} is again a white noise error term (with an error for each resale, multiple resales are treated as independent observations).⁷

Advocates of the repeat-sales methodology contend that using a repeat-sales measure more accurately controls for the attributes of houses since it is based on observed appreciation rates of the same house (Bailey *et al* 1963; Case and Shiller 1987). Repeat-sales measures also require much less data, with information on price, the sales date and the address being the only requirements.

However, repeat-sales measures are estimated on the premise that house characteristics (that is, quality) have not changed over time. Given the non-trivial amount of investment in renovations – often around 2–3 per cent of GDP – and that non-renovated house structures can depreciate with time, it seems unlikely that this will be true. One way to control for this is to use a sub-sample of repeat sales, where quality is thought to be relatively constant. The problem with this approach is that if the sub-sample is too small, the price changes inferred may no longer be indicative of price changes for the full sample of repeat sales. Another control, proposed by Goetzmann and Spiegel (1995), is to use all repeat-sales data and allow for a constant in the repeat-sales regression. In this case,

⁷ As noted by Shiller (1991), the treatment of multiple resales as independent observations should not be overly problematic because there is no overlap between the holding periods of multiple resales.

the constant is time invariant and might capture average quality change (across all characteristics), over the average holding period. The suitability of this will depend on whether quality change is correlated with the length of the holding period; a high correlation implies that it will not be suitable as simple repeat-sales methods cannot distinguish between quality and pure price changes temporally. It also depends on the extent to which quality change is not randomly distributed across repeat-sales observations.

Repeat-sales are inefficient in their use of information. The samples used, by construction, only contain information on those houses which have been sold at least twice. If there is a systematic difference between price changes in houses that have been sold only once and those which have been sold more than once, then repeat-sales will provide biased estimates of overall house price changes. Similarly, if there are systematic differences between different types of repeat-sales houses and their rate of turnover (that is, houses sold two, three, four times and so forth), then it is possible for houses with high turnover rates to become over-represented in the sample, again resulting in measurement bias.

Revisions are an issue that can affect both repeat-sales and hedonic measures, since re-estimation with additional data can result in changes in the coefficients estimated and thus the price indices inferred. There have been few empirical studies on this issue to date, though Clapham *et al* (2004) (Sweden) have found evidence to suggest hedonic indices are relatively more stable than repeat-sales indices.

There is a considerable body of literature advocating repeat-sales measures. Further to the main contributions by Bailey *et al* (1963), Case and Shiller (1987) and the intercept modification proposed by Goetzmann and Spiegel (1995), a number of alternative repeat-sales estimators have been proposed including arithmetic, geometric and hedonic-repeated measures (Shiller 1991, 1993), Bayesian and Stein-like estimators (Goetzmann 1992) and distance-weighted estimators (Goetzmann and Spiegel 1997). These papers explore several different estimation strategies and generally find that repeat-sales can provide useful additional information using US sales data in their empirical applications (see also Crone and Voith 1992). Using small samples of Australian data, Rossini *et al* (1995) and Costello (1997) find that a repeat-sales approach

compares favourably with a restricted hedonic approach, and that both approaches outperform a median.

3.3 A Simple Mean or Median

The simplest measures of house prices calculate some measure of central tendency from the distribution of prices for houses sold in a period. Since house price distributions are generally positively skewed (predominantly reflecting the heterogenous nature of housing, the positive skew in income distributions and the zero lower bound on transaction prices), the median is typically used rather than the mean. Further, as no data on housing characteristics are required to calculate a median or mean, a price series can be easily inferred.

The simplicity of a median or mean is mitigated, however, by the fact that these measures make no adjustment for the difficulties previously discussed. In particular, a mean or median transaction price is not necessarily representative of the mean or median price of the dwelling stock. This applies both within a given time period and across time periods, suggesting that changes in the mix of properties sold can bias these measures. In addition, a mean or median makes no allowance for changes in the quality of the housing stock over time.

In view of this, a mean or median measure will be an accurate guide to pure price changes only when there is little change in the composition of houses sold between periods, and when quality change is limited. If there is a correlation between turning points in house price cycles and compositional and quality change, then a median could be especially misleading in periods when the premium on accuracy is highest.

3.4 Mix-adjusted Measures

A simple approach to control for changes in the composition of houses sold between periods, but not quality change, is to use a mix-adjusted measure of house prices.⁸ Such measures control for variations in prices across different types of houses by separating the sample into subgroups according to individual house characteristics such as price, location, size, amenities and so forth. A measure

⁸ Mix-adjusted measures are also referred to as composition-adjusted, fixed-sample or weighted-average measures in the literature.

of central tendency, such as a median or mean, is then constructed for each group before being combined to construct the aggregate mix-adjusted index. For example, a geometric mix-adjusted index can be constructed as follows:

$$MP_t = \prod_{i=1}^n P_{it}^{w_i} \quad (5)$$

where MP_t is the mix-adjusted price at time t , w_i is the weight of group i (for instance, expenditure, turnover or housing-stock weights), P_{it} is the median house price of group i at time t , and n is the total number of groups. This mix adjustment is a relatively simple method of accounting for differences in house characteristics. The data requirements will depend upon the type of groups used, but are generally less intensive than for hedonic price measures. It is also less susceptible to any specification error associated with regression techniques. However, unlike hedonic measures, mix-adjusted measures take no account of quality changes in the housing stock over time.

The effectiveness of a mix-adjusted measure will depend upon the groups used. Generally, a mix-adjusted measure only controls for compositional change across the dimensions defined by each group. For example, if a mix-adjusted measure separates house sales according to their location, changes in turnover across locations should not have a large effect on measured price changes. However, if there is a change in the mix of property types sold that is unrelated to location, then such a mix-adjusted measure will not account for this. Similarly, mix-adjusted measures do not account for changes in the mix of properties sold within each subgroup defined – that is, changes in the mix of properties sold within the boundaries of each defined location.

Mix-adjusted measures of house prices have been used by numerous statistical offices and government agencies including the UK Department of the Environment (1982), the UK Office of the Deputy Prime Minister, and the ABS. Although discussions of this approach have received less attention in academic literature (being more commonly researched and used by statistical agencies), there is a developing body of work on market segmentation using statistical techniques such as cluster and factor analysis (see, for example, Dale-Johnson 1982, Goodman and Thibodeau 2003 and Thibodeau 2003). In principle, cluster and factor analysis can be used to define housing sub-markets

or groups, which can then be used as strata in the construction of a mix-adjusted measure. Concurrent research at the ABS (2005) has focused on this approach.

4. An Empirical Comparison of Alternative Measures

As previously discussed, there is no consensus regarding the preferred approach to measuring house prices, either theoretically or empirically. However, there is reason to believe that constructing more advanced measures of house prices, such as regression-based measures, may provide a better guide to pure price changes in housing than a simple median. To this end, I consider several hedonic and repeat-sales alternatives to find a preferred measure for each approach. I then compare the preferred hedonic and repeat-sales measures with each other, as well as two simple measures (a median and a mix-adjusted measure) to gauge the performance of the regression-based measures and the extent to which compositional and quality change matter.

4.1 Data

The data are based on a census of house sales (excluding apartments) in Australia's three largest cities – Sydney, Melbourne and Brisbane – which make up just over half of all house sales in Australia. These data originate from land titles offices and have been collated, matched and supplied by APM. I also use data from the REIV for Melbourne, since these data have address level information, which APM cannot provide for this city, and can be used to construct a repeat-sales measure.⁹ The data are comparable to those used by the ABS in compiling their quarterly measures of house prices for Sydney, Melbourne and Brisbane. For an overview of the procedures used to clean the data prior to constructing the alternative house price measures, see Appendix B.

The data contain unit record information on each house sale, including information on: location (street address, postcode, suburb, statistical local area, statistical sub-division, statistical division and state); property type (house, cottage, villa, semi-detached, townhouse or terrace); contract and settlement dates; and the sale method (auction or private treaty). In total, I use approximately 642 000 observations for Sydney, 630 000 observations for Melbourne (350 000

⁹ I would like to thank APM and REIV for their assistance in providing these data.

observations where REIV data are used) and 436 000 observations for Brisbane.¹⁰ In addition, a subset of the records in each sample have information on: zoning (residential, business, mixed etc); land size (measured in square metres); and the number of bedrooms and bathrooms. Finally, data are quarterly from March 1993 to September 2005, and are recorded according to contract dates.

4.2 Hedonic Measures

Since economic theory does not point to a unique and superior hedonic specification, several alternatives are considered. I begin with the following specification:

$$p_{it} = \sum_{t=1}^T D1_{it} \alpha_t + \sum_{t=1}^{v-1} [X_{it} \beta_1 + D2_{it} X_{it} \gamma_1] + \sum_{t=v}^T [X_{it} \beta_2 + D2_{it} X_{it} \gamma_2] + \varepsilon_{it} \quad (6)$$

The only difference between the original formulation of Equation (1) and Equation (6) is that the latter restricts β_t and γ_t to be constant within each of two sub-samples of the data – March 1993 to December 1998 and March 1999 to September 2005. This restriction is undertaken for computational simplicity (the full unrestricted model would require a regression of approximately 12 500 variables on 642 000 observations in the case of Sydney). For the initial regressions, the characteristic variables included in Equation (6) are postcode, property type, and sale method, which maximises the sample size.¹¹ While postcode and sale method are not ‘true’ hedonic variables since they do not measure actual house characteristics, the postcode can be thought of as a proxy for a range of characteristics associated with the houses’ location, such as the average amenities of the neighbourhood (distance from schools, the beach, the city, services and so forth), its general desirability, and the average quality of housing in the area. Similarly, the sale method might be correlated with the quality of the property being sold as higher quality housing is more likely to be auctioned.

Table 1 reports the results of these statistical tests. They generally reject the hypothesis that the implicit price relativities (implicit prices) – that is, the elasticity/semi-elasticity of price with respect to a given house characteristic – for

¹⁰ APM definitions are used for the regions covered.

¹¹ The results are qualitatively similar if additional characteristics such as log land size, and a smaller sample, are used.

single and repeat sales are the same.¹² Further, they reject the hypothesis that the implicit prices of characteristics do not vary through time (at least for the two subsamples of the data, and conditional on the assumption that the implicit prices of single and repeat sales are not statistically different). This suggests that the more general specification should be used, at least for measuring the implicit prices of house characteristics. However, whether this affects the temporal component of prices, the pure price changes, is an empirical question.

To test whether the temporal component of prices (α_t) are statistically different I estimate the general hedonic model in Equation (6) jointly with a restricted equation where $\gamma_t = 0$, using a Seemingly Unrelated Regression (SUR). The null hypothesis that each of the α_t are jointly equal for both equations cannot be rejected at conventional levels of significance. Similarly, if the SUR is re-estimated with the restricted equation $\gamma_t = 0$, and an equation where $\gamma_t = 0$ and β_t is constant over time, again I find that there are no statistical differences between the pure price changes inferred.¹³

Although the data reject the various restrictions commonly imposed on hedonic regressions in the literature (that is, $\beta_t = \beta$ and $\gamma_t = \gamma$), it is still worth examining the restricted regression results. The key results for Sydney, Melbourne and Brisbane are shown in Table 2. For each city, I use a subset of the data for which the complete set of information on all characteristics are available and estimate alternative specifications that include data on postcode, property type, log land size, sale method, bedrooms, bathrooms and zoning. Two broad results are noteworthy. First, the models fit the data reasonably, with the fully specified versions explaining between 62 and 78 per cent of the variation in log prices for the three cities. Second, nearly all of the implicit price coefficients have the expected sign and are statistically significant.

The most important characteristic in explaining log prices in these regressions is postcode. Including the postcode in which a house is sold (a proxy for location and the amenities associated with the location) explains around 39 per cent of the log

¹² A repeat-sales dummy could not be constructed for Melbourne using APM data. To overcome this, I use REIV data for testing the implicit prices of single- and repeat-sales characteristics for Melbourne.

¹³ Results are available from the author on request.

Table 1: Hypothesis Tests for Equality of Single- and Repeat-sales Implicit Prices and Equality of Implicit Prices over Time

	Single vs repeat sales ^(a)	Constant implicit prices ^(b)
	$\gamma_t = 0$	$\beta_t = \beta \gamma_t = 0$
<i>Sydney</i>		
Unrestricted RSS ^(c)	56 828	57 286
Restricted RSS ^(c)	57 286	57 690
F-statistic	11.6	22.1
(p-value)	0.00	0.00
Restrictions	493	249
Observations	641 668	641 668
<i>Melbourne</i> ^(d)		
Unrestricted RSS ^(c)	37 287	36 788
Restricted RSS ^(c)	36 788	36 577
F-statistic	8.2	214.9
(p-value)	0.00	0.00
Restrictions	493	264
Observations	348 689	348 689
<i>Brisbane</i>		
Unrestricted RSS ^(c)	52 092	52 421
Restricted RSS ^(c)	52 421	53 811
F-statistic	10.5	105.9
(p-value)	0.00	0.00
Restrictions	251	131
Observations	436 009	436 009

Notes: These restrictions are tested using F-tests that adjust for heteroskedastic-consistent standard errors.

(a) The null hypothesis is that $\gamma_1 = \gamma_2 = 0$.

(b) The null hypothesis is that $\beta_1 = \beta_2$, conditional on $\gamma_1 = \gamma_2 = 0$.

(c) RSS denotes the residual sum of squares.

(d) For Melbourne, REIV data are used to test the hypotheses.

Sources: APM; REIV; author's calculations

price variation in Sydney, 59 per cent in Melbourne, and 27 per cent in Brisbane when included in addition to the time dummy variables (the time dummies alone explain around 26 per cent of the variation in Sydney, 11 per cent in Melbourne and 8 per cent in Brisbane). Other characteristic variables such as log land size, property type, bedrooms, bathrooms, zoning and the sale method provide less explanatory power in total for Sydney (around 13 per cent) and Melbourne (around 8 per cent), and about the same explanatory power as the postcode for

Brisbane (27 per cent). Coefficient estimates are robust to including each of the characteristic variables by themselves in the restricted hedonic regressions (results are available on request).

Table 2: All Cities – Restricted Hedonic Specifications

	Sydney	Melbourne	Brisbane
Constant	10.62	10.71	8.97
Land size	0.28	0.19	0.39
<i>Property</i>			
Cottage	-0.07	<i>0.08</i>	-0.05
Semi-detached	-0.12	-0.23	-0.25
Terrace	-0.05	<i>-0.02</i>	
Townhouse	-0.44	0.09	-0.12
Villa	-0.26	<i>0.11</i>	
<i>Sale</i>			
Pre-auction	0.04	0.02	0.04
Auction	0.06	0.05	<i>0.01</i>
Post-auction	0.07	<i>0.03</i>	<i>0.02</i>
Bedrooms	0.07	0.16	0.16
Bathrooms	0.14		
Postcodes	Yes	Yes	Yes
Zoning	Yes	No	Yes
Prices growth	8.79	9.69	10.00
Adjusted R^2 ^(a)	0.78	0.78	0.62
RMSE	0.27	0.25	0.28

Notes: Based on a common sub-sample of 25 122 observations for Sydney (4 per cent of the total Sydney sample), 18 229 observations for Melbourne (3 per cent of the total Melbourne sample) and 4 683 observations for Brisbane (1 per cent of the total Brisbane sample); insignificant coefficients are italicised at the 5 per cent level of significance.

(a) The adjusted R^2 is presented for indicative purposes since the model is estimated with heteroskedastic-consistent standard errors.

Sources: APM; author's calculations

The results in Table 2 also appear to provide plausible estimates of the value of a range of housing characteristics.¹⁴ Holding other things equal, a 1 per cent increase in land size corresponds to a 0.28 per cent price increase in Sydney, a

¹⁴ To include as many attributes as possible meant using relatively small sub-samples (see notes in Table 2). Results are generally robust to more parsimonious specifications which excluded, in turn, zoning, bathrooms, bedrooms and sale type as explanatory variables.

0.19 per cent increase in Melbourne and a 0.39 per cent increase in Brisbane.¹⁵ The size and amenities of the house, as measured through the number of bedrooms and bathrooms, also has a positive effect on price. In Sydney, an additional bedroom corresponds to a 7 per cent increase in price, while an additional bathroom results in a 14 per cent increase. It should be noted, however, that the bedroom and bathroom variables are quite collinear (a correlation of 0.87 for Sydney) and that part of the strength in the magnitude of the bathroom coefficient may reflect an unobserved correlation between the number of bathrooms and other measures of the size of the house. For both Melbourne and Brisbane, an additional bedroom leads to a 16 per cent higher price (bathroom data are very limited for these cities and therefore are not used in the final specification).

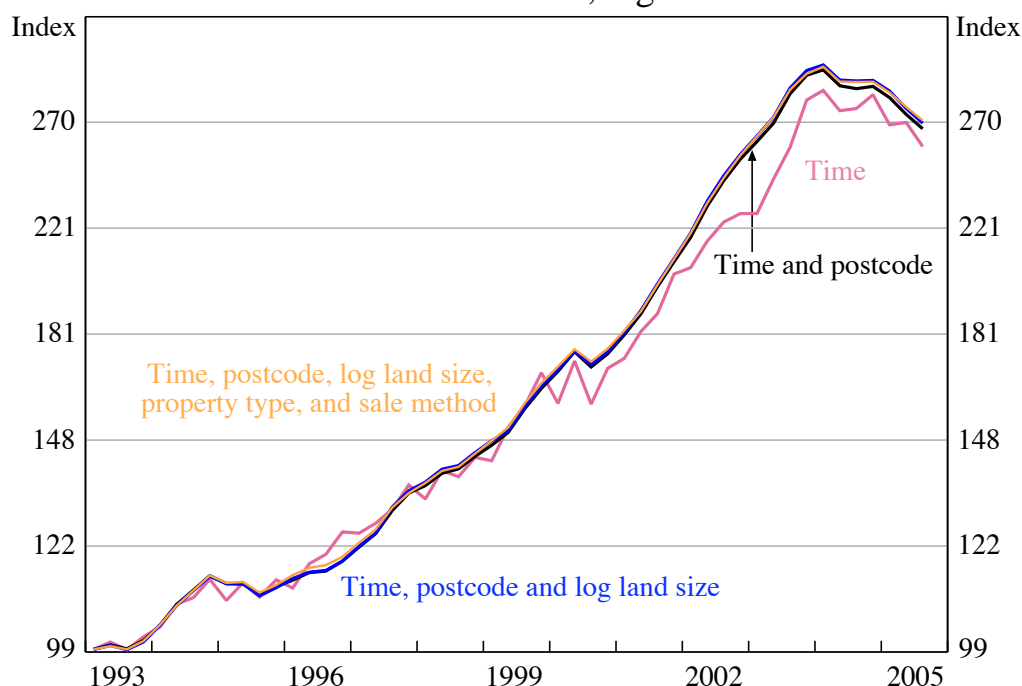
Houses generally sell for more than other types of detached or semi-detached dwellings (Table 2). In each city, coefficient estimates on the dummy variables for cottages, semis, terraces, townhouses and villas are mostly negative and significant (detached houses are the omitted property type dummy). The coefficient estimates on the method of sale suggest that properties sold through an auction process (either before, at or after an auction) sell for slightly higher prices than houses sold through a private treaty (private treaty sales are the omitted sale method dummy). However, since the decision regarding sale method is endogenous, this effect most likely reflects a positive correlation between the sale method and the quality of the house.

Finally, it seems that the estimates of pure price changes (as measured through the time dummy coefficients) are quite robust to variation in the specification. Reverting to a much larger sample of data where information on postcode, property type, sale method, and land size are available, we can see that omitting some of the key characteristic variables (with the exception of postcode) makes little difference to the pure price change estimates (Figure 1).¹⁶

¹⁵ The standard deviation of the log land size in the median postcode is 0.38 for Sydney, 0.45 for Melbourne and 0.52 for Brisbane.

¹⁶ Although this result cannot be generalised to the full sample using all characteristics data for Sydney (postcode, property type, sale method, land size, bedrooms, bathrooms, zoning), it does hold for the characteristics that are available for the full sample, which include postcode, property type and sale method; the same is true for Melbourne and Brisbane.

Figure 1: Restricted Hedonic Measures for Sydney
 March 1993 = 100, log scale



Note: Based on a sub-sample of approximately 500 000 observations.

Sources: APM; author's calculations

4.3 Repeat-sales Measures

I now estimate alternative repeat-sales specifications, limiting the dataset to houses which have turned over at least twice in the sample period. Specifically, I compare the repeat-sales formulation in Equation (4), which is an equally-weighted geometric measure, with two alternatives proposed by Shiller (1991): an equally-weighted arithmetic measure; and a value-weighted arithmetic measure.¹⁷ The equally-weighted geometric and arithmetic measures, by construction, give an equal weight to price changes in houses of different value. Each can be interpreted as an index of the value of a portfolio of housing with equal dollar amounts invested in houses of different value (the only difference is that the former uses geometric means in its formulation while the latter uses arithmetic means). In contrast, the value-weighted arithmetic index places a higher weight on price changes in more expensive houses. Accordingly, it can be interpreted as an index of the value of a portfolio which replicates the aggregate stock of housing.

¹⁷ For an overview of the construction of these indices see Appendix C.

While APM data can be used for both Sydney and Brisbane, REIV data must be used for Melbourne (since this allows repeat sales to be matched). For each of these three indices, I estimate a version without a constant (the base case), and another with a constant. In the case of the equally-weighted geometric measure these regressions are:

$$p_{it} - p_{i\tau} = \sum_{t=1}^T G_{it} \lambda_t + \eta_{it} \quad (7)$$

and:

$$p_{it} - p_{i\tau} = \sigma + \sum_{t=1}^T G_{it} \lambda_t + \eta_{it} \quad (8)$$

Equation 8 is a modification proposed by Goetzmann and Spiegel (1995) where the constant (σ) is designed to capture the average of any non-temporal effects on prices growth. This may be a reasonable approximation if quality change is related to the act of resale rather than the length of the holding period.

Table 3 summarises the average rate of prices growth (defined as average annualised growth between March 1993 and September 2005), the root mean squared error (RMSE) of the estimated rates of prices growth, and the squared sample correlation (SSC). The RMSE provides a guide to the magnitude of the variability in house prices growth that cannot be explained by each of the models. It comprises both idiosyncratic variation – that variation in prices growth which cannot be explained by the model and is house-specific – and error, which is variation associated with imperfect data or misspecification (Case and Szymanoski 1995).¹⁸ The SSC provides a gauge of the fit of the model – that is, the extent to which a high RMSE can be explained by idiosyncratic variation or, alternatively, a poor-fitting model.¹⁹ In other words, a high value of the SSC indicates that the error associated with mismeasurement or misspecification is likely to be low relative to idiosyncratic error.

¹⁸ For a more thorough discussion of the use of regression diagnostics in comparing different approaches to house price measurement, see Case and Szymanoski (1995) and Crone and Voith (1992).

¹⁹ In models with a constant, the SSC is equivalent to the unadjusted R^2 .

Table 3: Repeat-sales Measures

	Equally-weighted geometric	Equally-weighted arithmetic	Value-weighted arithmetic
<i>Sydney – no constant</i>			
Prices growth ^(a)	8.8	9.3	9.0
RMSE	25.2	25.4	25.4
SSC	49.0	48.8	48.4
<i>Sydney – constant</i>			
Prices growth ^(a)	7.8	8.1	7.9
RMSE	25.1	25.4	25.7
SSC	49.1	48.8	48.6
Constant	5.1	5.4	11 960
(p-value)	0.00	0.00	0.00
<i>Melbourne – no constant</i>			
Prices growth ^(a)	9.5	10.2	9.6
RMSE	25.5	25.6	25.5
SSC	54.1	54.0	54.0
<i>Melbourne – constant</i>			
Prices growth ^(a)	8.5	8.8	8.7
RMSE	25.3	25.7	25.7
SSC	54.1	54.0	54.1
Constant	5.1	5.7	7 675
(p-value)	0.00	0.00	0.00
<i>Brisbane – no constant</i>			
Prices growth ^(a)	7.8	8.4	8.1
RMSE	25.5	25.7	25.7
SSC	50.7	50.0	49.4
<i>Brisbane – constant</i>			
Prices growth ^(a)	6.0	6.3	6.3
RMSE	25.0	26.1	26.3
SSC	51.3	51.0	50.7
Constant	8.6	10.3	12 873
(p-value)	0.00	0.00	0.00

Notes: APM data are used for Sydney and Brisbane. REIV data are used for Melbourne. All figures are percentage point terms except for the p-values, which are probabilities, and the value-weighted arithmetic constant, which is a measure of the average increase in the price level associated with non-temporal quality change.
(a) Estimated average annual rate of prices growth.

Sources: APM; REIV; author's calculations

The three measures are remarkably similar in terms of their RMSE and SSC statistics. The average RMSE is around 25 per cent for all cities. This compares to an average price change of around 43 per cent for Sydney, 42 per cent for Melbourne (using REIV data) and 35 per cent for Brisbane. The average SSC is around 50 per cent for all cities, which implies that approximately half of the variation in prices growth is common across houses and half is idiosyncratic.

The similarities in the RMSE and SSC statistics for the different repeat-sales measures confirm that the repeat-sales estimator chosen does not have a large effect on model fit. There is, however, some (typically small) difference in the average prices growth inferred. The equally-weighted arithmetic measure generally points to higher prices growth than the equally-weighted geometric measure and the value-weighted arithmetic measure, implying that prices of high-value houses grew less, on average, than other houses between 1993 and 2005.

The data reject the hypothesis that the constant should be excluded in the repeat-sales regression for all cities. The positive estimates of the constant imply that the pure price changes have been lower than suggested by actual prices. The estimated value of the constant suggests that non-temporal price change is around 5 per cent for Sydney and Melbourne and around 9 per cent for Brisbane. However, the improvement in model fit associated with the inclusion of a constant is small.

4.4 Comparing Preferred Hedonic and Repeat-sales Measures

I now compare the hedonic and repeat-sales specifications. For the hedonic regression, I use a restricted specification with implicit price relativities set to be equal for both single and repeat sales ($\gamma_t = 0$) and constant over time ($\beta_t = \beta$).²⁰ Although this restricted specification is rejected by the data, it is the simplest, is commonly used and, more importantly, makes no difference to the estimates of the pure price changes. For the repeat-sales measure, I use the equally-weighted geometric measure without a constant (see Equation (7)), since this is conceptually closest to the preferred hedonic measure.

²⁰ The characteristic variables used in the restricted hedonic regression include postcode, property type and sale method because these data are available for the full sample. The results are similar if additional characteristic variables, such as log land size, are included and a smaller sample is used.

The first two columns of Table 4 report the RMSE and SSC comparing estimated price changes with the actual price changes for each house in the repeat-sales sample (single sales are excluded). The RMSE statistics are very close for both the hedonic and repeat-sales regressions, and indeed very similar across cities, at around 25 per cent. Similarly, the SSC statistics are close with approximately 50 per cent of the variation in prices growth in the repeat-sales sub-sample explained by each of the models. These results suggest that using either a restricted hedonic approach, which controls for postcode, property type and sale method, or a repeat-sales measure is broadly equivalent in terms of model fit.

Table 4: Comparison of the Parametric Measures

	Comparison of actual and fitted growth rates (RS)		Comparison of actual and fitted log prices (RS v AS)	
	RMSE (percentage points)	SSC (per cent)	RMSE (per cent)	SSC (per cent)
<i>Sydney</i>				
Hedonic (RS)	25.3	49.0	28.4	80.2
Repeat-sales (RS)	25.2	49.0	na	na
Hedonic (AS)	25.3	48.8	30.0	77.9
<i>Melbourne</i>				
Hedonic (RS)	25.7	53.9	32.4	72.3
Repeat-sales (RS)	29.4	44.9	na	na
Hedonic (AS)	25.8	53.8	32.7	72.3
<i>Brisbane</i>				
Hedonic (RS)	25.6	49.9	33.5	62.4
Repeat-sales (RS)	25.5	50.7	na	na
Hedonic (AS)	25.6	50.3	35.1	59.1

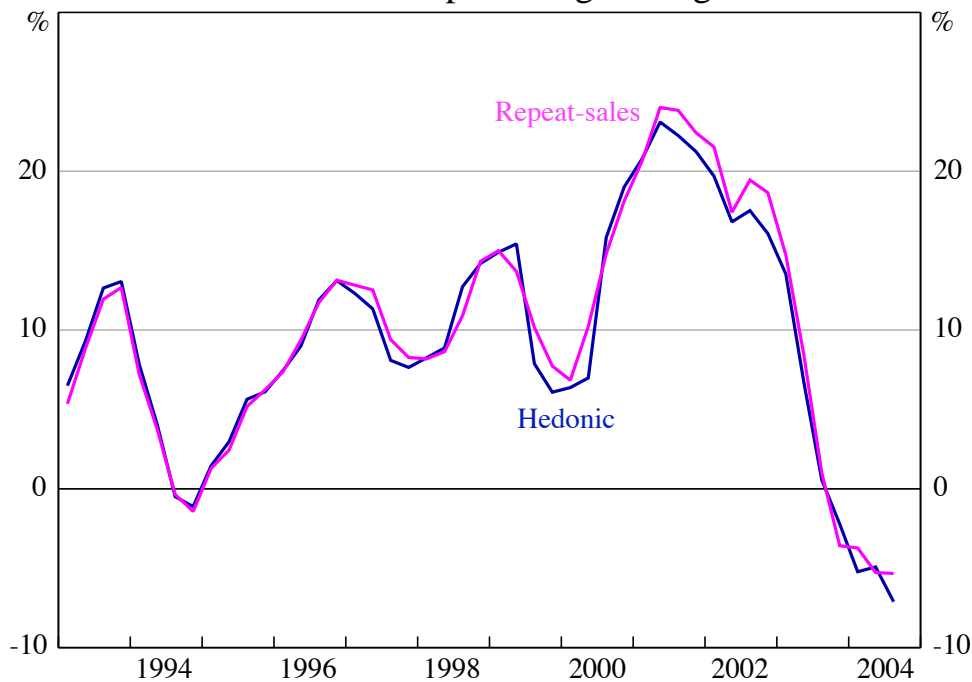
Notes: All statistics are calculated using data between the March quarter 1993 and the September quarter 2005. APM data are used for Sydney and Brisbane. REIV data are used for Melbourne. RS uses the repeat-sales sub-sample for estimation and AS uses the full sample (including single sales) for estimation.

Sources: APM; REIV; author's calculations

I also consider whether the inclusion of single sales, which may have different idiosyncratic price variability than repeat sales, can influence the fit of the restricted hedonic model. The final two columns of Table 4 show that the RMSE is higher and the SSC is lower when including single sales in the restricted hedonic model. This confirms that single sales are harder to predict and exhibit more idiosyncratic variation than repeat sales. Consistent with the previous findings, estimates of the pure price changes inferred from the restricted hedonic and

repeat-sales approaches are very similar. Using Sydney as an example (Figure 2), estimates of pure price changes are remarkably similar for both measures, even though repeat-sales exclude all single sale information. This seems to imply that, when using very large samples, theoretical concerns regarding the most appropriate specification may not be as much of a problem empirically as studies that use smaller samples of data suggest.

Figure 2: Hedonic and Repeat-sales Measures for Sydney
Year-ended percentage change

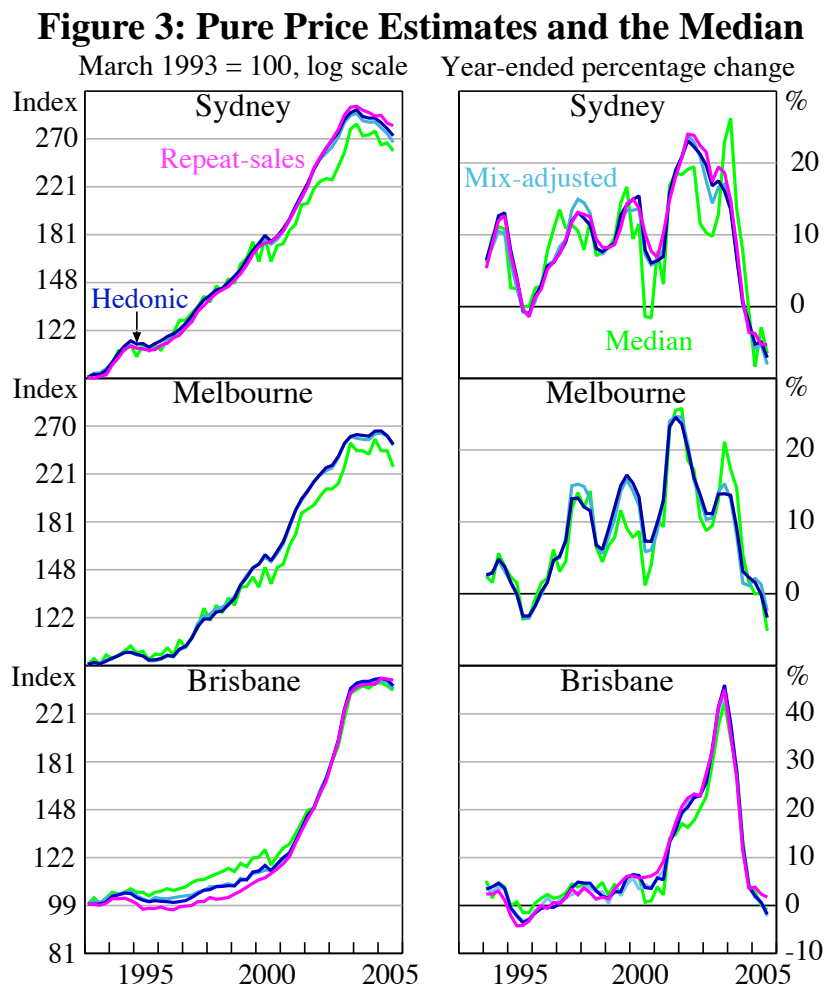


Sources: APM; author's calculations

4.5 Regression-based and Non-regression-based Measures

I also compare the preferred hedonic and repeat-sales measures of pure price changes with a mix-adjusted approach developed by Prasad and Richards (2006) and a simple median. The results using APM data for the three cities are shown in Figure 3. They demonstrate that there are noticeable differences between the median and the more advanced measures (hedonic, repeat sales and mix-adjusted), suggesting that adjusting for the composition, and to a much lesser extent, quality of properties sold, may provide better estimates of pure house price changes.

Focusing on Sydney, there is substantially less variability in the regression-based measures when compared with the median, which points to much larger short-term swings in prices growth. Further, since the timing of turning points in the median does not always coincide with those inferred from the more complex measures, there appears to be several situations in which these measures have provided more consistent signals of the direction of pure house price changes. There is a strong similarity between the hedonic, repeat-sales and mix-adjusted measures. This suggests that a simple stratification-based approach can produce qualitatively similar results to regression-based approaches, which adjust for compositional and limited quality change (see Section 4.6 for further discussion of quality change).



Sources: APM; author's calculations

Similar results are observed for Melbourne, although a repeat-sales measure cannot be constructed for this city using APM data. Repeating the exercise

using REIV data, which permit the construction of repeat-sales, provides a similar picture (see Appendix D). The regression-based measures are comparable, whereas the median appears to underestimate pure price changes. For Brisbane, the median price index is somewhat closer to the regression-based pure price indices. Even so, there are still periods of noticeable divergence. The more advanced measures of pure price changes provide higher estimates of average annual growth than the median for Sydney and Melbourne (Table 5). Over the full sample, this amounted to a 0.6 and 1.2 percentage point difference in average annual growth between the advanced measures and the median for Sydney and Melbourne (using REIV data) respectively. This may have been due to an increase in turnover in lower-value postcodes, usually the outer suburbs, where new additions to the housing stock have become more prevalent in recent years. This does not appear to be as prominent in Brisbane, however, where the average annual growth of the more advanced measures is only slightly higher than that of the median.

Table 5: House Prices Growth and Volatility

	Average annual growth ^(a)	Standard deviation ^(b)
<i>Sydney</i>		
Median	7.84	4.35
Mix-adjusted	8.16	2.33
Hedonic	8.39	2.26
Repeat-sales	8.76	2.21
<i>Melbourne</i> ^(c)		
Median	8.01	5.23
Mix-adjusted	8.72	2.52
Hedonic	9.44	2.45
Repeat-sales	9.50	2.53
<i>Brisbane</i>		
Median	7.41	3.23
Mix-adjusted	7.46	3.09
Hedonic	7.57	3.14
Repeat-sales	7.78	3.04

Notes: (a) Average effective annual growth between the March quarter 1993 and the September quarter 2005.
(b) Calculated using the standard deviation of the quarterly percentage changes between the June quarter 1993 and the September quarter 2005.
(c) REIV data are used for all Melbourne calculations.

Sources: APM; REIV; author's calculations

A comparison of the standard deviations of quarterly growth rates of alternative approaches suggests that the regression-based measures of pure prices tend to be smoother than the median, on average. Specifically, the average standard deviation of the hedonic and repeat-sales measures is approximately half the standard deviation of the median for Sydney and Melbourne (using REIV data). The decline in the standard deviation is much smaller for Brisbane with the average standard deviation of the regression measures only marginally below that of the median. It is also possible to examine whether the various measures constructed are different in a statistical sense – that is, whether there is any overlap between the confidence intervals of the level of each measures' index constructed at the 95 per cent level of significance.²¹ Table 6 reports the proportion of the sample over which the various measures are statistically different. For all cities, the median is, on average, statistically different to the more advanced measures for at least half of the sample. In contrast, the more advanced measures tend to be more similar, as there are fewer periods where the measures are statistically different.

These results are consistent with findings from previous Australian studies that are based on smaller geographic regions. Specifically, using Port Pirie (South Australia) as a case study, Rossini *et al* (1995) find large differences in the annual prices growth of a median when compared with a hedonic measure and a repeat-sales median. Similarly, Costello (1997) shows, using strata title property for Scarborough (Western Australia), that hedonic and repeat-sales regressions provide better estimates of pure price changes than a mean or median, though he emphasises the importance of choosing a correct regression relationship. My findings suggest, at least for very large samples, that specification, while not inconsequential, is a second-order issue (so long as there is some control for compositional change). Flaherty (2004) uses house sales data for 10 Melbourne suburbs (Victoria) and finds that a hedonic index, estimated separately for each suburb, is significantly different from the median or mean for each suburb.

²¹ For further discussion of the construction of the confidence intervals for each measure, see Appendix A.

Table 6: Proportion of Sample over which Measures are Statistically Different

	Median	Mix-adjusted	Hedonic	Repeat-sales	Average CI width ^(a)
<i>Sydney</i>					
Median	0.00				4.25
Mix-adjusted	0.42	0.00			7.84
Hedonic	0.58	0.00	0.00		3.21
Repeat-sales	0.68	0.16	0.34	0.00	3.99
Average ^(b)	0.56	0.19	0.31	0.39	4.82 ^(d)
<i>Melbourne^(c)</i>					
Median	0.00				5.02
Mix-adjusted	0.16	0.00			11.15
Hedonic	0.90	0.48	0.00		7.21
Repeat-sales	0.82	0.62	0.02	0.00	11.94
Average ^(b)	0.63	0.42	0.47	0.49	8.83 ^(d)
<i>Brisbane</i>					
Median	0.00				3.47
Mix-adjusted	0.28	0.00			8.27
Hedonic	0.68	0.00	0.00		2.89
Repeat-sales	0.76	0.16	0.50	0.00	3.00
Average ^(b)	0.57	0.15	0.39	0.47	4.41 ^(d)

Notes: Calculated using the 95 per cent level of significance between the June quarter 1993 and the September quarter 2005.

(a) Average confidence interval width calculated using the log of the index level (March 1993 = 100).

(b) Average proportion compared with the other measures.

(c) REIV data are used in all Melbourne calculations.

(d) Average of all measures.

Sources: APM; REIV; author's calculations

4.6 Quality Change

Figure 3 demonstrates that the hedonic, repeat-sales (without a constant) and mix-adjusted measures are all quite similar. This may be somewhat surprising because the hedonic measure is constructed, in principle, so as to control for quality change over time while the other two measures are not. It is likely, however, that the hedonic measure shown may not be adjusting adequately for quality change given the limited information on characteristics it includes (that is, postcode, property type and sale method).

To explore this further, I examine whether the pure price estimates from a hedonic specification that uses all available data on quality are different from the hedonic specification shown in Figure 3. Using a common sample, the results suggest that controlling for additional characteristics (namely, log land size, bedrooms, bathrooms and zoning) leads to higher estimates of pure prices growth (about 0.9 percentage points per annum for Sydney, 0.5 percentage points per annum for Melbourne and 2 percentage points per annum for Brisbane). On face value, this result implies that overall quality has actually fallen over the sample period. It appears, for the relatively small Sydney sample where complete data on quality are available, that on average, across all postcodes, the number of bedrooms and bathrooms of houses sold has declined from the first half to the second half of the sample period (a similar decline can be observed in the average number of bedrooms across postcodes in Melbourne). Whether such a result reflects actual quality change or a shift in the types of properties sold (compositional effects), and whether it would hold for larger samples of data and over other features of quality is unclear.

An alternative way to account for quality change is to include a constant in the repeat-sales regression. Based on previous estimates (see Table 3), non-temporal quality change is estimated at around 5 per cent for Sydney and Melbourne and around 9 per cent for Brisbane (using the equally-weighted geometric repeat-sales measures). Using the average rate of turnover for resales (around 15 quarters for Sydney and 14 quarters for Melbourne and Brisbane), this would suggest a quality-related price increase over the sample period of around 1.3, 1.4 and 2 per cent per annum for Sydney, Melbourne and Brisbane respectively. In comparison, repeat-sales estimates of pure prices growth from the same regressions amount to 7.8, 8.5 and 6.0 per cent per annum respectively for the three cities (Table 3).

5. Conclusion

This paper has summarised some of the key theoretical issues in measuring house prices and how different approaches to price measurement attempt to control for compositional and quality change. In principle, hedonic and repeat-sales approaches can provide the best estimates of pure house price changes as they can adjust for both effects. Mix-adjusted measures also have the potential to be useful in circumstances where changes in the quality of the dwelling stock are relatively minor, which is likely to be the case over short horizons.

Notwithstanding these theoretical advantages, whether the regression-based measures offer a better estimate of pure price changes than a simple median or mix-adjusted measure is largely an empirical question. To examine this I compare several regression-based alternatives using unit record sales for approximately half of the Australian market, between March 1993 and September 2005. The results suggest that hedonic and repeat-sales measures are not overly sensitive to alternative specifications and provide similar estimates of pure price changes. These measures are also comparable to a simple mix-adjusted approach developed by Prasad and Richards (2006). In contrast, the estimates are quite different from the price changes observed in the median, suggesting that compositional change does matter in Australia.

A caveat to these results is that the basic hedonic measure does not appear to capture changes in the quality of houses over time. Using additional quality regressors in the hedonic approach seems to suggest that, if anything, quality may have declined marginally over time (or there has been some compositional shift to smaller properties). This result could reflect the fact that the sub-samples which have most data on housing characteristics are relatively small, and that many aspects of quality are not captured in the available data (for example, quality related to fittings, fixtures, building materials, size of the dwelling structure and so forth). Indeed, using a repeat-sales measure with a constant as an alternative control for quality infers a modest quality-related price increase over the sample period.

In view of the desirable theoretical and practical properties of hedonic and repeat-sales measures, they appear to complement existing house price measures. They provide useful estimates of pure price changes, and information about the magnitude of compositional and quality change in Australia.

Appendix A: Confidence Intervals

For the median confidence interval, I assume that house prices are log-normally distributed. Therefore, the median will be approximately log-normally distributed in large samples as follows (Miller and Miller 1999):

$$\ln(M_t) \sim N[\ln(M_t), \Pi\sigma_t^2/4n_t] \quad (\text{A1})$$

where M_t is the median price of houses sold at time t , σ_t is the standard deviation of log prices at time t and n_t is approximately half the total number of sales at time t (it is the number of sales up to and including the median).²²

For the mix-adjusted interval, I first calculate the distribution of the median for each decile in each time period. As above, it is assumed that prices are log-normally distributed and therefore:

$$\ln(M_{i,t}) \sim N[\ln(M_{i,t}), \Pi\sigma_{i,t}^2/4n_{i,t}] \quad (\text{A2})$$

Given $\bar{m}_t = (\sum_{i=1}^{10} \ln(M_{i,t}))/10$ (where \bar{m}_t is the log of the mix-adjusted measure at time t), and assuming that the sample median of each of the deciles are independently distributed:

$$\bar{m}_t \sim N[\bar{m}_t, (\sum_{i=1}^{10} \sigma_{i,t}^{adj}/10)^2] \quad (\text{A3})$$

where $\sigma_{i,t}^{adj} = \sqrt{\Pi\sigma_{i,t}^2/4n_{i,t}}$. Both the median and mix-adjusted intervals should be treated as indicative, given that the assumptions of log-normality (and independence across decile medians) are not clearly supported by the data.

For our preferred hedonic and repeat-sales measures, the confidence intervals constructed use heteroskedastic-consistent standard errors from their respective OLS regressions.

²² It should be noted that Equation (A1) is also an approximation in the sense that it assumes the log of the median price is sufficiently close to the median of log prices. This is reasonable given the large samples of data used.

Appendix B: Data Preparation

The data used in this study were provided by Australian Property Monitors (APM) and the Real Estate Institute of Victoria (REIV). APM provided house sales data for Sydney, Melbourne and Brisbane from the March quarter 1993 to the September quarter 2005 (REIV provided data for Melbourne). The data were separated into their respective cities and all observations satisfying the following criteria were removed:

- no valid contract date (including missing observations and observations outside of the sample period);
- undisclosed price or an inconsistency in the price recorded (as noted by APM or REIV);
- outside the statistical division of each respective city;
- missing postcode;
- negative or zero sale prices;
- property types other than a cottage, house, semi-detached, terrace, townhouse or villa;
- duplicate observations, in terms of all house characteristics, the date of sale and price; and
- properties in suburbs outside of the metropolitan area (as defined by APM).

A small number of observations were also removed when comparing alternative hedonic specifications on sub-samples of the data (Table 2). Specifically, records with a land size in the top and bottom 1 percentile of the data for each city were excluded from estimation. Also, one record with 91 bedrooms was omitted for Sydney. These observations were omitted to reduce the influence of outliers and ensure plausible estimates of the implicit price relativities.

Appendix C: Repeat-sales Alternatives

Consistent with Shiller (1991), the value-weighted arithmetic repeat-sales index can be inferred from the following regression:

$$Y = X\beta + \mu \quad (\text{C1})$$

where X is a $(i \times t)$ matrix of independent variables where each element i,t is equal to: the resale price if house i was resold in period t ; the previous sale price if house i was previously sold in period t ; and 0 otherwise.²³ The vector Y of dependent observations is defined such that Y_i equals the initial sale price of house i if sold in the base period, and 0 otherwise. The reciprocal of the element t of β provides an estimate of the mean price in period t relative to the mean price in the base period.

However, as pointed out by Shiller (1991), with stochastic independent variables there exists an errors-in-variables problem. To correct for this, I take the instrumental-variables estimator proposed by Shiller, $\hat{\beta} = (Z'X)^{-1}Z'Y$, where the element i,t of Z is 1 if house i was resold in period t , -1 if house i was previously sold in period t , and 0 otherwise.

For the equally-weighted arithmetic repeat-sales index, row i of the instrumental variables regression of Equation (C1) is divided by the initial sale price of house i (for all i). The resulting index will be an equally-weighted arithmetic index. The advantage of this approach is that efficiency may be improved in estimation – a proportional error is obtained rather than a levels error – and an equally-weighted index may be conceptually preferred to a value-weighted index.

²³ To avoid perfect multicollinearity, the first column of X relates to the first period of sales after the base period.

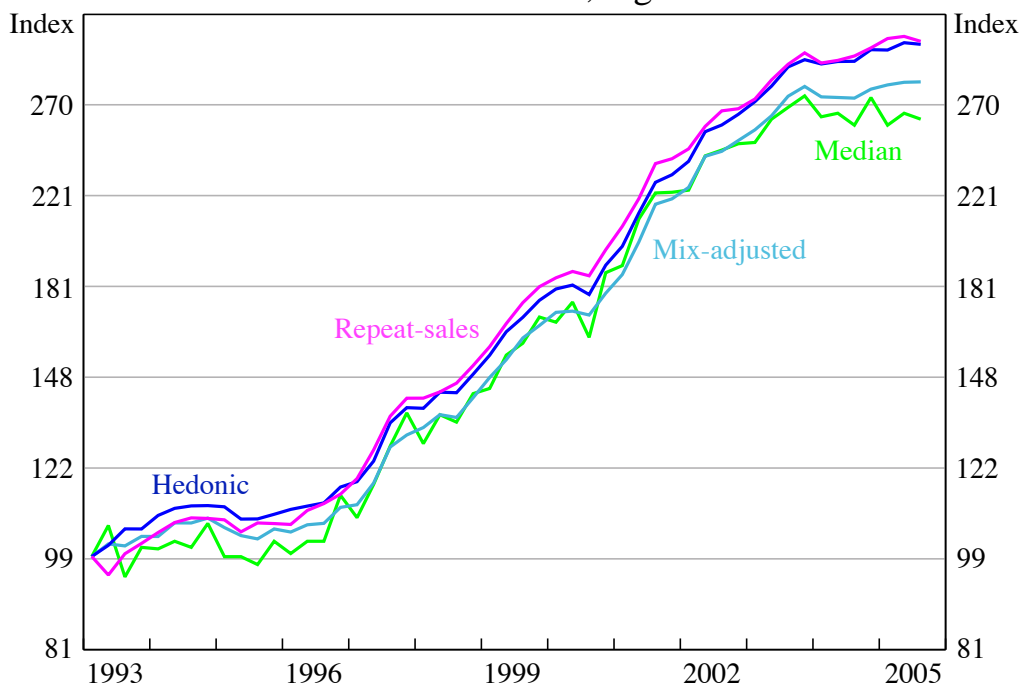
Appendix D: REIV Comparison

The Real Estate Institute of Victoria (REIV) supplied house-record data for Melbourne (approximately 350 000 observations). The advantage of using REIV data is that it includes information on the street number of the house sold, which allows a repeat-sales measure to be constructed. It also contains more detailed house characteristics data allowing analysis of potentially richer hedonic specifications. While this may be an avenue for further research, I focus on using REIV data to compare the preferred hedonic and repeat-sales measures with a mix-adjusted and median measure.

Figure D1 highlights that the regression-based measures using REIV data are qualitatively similar, as in the case of these same measures based on APM data (Figure 3). In particular, the hedonic and repeat-sales measures follow each other closely, and imply a less volatile and higher path of pure prices growth over time when compared with the median. The mix-adjusted measure based on REIV data follows the median relatively closely, suggesting that it provides less of an adjustment for compositional change than in the case of measures based on APM data.

Figure D1: All Measures Using REIV data

March 1993 = 100, log scale



Sources: REIV; author's calculations

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