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Predicting Dwelling Prices with Consideration of the Sales Mechanism

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Abstract

Using dwelling prices in Australia's two largest cities, we consider whether the way in which a property is sold, either through an auction or a private-treaty negotiation, is informative for predicting dwelling prices. We find evidence to suggest that average prices of dwellings sold at auction are informative for forecasting growth in average private-treaty prices and average sales prices overall. In contrast, we find little evidence to suggest that dwellings sold through private-treaty are similarly informative.

Interpreting these results using two models of price determination – an English auction where buyer values are positively correlated, and inferred through the auction process, and a private-treaty sale where the price is determined by a Nash bargain – we find that auction prices better reflect a common trend in prices and are therefore more useful when forecasting. In contrast, private-treaty prices are affected by shocks that are specific to that mechanism of trade, such as changes in the relative strength of the bargaining positions of buyers and sellers, or changes to the dispersion of valuations. These shocks appear to reduce the usefulness of private-treaty prices for forecasting or measuring short-run movements in the common price trend.

JEL Classification Numbers: D44, R31

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1. Introduction

The dramatic run-up in dwelling prices in many countries is generally accepted as playing a key role in the global financial crisis. Moreover, subsequent price falls have had large effects on economic activity and inflation. For these reasons, as well as more generally, policymakers are interested in understanding dwelling prices to help inform their views on the appropriate stance of monetary, fiscal and financial stability policies.

This paper asks whether the prices of dwellings traded under different sales mechanisms have different statistical properties and provide different information for understanding and forecasting dwelling prices. To answer this question, we investigate the time series properties of dwelling price indices in Sydney and Melbourne, which cover roughly 40 per cent of all Australian dwelling sales, and distinguish between the prices of dwellings transacted via bilateral negotiations (private-treaty sales) and the prices of dwellings that were auctioned.

There are several reasons why auction and private-treaty prices might provide different information and perform differently when forecasting future prices. First, auction prices could measure the common stochastic trend underlying all dwelling prices (hereafter the common trend) more precisely. One reason for this is that prices determined through auction have the potential to incorporate information (views about the value of a dwelling) from every bidder (hereafter buyer) that participates.

An example of such a case is when buyer valuations are correlated (or formally, affiliated), bids are publicly announced (known to other buyers), and bidding strategies are symmetric (the same across buyers).[1] With these assumptions, the

1 A model of affiliation is discussed in Section 5. In broad terms, affiliation and publically announced bids imply that if other buyers continue to actively make bids as the price of the dwelling rises during an auction, then each buyer upwardly revises their own assessment of the dwelling's value using the information contained in others' bids.

English auction – the mechanism commonly used in Australia – yields a sale price that incorporates information from every buyer who actively makes a bid in the auction. This is because buyers use information contained in other participants' bids to help refine their own estimate of a dwelling's value.

In contrast, when prices are determined through a private-treaty sale, the number of views that have a role in determining the sale price for a dwelling is much smaller. In the case of a two-party bilateral negotiation between a buyer and seller, only information from those two parties may be directly incorporated into the price.

Price indices are, however, formed by averaging prices across a large set of transactions. In the data we have, there are seven (Melbourne) to ten (Sydney) times as many private-treaty transactions as there are auctions. This means that the disadvantage of fewer views being incorporated into each private-treaty price could be offset by having a larger set of views incorporated into the average price through more transactions. Whether average auction prices are a more precise measure of the common trend in dwelling prices is, therefore, an empirical question that we address in Sections 3 and 4.

A second reason that the sale mechanism could matter is that auctions and private-treaties weight buyers' and sellers' valuations differently. We argue that auctions are likely to place a relatively higher weight on buyers' valuations.[2] If buyers' and sellers' valuations evolve differently over time or the gap between the valuations of these two groups changes, this could be a second channel through which the type of sale is informative.

Indeed, a lag in the response of sellers' valuations to new information is consistent with a number of documented phenomena in the housing market including: that sellers' liquidity can be affected by changing prices (also known as equity lock-in: Stein (1995); Genesove and Mayer (1997)); that sellers may weight losses as compared to gains from a sale asymmetrically (for example, being more reluctant to incur a loss: Genesove and Mayer (2001)); and that sellers may have different

2 In the absence of a reserve price, auctions will put all the weight on buyers' values. Even when reserve prices are used, we show that prices are still primarily determined by buyers when valuations are affiliated (Appendix D). In contrast, private-treaty prices typically reflect both buyers' and sellers' values, with weights equal to relative bargaining power for the Nash bargaining case.

information than buyers (Carrillo (2012); Genesove and Han (2012)). In contrast, buyers are less likely to respond with a lag to new information because they visit more properties and are less likely to be constrained by factors such as loss aversion or equity lock-in. Differences in the stickiness of valuations could result in differences in the autocorrelation of price growth from auction and private-treaty sales.

Using these ideas as our motivation, we investigate whether auction and private-treaty prices have different statistical properties and provide different information about dwelling prices and their forecasts. In particular, we investigate the extent to which alternative price measures are autocorrelated, can be used to predict one another, and can be used to predict average price growth overall. We also investigate whether the effects of shocks with differing degrees of persistence can be identified.

Using dwelling prices in Sydney and Melbourne, we find that auction prices can be used to predict both private-treaty prices and average dwelling prices (Section 3). For example, including lagged auction prices can reduce the one-quarter-ahead mean-squared forecasting error for average dwelling price growth by 10 and 18 per cent when compared with a simple forecasting benchmark, for Sydney and Melbourne respectively. In contrast, private-treaty prices are not useful for predicting auction price growth and have only limited predictive content for price growth in general. These results are quite remarkable, given that auctions are a small share of overall transactions.

We also find that auction prices have less autocorrelation in their changes (growth) than private-treaty prices, are less sensitive to transitory shocks, and converge more quickly to their new long-run or equilibrium value in response to a permanent shock (Section 4). As an example of the latter, at least 60 per cent of the adjustment to a permanent shock occurs within one quarter for auction prices, whereas less than 35 per cent of the adjustment occurs in private-treaty prices over the same time frame. In sum, our empirical results suggest that auction prices better reflect the common trend in all prices, incorporate new information more quickly, and are therefore more useful for forecasting.

We examine whether our results are consistent with two simple models of price determination (Section 5) – an English auction where buyers' valuations are linearly affiliated, and a bilateral Nash bargain. Our analysis points to a few core ideas that are required to link these two models with our empirical findings. First, even if an individual auction price incorporates more information (a larger set of valuations) than a private-treaty price, this by itself cannot account for the empirical results. In particular, once prices are averaged across a large set of transactions, any additional precision in the measurement of the common trend in price using auctions is unlikely to be large.

Second, a more plausible explanation of our findings is that there is a difference in the relative importance of buyers' and sellers' valuations across the two sale mechanisms. As discussed above, the theoretical models provide insight into why average auction prices weight buyer valuations more than average private-treaty prices. We further show that this can only explain the different autocorrelation properties observed in the data if seller valuations take time to respond to new information.

Third, we show that the average dispersion of sellers' valuations and the relative bargaining strength of buyers and sellers are important for the determination of private-treaty prices, but not auction prices. This is related to the differential weighting of buyers and sellers across the two price mechanisms. It is also reflects the fact that negotiation is crucial in bilateral trade, but less important for auctions.

Finally, although differences in the relative importance of buyers' and sellers' valuations, in the dispersion of valuations, and in relative bargaining strength are all important for price determination in the short run, they do not affect prices in the long run. In the long run, theory and the data suggest that both auction and private-treaty prices converge to a single common trend.

Bringing these ideas together, our results point to important differences in the short-term factors that drive changes in auction prices, compared with private-treaty prices. These differences are useful for identifying a common stochastic trend in dwelling prices, separating permanent shocks from transitory shocks, and improving forecasts of average price growth overall. Our results should prove useful both narrowly, in arguing for using auction prices (separately) in predicting near-term dwelling prices, and broadly, in demonstrating that the sale mechanism matters for price formation.

2. Data and Measurement

Our primary data source is a near-census of all dwelling sales in Sydney and Melbourne between March 1993 and December 2012, which make up about 40 per cent of all sales in the Australian housing market over that period. These data are provided by Australian Property Monitors (APM),[3] and are an update of data previously used by Prasad and Richards (2008) and Hansen (2009).

Private-treaty is the most common mechanism used for selling dwellings in these two cities. Sales where an auction mechanism was used (or planned to be used) as part of a successful sale make up around 12 per cent of the Sydney sample and 17 per cent for Melbourne (Table 1, columns one and two).

Table 1: Overview of Sales Mechanisms Used

	Percentage of total observations[(a)]		Percentage of observations filtered for analysis[(b)]	
Transaction type	Sydney	Melbourne	Sydney	Melbourne
Pre- or post-auction	2.73	3.72	na	na
Sold at auction	8.83	13.01	9.30	13.90
Private treaty	88.46	83.26	90.70	86.10
Auction frequency	11.56	16.73	9.30	13.90
Total observations	1 763 032	1 677 925	1 652 585	1 498 549

Notes: (a) Percentage of total observations where an auction was used (or planned to be used) as part of a successful sale
(b) Percentage of observations after removing identified pre- and post-auction sales, private-treaty sales where an auction was used in the 90 days prior to the exchange of contracts, and observations where prices are not disclosed or there are address inconsistencies

In the analysis that follows (Table 1, columns three and four), we restrict our attention to properties sold successfully at auction when measuring auction prices. When measuring private-treaty prices, only those properties sold directly via a bilateral negotiation, with no involvement of an auction in the selling process, are used.[4] Using hedonic price regressions similar to those discussed below, the average conditional price difference between a property sold through an auction

3 In providing these data, APM relies on a number of external sources. These include the NSW Department of Finance and Services for property sales data in Sydney and the State of Victoria for property sales data in Melbourne. For more information about these data, see the Copyright and Disclaimer notices at the end of this paper.

4 See Table 1, Note (b).

and through a private-treaty is 4.2 per cent for Sydney and 5.1 per cent for Melbourne.[5]

To measure average prices we use hedonic price regressions. At the city-wide level, Hansen (2009) has shown that hedonic regressions can provide an accurate estimate of the composition-adjusted price change in dwellings – that is, average price growth after adjusting for changes in the mix of dwellings sold. The specification we use has the general form:

$$\ln P_{ijt} = \sum_{t=0}^{T} \gamma_t D_{it} + \sum_{j=1}^{J} \beta_j PC_{ij} + \sum_{k=1}^{K} \theta_k C_{ikt} + \varepsilon_{ijt}$$

The variable $\ln P_{ijt}$ is the logarithm of the sale price for dwelling i, in postcode j and at time t; D_{it} is a time dummy equal to 1 if sold in quarter t and zero otherwise; PC_{ij} is a postcode dummy equal to 1 if dwelling i is located in postcode j and zero otherwise; and C_{ikt} is the measure of the kth characteristic (or hedonic) control relating to the attributes of the dwelling at time t.

For Sydney, the hedonic controls include the number of bedrooms, number of bathrooms and the logarithm of a measure of the size of the dwelling.[6] We also allow for interaction effects between each of these characteristics and the type of the dwelling sold (for example, house, semi-detached, terrace, townhouse, cottage, villa, unit, apartment, duplex, studio).[7] For Melbourne, there are only limited data available on characteristics prior to the December quarter of 1997. To avoid an otherwise substantial reduction in sample size, we omit the bedroom, bathroom and size controls, but include controls for the dwelling type. Similar results are found when including the additional characteristic controls but using a smaller sample that begins in the December quarter of 1997.

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5 This is measured using an additional dummy variable for whether the dwelling is sold via auction or private-treaty.

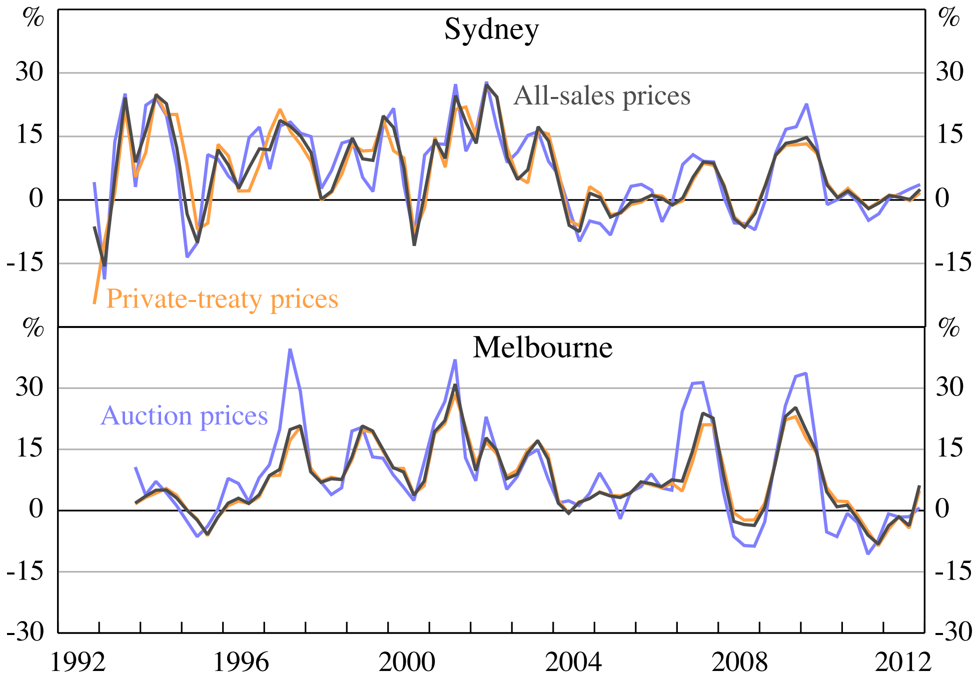
6 In the case of a house, the size is the total land area in square metres. In the case of a unit or apartment, it is typically a measure of the building area, but can also be the internal area in square metres depending on the source of the data.

7 The exception is when comparing forecasts out-of-sample. Given limited attributes data in the early part of the sample, and to avoid an otherwise substantial reduction in sample size, we exclude the bedroom, bathroom and size controls when estimating recursively and comparing out-of-sample forecasts.

Figure 1 reports, for Sydney and Melbourne, two-quarter-ended annualised growth of separate hedonic price indices for auction prices, private-treaty prices and all-sales prices. Figure 1 highlights that there are cycles in price growth over the sample period and that all three measures are highly correlated. However, it also clear that the price cycles are not fully synchronised, with some evidence to suggest that auction price changes lead the dwelling price cycle. This is most noticeable around turning points in price growth in both Sydney and Melbourne.

Figure 1: Comparison of Auction, Private-treaty and All-sales Prices

Two-quarter-ended annualised growth



3. Prediction

In this section we examine three questions:

1. Do auction prices and private-treaty prices have different autocorrelation properties (momentum)?
2. Do they perform differently when forecasting out-of-sample?
3. Do they perform differently when predicting one another in-sample?

Answering the first question speaks to the well-established literature on the efficiency of housing markets, which suggests that dwelling prices are positively autocorrelated, as discussed in Case and Shiller (1989), Cutler, Poterba and Summers (1991), Cho (1996) and Capozza, Hendershott and Mack (2004) among others. Differences in momentum can also provide insight into the ability of the data to discriminate between alternative theoretical models of the autocorrelation in buyers' and sellers' valuations (this is discussed further in Section 5). The second question addresses whether any gains in predictive content can be useful in real time and considers forecasting growth in a measure of average prices using all sales.

We also consider in-sample analysis, the third question, for three reasons. First, it is possible that revisions to the estimated price indices for either auction or private-treaty prices could affect out-of-sample forecasting performance. By focusing on the full sample of data we are able to abstract from the effects of revisions to the estimated price indices.

Second, in-sample analysis allows us to relax some of the assumptions maintained in the out-of-sample analysis. In particular, using in-sample techniques we can compare the ability of the two series to predict each other without necessarily assuming a vector error correction model (VECM) representation with finite lags.[8] Third, it has been argued that out-of-sample analysis can imply a loss of information and power relative to in-sample analysis (see, for example, Inoue and Kilian (2005)).

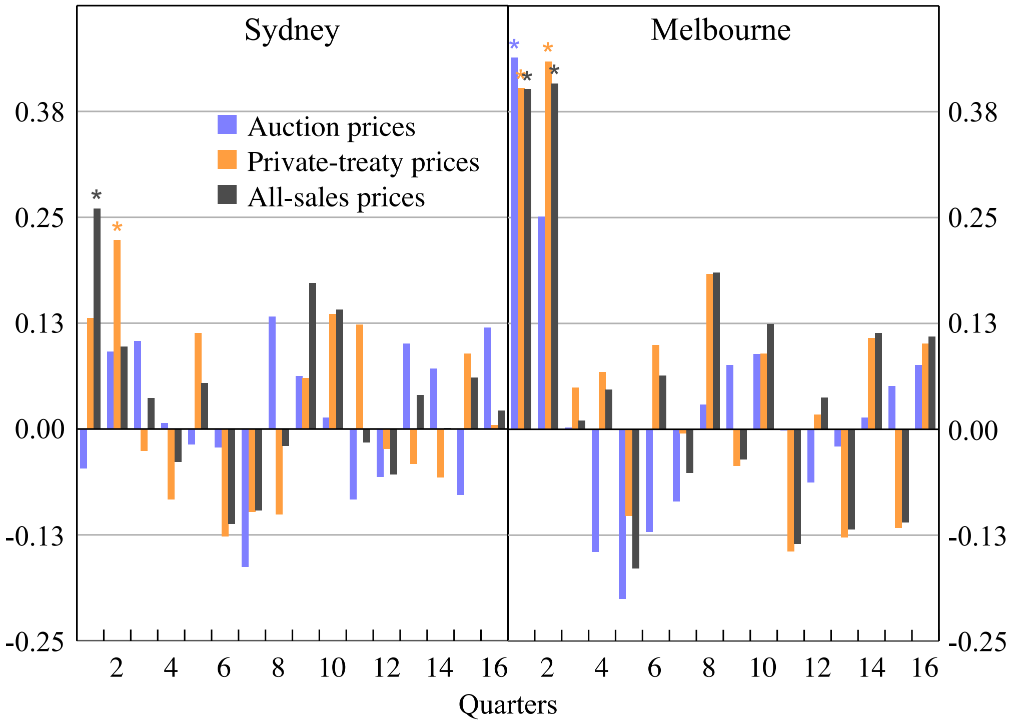
3.1 Momentum

Focusing first on the differences in autocorrelation properties, autocorrelation functions show that growth of average prices (all-sales price growth) is positively autocorrelated for up to one year, but that the strongest correlations are for the first two lags of quarterly growth (Figure 2). Considering the autocorrelation functions by sale mechanism highlights that all of the positive autocorrelation

8 Although a VECM with finite lags is a natural framework for modelling prices given that they are likely to share the same common trend, it is not an immediate implication of theory and so we build up a case to support this representation, rather than simply assume it is valid (see Appendices B and C).

in aggregate price growth for Sydney arises from the autocorrelation in private-treaty price growth; there is no evidence to suggest that auction price growth is positively autocorrelated. Indeed, auction prices follow a random walk with drift. This is a quite striking result and suggests that all available information concerning dwelling prices is fully incorporated into auction prices within a quarter, which is consistent with a weak version of the efficient market hypothesis.[9]

Figure 2: Autocorrelation Functions for Prices Growth



Note: Columns with asterisks denote significance at the 5 per cent level when using Bartlett's MA(q) formula.

For Melbourne, most of the autocorrelation in all-sales price growth is also driven by autocorrelation in private-treaty price growth, although there is some evidence of first-order autocorrelation in auction price growth. The difference in autocorrelation functions, with private-treaty price growth being more autocorrelated than auction price growth, will subsequently be useful for determining whether buyer or seller valuations are autocorrelated, as discussed further in Section 5.

9 See, for example, Cho (1996).

3.2 Out-of-sample

We now consider whether measures of average prices, separated according to the type of sale, are useful for predicting all-sales price growth out-of-sample and in real time. Specifically, we consider whether the inclusion of either lagged auction prices or lagged private-treaty prices can improve upon the one-quarter-ahead forecasts of all-sales price growth when using a single equation autoregressive model. To do this, we compare the following three forecasting models:[10]

$$\Delta s_t = \mu_s + \sum_{j=1}^{J} \phi_j \Delta s_{t-j} + \varepsilon_t^s \quad (1)$$

$$\Delta s_t = \mu_s + \Gamma_s s_{t-1} + \Gamma_a a_{t-1} + \sum_{j=1}^{J} \phi_j \Delta s_{t-j} + \sum_{j=1}^{J} \gamma_j^a \Delta a_{t-j} + \varepsilon_t^{s,a} \quad (2)$$

$$\Delta s_t = \mu_s + \Gamma_s s_{t-1} + \Gamma_p p_{t-1} + \sum_{j=1}^{J} \phi_j \Delta s_{t-j} + \sum_{j=1}^{J} \gamma_j^p \Delta p_{t-j} + \varepsilon_t^{s,p} \quad (3)$$

where s_t is the average dwelling price based on all sales, a_t is the average auction price and p_t is the average private-treaty price (all measured in logs). Equation (1) is the benchmark model, a univariate autoregression in average all-sales price growth. Equation (2) nests the same autoregression, but also includes lags in auction prices. It also allows for all-sales and auction prices to be cointegrated, consistent with the idea that these price measures share the same common trend. Equation (3) incorporates lags of private-treaty prices instead of lags of auction prices and also allows for cointegration.

We define:

$$\sigma_i^2 \equiv E\left(\hat{s}_{t+1|t}^i - s_{t|t} - \left(s_{t+1|t+1} - s_{t|t+1}\right)\right)^2$$

for $i = 1, 2, 3$ as the respective mean-squared prediction errors (MSPEs) for one-quarter-ahead all-sales price growth associated with Equations (1), (2) and (3)

10 In these, and all subsequent out-of-sample forecasting tests, we use four lags when using Sydney data and three lags when using Melbourne data. This is based on likelihood-ratio and residual serial correlation tests, as well as information criteria (see Appendix A). For Melbourne, quarterly seasonal dummies are included as additional control variables, consistent with evidence of seasonality in Melbourne.

respectively. $\hat{s}^{i}_{t+1|t} \equiv E\left(s^{i}_{t+1} \mid I_t\right)$ is the one-quarter-ahead forecast of the log all-sales price level based on Equation i (for $i = 1,2,3$) and using all available information up to time t. $s_{t|\tau}$ is the measured value of the log all-sales price level at time t given all available information up to time $\tau \geq t$. We consider whether the MSPEs are statistically different between Equations (1), (2) and (3) using pairwise comparisons and the MSE-t test statistic discussed in McCracken (2007).[11]

The results in Table 2 suggest that Equation (2) can outperform the benchmark model – that is, there is information content in lagged auction prices. In both cities, the MSPEs for Equation (2) are significantly lower relative to the benchmark model in the order of 10 and 18 per cent for Sydney and Melbourne (column one, rows one and three). In contrast, there is no evidence to suggest that private-treaty prices can also improve upon forecasts relative to the benchmark model; the null that the forecast accuracy of Equation (3) is the same as that of the benchmark cannot be rejected at conventional significance levels (column one, rows two and four).

Table 2: Pairwise Nested Model MSPE Comparison

	$\frac{\sigma^2_{y\in\{a,p\}}}{\sigma^2_s}$	MSE-t statistic
Sydney		
$H_0 : \sigma^2_s - \sigma^2_a = 0$	0.90**	0.85
$H_0 : \sigma^2_s - \sigma^2_p = 0$	0.93	0.26
Melbourne		
$H_0 : \sigma^2_s - \sigma^2_a = 0$	0.82**	1.46
$H_0 : \sigma^2_s - \sigma^2_p = 0$	0.97	0.17

Notes: The alternative hypothesis for each test is that the MSPE of the restricted model, σ^2_s, is greater than the unrestricted alternative (either σ^2_a or σ^2_p); recursive estimation is used starting with the sample period from March 1992 to March 2007 for Sydney and from March 1993 to September 2008 for Melbourne; ***, ** and * denote significance at the 1, 5 and 10 per cent levels respectively

11 The MSE-t statistic we compute is equivalent to the S_1 test statistic proposed by Diebold and Mariano (1995). It uses a mean-squared loss criterion, allows for contemporaneous and serially correlated prediction errors, and is computed under the null that the difference in the mean-squared prediction errors (one-quarter-ahead) for two alternative forecasting equations is zero. As noted in McCracken (2007), when working with nested prediction equations the MSE-t test statistic may not be well approximated by a normal distribution, and so we use the alternative critical values tabulated in the same paper. Qualitatively similar results are obtained using the MSPE-adj t statistic suggested in Clark and West (2007).

To further establish whether it is in fact auction prices or private-treaty prices that contain predictive information for future price growth, we consider whether these price measures are useful in predicting one another. Specifically, we use out-of-sample Granger causality tests assuming that auction and private-treaty prices are cointegrated.

The unrestricted model used for our tests is given by:

$$\Delta a_t = \mu_a + \alpha_a \left(a_{t-1} - \beta p_{t-1}\right) + \sum_{j=1}^{J} \Gamma_j^{aa} \Delta a_{t-j} + \sum_{j=1}^{J} \Gamma_j^{ap} \Delta p_{t-j} + \varepsilon_t^a \quad (4)$$

$$\Delta p_t = \mu_p + \alpha_p \left(a_{t-1} - \beta p_{t-1}\right) + \sum_{j=1}^{J} \Gamma_j^{pa} \Delta a_{t-j} + \sum_{j=1}^{J} \Gamma_j^{pp} \Delta p_{t-j} + \varepsilon_t^p \quad (5)$$

The null hypotheses are that auction prices do not Granger cause private-treaty prices, $H_0 : \alpha_p = \Gamma_j^{pa} = 0$ for all j, and that private-treaty prices do not Granger cause auction prices, $H_0 : \alpha_a = \Gamma_j^{ap} = 0$ for all j. Testing these hypotheses using the approaches suggested by McCracken (2007) and Clark and West (2007), the results in Table 3 highlight that we can reject the null that auction prices do not Granger cause private-treaty prices, but fail to reject the null that private-treaty prices do not Granger cause auction prices in Sydney (and only find weak evidence to reject the null in Melbourne). These results confirm that auction prices appear to be more useful when forecasting out-of-sample.

Table 3: Out-of-sample Granger Causality Tests

	Sydney	Melbourne
H_0 : Auction prices do not Granger cause private-treaty prices		
McCracken: MSE-t	1.55***	1.38**
Clark and West: MSPE-adj t	2.82***	2.34***
H_0 : Private-treaty prices do not Granger cause auction prices		
McCracken: MSE-t	–1.06	0.63*
Clark and West: MSPE-adj t	0.50	1.46*

Notes: ***, ** and * denote significance at the 1, 5 and 10 per cent levels of significance respectively; McCracken: MSE-t is the Diebold and Mariano test statistic used in the context of a nested model forecast comparison as discussed in McCracken (2007); Clark and West: MSPE-adj t is an alternative test statistic proposed by Clark and West (2007); estimates and out-of-sample forecasts are generated recursively with the initial in-sample estimation period from March 1992 to September 2002 for Sydney, and from March 1993 to September 2002 for Melbourne

3.3 In-sample

Although out-of-sample findings are informative for comparing forecasting performance in real time, a limitation of the previous comparisons is that they can imply a loss of information and power relative to in-sample prediction comparisons (see, for example, Inoue and Kilian (2005)), and can be affected by revisions.

To consider whether these issues are important, we undertake the previous bivariate causality tests in-sample using the testing procedure discussed in Toda and Yamamoto (1995) and Dolado and Lütkepohl (1996). One useful feature of this approach is that it only requires the order of integration of the data to be correctly specified, as the test remains consistent irrespective of whether auction and private-treaty prices are cointegrated or not.[12]

The results in Table 4 highlight that the previous causality results are supported. We are able to reject the null that auction prices do not Granger cause private-treaty prices in both Sydney and Melbourne, but are unable to reject the null that private-treaty prices do not Granger cause auction prices.

Table 4: In-sample Granger Causality Tests
Test statistic

Null hypothesis	Sydney	Melbourne
Auction prices do not	68.74***	36.70***
Granger cause private-treaty prices	(0.00)	(0.00)
Private-treaty prices do not	5.75	2.15
Granger cause auctions prices	(0.30)	(0.71)

Notes: All data are treated as I(1) consistent with the results from unit root tests; ***, ** and * denote significance at the 1, 5 and 10 per cent levels respectively; p-values are reported in parentheses

We also conduct two further in-sample specification checks. First, we test the null hypothesis that auction prices follow a random walk with drift, and so cannot be explained using either lagged auction or private-treaty price information.[13] Results from this test for the two cities (available on request), suggest that the null cannot be rejected for Sydney at conventional significance levels; but it can be rejected for

12 Conditioning on the assumption of cointegration provides similar results.

13 This is not a relevant test in the case of private-treaty prices as we have already established that lagged auction prices can be used to forecast them.

Melbourne, as lagged auction prices do appear to contain some predictive content for that city.

In the second, we check whether auction and private-treaty prices share the same common trend in prices and are, therefore, cointegrated as assumed in the previous out-of-sample analysis. Evidence in favour of cointegration, using the full sample of data, is reported in Appendix A. Estimates of the cointegrating vectors and adjustment parameters are reported in Table 5. Consistent with our previous findings, the results highlight that private-treaty prices respond to past deviations between auction and private-treaty prices as the adjustment parameters on the lagged cointegrating relationship – α_p in Equation (5) – are significant in both Sydney and Melbourne (column two). In contrast, auction prices do not respond to the same deviation as the adjustment parameters – α_a in Equation (4) – are insignificant in both cities (column one). The cointegration parameter, β for each city, also looks reasonable and not too far from 1, as one might expect.[14]

Table 5: Cointegration and Adjustment Parameter Estimates

	Auction prices	Private-treaty prices
Sydney		
Cointegration parameter	1	1.05***
	(.)	(0.01)
Adjustment parameter	–0.10	0.42***
	(0.23)	(0.15)
Melbourne		
Cointegration parameter	1	1.08***
	(.)	(0.01)
Adjustment parameter	–0.02	0.18**
	(0.14)	(0.07)

Notes: Cointegration and adjustment parameter estimates are obtained using Johansen MLE and normalising the coefficient on auction prices to 1; ***, ** and * denote significance at the 1, 5 and 10 per cent levels respectively and are with respect to 0 for the adjustment parameters and 1 for the cointegration parameters; standard errors are reported in parentheses

In sum, the data are consistent with the following empirical facts:

1. Forecasts from an autoregression of all-sales prices can be significantly improved upon by including lagged auction price information. Lagged private-treaty prices are less informative.

14 Including additional characteristic controls for Melbourne and restricting the sample to begin from December 1997 leads to an estimated β of 1.05.

2. Auction prices Granger cause private-treaty prices, but private-treaty prices do not Granger cause auction prices. This holds both in- and out-of-sample.

3. The auction price level process is not statistically different from a random walk with drift in Sydney. There is some evidence that the first lag of auction price growth can be used to forecast auction price growth in Melbourne.

4. Auction and private-treaty prices are cointegrated.

4. The Persistence of Shocks

We now consider whether alternative measures of average prices, based on the type of sale, can provide information about the persistence of shocks to dwelling prices. To answer this question, we use two conditions supported in the data: (a) that auction and private-treaty prices are cointegrated and can be represented by a VECM ; and (b) that private-treaty prices do not Granger cause auction prices. That is:

$$\Delta a_t = \mu_a + \sum_{j=1}^{J} \Gamma_j^{aa} \Delta a_{t-j} + \varepsilon_t^a \tag{6}$$

$$\Delta p_t = \mu_p + \alpha_p \left(a_{t-1} - \beta p_{t-1}\right) + \sum_{j=1}^{J} \Gamma_j^{pa} \Delta a_{t-j} + \sum_{j=1}^{J} \Gamma_j^{pp} \Delta p_{t-j} + \varepsilon_t^p \tag{7}$$

Together, these conditions are sufficient for identifying the effects of permanent and transitory shocks to auction and private-treaty prices.[15] A permanent shock is defined as having an effect on long-run forecasts of auction and private-treaty prices whereas a transitory shock has no such effects.

Table 6 reports forecast error variance decompositions for Sydney and Melbourne of the permanent and transitory shocks assuming that both conditions hold. We only report the decomposition for private-treaty prices, as conditions (a) and (b) together necessarily imply that variation in auction prices can only be attributed to permanent shocks. Relaxing assumption (b) and assuming that only the long-run

15 For further discussion on this point, see Fisher and Huh (2007) and Pagan and Pesaran (2008).

adjustment parameter in the auction price equation is zero[16] leads to very similar results.

Table 6 highlights that almost half of the forecast error variation in private-treaty prices one-quarter-ahead is due to transitory shocks. At the two-quarter- and four-quarter-ahead horizons, transitory shocks account for about 20 and 10 per cent of the forecast error variances respectively.

Table 6: Forecast Error Variance Decompositions for Private-treaty Prices

Forecast horizon	**Sydney** Permanent	**Sydney** Transitory	**Melbourne** Permanent	**Melbourne** Transitory
1	0.45	0.55	0.53	0.47
2	0.77	0.23	0.81	0.19
3	0.82	0.18	0.87	0.13
4	0.89	0.11	0.91	0.09
32	0.99	0.01	0.99	0.01

Figure 3 graphs estimates of the permanent and transitory shocks over time. We see very clearly that the estimated permanent shocks are much larger than the estimated transitory shocks. In particular, the period covering the mid 1990s to the 2000s is a period in which permanent shocks were having a noticeable positive effect on dwelling price growth. This is consistent with the typical explanations for changes in dwelling prices during this period, including the effects of financial deregulation and productivity improvements, and a shift to easier access to credit and lower real interest rates.[17]

In contrast, the transitory shocks to auction and private-treaty prices are smaller in magnitude. The most prominent periods of positive transitory shocks were in the recovery from the early 1990s recession and around 2001 to 2003. Even during the global financial crisis, the estimates suggest that there were no large transitory shocks to dwelling prices. This is interesting given that for other countries the crisis has generally been interpreted as a demand shock, and the conventional wisdom is that demand shocks have only transitory effects on dwelling prices.

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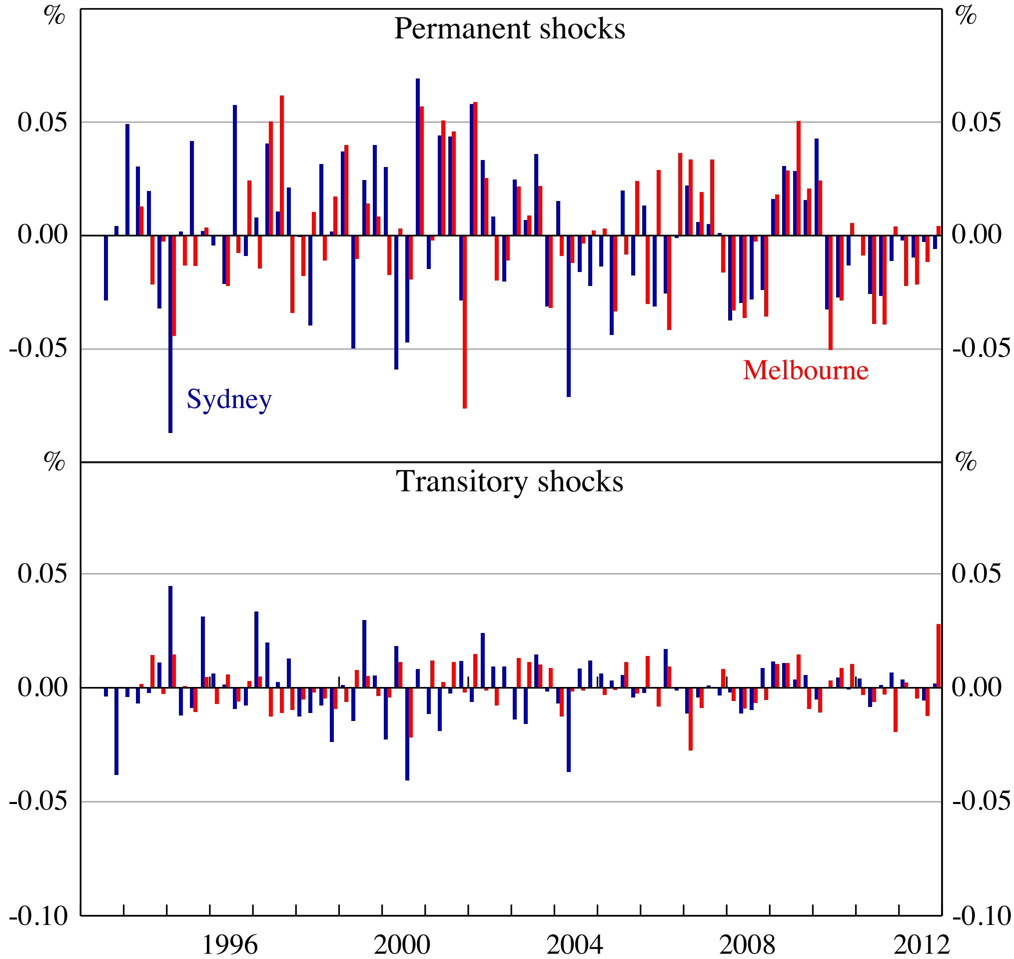
16 That is, if we only impose the restriction that $\alpha_a = 0$ rather than $\alpha_a = \Gamma_j^{ap} = 0$ for all $j = 1, \ldots, J$ with respect to Equation (4).

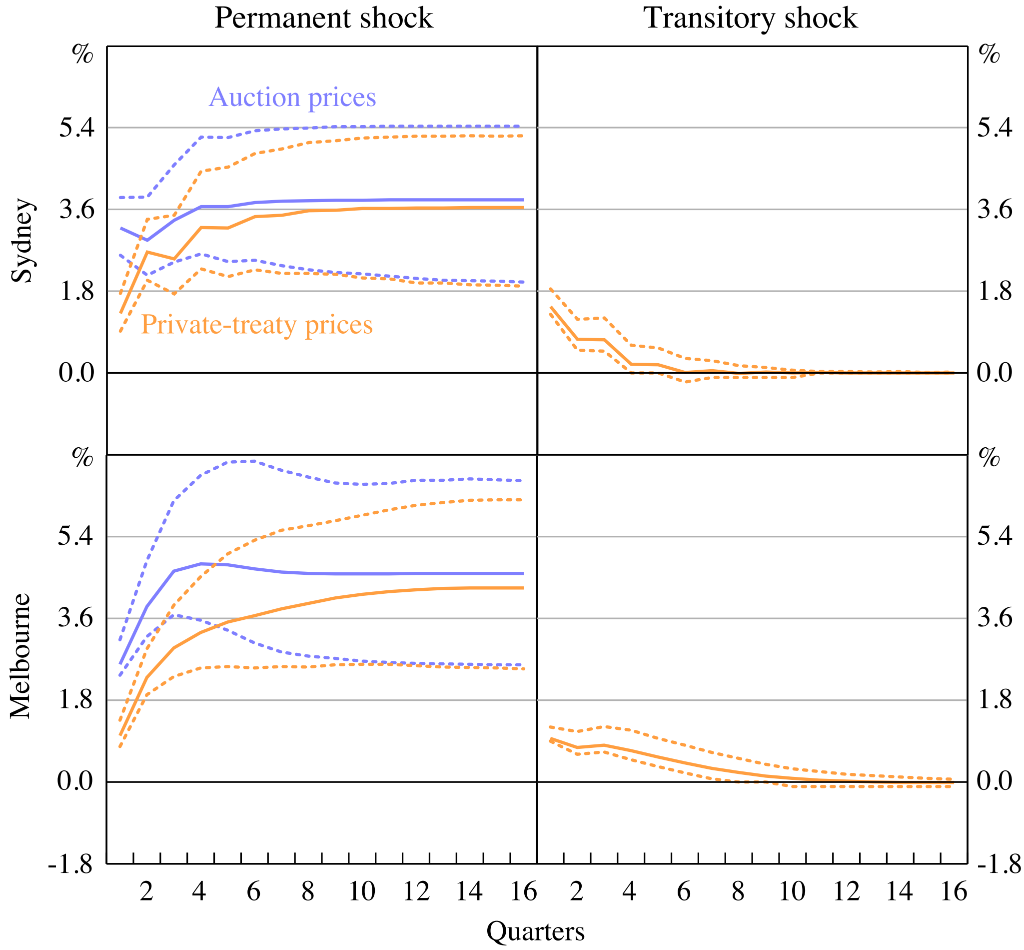
17 See, for example, Ellis (2006) and Yates (2011).

Figure 3: Estimates of Permanent and Transitory Shocks



Two key properties of the propagation of permanent and transitory shocks are highlighted by the impulse response to a one standard deviation permanent shock, and a one standard deviation transitory shock respectively (Figure 4). The first is that auction prices adjust more quickly than private-treaty prices in response to a permanent price shock. Calculating the fraction of the long-run increase in prices ($\lim_{h\rightarrow\infty} E_t\left(y_{t+h}\right)$ for $y_t = a_t, p_t$) that has occurred in a given period, we see that around 80 (Sydney) to 60 (Melbourne) per cent of the long-run increase in prices occurs within the first quarter for auction prices, but only around 35 to 25 per cent of the adjustment has occurred for private-treaty prices. After four quarters, roughly 95 per cent of the adjustment to the long-run auction price has occurred for both Sydney and Melbourne. In contrast, when using private-treaty prices approximately 85 to 75 per cent of the adjustment to their long-run price level has been completed after four quarters.

Figure 4: Impulse Response Functions to a One Standard Deviation Shock



Notes: Impulse response functions to a one standard deviation shock estimated under the assumption that auction and private-treaty prices admit a VECM and that private-treaty prices do not Granger cause auction prices; confidence intervals are at the 95 per cent level of significance and are bootstrapped using Hall's percentile method

The second property to note is that transitory price shocks have smaller effects on private-treaty prices than do permanent shocks. The restrictions supported by our previous empirical findings – that auction and private-treaty prices can be represented by a VECM and that private-treaty prices do not Granger cause auction prices – imply that transitory shocks have no effect on auction prices.

5. Why Does the Mechanism of Sale Matter?

This section shows how the micro structure of the different trade mechanisms, and the nature of shocks to agents' valuations, can provide an interpretation of our previous empirical findings. The first step is to justify our assertion that, relative to private-treaty prices, prices at auctions are more responsive to shocks to buyers' valuations than they are to sellers' valuations (Section 5.1). The second step is to rationalise why buyers' valuations respond to new information about dwelling prices more quickly than sellers' valuations (Section 5.2). The third is to bring these two results together to explain our previous empirical findings (Section 5.3).

5.1 Some Intuition for the Theory

We begin by considering the simplest trade mechanisms: an ascending open-bid (or English) auction (the mechanism most commonly used in Australia), without a seller reserve price, to model auctions; and a Nash bargaining solution to model sales that use bilateral private-treaty negotiations. In the English auction, the price rises until no bidder (hereafter buyer) is willing to offer more. In the Nash bargaining solution, the price is a weighted average of the buyer and seller valuation. To further simplify, we assume that buyers at auctions have private values,[18] and that any buyer values the dwelling more than any seller. That is, the dwelling is always sold through either mechanism. These assumptions are unrealistic, but they are useful to provide the basic intuition. They are relaxed in a formal analysis below.

It is a dominant strategy for a buyer to bid until the point at which his or her private valuation is reached, and then exit the auction.[19] Thus, bidding continues until the buyer with the second-highest valuation exits the auction, leaving only the buyer with the highest valuation who wins the auction and pays a price equal to the second-highest valuation. An implication of this model is that a common shock to *all* buyers' valuations will increase the auction price one for one. Furthermore, since there is no seller reserve, sellers' valuations have no effect on the equilibrium auction price.

In a private-treaty negotiation with Nash bargaining, a shock to the buyer's valuation will only partially increase the price, since the negotiated price is a

18 That is, knowledge of other buyers' valuations has no impact on any given buyer's valuation.

19 To see why, suppose a seller exited before the price reached their valuation. In this case, there is a positive probability that the buyer could have remained in the auction and paid a price less than their valuation. The buyer has thus forgone a profitable trading opportunity and so this cannot be an equilibrium strategy. Conversely, suppose the buyer remained in the auction when the price is above their valuation. In this case, there is a positive probability the buyer wins and pays a price that is higher than their valuation, thus engaging in trade that is not profitable to them. This also cannot be an equilibrium strategy.

weighted average of the buyer's and seller's valuation. In particular, the price will only go up by the weight on the buyer's valuation, which under Nash bargaining, reflects the relative bargaining strength of the *seller*.[20] In a market where buyers and sellers have equal bargaining power, prices will be equally responsive to a common shock to buyers' valuations as they are to a common shock to sellers' valuations. Only if sellers have all the bargaining power will private-treaty prices behave like auction prices, responding only to buyer shocks and not seller shocks.

The assumptions we have maintained so far, that all auctions and bilateral negotiations end in a sale and that buyers have private values, are useful in making our general point, but they are restrictive. We relax them below.

5.1.1 When not all auctions or negotiations end in a sale

When not all auctions end in a sale, sellers' valuations will matter. To incorporate this phenomenon in our theoretical analysis, we consider the reserve price, which is a minimum price demanded by the seller. In auctions in NSW and Victoria, a vendor bid, which is a bid made by the auctioneer on behalf of the seller, can be used to effect a reserve price that conditions on the information revealed through the auction.[21] Alternatively, the seller can simply choose not to sell the property if bidding does not exceed their reserve price.[22]

The first implication of the seller using a reserve price R is that not all auctions end in a transaction: when R is above the valuation of the highest buyer the dwelling does not sell. R can affect the value of the winning bid: when R is below the valuation of the highest buyer, but higher than the second-highest buyer's valuation, the dwelling sells at the price R. Only when R is below the second-highest buyer's valuation does the reserve price have no effect on the auction outcome or the price obtained.

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20 Recall that with a Nash bargain, a stronger seller position implies a transaction price that is closer to the buyer's valuation (and so more of the surplus from trade accrues to the seller).

21 This is different from a reserve price set prior to the auction. Even if a reserve price is set prior to auction, the ability to make a vendor bid implies that the seller can effectively revise their reserve price, conditioning on information revealed through the auction. In the private values case, the optimal pre-announced reserve price and vendor bid are equivalent. Vendor bids are permissible in both Sydney and Melbourne – see, for example, Consumer Affairs Victoria (2014) and NSW Fair Trading (2014).

22 Again, refer to Consumer Affairs Victoria (2014) and NSW Fair Trading (2014).

Consider now the effect on the auction price of an increase in *R*. When the auction ends without a sale, an increase in *R* has no effect on the auction outcome or the absence of price due to the fact the dwelling is passed in. When the auction is successful, there are three possible cases: one, an increase in *R* does not cross the threshold of the second-highest buyer's valuation and so has no effect on the equilibrium price; two, it does cross the threshold, in which case an increase in *R* will affect prices but less than one for one (by the amount by which *R* exceeds the second-highest valuation); and three, *R* is initially above the second-highest valuation and is raised, increasing prices one for one. If *R* becomes too high, however, crossing the valuation threshold for the buyer with the highest valuation, the auction is passed in and excluded from the dwelling price transactions data.

Thus *R* plays one of two roles, if any, at a given auction: either an increase in *R* weakly increases the winning bid to the seller, with the magnitude depending upon the initial and final values of *R* in relation to the highest and second-highest buyer valuations; or it prevents a trade that would otherwise occur from taking place. The latter is a selection effect and leads to higher prices in the observed transactions data. The total effect of a change in *R* on the average auction price is the weighted average of these two effects.

Our interest is in how shocks to sellers' valuations affect the average auction price in this more complicated environment. The effect operates solely through the reserve price. Thus, the effect of a common shock to sellers' valuations is the composition of the effect of the shock on reserve prices and the effect of the reserve price on the transaction price. Assuming that the seller chooses the reserve price optimally – that is, with the goal of maximising the expected auction price – we can determine the overall effect conditioning on the distribution of buyers' valuations and that of sellers. When both are uniform, and there are more than three buyers, then the effect of a seller shock on average price is an order of magnitude less than that of a buyer shock. This conclusion holds more generally among (weakly) left-skewed distributions that belong to the generalized Pareto distribution family, and which nests the uniform distribution.

The arguments for private-treaties with Nash bargaining are quite different. In private-treaties, an increase in all sellers' valuations will increase prices in transactions that remain profitable to the buyer and the seller by the amount of the buyer's bargaining weight. This also results in a selection effect, removing from the transactions data those dwellings where the seller now values the dwelling more than the buyer they meet. What we show below is that if the dispersion of buyers' and sellers' valuations are constant, then the selection effect is again less important for changes in private-treaty prices. What is of primary importance is the sensitivity of prices to average buyers' and sellers' valuations, as reflected in the relative bargaining strengths of the two groups. Unless there is a special reason to believe that sellers have all of the power in dwelling transaction negotiations, in all states of the dwelling price cycle, it is difficult to move away from the interpretation that both buyers and sellers are important in changes in private-treaty prices.

5.2 Differences in the Response to New Information

The previous intuition argues that changes in auction prices mainly reflect changes in buyers' valuations, whereas changes in private-treaty prices reflect changes in both buyers' and sellers' valuations. If we extend this argument, and assume that buyers' valuations respond more quickly to news relevant to dwelling prices than do sellers', these two facts can explain the previous empirical findings: that auction price growth is not highly autocorrelated but private-treaty price growth is; that auctions are more useful for forecasting; and that auctions better reflect the common trend in all prices.

In particular, if there is a shock to the common stochastic trend in all prices (which is a permanent shock), and all buyers update their valuations quickly, then auction prices must be indicative of the common trend and respond quite quickly to permanent shocks as highlighted in Figure 3. Conversely, if sellers update their valuations more slowly, private-treaty prices will still be indicative of the common trend (prices are cointegrated), but will also measure transitory departures from this trend. This can explain why private-treaty price growth is more autocorrelated than auction price growth (because the transitory component induces autocorrelation); why auction prices are more useful for forecasting (because they quickly capture changes in the common trend, whereas it takes more time for private-treaty prices to fully update to this trend); and why auction prices are a better measure of the underlying common stochastic trend – because they are not perturbed by transitory shocks that are specific to sellers' valuations.

Theoretical explanations for why sellers respond more slowly include: equity lock-in (Stein 1995; Genesove and Mayer 1997); rigidity of seller reservation prices due to reference point pricing, whether with respect to the seller's purchase price (Genesove and Mayer 2001) or original list price; and differential non-centralised information flows (Carrillo 2012; Genesove and Han 2012). We now consider the more formal analysis that underpins the previous intuition.

5.3 A More Formal Treatment

We consider two simple models of price determination; an affiliated values English auction and a Nash bargain for bilateral (private-treaty) negotiations. These two models are plausible characterisations of the Australian property market. A formal description of the two models is outlined in Appendix B.

5.3.1 Auction prices

Focusing first on auctions, we assume that in each quarter there are many English auctions – the auction mechanism most commonly used in the Australian housing market. In any one auction, bids are observed by all other buyers and the buyer with the highest bid wins, paying that amount. We assume that buyers are risk neutral and have valuations that are linear and affiliated (Milgrom and Weber 1982; Klemperer 1999) as follows:[23]

$$v_{it}^{a} = \psi_{at} s_{it}^{a} + \frac{\gamma_{at}}{n_{at}-1} \sum_{j \neq i} s_{jt}^{a}$$
$$s_{it}^{a} = \mu_{t}^{P} + \varepsilon_{it}^{a}$$

The valuation of buyer i in auction a held at time t is given by v_{it}^{a} and s_{it}^{a} is buyer i's signal (or estimate) of the value of the dwelling. Importantly, the above modelling device assumes that buyer valuations are a function of their own signal and other buyer's signals (in the same auction). As bids are announced during an auction, buyers update their valuations to reflect the information contained in other buyers' bids.

23 Although the results we derive below are conditioned on the assumption of risk neutrality, this assumption can be relaxed if common values – a specific case of affiliation – are assumed.

For example, if there are many buyers who participate in auction a at time t and continue to make bids as the price in that auction rises, then this provides information to other active buyers – namely that many other buyers must have high estimates of that dwelling's value. Each buyer then infers that it is more likely that the true value of dwelling a at time t is high, and revises their own valuation upwards.

What stops the process is that buyers only update their signal partially in response to the information contained in others' bids (by the weighting $\frac{\gamma_{at}}{n_{at}-1}$). When the price becomes sufficiently high, buyers start to exit the auction (stop making bids), which is observed by other participants. This continues until there is a single buyer remaining, at which point the auction concludes and the dwelling is sold.[24] Although we have abstracted from the effects of a seller reserve price, the underlying intuition remains similar.[25]

We assume that each signal comprises a common component μ_t^P (the common stochastic trend) and an idiosyncratic component ε_{it}^a, where the latter is drawn from a uniform distribution on the bounded interval $[-\theta_{at}, \theta_{at}]$. The weights ψ_{at} and γ_{at} can be interpreted as the weights attached to a buyers' own signal and the mean signal of other buyers in the auction respectively.

The assumption of linear affiliation,[26] in conjunction with symmetric bidding strategies and an English auction, implies that the sale price for a successful auction will, in general, be a function of all buyers' signals. For this reason, information is both revealed and aggregated into the price during the auction. It should be noted that the type of affiliation we have modelled can be used to

24 Another way to think of our modelling device is that all players in the auction hold a bidding card which remains raised until the price quoted hits the maximum that that buyer is willing to bid, at which point they lower the card and exit the auction, and all other players observe this. Importantly, with affiliation, the maximal bid for any given buyer is a function of both the number of buyers who have already exited the auction and the price point at which each buyer stopped participating.

25 It also does not materially affect the analysis that follows (see Appendix D).

26 Intuitively, affiliation of buyers' values implies that there is correlation between values. For example, with two buyers, affiliation implies that an increase in the valuation of buyer 1 also increases the likelihood that buyer 2 holds a higher valuation. The converse is also true: an increase in buyer 2's valuation increases the likelihood that buyer 1 has a higher valuation. Affiliation is a stronger concept than correlation, as it requires local positive correlation everywhere with respect to the joint distribution of valuations (see Klemperer (1999)).

represent, under appropriate restrictions on ψ_{at} and γ_{at}, either a pure private values auction where valuations are independent, or a pure common values auction where all buyers receive a noisy signal of the same common component in price.

An example of affiliated values is where each buyer has an imperfect signal of the common component of the value of the dwelling and, consistent with the above specification, uses the behaviour of other buyers during the auction to infer it. As buyers are engaged in a search process, the willingness to pay for a dwelling will equal the difference between the net present value of the flow of utility from living in that dwelling, less the value of continued search. Accordingly, there are common factors that will affect all buyers' valuations. Some, like the interest rate, credit terms and other economy-wide factors are likely to be near-perfectly observed; but others, like the quality of a specific dwelling, the prices of similar homes, and the degree of competition from other buyers, are likely to observed with noise, thus leading to the inference problem.

The average auction price is defined as the average price for all successful auctions. Given our assumptions, we show that that this average price can be approximated by (Appendix B.1):

$$a_t \approx \beta_t \mu_t^P + \psi_t \theta_t \tag{8}$$

where a_t is the average auction price and ψ_t is the average weight placed on buyers' own signals (averaged across all buyers in all auctions: $\frac{1}{A_t}\sum_{a_t=1}^{A_t} \psi_{at} \xrightarrow{p} \psi_t$), and θ_t is a measure of the average dispersion of all buyers (again averaged across all buyers in all auctions: $\frac{1}{A_t}\sum_{a_t=1}^{A_t} \theta_{at} \xrightarrow{p} \theta_t$).

The parameter that affects the cointegration relationship with private-treaty prices is given by $\beta_t = \psi_t + \gamma_t$. It reflects the average weight on buyers' own signals and the average weight on the mean of all other buyers' signals, $\frac{1}{A_t}\sum_{a_t=1}^{A_t} \gamma_{at} \xrightarrow{p} \gamma_t$. If β_t is normalised to one, these average weights can be interpreted as information shares. For example, $\psi_t = 0.7$ and $\gamma_t = 0.3$ would imply that buyers, on average, have 70 per cent of their valuation formed from their own signal and 30 per cent from the signals inferred from others' bids during an auction.

Importantly, auction prices reflect the common component buyers share in their valuations. With affiliated values, many buyers and many auctions, auction prices converge to a linear function of the common price trend, $\beta_t \mu_t^P$, up to a shift factor of $\psi_t \theta_t$. The latter term comprises the average weight that buyers assign to their own signal, and the average dispersion of buyers' valuations. Thus, for auctions, an increase in the weight that buyers assign to their own signal or an increase in the dispersion of buyers' valuations could, in principle, lead to temporary deviations of auction prices from the common price trend.

Greater dispersion in buyers' valuations will tend to raise the average price because it is the indifference condition for the second-last buyer remaining (i.e. the point at which the buyer with the second-highest valuation drops out) that is important for determining the final price. With a large number of buyers, greater dispersion in buyers' valuations will not affect the inferred common component of signals from buyers who have already exited the auction, but it will raise the probability that the buyers with the highest and second-highest valuations will have high valuations and so a higher price will be more likely. Accordingly, a higher average auction price could reflect an increase in average buyer dispersion, rather than an increase in the common trend in prices.

Similarly, an increase in the weight that buyers assign to their own signal could also drive a temporary increase in auction prices. Again, this relates to the fact that prices are determined by the indifference condition for the buyer with the second-highest valuation. This buyer, like all buyers, weights their own signal differently to the weight placed on other buyers' signals.[27] In particular, when there are many buyers, the importance of any one buyer (including the buyer with the highest signal) on the mean signal is equal and small. In contrast, the weight the buyer with the second-highest valuation places on their own signal is more important: changes in this weight can lead to transitory changes in auction prices, even when averaged across a large number of transactions.

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27 At the price at which the buyer with second-highest valuation is indifferent between quitting or remaining in the auction, this buyer is comparing their own signal (with weight ψ_{at}) with the likely signal of the other buyer who has not yet quit (with weight $\frac{\gamma_{at}}{n_{at}-1}$). The fact that the weight on the second-last buyer's own signal is potentially different from the weight on the other buyer's signal (which is the same as for all other buyers who already exited the auction) means that it is the own-signal weight that becomes pivotal in price determination. For this reason, a transitory change in the information weights, towards a greater weight on idiosyncratic information and a lower weight on other buyers' information, could have a transitory effect on auction prices.

To understand these results in the context of the intuition given in Section 5.1, we have shown that under more general assumptions about buyers' information, and when there are many buyers in each auction, the argument for the claim that auctions are relatively more responsive to buyers' than sellers' valuations, when compared with private-treaty sales, is similar to the private values case. Including optimal seller reserve prices, set by the seller after he or she has observed the winning bid and therefore on the basis of the information revealed during the auction (Lopomo 2001), introduces a role for the seller's valuation. However, here too, as in the private values case, the responsiveness of average auction prices to a common shock in sellers' valuations is substantially less than to a common shock in buyer valuations. This is true given a sufficient number of buyers and in the baseline uniform distributions case, and with more general left-skewed distributions of buyers' valuations.

5.3.2 Private-treaty prices

For private-treaty prices, we assume that the price is the result of a Nash bargain between one buyer and one seller. That is, the surplus from trade (the difference between the buyer's and the seller's reservation values) is split between the buyer and seller according to their relative bargaining power. Again, we assume that buyers and sellers have a common stochastic trend and an idiosyncratic component in their valuations:

$$\begin{aligned} v_{it}^{ps} &= \mu_t^P + \varepsilon_{it}^{ps} \\ v_{it}^{pb} &= \mu_t^P + \varepsilon_{it}^{pb} \end{aligned}$$

where the prospective seller's idiosyncratic signal, ε_{it}^{ps}, is drawn randomly from a uniform distribution on $[-\phi_{it}, \phi_{it}]$ and the prospective buyer's idiosyncratic signal, ε_{it}^{pb}, is drawn randomly from a uniform distribution on $[-\theta_{it}, \theta_{it}]$. For a sale to occur, the idiosyncratic signal for the buyer must be weakly higher than that for the seller, $\varepsilon_{it}^{pb} \geq \varepsilon_{it}^{ps}$. The average measured private-treaty price is the average price of all successful private-treaty sales within a quarter. It can be approximated by (see Appendix B.2):

$$p_t \approx \mu_t^P + f(\widetilde{\psi}_t, \phi_t, \theta_t) \tag{9}$$

The transitory or idiosyncratic components of buyers' and sellers' valuations are given by the function f, which has the Nash bargaining weight $(\widetilde{\psi}_t)$, the dispersion of sellers (ϕ_t) and the dispersion of buyers (θ_t) in its arguments. We assume that the function $f(\widetilde{\psi}_t, \phi_t, \theta_t)$ can be approximated by a stationary autoregressive moving average (ARMA) process to be consistent with the autocorrelation in private-treaty price growth observed in the data (Section 3.1).

The reason that the function f is not zero, even when averaging across a large set of transactions, is that prices only reflect successful negotiations. This implies that buyer and seller valuations are correlated (with all buyer valuations weakly higher than that of the respective seller) and so idiosyncratic factors do not wash out on average.

The valuation of the common component of prices is identical for buyers and sellers and is assumed not to be predictable: $\mu_t^P = c + \mu_{t-1}^P + \eta_t^P$. We also make the additional assumption that the average overall weight on information in auctions is constant, $\beta_t = \beta$. Under these assumptions, we can see that average auction prices, Equation (8), and average private-treaty prices, Equation (9), are cointegrated with cointegrating vector $\begin{bmatrix} 1 & -\beta \end{bmatrix}$. To link these equations to our empirical findings, Appendix C shows that Equations (8) and (9) can be approximated using the VECM:

$$\Delta a_t \approx \beta c + \beta \eta_t^P \tag{10}$$

$$\Delta p_t \approx \tilde{c} + \alpha \left(a_{t-1} - \beta p_{t-1}\right) + \sum_{j=1}^{J} \gamma_{aj} \Delta a_{t-j} + \sum_{j=1}^{J} \gamma_{pj} \Delta p_{t-j} + \eta_t^P + u_t \tag{11}$$

This representation is valid provided we assume that average dispersion in buyers' valuations and the average weight that buyers place on their own information (averaged across all auctions in a given quarter) are constant. These assumptions are sufficient for ensuring that changes in auction prices reflect changes in the common price trend, as found in our empirical analysis.

Importantly, the above VECM is fully consistent with our previous empirical findings. In particular, it implies that: growth in auction prices is not autocorrelated; that growth in private-treaty prices is autocorrelated; and that auction prices will Granger cause private-treaty prices but that private-treaty prices will not Granger cause auction prices.

There are four key implications to be drawn from the theoretical analysis. First, both auction prices and private-treaty prices measure the common trend in all prices, μ_t^P, when averaging across a large set of transactions. For this reason, auctions are not necessarily more efficient at measuring the common trend in all prices.

Second, the different weighting of buyers' and sellers' valuations in different sales mechanisms appears to be important. Assuming our theoretical structure provides a reasonable approximation of actual price formation, our results imply that there is a large set of distributions for which auction prices weight buyers' valuations more highly than sellers' valuations, when compared with private-treaty prices. If this is right, then it follows that the autocorrelation observed in private-treaty prices is more likely to be coming from the valuations of sellers.

Third, since private negotiation is intrinsic in the determination of private-treaty prices, the average dispersion of seller values and the relative bargaining strength of buyers and sellers affect average private-treaty prices. These become plausible sources of autocorrelation in private-treaty prices, but not auction prices.

Fourth, our theory is consistent with the idea that auction prices and private-treaty prices are cointegrated and measure the same common trend. As such, variation in either the average dispersion of sellers or relative bargaining strength can only induce transitory variation in private-treaty prices and must, therefore, dissipate with time.

6. Conclusion

This paper analyses whether the mechanism of sale is useful for forecasting average dwelling prices. Using hedonic price indices for Sydney and Melbourne, we show that auction prices and private-treaty prices have different statistical properties, including significant differences in their momentum, ability to forecast each other, and ability to forecast average growth of prices overall.

Our results suggest that growth in auction prices is much less autocorrelated than growth in private-treaty prices – indeed, we could not reject the null of a random walk with drift in Sydney auction prices. This surprisingly strong result, which holds even though the two measures share the same common price trend, suggests that auction prices incorporate new information more quickly than private-treaty prices. Consistent with this, we find that including lagged information on auction prices improves forecasts of average dwelling prices growth overall.

In addition, we find that auction prices Granger cause private-treaty prices, but that the reverse is not true. When combined with the assumption that these two price series are cointegrated, this result is useful for separating prices into their transitory and permanent components and for forecasting the evolution of prices at short-term forecasting horizons.

Empirically, we find that auction prices are driven by permanent shocks, whereas private-treaty prices are affected by both permanent and transitory shocks. If permanent shocks are an accurate measure of changes in the common trend in all prices, as should be the case when there is cointegration, our results suggest that auction prices are likely to be a better reflection of this common trend. Furthermore, the presence of transitory shocks in private-treaty prices implies that they take longer to incorporate changes in the common trend. This also helps to explain why private-treaty prices are less useful when forecasting.

We interpret our empirical findings using two models of price formation – an English auction with linearly affilated values and a bilateral Nash bargain. We show that these two models imply a VECM approximation that is consistent with our data. These two models of price formation, when combined with our empirical findings, suggest that the key issues at hand are: the extent to which the average dispersion of valuations and the average bargaining strength of buyers and sellers affect prices; whether the relative importance of buyers' and sellers' valuations differs according to the mechanism of sale; and whether buyers and sellers behave differently in response to shocks.

The question we are interested in is whether distinguishing prices by the mechanism of trade can assist in the forecasting of dwelling prices and in understanding the dwelling price cycle. On both empirical and theoretical grounds, we argue that the answer is yes. Separating prices by the type of sale, and more specifically focusing on auction prices, can improve forecasting and in identifying the persistence of shocks. We believe that these results are interesting both narrowly, for those concerned with forecasting prices, and more broadly for understanding how price formation can provide alternative insights into dwelling price cycles.

Appendix A: Specification Checks

To choose the appropriate number of lags in both the in- and out-of-sample analysis we use likelihood ratio tests, information criteria and tests for low-order serial correlation in the VAR residuals (see Table A1). Taking these results into consideration, and the relative sample size, we use four lags for Sydney and three lags for Melbourne in our analysis (when working with data in its first-difference or VECM representation).

Table A1: Lags Suggested According to Selection Criteria and Model

	VAR in auction and all-sale prices	VAR in private-treaty and all-sale prices	VAR in auction and private-treaty prices
Sydney			
Sequential LR tests[(a)]	7	5	1
Akaike information criteria	7	2	1
Sequential serial correlation tests[(b)]	7	7	7
Melbourne			
Sequential LR tests[(a)]	4	6	4
Akaike information criteria	4	4	4
Sequential serial correlation tests[(b)]	4	4	4

Notes: (a) Denotes the number of lags suggested by applying sequential likelihood ratio (LR) tests (with a maximum lag length of 8)
(b) Denotes the number of lags by parring back the number of lags using sequential Lagrange-multiplier tests; starting with a maximum lag length of 8, lags are sequentially dropped until the null hypotheses of no low order (first or second) serial correlation is rejected at the 5 per cent level of significance

To test the order of integration of prices, Dickey-Fuller (DF) GLS regressions (Elliott, Rothenberg and Stock 1996; Ng and Perron 2001) are estimated (Table A2). Other tests for a unit root are also consistent with the prices data being I(1).

Table A2: Dickey-Fuller GLS Regressions

	Lags	DF GLS τ test statistic	5 per cent critical value
Sydney auction prices			
Ng-Perron sequential t[(a)]	2	–0.97	–3.06
Minimum Scharwz criteria[(b)]	1	–0.60	–3.08
Minimum modified AIC[(c)]	2	–0.97	–3.06
Sydney private-treaty prices			
Ng-Perron sequential t[(a)]	10	–1.54	–2.78
Minimum Scharwz criteria[(b)]	1	–0.90	–3.08
Minimum modified AIC[(c)]	1	–0.90	–3.08
Melbourne auction prices			
Ng-Perron sequential t[(a)]	1	–2.04	–3.09
Minimum Scharwz criteria[(b)]	1	–2.04	–3.09
Minimum modified AIC[(c)]	1	–2.04	–3.09
Melbourne private-treaty prices			
Ng-Perron sequential t[(a)]	6	–2.05	–2.93
Minimum Scharwz criteria[(b)]	3	–1.82	–3.04
Minimum modified AIC[(c)]	3	–1.82	–3.04

Notes: (a) Lag length selected using Ng-Perron sequential t method as suggested by Ng and Perron (1995)
(b) Lag length selected using Scharwz criteria
(c) Lag length selected using modified Akaike information criteria (AIC)

Table A3 suggests that auction and private treaty sales prices are cointegrated when using Johansen's trace test. Evidence of cointegration is also found at conventional significance levels assuming a known cointegrating vector, $\begin{bmatrix} 1 & -1 \end{bmatrix}$, and using univariate unit root tests such as augmented Dickey-Fuller and Phillips-Perron tests (results are available on request).

Table A3: Cointegration Test Results

	H_0: No cointegration		**H_0: Single cointegrating vector**		
City	Test statistic[(a)]	Critical value[(b)]	Test statistic[(a)]	Critical value[(b)]	Lags
Sydney	19.71	15.41	3.04	3.76	5
Melbourne	16.21	15.41	1.42	3.76	4

Notes: (a) Johansen's trace test statistic
(b) The critical values reported are measured at the 5 per cent level of significance

Appendix B: A Theoretical Example

B.1 Auction Prices

For the auction price mechanism, we use a linear example of an affiliated values auction as discussed by Milgrom and Weber (1982) and Klemperer (1999). We assume each time period (quarter) t that multiple English auctions occur. Each auction (indexed by dwelling a at time t) has n_{at} risk-neutral bidders (hereafter buyers). Buyers' valuations are given by:

$$v_{it}^{a} = \psi_{at} s_{it}^{a} + \frac{\gamma_{at}}{n_{at} - 1} \sum_{j \neq i} s_{jt}^{a} \qquad \text{(B1)}$$

where s_{it}^{a} is buyer i's private signal (estimate) of the worth of dwelling a in quarter t, and $\psi_{at} \geq 0$ is the weight attached to a buyer's own signal and $\gamma_{at} > 0$ is the weight attached to the mean of other buyers' signals.

We assume that each buyers' own estimate of the worth of dwelling a in period t is given by a common component, μ_t^P, and an idiosyncratic component ε_{it}^{a}:

$$s_{it}^{a} = \mu_t^P + \varepsilon_{it}^{a} \qquad \text{(B2)}$$

We assume that ε_{it}^{a} is uniformly distributed with support $[-\theta_t^a, \theta_t^a]$.

We assume buyers participate in an ascending bids English auction – the mechanism commonly used to sell dwellings in Australia – and we abstract from the possibility that sellers can post a reserve price.[28]

28 See Appendix D for the inclusion of seller reserve prices.

A bidding strategy is given by the prices at which buyers are no longer willing to remain in the auction. The following bidding strategy is consistent with a symmetric equilibrium:

$$
\begin{aligned}
B_o\left(v_{it}^a\right) &= \left(\psi_{at}+\gamma_{at}\right) v_{it}^a \\
B_1\left(s_{n_{at}:n_{at}}, v_{it}^a\right) &= \frac{\gamma_{at}}{n_{at}-1} s_{n_{at}:n_{at}}^a + \left(\psi_{at}+\frac{\left(n_{at}-2\right)\gamma_{at}}{n_{at}-1}\right) v_{it}^a \\
B_2\left(s_{n_{at}:n_{at}}^a, s_{n_{at}-1:n_{at}}^a, v_{it}^a\right) &= \frac{\gamma_{at}}{n_{at}-1}\left(s_{n_{at}:n_{at}}^a + s_{n_{at}-1:n_{at}}^a\right) \\
&\quad + \left(\psi_{at}+\frac{\left(n_{at}-3\right)\gamma_{at}}{n_{at}-1}\right) v_{it}^a \\
&\vdots \\
B_{n_{at}-2}\left(s_{n_{at}:n_{at}}^a, \ldots, s_{2:n_{at}}^a, v_{it}^a\right) &= \frac{\gamma_{at}}{n_{at}-1}\sum_{j=3}^{n_{at}} s_{j:n_{at}}^a + \left(\psi_{at}+\frac{\gamma_{at}}{n_{at}-1}\right) v_{it}^a
\end{aligned}
$$

where $B_k\left(., v_{it}^a\right)$ represents the price at which a buyer with valuation v_{it}^a drops out given that k players have previously dropped out of the auction, and $s_{j:n_{at}}^a$ is the jth highest signal of the value of dwelling a in period t (and so $s_{1:n_{at}}^a > s_{2:n_{at}}^a > \ldots > s_{n_{at}:n_{at}}^a$). Note that in this equilibrium other buyers' signals can be inferred as they exit the auction. That is, information about the value of the dwelling is revealed through the auction process.

That this is a symmetric equilibrium bidding strategy can be checked by noting that all of the above exit points occur when the buyer with valuation v_{it}^a is indifferent to exiting and remaining in the auction, given the observed exit of k players previously.

The equilibrium sale price in this auction is given by the point at which the second-last buyer drops out of the auction, and so there is only one remaining buyer:

$$
p_t^a\left(s_{n_{at}:n_{at}}^a, \ldots, s_{2:n_{at}}^a\right) = \frac{\gamma_{at}}{n_{at}-1}\sum_{j=3}^{n_{at}} s_{j:n_{at}}^a + \left(\psi_{at}+\frac{\gamma_{at}}{n_{at}-1}\right) s_{2:n_{at}}^a \qquad \text{(B3)}
$$

Using Equation (B2) we can rewrite Equation (B3) as:

$$p_t^a = (\psi_{at} + \gamma_{at})\,\mu_t^P + \frac{\gamma_{at}}{n_{at}-1}\sum_{j=2}^{n_{at}} \varepsilon_{j:n_{at}}^a + \psi_{at}\varepsilon_{2:n_{at}}^a$$

where $\varepsilon_{j:n_{at}}^a$ is the jth highest idiosyncratic component of the estimate of dwelling a's value in period t.

Taking an average price of all auctions that occurred in period (quarter) t, we have:

$$\begin{aligned} a_t &\equiv \frac{1}{A_t}\sum_{a=1}^{A_t} p_t^a \\ &= \frac{1}{A_t}\sum_{a=1}^{A_t}(\psi_{at} + \gamma_{at})\,\mu_t^P + \frac{1}{A_t}\sum_{a=1}^{A_t}\sum_{j=2}^{n_{at}} \frac{\gamma_{at}}{n_{at}-1}\varepsilon_{j:n_{at}}^a \\ &+ \frac{1}{A_t}\sum_{a=1}^{A_t}\psi_{at}\varepsilon_{2:n_{at}}^a \end{aligned} \tag{B4}$$

where A_t is the total number of successful auctions that occurred.

B.2 Private-treaty Prices

We now model price determination in private-treaty negotiations. In particular, we assume that the bilateral negotiation between a buyer and seller is consistent with a Nash bargaining outcome. We assume a single buyer and seller who have valuations for dwelling i in quarter t of:

$$v_{it}^{ps} = \mu_t^P + \varepsilon_{it}^{ps}$$
$$v_{it}^{pb} = \mu_t^P + \varepsilon_{it}^{pb}$$

where idiosyncratic components are drawn randomly from uniform distributions on the intervals $\left[-\theta_t^i, \theta_t^i\right]$ and $\left[-\phi_t^i, \phi_t^i\right]$ respectively. Again, μ_t^P is the common valuation of the dwelling.

A valid sale requires $\varepsilon_{it}^{pb} \geqslant \varepsilon_{it}^{ps}$ (we have a valid match) and the match surplus is given by:

$$m_{it}^{p} = \varepsilon_{it}^{pb} - \varepsilon_{it}^{ps}$$

With Nash bargaining the negotiated private-treaty sale price is:

$$p_t^i = \mu_t^P + (1 - \psi_{it}) \left(\varepsilon_{it}^{pb}\right) + \psi_{it} \left(\varepsilon_{it}^{ps}\right)$$

where $\psi_{it} \in [0, 1]$ is the bargaining weight of the buyer and $(1 - \psi_{it})$ is the bargaining weight of the seller.

The average private-treaty sale price given P_t successful private-treaty sales in a quarter will be:

$$\begin{aligned} p_t &\equiv \frac{1}{P_t} \sum_{i=1}^{P_t} p_t^i \\ &= \mu_t^P + \frac{1}{P_t} \sum_{i=1}^{P_t} (1 - \psi_{it}) \varepsilon_{it}^{pb} + \frac{1}{P_t} \sum_{i=1}^{P_t} \psi_{it} \varepsilon_{it}^{ps} \end{aligned} \tag{B5}$$

B.3 An Unobserved Components Representation

To link the theoretical models to our empirical findings, we first show that average auction and private-treaty prices admit an unobserved components representation. We then show, given certain restrictions, this unobserved components representation admits a VECM representation with finite lags.

To derive the unobserved components representation of average auction and private-treaty prices, we take asymptotic approximations of each average price. For auctions, we take the approximation as both the number of buyers in each auction and the overall number of auction transactions become large. For private-treaty prices, the approximation is taken as the number of overall private-treaty negotiations (which includes successful and unsuccessful negotiations) becomes large.

B.3.1 Auction prices

Recall that $\varepsilon^a_{j:n_{at}}$ is the jth highest order statistic after n_{at} random draws from a uniform distribution with support $\left[-\theta^a_t, \theta^a_t\right]$. To conserve notation, we will assume $n_{at} = n$ for all a and t, without loss of generality. We first discuss convergence of an indiviudal auction price, as $n \to \infty$, and then convergence of the average auction price as the number of auctions grows large (approaches infinity).

The equilibrium price for auction a at time t is given by:

$$p^a_t = (\psi_{at} + \gamma_{at})\,\mu^P_t + \frac{\gamma_{at}}{n-1}\sum_{j=2}^{n} \varepsilon^a_{j:n} + \psi_{at}\varepsilon^a_{2:n}$$

Lemma 1. *An individual auction converges to a weighted sum of the common component of valuations and the upper bound from which idiosyncratic signals are drawn. That is:*

$$p^a_t \xrightarrow{p} (\psi_{at} + \gamma_{at})\,\mu^P_t + \psi_{at}\theta^a_t \;\; \textit{as } n \to \infty$$

Proof. We begin studying the convergence of the term $\frac{\gamma_{at}}{n-1}\sum_{j=2}^{n} \varepsilon^a_{j:n}$. First, note that:

$$\frac{1}{n}\sum_{j=1}^{n} \varepsilon^a_{j:n} \xrightarrow{p} 0 \;\; \text{as } n \to \infty$$

And so:

$$\frac{\gamma_{at}}{n-1}\sum_{j=2}^{n} \varepsilon^a_{j:n} = \frac{n\gamma_{at}}{n-1}\frac{1}{n}\sum_{j=1}^{n} \varepsilon^a_{j:n} - \frac{n}{n-1}\frac{\gamma_{at}}{n}\varepsilon^a_{1:n,t} \xrightarrow{p} 0 \;\; \text{as } n \to \infty$$

Next note that:

$$\psi_{at}\varepsilon^a_{2:n} \xrightarrow{p} \psi_{at}\theta^a_t \;\; \text{as } n \to \infty$$

Finally, since ψ_{at}, γ_{at} and μ^P_t are not functions of n, we obtain

$$(\psi_{at} + \gamma_{at})\,\mu^P_t + \frac{\gamma_{at}}{n-1}\sum_{j=2}^{n} \varepsilon^a_{j:n} + \psi_{at}\varepsilon^a_{2:n} \xrightarrow{p} (\psi_{at} + \gamma_{at})\,\mu^P_t + \psi_{at}\theta^a_t \text{ as } n \to \infty$$

as required.

Turning to average prices, the average auction price is:

$$a_t = \frac{1}{A_t}\sum_{a=1}^{A_t}(\psi_{at}+\gamma_{at})\,\mu_t^P + \frac{1}{A_t}\sum_{a=1}^{A_t}\sum_{j=2}^{n_{at}}\frac{\gamma_{at}}{n_{at}-1}\varepsilon_{j:n_{at}}^a + \frac{1}{A_t}\sum_{a=1}^{A_t}\psi_{at}\varepsilon_{2:n_{at}}^a$$

We study convergence of the average price as $A_t \to \infty$; that is, the number of auctions is large. Applying the previous results and assuming that:

$$\frac{1}{A_t}\sum_{a=1}^{A_t}(\psi_{at}+\gamma_{at}) \xrightarrow{p} \psi_t+\gamma_t \text{ as } A_t \to \infty$$
$$\frac{1}{A_t}\sum_{a=1}^{A_t}\psi_{at}\theta_t^a \xrightarrow{p} \psi_t\theta_t \text{ as } A_t \to \infty$$

it is straightforward to verify:

$$a_t \xrightarrow{p} (\psi_t+\gamma_t)\,\mu_t^P + \psi_t\theta_t$$
$$\text{as } n \to \infty \text{ and } A_t \to \infty$$

B.3.2 Private-treaty prices

We next study the convergence of private-treaty prices as the number of bilateral negotiations becomes large. Let $\varepsilon_{1t}^b, \varepsilon_{1t}^s, \varepsilon_{2t}^b, \varepsilon_{2t}^s, ..., \varepsilon_{\widetilde{n}t}^b, \varepsilon_{\widetilde{n}t}^s$ be $\widetilde{n}$ pairs of random draws with each buyer draw from a uniform distribution with support $\left[-\theta_t^i, \theta_t^i\right]$ and each seller draw is from a uniform distribution with support $\left[-\phi_t^i, \phi_t^i\right]$, where $\widetilde{n}$ now refers to the total number of private-treaty negotiations, including those that are successful and those that are not. The average private-treaty price, based on successful transactions, is:

$$p_t = \frac{\widetilde{n}}{\sum_{i=1}^{\widetilde{n}} I_i}\frac{1}{\widetilde{n}}\sum_{i=1}^{\widetilde{n}} I_i \times \left(\mu_t^P + (1-\psi_{it})\,\varepsilon_{it}^b + \psi_{it}\varepsilon_{it}^s\right)$$

where $I_i \equiv I\left\{\varepsilon_i^b, \varepsilon_i^s\right\}$ is an indicator function used to identify successful sales:

$$I\left\{\varepsilon_{it}^b, \varepsilon_{it}^s\right\} = \begin{cases} 1 \text{ if } \varepsilon_{it}^b \geq \varepsilon_{it}^s \\ 0 \text{ otherwise} \end{cases}$$

We are interested in the convergence of p_t as $\widetilde{n} \to \infty$. That is, as the number of negotiations becomes very large.

Lemma 2. *Average private-treaty prices converge to a mixture of common and idiosyncratic components. The idiosyncratic components are a non-linear function of the dispersion of buyers and sellers, and the Nash bargaining parameter. Formally:*

$$p_t \xrightarrow{p} \mu_t^P + f\left(\widetilde{\psi}_t, \phi_t, \theta_t\right)$$

where

$$f\left(\widetilde{\psi}_t, \phi_t, \theta_t\right) = \begin{cases} -\left(1-\widetilde{\psi}_t\right)\frac{\phi_t^2}{2\theta_t} + \widetilde{\psi}_t \frac{\theta_t}{2} \text{ if } \phi_t \leq \theta_t \\ -\left(1-\widetilde{\psi}_t\right)\frac{\phi_t}{2} + \widetilde{\psi}_t \frac{\theta_t^2}{2\phi_t} \text{ if } \phi_t > \theta_t \end{cases}$$

Proof. First notice that:

$$\frac{1}{\widetilde{n}} \sum_{i=1}^{\widetilde{n}} I_i \mu_t^P \xrightarrow{p} \mu_t^P \Pr\left(\varepsilon_{it}^b \geq \varepsilon_{it}^s\right)$$

It is straightforward to show:

$$\frac{1}{\widetilde{n}} \sum_{i=1}^{\widetilde{n}} I_i \times \left(\left(1-\psi_{it}\right)\varepsilon_i^b + \psi_{it}\varepsilon_i^s\right) \xrightarrow{p} f\left(\widetilde{\psi}_t, \phi_t, \theta_t\right) \times \Pr\left(\varepsilon_{it}^b \geq \varepsilon_{it}^s\right)$$

This follows since:

$$\begin{aligned} E\left(I_i\left(\left(1-\psi_{it}\right)\varepsilon_{it}^b + \psi_{it}\varepsilon_{it}^s\right)\right) &= E\left(\left(1-\psi_{it}\right)\varepsilon_{it}^b + \psi_{it}\varepsilon_{it}^s \mid \varepsilon_{it}^b \geq \varepsilon_{it}^s\right) \\ &\times \Pr\left(\varepsilon_{it}^b \geq \varepsilon_{it}^s\right) \\ &= f\left(\widetilde{\psi}_t, \phi_t, \theta_t\right) \times \Pr\left(\varepsilon_{it}^b \geq \varepsilon_{it}^s\right) \\ var\left(\frac{1}{\widetilde{n}} \sum_{i=1}^{\widetilde{n}} I_i \begin{pmatrix} \left(1-\psi_{it}\right)\varepsilon_{it}^b \\ +\psi_{it}\varepsilon_{it}^s \end{pmatrix}\right) &= \frac{var\left(I_i\left(\left(1-\psi_{it}\right)\varepsilon_{it}^b + \psi_{it}\varepsilon_{it}^s\right)\right)}{\widetilde{n}} \end{aligned}$$

where $var\left(I_i\left\{\varepsilon_{it}^b,\varepsilon_{it}^s\right\}\left((1-\psi_{it})\,\varepsilon_{it}^b+\psi_{it}\varepsilon_{it}^s\right)\right)<\infty$. We have assumed $\frac{1}{\widetilde{n}}\sum_{i=1}^{\widetilde{n}}\psi_{it}\xrightarrow{p}\widetilde{\psi}_t$ (note ψ_{it} is statistically independent of the signals ε_{it}^b and ε_{it}^s) and applied Chebyshev's inequality.

Next note:

$$\frac{\sum_{i=1}^{\widetilde{n}} I_i}{\widetilde{n}}\xrightarrow{p}\Pr\left(\varepsilon_{it}^b\geq\varepsilon_{it}^s\right)$$

Bringing these results together and applying Slutsky's theorem:

$$p_t\xrightarrow{p}\mu_t^P+E\left((1-\psi_{it})\,\varepsilon_{it}^b+\psi_{it}\varepsilon_{it}^s\mid\varepsilon_{it}^b\geq\varepsilon_{it}^s\right)$$

where the final term is simply given by $f(\widetilde{\psi}_t,\phi_t,\theta_t)$ as required.

B.3.3 Summary of results

In sum, we have established that average auction and private-treaty prices can be approximated in large samples using the unobserved components model:

$$\begin{aligned}a_t&\approx\beta_t\mu_t^P+\psi_t\theta_t\\p_t&\approx\mu_t^P+f(\widetilde{\psi}_t,\phi_t,\theta_t)\end{aligned}$$

where $f(\widetilde{\psi}_t,\phi_t,\theta_t)$ is defined in Lemma 2 and we define $\beta_t=\psi_t+\gamma_t$.

Appendix C: Existence of VECM Representation

From the previous sections, auction and private-treaty prices can be approximated by the unobserved components representation:

$$\begin{aligned} a_t &\approx \beta \mu_t^P + \psi\theta && \text{(C1)} \\ p_t &\approx \mu_t^P + f\left(\widetilde{\psi}_t, \phi_t, \theta\right) && \text{(C2)} \end{aligned}$$

where we have assumed that total information weight ($\psi_t + \gamma_t = \beta$), the average weight on buyers own information ($\psi_t = \psi$) and the average dispersion of buyers ($\theta_t = \theta$) are all constant. If we further assume that $f\left(\widetilde{\psi}_t, \phi_t, \theta\right)$ can be linearly approximated by a stationary ARMA process, z_t, the above unobserved components model can be written as:

$$\begin{aligned} \Delta a_t &= \beta c + \beta \eta_t^P && \text{(C3)} \\ \Delta p_t &= \beta^{-1} \Delta a_t + \beta^{-1} \left(a_{t-1} - \beta p_{t-1} - \psi\theta\right) + z_t && \text{(C4)} \end{aligned}$$

Using a similar approach to the discussion in Lütkepohl (2006, pp 546–548), and noting that z_t and η_t^P are statistically independent of each other, we assume that z_t admits an infinite-order VAR representation:

$$z_t = \sum_{j=1}^{\infty} g_j z_{t-j} + u_t$$

where u_t is white noise. We further assume the regularity conditions:

$$\begin{aligned} 1 - \sum_{j=1}^{\infty} g_j L^j &\neq 0 \text{ for } |L| \leq 1 \\ \sum_{j=1}^{\infty} j \left|g_j\right| &< \infty \end{aligned}$$

Defining:

$$\begin{aligned}
g_j^* &= \begin{cases} -\left(g_{j+1}+...+g_n\right) & \text{for } j=0,1,...,n-2 \\ g_n & \text{for } j=n-1 \end{cases} \\
g_{n-1}^*\left(L\right) &\equiv \sum_{j=0}^{n-1} g_j^* L^j \\
g_n\left(L\right) &\equiv 1-\widetilde{g}_n\left(L\right) \\
\widetilde{g}_n\left(L\right) &\equiv \sum_{j=1}^{n} g_j L^j
\end{aligned}$$

it is straightforward to verify that:

$$g_n\left(L\right)=g_n\left(1\right)-g_{n-1}^*\left(L\right)\left(1-L\right)$$

Pre-multiplying Equation (C4) by $g_n\left(L\right)$ and re-arranging terms:

$$\Delta p_t=\beta^{-1}\Delta a_t-\alpha\left(a_{t-1}-\beta p_{t-1}-\psi\theta\right)+\sum_{j=1}^{n}\gamma_{pj}\Delta p_{t-j}+\sum_{j=1}^{n}\gamma_{aj}\Delta a_{t-j}+e_t$$

where:

$$\begin{aligned}
\alpha &= \left(1-\sum_{j=1}^{n} g_j\right)\beta^{-1} \\
\gamma_{pj} &= g_j+\left(g_j+.....+g_n\right) \\
\gamma_{aj} &= -\beta^{-1}\left(g_j+\left(g_j+.....+g_n\right)\right) \\
e_t &= u_t+\sum_{j=n+1}^{\infty} g_j L^j z_t
\end{aligned}$$

Although we haven't made it explicit, it should be noted that the above coefficients are, in general, functions of the sample size. Taking an asymptotic approximation as the sample size increases, (formally $n_T \to \infty$, $\frac{n_T^3}{T} \to 0$ as $T \to \infty$) given the previous assumptions, implies (see Lütkepohl (2006)):

$$\sqrt{T} \sum_{j=n_T+1}^{\infty} \left|g_j\right| \to 0 \text{ as } T \to \infty$$

and so asymptotically the approximation error becomes sufficiently small such that, $e_t \approx u_t$.

To recap, we have shown that the unobserved components model in Equations (C1) and (C2) can be approximated by a structural VECM of the form:

$$\begin{aligned} \Delta a_t &= \beta c + \beta \eta_t^P \\ \Delta p_t &= \beta^{-1} \Delta a_t - \alpha \left(a_{t-1} - \beta p_{t-1} - \psi\theta\right) + \sum_{j=1}^{n} \gamma_{pj} \Delta p_{t-j} + \sum_{j=1}^{n} \gamma_{aj} \Delta a_{t-j} + u_t \end{aligned}$$

Substituting for Δa_t in the second equation yields Equations (10) and (11) in the main text (where we let $J = n$ and $\tilde{c} = c + \alpha\psi\theta$).[29]

29 Although the previous theory is developed for models of prices in levels, it is straightforward to generalise to log-linear models for prices. In the latter, differences in buyers' and sellers' valuations are measured in percentage terms. The log-linear model is strictly equivalent to our empirical regressions.

Appendix D: Seller Reserve Prices

D.1 Non-optimal Seller Reserve Prices

Consider the case of a non-optimal seller reserve in the English auction. Specifically, there is a single buyer remaining in the auction, and the seller compares the highest outstanding bid with their own (private) reservation value:

$$v_{st}^{a} = \mu_t^P + \varepsilon_{st}^{a}$$

where ε_{at}^{s} is again drawn uniformly on $\left[-\phi_t^a, \phi_t^a\right]$. The seller accepts the highest bid made if $p_t^a \geq v_{st}^a$, and the sale occurs. If $p_t^a < v_{st}^a$, the seller rejects the bid and the dwelling is passed in. In the case that the final bid is accepted, the price is given by:

$$p_t^a = (\psi_{at} + \gamma_{at})\,\mu_t^P + \frac{\gamma_{at}}{n-1}\sum_{j=2}^{n}\varepsilon_{j:n}^{a} + \psi_{at}\varepsilon_{2:n}^{a}$$

To be clear, seller bids are non-optimal in this case for two reasons. First, as discussed in Milgrom and Weber (1982), sellers choosing a reserve that is not state-contingent and that maximises revenue will, in general, want to disclose the reserve price before the auction commences. Second, as discussed in Lopomo (2001), an optimal seller reserve that conditions on the highest bid (is state-contingent) and that maximises expected revenue, will in general not be the same as the seller's own estimate of the value of the dwelling. We will consider the second case further below. Proceeding under the assumption of a non-optimal reserve price, and assuming for simplicity that $\psi_{at} + \gamma_{at} = 1$, we note that in an individual auction the price still converges to:

$$p_t^a \xrightarrow{p} \mu_t^P + \psi_{at}\theta_t^a$$

as the number of buyers grows large. Whether an individual auction will be successful (with infinitely many buyers) or not will therefore depend on whether $\psi_{at}\theta_t^a \geq \varepsilon_{st}^a$, in which case the auction will be successful, or $\psi_{at}\theta_t^a < \varepsilon_{st}^a$, in which case it will not.

With a non-optimal seller reserve price, the average auction price, is given by:

$$
\begin{aligned}
a_t = & \frac{\widetilde{\widetilde{n}}}{\sum_{a=1}^{\widetilde{\widetilde{n}}} I\left\{\psi_{at}\theta_t^a, \varepsilon_{st}^a\right\}} \frac{1}{\widetilde{\widetilde{n}}} \sum_{a=1}^{\widetilde{\widetilde{n}}} I\left\{\psi_{at}\theta_t^a, \varepsilon_{st}^a\right\} \mu_t^P \\
& + \frac{\widetilde{\widetilde{n}}}{\sum_{a=1}^{\widetilde{\widetilde{n}}} I\left\{\psi_{at}\theta_t^a, \varepsilon_{st}^a\right\}} \frac{1}{\widetilde{\widetilde{n}}} \sum_{a=1}^{\widetilde{\widetilde{n}}} I\left\{\psi_{at}\theta_t^a, \varepsilon_{st}^a\right\} \sum_{j=2}^{n} \frac{\gamma_{at}}{n-1} \varepsilon_{j:n}^a \\
& + \frac{\widetilde{\widetilde{n}}}{\sum_{a=1}^{\widetilde{\widetilde{n}}} I\left\{\psi_{at}\theta_t^a, \varepsilon_{st}^a\right\}} \frac{1}{\widetilde{\widetilde{n}}} \sum_{a=1}^{\widetilde{\widetilde{n}}} I\left\{\psi_{at}\theta_t^a, \varepsilon_{st}^a\right\} \psi_{at} \varepsilon_{2:n}^a
\end{aligned}
$$

where we are now explicitly accounting for the fact that there are auctions where the dwelling is passed in, and so $\widetilde{\widetilde{n}}$ is the total number of auctions, including both successful and unsuccessful auctions. $I\left\{\psi_{at}\theta_t^a, \varepsilon_{at}^a\right\}$ is an indicator function such that:

$$
I\left\{\psi_{at}\theta_t^a, \varepsilon_{st}^a\right\} = \begin{cases} 1 \text{ if } \psi_{at}\theta_t^a \geq \varepsilon_{st}^a \\ 0 \text{ otherwise} \end{cases}
$$

Taking the limit as both the total number of buyers and total number of auctions become large, one can verify that:

$$
a_t \xrightarrow{p} \mu_t^P + E\left(\psi_{at}\theta_t^a \mid \psi_{at}\theta_t^a \geq \varepsilon_{st}^a\right)
$$

and so, in principle, the average auction price depends on the distribution of the upper bound of buyer valuations, the distribution of seller valuations (which is assumed to be independent of the former), and the distribution of weights that buyers place on their own signals.

Nevertheless, as discussed in the main text, for a valid VECM approximation to exist, the selection effect term, $E\left(\psi_{at}\theta_t^a \mid \psi_{at}\theta_t^a \geq \varepsilon_{st}^a\right)$, must be approximately constant. If this were not the case, then a VECM with finite lags and serially uncorrelated residuals could not be used to represent the underlying data-generating process. From this perspective, including a non-optimal seller reserve value does not change the main results discussed in the paper. For example, consider the case in which $\psi_{at}\theta_t^a = \psi\theta$ and is constant across all auctions. In this case, $E\left(\psi_{at}\theta_t^a \mid \psi_{at}\theta_t^a \geq \varepsilon_{st}^a\right) = \psi\theta$ but $\Pr\left(\psi_{at}\theta_t^a \geq \varepsilon_{st}^a\right)$ is not constant. This is an example of how there can be time variation in the auction clearance rate that is autocorrelated and due to the role of sellers. However, auction prices themselves are not influenced by sellers values nor are they autocorrelated.

D.2 Optimal Seller Reserve Prices

The previous case considered a non-optimal seller reserve price. An alternative case of interest is when sellers set their reserve price optimally. Lopomo (2001, Proposition 1) derives the optimal state-contingent seller reserve price for a seller who maximises their expected revenue when selling an object through an English auction, and where buyer values are affiliated as defined by Milgrom and Weber (1982). We use the word state-contingent here to capture the idea that the seller observes the auction process, and then determines an optimal seller reserve price that can be affected through a single seller (vendor) bid made at the point in which there is only one buyer remaining in the auction. The remaining buyer can then choose to match that bid and the dwelling is sold, or exit the auction and the dwelling is passed in.

Following Lopomo, let the seller face n risk-neutral buyers who participate in an English auction. Define $N \equiv \{1,...,n\}$. Each buyer, $i \in N$, observes a private signal of the value of the dwelling, s^a_{it}, drawn jointly with the other $n-1$ signals $s^a_{-it} \equiv \left(s^a_1,...,s^a_{i-1},s^a_{i+1},...,s^a_n\right)$ from a symmetric distribution with density f that is strictly positive on its support $S \equiv [0,1]^n$. The restriction on the support is less general than assumed in the previous appendices, but can matched by assuming that $\mu^P_t = \frac{1}{2}$ and that ε^a_{it} is continuously distributed on the support $\left[-\frac{1}{2},\frac{1}{2}\right]$. To conserve notation, we will drop the a superscript and the t subscript, but it should be noted that the following arguments apply to a single auction of dwelling a at time t.

Signals are assumed to be affiliated:

$$f\left(s \vee s'\right) f\left(s \wedge s'\right) \geq f\left(s\right) f\left(s'\right) \text{ for all } s,s' \in S$$

And buyers have a valuation function:

$$v : S_i \times S_{-i} \rightarrow \mathbb{R}$$

where $S_i \equiv [0,1]$ and $S_{-i} \equiv [0,1]^{n-1}$ and the valuation function v is strictly increasing in its first argument, and weakly increasing and symmetric in its last

$n-1$ arguments such that $u\left(s_i, s_{-i}\right) \equiv u_i\left(s_1, \ldots, s_n\right)$ for each $i \in N$. The overall pay-off function of buyer i is:

$$\pi_i \equiv u\left(s_i, s_{-i}\right) Q^i - M^i$$

where Q^i denotes the probability that buyer i is awarded the dwelling and M^i denotes the expected payment to the seller. Restated here for convenience, Lopomo (2001) proves the following proposition:

Proposition 1. *Given the following assumptions:*

A1: Fix any $(s_1, \ldots, s_N) \in S$*, pick two elements* s_i *and* s_j*, and let* $s_{-ij} \in [0,1]^{n-2}$ *denote the vector containing the remaining* $n-2$ *signals. Then,* $s_i > s_j$ *implies* $u\left(s_i, s_j, s_{-ij}\right) \geq u\left(s_j, s_i, s_{-ij}\right)$

A2: $u_{11} \equiv \frac{\partial^2 u_i}{\partial s_i^2} \leq 0$

A3: $u_{1j} \equiv \frac{\partial^2 u_i}{\partial s_i \partial s_j} \geq 0$ *for* $j \neq i$

A4: All conditional hazard ratios $\frac{f_{|-i}(s_i|s_{-i})}{1-F_{|-i}(s_i|s_{-i})}$ *are non-decreasing in* s_i*, where* $f_{|-i}\left(s_i \mid s_{-i}\right)$ *and* $F_{|-i}\left(s_i \mid s_{-i}\right)$ *denote the distribution and density functions of* s_i *conditional on* $s_{-i} \in S_{-i}$

A5: The derivative $\frac{\partial f_{|i}(s_{-i}|s_i)}{\partial s_i}$ *exists for all* $s \in S$

Then, the optimal seller reserve price, set after $n-1$ *buyers drop out, is given by:*

$$r\left(s_{-i}\right) \equiv u\left(t_0\left(s_{-i}\right), s_{-i}\right)$$

where the function $t_0\left(s_{-i}\right)$ *must satisfy:*

$$0 = u\left(t_0\left(s_{-i}\right), s_{-i}\right) - \frac{1 - F_{|-i}\left(t_0\left(s_{-i}\right) \mid s_{-i}\right)}{f_{|-i}\left(t_0\left(s_{-i}\right) \mid s_{-i}\right)} \frac{\partial u\left(s_i, s_{-i}\right)}{\partial\left(s_i\right)}_{|s_i = t_0(s_{-i})}$$

Proof. See Lopomo (2001).

Moreover, Lopomo (2001) shows that the seller's expected revenue is maximised among all posterior-implementable and individually rational outcome functions.

A few comments are worth noting at this point. First, Lopomo's assumptions are relevant to the linear example of affiliated values with independent signals that we use. To see this, note that:

$$u\left(s_i, s_{-i}\right) \equiv \psi_{at} s_i + \frac{\gamma_{at}}{n-1} \sum_{j \neq i} s_j$$

$$u_{11} = 0$$

$$u_{1j} = 0$$

$$\frac{f_{|-i}\left(s_i \mid s_{-i}\right)}{1 - F_{|-i}\left(s_i \mid s_{-i}\right)} = \frac{1}{1 - s_i}$$

$$\frac{\partial f_{|i}\left(s_{-i} \mid s_i\right)}{\partial s_i} = 0$$

which satisfies assumptions A1 to A5. Further, assuming $\mu_t^P = \frac{1}{2}$ and ε_{it}^a is uniformly distributed on $\left[-\frac{1}{2}, \frac{1}{2}\right]$, ensures that each signal, s, has a continuous distribution with support $[0,1]$, consistent with Lopomo (2001).

Second, the seller is assumed to be able to set their reserve optimally, after observing the auction proceed until the point at which there is a single buyer remaining. In effect, the seller acts as a buyer in the final stage of the auction competing with the one remaining buyer. In practice this could be implemented through a single vendor bid made at the point at which there is one buyer left in the auction. A single vendor bid is allowed in a standard auction format in NSW and Victoria.

Third, and importantly for our results, the seller's optimal reserve is a function only of the signals of $n-1$ buyers who have already exited the auction. This is important, because it suggests that the optimal reserve in effect is determined by buyers' information.

Fourth, solving for the optimal reserve explicitly, in our linear example of affiliated values, we have (applying Proposition 1):

$$r\left(s_{-i}\right)=\frac{\psi_{at}}{2}+\frac{1}{2}\frac{\gamma_{at}}{n-1}\sum_{j=2}^{n}s_{j:n}$$

$$t_{o}\left(s_{-i}\right)=\frac{1}{2}-\frac{1}{2\psi_{at}}\frac{\gamma_{at}}{n-1}\sum_{j=2}^{n}s_{j:n}$$

The remaining buyer (with highest signal) will accept this reserve (match the vendor bid) if:

$$s_{1:n}\geq t_{o}\left(s_{-i}\right)$$

or will otherwise exit the auction.

Accordingly, the effect of introducing an optimal seller reserve is to change the equilibrium price of the auction. The intuition for why this occurs is that the seller knows with positive probability that the remaining buyer is willing to pay more than the price at which the second-last buyer dropped out (recall that the second-last buyer does not observe the signal of the final remaining buyer). For this reason, the seller optimises between the expected gain from placing a higher vendor bid that the remaining buyer may be willing to pay if their signal is high enough, and the expected cost that the vendor bid is too high and the remaining buyer exits the auction (and so the gains from trade are foregone).

In terms of the implications for an individual auction price, with an optimal seller reserve, it follows that the equilibrium price when the auction clears $\left(p_t^a=r\left(s_{-i}\right)\right)$, and there are many buyers, converges to

$$p_t^a\xrightarrow{p}\frac{\psi_{at}+\frac{1}{2}\gamma_{at}}{2}$$

Recall, to be strictly compatible with Lopomo we have assumed $\mu_t^P=\frac{1}{2}$ and $\varepsilon_{it}^a\sim U\left[-\frac{1}{2},\frac{1}{2}\right]$. Thus, with an optimal seller reserve price, the average auction price still converges to the common component in all prices up to a scaling factor.

Finally, although we have presented this argument abstracting from a positive seller outside option and have not accounted for the fact that not all dwellings sell when determining average prices, these too can be incorporated. Specifically, there is a significant selection effect that depends on the term $E\left(\varepsilon_{at}^{s} \mid \varepsilon_{1:n}^{a} \geq t_0\left(s_{-i}\right)\right)$. However, again our empirical work suggests that this selection effect is unlikely to be an important driver of changes in auction prices.

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