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DOI:
10.57938/130198f0-e743-4985-9177-b5e0d5ae6b5c

Published: 01/07/2019

Department of Economics
Working Paper No. 285

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July 2019

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6 June 2019

Abstract:
The treatment of owner-occupied housing (OOH) is probably the most important unresolved issue in inflation measurement. How – and whether – it is included in the Consumer Price Index (CPI) affects inflation expectations, the measured level of real interest rates, and the behavior of governments, central banks and market participants. We show that none of the existing treatments of OOH are fit for purpose. Hence we propose a new simplified user cost method with better properties. Using a micro-level dataset, we then compare the empirical behavior of eight different treatments of OOH. Our preferred user cost approach pushes up the CPI during housing booms (by 2 percentage points or more). Our findings relate to the following important debates in macroeconomics: the behavior of the Phillips curve in the US during the global financial crisis, and the response of monetary policy to housing booms, secular stagnation, and globalization. (JEL. C31; C43; E01; E31; E52; R31)

Keywords: Measurement of inflation; Owner occupied housing; User cost; Rental equivalence; Quantile regression; Hedonic imputation; Housing booms and busts; Inflation targeting; Leaning against the wind; Phillips curve; Disinflation puzzle; Secular stagnation

We thank Erwin Diewert and Martin Eiglsperger for helpful comments, the Austrian Research Promotion Agency (FFG) (grant #10991131) for funding, and Australian Property Monitors (APM) for providing the data. Drafts of this paper have been presented at Oxford University (February 2017), the Statistical Institute of Luxembourg (April 2017), the Institute of Fiscal Studies, London (May 2017), the GGDC 25th Anniversary Conference, Groningen (June 2017), the Society for Economic Measurement Conference at MIT (July 2017), the Reserve Bank of Australia (April 2018), the Economics Statistics Centre of Excellence Conference on Economic Measurement 2018 at the Bank of England (May 2018), and the International Conference on Real Estate Statistics, Eurostat, Luxembourg, (February 2019). Any errors are our own.

1 Introduction

> The big question for inflation measurement - as big as the decision about how to treat government expenditures in calculating GDP - is whether to include owner-occupied housing in aggregate consumer price statistics. And if the answer is that we should, which I think it is, then how should we do it? (Cecchetti, 2007, p. 1)

The consumer price index (CPI) is a key macroeconomic statistic. It is used by central banks for setting monetary policy. Governments and the private sector use it to index wages, pensions, and contracts. It informs market participants about price developments, real interest rates, and guides their expectations about the overall health of the economy.

The treatment of housing in the CPI, therefore, is more than merely an accounting exercise. It is not just like switching from Fahrenheit to Celsius. It will actually change people's perception of how hot it is. More specifically, it will affect inflation expectations, and hence behavior.

Mismeasurement of inflation can undermine the effectiveness of monetary policy. For example, inflation targeting has been implicated as a causal factor in the global financial crisis (GFC), since it encouraged central banks to focus primarily on price stability and not enough on asset markets (see Blanchard, Dell'Ariccia, and Mauro, 2010). From our perspective, the problem was not so much inflation targeting itself, as the unresponsiveness of existing inflation measures to developments in the housing market. In this sense, the treatment of housing in the CPI can also be implicated as a causal factor in the GFC.

Our focus here is on how the housing market should enter into the CPI, as it pertains to monetary policy. There is not much disagreement over the treatment of rents.[1] The problematic part of housing is owner occupied housing (OOH). As housing is at least partly a consumer durable, there is broad agreement that, one way or another, OOH should be included in the CPI (see for example Goodhart 2001, Diewert 2003, Cecchetti 2007, and European Central Bank 2016).[2] The question is how to include it.

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[1]Even here though there are some important measurement issues with regard to how the rent index and expenditure share are constructed (see Ambrose, Coulson, and Yoshida, 2018).

[2]The situation is less clear with regard to a CPI used for the indexation of wages and pensions, since any

OOH, when included, is typically the biggest component of the CPI. However, many countries exclude OOH from their CPIs on the grounds that it is too difficult to measure. In particular, the harmonized index of consumer prices (HICP) in the European Union (EU) currently excludes OOH.[3] The HICP is the flagship CPI in the EU that is used by the European Central Bank (ECB) for price stability purposes as well as for assessing whether countries are ready to join the Euro area. As the following quote illustrates, there is a general desire to include OOH in the HICP once the measurement problems have been sufficiently resolved.

> Establishing price indexes for dwellings, and in particular for owner-occupied housing (OOH), is an important step towards further improving the relevance and comparability of the HICP. [...] By 31 December 2018, the Commission should prepare a report addressing the suitability of the OOH price index for integration into the HICP coverage.[4]

This deadline has come and gone without any resolution to the OOH dilemma. Including prices related to both tenure alternatives – renting and owner-occupying – is particularly important for a transnational CPI such as the HICP, due to the large heterogeneity in the share of owner-occupiers in the Euro area (ranging between roughly 50% in Germany and 90% in Slovakia; see footnote 13). Excluding OOH from the HICP leads to strikingly asymmetric treatments of housing costs across countries, undermining the goal of a truly harmonized index.

Housing can be included in the CPI via different methods, the main alternatives being the acquisitions, rental-equivalence, and user-cost methods (see for example Blinder 1980, Diewert 2003, 2009, and Eiglsperger 2006).[5] The approaches differ in how expenditure weights and/or

increase in the cost of OOH services faced by owner occupiers is offset by the extra imputed rent received.

[3]The HICP is jointly compiled by Eurostat (the statistical institute of the European Union) and national statistical institutes following a harmonized statistical methodology.

[4]Source: Regulation 2016/792 of the European Parliament and of the Council of 11 May 2016, Official Journal of the European Union, 24.05.2016, L 135/12, paragraph 10.

[5]Two other methods have been proposed in the literature that we do not consider explicitly here. These are the payments and opportunity cost methods. The payments method, in our opinion, lacks sufficient theoretical foundations to warrant serious consideration. Austria and Ireland are the only countries, that we are aware of, that still use it. The weaknesses of the payments approach are discussed in Diewert (2003, 2009). More recently,

price indexes are constructed. The acquisitions method treats housing as if it was another consumer durable. Hence it focuses on newly built dwellings in the period in which they are purchased. The other two main methods, rental-equivalence and user cost, share the idea that OOH costs should enter the CPI as a flow of housing services over multiple periods. Rental-equivalence looks to the rental market to measure this service flow, while the user cost approach attempts to measure the cost of the housing flow more directly.

Among countries currently including OOH in their CPI, rental equivalence is the most widely used method. Even though a number of European countries use rental equivalence in their national CPIs, Eurostat recommends using the acquisitions method on an experimental basis in the HICP (see Eurostat, 2012).[6] Versions of the user cost method are used by Canada, Sweden and Iceland (see Eiglsperger and Goldhammer, 2018).

We argue here that none of these existing methods is fit for purpose. Our criticisms of the acquisitions and rental equivalence methods are outlined in section 2. Conceptually, the user cost method has better properties. However, it can cause erratic fluctuations in the CPI (a point we demonstrate empirically in section 4). As a result, not surprisingly, central banks have tended to be wary of the user cost method. The problems relate to the user cost method's inclusion of an interest rate term, expected capital gains, and a risk premium.

We propose a simplified yet novel version of the user cost method that generates a CPI that is responsive to changes in house prices, while avoiding the controversies arising from the inclusion of interest rates, expected capital gains or risk premiums. Our simplified user cost method has appealing statistical properties due to its more stable expenditure shares, and it has less onerous data requirements than the rental equivalence and acquisitions approaches. Our proposed method hence constitutes a practically feasible solution to a monetary policy

Diewert (2008) and Diewert, Nakamura and Nakamura (2009) proposed another method – the opportunity cost method – that sets the cost of OOH equal to the maximum of rental equivalence and user cost. This maximum should in principle be calculated at the level of each individual dwelling. Shimizu, Diewert, Nishimura and Watanabe (2012) and Aten (2018) have experimented with applying this method to Japanese and US data, respectively (see also Diewert and Shimizu, 2018). While we do not consider it further here, we agree that the opportunity cost method warrants further investigation.

[6]Most EU countries are computing experimental HICPs that include OOH using the acquisitions method.

dilemma.

It is important also to know how the alternative methods for including OOH in the CPI perform empirically, and how much difference it makes which method is used. For this purpose, we use a detailed micro-level dataset consisting of over 1 million price and rent observations from Sydney (Australia) over the period 2004-2014. We estimate hedonic quantile models and then use them to impute prices and rents for every dwelling in every year. The use of quantile regression methods ensures that prices and rents in all parts of the price and rent distributions are imputed as accurately as possible and avoids a regression-to-the-mean effect.[7] With these imputed prices and rents we then empirically compare eight versions of the CPI for Sydney that differ in their treatment of OOH. These are four variants on the user cost method, the rental equivalence method, the official CPI for Sydney computed using the Australian version of the acquisitions method, Eurostat's version of the acquisitions method, and a CPI that excludes OOH.

We show that the treatment of OOH significantly affects the measured rate of inflation in Sydney. Our preferred user cost approach pushes up the CPI during the housing boom of 2013-14 by more than 2 percentage points.

The treatment of OOH relates to some important debates in macroeconomics. First, the inclusion of OOH in the US CPI using our preferred user cost method can at least partly resolve the disinflation puzzle, where inflation during the GFC did not fall as much as a standard Phillips curve predicted. Second, the debate over whether central banks should raise interest rates during a housing boom is intertwined with the question of how OOH should be included in the CPI. Adopting our preferred user cost method could potentially make it no longer necessary for central banks to use monetary policy to lean on housing booms. Third, changing the treatment of OOH in the CPI could be a useful weapon for fighting secular stagnation, and for reducing the damage caused by a central bank pursuing an inflation target that is incompatible with the inflation rate prevailing in the global economy.

The remainder of the paper is structured as follows. Section 2 discusses the main features of

[7] A number of methodological innovations are introduced here, and hence our quantile based estimation by itself constitutes a significant contribution (see Appendix B).

the acquisitions, rental equivalence and user cost methods for including OOH in the CPI. Section 3 proposes a simplified version of the user cost and highlights its attractive properties. Section 4 compares the methods discussed in sections 2-3 empirically, using micro-level data from Sydney, Australia. Section 5 considers the implications of our results for three key macroeconomic debates. Our main findings are summarized in section 6.

2 Alternative Treatments of OOH in the CPI

2.1 The acquisitions approach

The acquisitions approach treats OOH in the CPI in the same way as consumer durables such as cars and refrigerators, by focusing on expenditure on new housing.[8] The acquisitions approach is used by Australia, New Zealand, Finland, and – on an experimental basis – by the member states of the European Union. Australia and New Zealand differ from Europe in the way the price index for new dwelling purchases by owner-occupiers is constructed. While Australia and New Zealand use cost indexes for residential construction building materials, Eurostat recommends using price indexes for new residential housing based on actual transaction prices (see Eurostat, 2012). As transaction prices contain the cost of land as well as structure, the land component is hence included in the price index.

Expenditure on OOH under the acquisitions approach consists of three components:

$$\begin{aligned} Y_t = &\text{New dwelling purchases by owner-occupiers (excluding land)} \\ &+ \text{Maintenance and repair of dwellings} \\ &+ \text{Property rates and charges.} \end{aligned}$$

The first of these components, which also includes major renovations and existing dwellings that are new to the residential sector, is by far the largest. It can be taken straight from new residential construction in the national accounts. The average expenditure per household, y_t^A,

[8]By including the price of housing in the CPI only in the purchase year, the CPI confounds current and future consumption. This criticism applies to all durable goods, not just housing. Sabourin and Duguay (2015), for example, have argued for a flow approach for including cars as well as housing in the CPI.

is obtained by dividing Y_t by the total number of households H_t (i.e., both owner-occupiers and renters). The acquisitions price index p_t^A/p_{t-1}^A, with the Eurostat version, is a price index for newly built housing (denoted here by $P_{t-1,t}^N$). Hence the required input data are as follows:

$$y_t^A = Y_t/H_t, \quad \text{and} \quad \frac{p_t^A}{p_{t-1}^A} = P_{t-1,t}^N.$$

The analogy between houses and consumer durables is problematic since a house consists of a produced part – the structure – and a pre-existing part – the land. The Australia/New Zealand version of the acquisitions approach focuses exclusively on the structure, and hence ignores the role played by land. But land prices are generally the driving force in house price increases. Based on a sample of 14 OECD countries, Knoll, Schularick and Steger (2017) show that almost all of the rise in real house prices since 1870 can be attributed to changing land prices. Davis and Heathcote (2007) obtain similar results across regional metropolitan statistical areas in the United States. Omitting land therefore deprives OOH of most of its content.[9]

A further weakness of the acquisitions approach is that new residential construction is a very volatile component of GDP, that rises strongly during housing booms, only then to collapse when house prices start falling (see Leamer, 2007). Hence, the expenditure weights on OOH under the acquisitions approach can fluctuate very significantly over the housing cycle. If the weights are updated regularly this may have a destabilizing effect on the CPI. If the weights are not updated regularly, then the treatment of OOH may be highly sensitive to the choice of reference year.

In the European context, this issue could be particularly problematic given that the housing cycles of many Euro area countries seem to be out of sync with each other.[10] In any given period, Euro area countries with rising house prices will tend to have large expenditure weights for housing, while countries with stagnant housing markets will tend to have small expenditure weights, thus potentially undermining the comparability of the HICP across countries.

Even when housing cycles are aligned, the international comparability of new residential

[9]This criticism does not apply as strongly to the Eurostat version of the acquisitions method since in this case the price index used does include land.

[10]For example, German and Austrian house prices were falling/stable from 1990 to 2007, while Spanish and Irish prices were rising strongly. Interestingly, this pattern reversed once the Euro area crisis started.

construction, as recorded in the national accounts, could be quite poor. For example, the proportion of new houses that are self-builds (which are often not recorded by national statistical institutes) can vary enormously across countries.[11]

Finally, as was noted above, the Eurostat version of the acquisitions method requires, where possible, a price index for newly built housing. Constructing such an index may be extremely problematic for some countries when the number of new dwelling sales recorded each period is low. This can happen when the country has a small population, a high proportion of self-builds, or when it is experiencing an economic downturn. In short, we do not recommend using the acquisitions method.

2.2 The rental equivalence approach

Both the rental equivalence and user cost approaches attempt to measure expenditure on OOH services. Focusing on the stream of services provided by OOH ensures consistency with the treatment of rental dwellings.

The rental equivalence method measures the service flow by the amount it would cost to rent owner occupied properties. It is the most widely used method for including OOH in the CPI. It is used for example by the USA, Japan, Denmark, Norway, Switzerland, the Czech Republic, Mexico, and South Africa in the target CPI for monetary policy (see OECD, 2015). For wage indexation purposes, Germany, the Netherlands, and the UK use a CPI that includes a rental equivalence version of OOH (see Office of National Statistics, 2016a).[12]

Average household expenditure on OOH under rental equivalence (y_t^R) is the average imputed rent on OOH dwellings obtained by multiplying the average rent of OOH dwellings, $\bar{R}_t$, by the share of households that are owner occupiers. The rental equivalence price index, p_t^R/p_{t-1}^R, is a

[11] Related to this is the problem of distinguishing between renovations and repairs. Under the acquisitions approach, renovations and repairs should be included in different headings. Inconsistencies across countries could arise if these definitions are not carefully harmonized.

[12] The UK is an interesting case. It is in the process of switching from the HICP – known as the CPI in the UK – to CPIH (an index that includes OOH using rental equivalence) for indexation purposes. Thus far the Bank of England has not likewise switched from the CPI to CPIH for monetary policy purposes.

rent index, $R_{t-1,t}$. Hence the required input data are as follows:

$$y_t^R = \bar{R}_t \times \frac{H_t^{OOH}}{H_t}, \quad \text{and} \quad \frac{p_t^R}{p_{t-1}^R} = R_{t-1,t}. \tag{1}$$

where H_t^{OOH} is the number of OOH households while H_t is the total number of households.

The rental rate for a property is typically estimated using either hedonic regression methods or by surveying owner-occupiers. While an improvement on the acquisitions approach, rental equivalence has some weaknesses. First, there is the question of whether the services a household obtains from renting are the same as the services obtained by owner-occupying. For example, renters and owner-occupiers may value maintenance, improvements, and local amenities differently. Second, the rental market may not be a good indicator of OOH costs if there is rent control, or the rental market is too small, concentrated in urban areas, and/or dominated by certain groups (e.g., expatriates or students). This is an important issue in the European Union. The HICP requires that all member states use the same method to measure the costs of OOH. However, the share of the rental market of most Eastern European countries is below 20 percent, and for some western EU countries such as Spain and Italy it is less than 30 percent.[13]

Regarding surveys, Heston (2009) and Heston and Nakamura (2009) have suggested that owner occupiers may be over-optimistic about the rent they could charge for their properties, thus causing imputed rents to be overestimated. Hedonic modeling can also be problematic since owner-occupied and rented dwellings may systematically differ in their characteristics (e.g., urban versus rural locations, or the size of dwellings). In countries with smaller rental markets, hedonic models are therefore unlikely to produce reliable imputations. Furthermore, to the extent that owner-occupied dwellings perform better on the omitted variables in the hedonic model (e.g., the quality of the structure), they will systematically underestimate the imputed rent (see Halket, Nesheim, and Oswald 2015, Hill and Syed 2016, Katz 2017, and Aten 2018). Hence obtaining reliable estimates of imputed rent for owner-occupied dwellings is not straightforward.

[13] See `http://appsso.eurostat.ec.europa.eu/nui/show.do?dataset=ilc_lvho02&lang=en` (accessed on April 15, 2019).

The rent index used by the rental equivalence method to deflate OOH expenditure should ideally focus on new, rather than existing, rental contracts. By contrast, the normal practice is to mainly follow the same properties over time (see for example Office of National Statistics, 2016b). Due to common regulation of the allowed rent increase within existing contracts, new and existing rents may differ substantially. In particular, Ambrose, Coulson, and Yoshida (2015, 2018) show that the owner's equivalent rent (OER) index, which is used to deflate OOH in the US CPI, suffers from this problem. As a result the US CPI fails to react to recent developments in the rental market. We revisit this issue in section 5.2.

Even if the rent index is based on new contracts and is properly quality-adjusted, there is still a second problem: Rent indexes and house price indexes can follow very different paths over the short to medium term (see for example Hill and Syed, 2016). Rental equivalence could be implicated in contributing to the GFC, given that rental prices hardly rose in the US during the housing boom that ended in 2006. The development of the house price bubble did not exert inflationary pressure on the US CPI, and hence there was no contractionary impact on monetary policy (again see section 5.2 and Figure II).

Such a situation is not uncommon during booms, which are often driven by the expectation of future capital gains rather than rising rents. Indeed, in this regard it is informative to consider Stiglitz's (1990) definition of a bubble.

> [I]f the reason the price is high today is *only* because investors believe the selling price will be high tomorrow – when "fundamental" factors do not seem to justify such a price – the a bubble exists. (Stiglitz, 1990, p. 13)

The rental equivalence approach is therefore not only likely to fail, but actually expected to fail, to register the presence of a bubble. This is problematic from a monetary policy standpoint.

2.3 The user cost approach

The user cost method measures the costs associated with housing services incurred by owners in a given period. Versions of the user cost method are used in the official CPIs of Canada (see Baldwin, Nakamura, and Prud'homme 2009, and Sabourin and Duguay 2015), Sweden (see

Sveriges Riksbank, 2016), and Iceland (see Gudnason and Jónsdóttir 2009, and Diewert 2009).

The basic idea of the user cost approach dates back at least to Keynes (1936). The approach was developed by Jorgenson (1967) and Hall and Jorgenson (1967) to provide an imputed rent for purchased capital used by firms in production. The concept can equally well be applied to housing to measure the cost of OOH services directly (see Blinder 1980 and Poterba 1984). For each dollar invested in OOH the user cost is usually assumed to consist of the following components (or something similar):[14]

$$u_t = r_t + \delta_t + \omega_t + \gamma_t - \pi_t - g_t, \tag{2}$$

where

- u_t is per dollar user cost,
- r_t is the interest rate,
- δ_t is depreciation,
- ω_t is running and average transaction costs (including taxes),
- γ_t is the risk premium,
- π_t is the expected rate of inflation, and
- g_t is the expected real capital gain on housing.

The formula includes an additional term if owner-occupiers can tax deduct mortgage interest payments (again see Blinder 1980), as they can in the US, but not in Australia. We return to this issue in section 3.

The formula in (2) is a simplification of a more general user cost formula provided by Diewert (2003):

$$u_t = (1 + r_t) - (1 - \delta_t - \omega_t - \gamma_t + \pi_t)(1 + g_t) = r_t + \delta_t + \omega_t + \gamma_t - \pi_t - g_t + (\delta_t + \omega_t + \gamma_t - \pi_t)g_t.$$

[14] Some versions of the user cost method draw a distinction between the debt and equity components of housing wealth, where a mortgage interest rate is used for the debt part and a long-term government bond rate for the equity part.

A similar specification is derived in Christensen and Jorgenson (1969). The Diewert formula reduces to (2) when it is assumed that

$$(\delta_t + \omega_t + \gamma_t - \pi_t)g_t \approx 0.$$

In our empirical comparisons, this is a reasonable assumption. Omitting this term has virtually no impact on the results. Henceforth, therefore, we measure user cost using the formula in (2).

Let $\bar{P}_t$ is the average estimated price of an OOH dwelling in period t. The average OOH user cost for owner-occupiers is therefore given by $\bar{P}_t u_t$. Average household expenditure on OOH (y_t^U) is calculated by multiplying the average user cost of OOH dwellings, $\bar{P}_t u_t$, by the share of households that are owner occupiers. The user cost price index, p_t^U/p_{t-1}^U, measures the change in the average user cost from one period to the next. Hence the required input data are as follows:

$$y_t^U = \bar{P}_t u_t \times \frac{H_t^{OOH}}{H_t}, \quad \text{and} \quad \frac{p_t^U}{p_{t-1}^U} = \frac{u_t P_t}{u_{t-1} P_{t-1}}, \tag{3}$$

where H_t^{OOH}/H_t is again the share of households that are owner occupiers.

3 Making the User Cost Method Operational in Practice

The depreciation rate, δ_t, and running and average transaction costs (including taxes), ω_t, in the per dollar user cost formula in (2), while not necessarily easy to compute, can generally be assumed to remain constant over time. If, with more experience, the initial estimate is deemed incorrect, it can be adjusted. Canada for example in 1998 revised downwards its estimate of depreciation from 2 percent to 1.5 percent (see Baldwin, Nakamura, and Prud'homme, 2009). The problems with the user cost method arise from the other elements of the per dollar user cost formula.

> [The user cost method measures] the cost foregone by living in an owner-occupied property as compared with selling it at the beginning of the period and repurchasing it at the end. [...] But this gives the absurd result that as house prices rise, so the opportunity cost falls; indeed the more virulent the inflation of housing asset prices,

> the more negative would this measure become. Although it has some academic afficionados, this flies in the face of common sense. (Goodhart, 2001, p. F351)

The problem highlighted by Goodhart relates to the expected capital gain term in the per dollar user cost formula. The capital gain g_t is typically either measured ex post based on actual market performance in that period, or it is assumed that market participants extrapolate expectations from the past performance of the housing market.[15] In this regard, two problems are worth mentioning here. First, including capital gains in these ways can cause high levels of volatility in the CPI (see Gillingham, 1983, Verbrugge, 2008, Garner and Verbrugge, 2009, and Hill and Syed, 2016). We provide compelling evidence of how the user cost approach can destabilize the CPI in section 4.

Second, the quote from Goodhart could be interpreted as suggesting that the user cost method causes a downward bias in the CPI. The issue is that with the user cost method the weight on housing in the CPI goes down during housing booms. Conversely, when house prices are falling, the weight on housing goes up. We explore this issue in Appendix A. We show there that the CPI does indeed have a systematic downward bias when capital gains are included ex post or expectations of capital gains are extrapolated over a short time horizon. In practice, however, this bias is likely to be swamped by the high level of volatility arising from the inclusion of capital gains.

Another alternative is to assume that expectations are always at the break-even level at which households are indifferent between owning and renting. In other words, it is assumed that g_t always adjusts such that $R_t = u_t\bar{P}_t$. In this case, as has been previously noted by Diewert (1983), the user cost method reduces to the rental equivalence method, and hence is subject to all the criticisms discussed in section 2.2.

Canada, Sweden and Iceland avoid these problems by excluding capital gains from their CPIs (see Eiglsperger and Goldhammer, 2018). These countries' treatments of OOH in their CPIs are discussed in more detail in section 4.4.

The presence of an interest rate term, r_t, is also problematic, particularly for central banks.

[15] Some empirical support for the assumption that expectations in the housing market are extrapolated from past performance is provided by Armona, Fuster and Zafar (2019).

Its inclusion implies that the CPI may jump upwards whenever monetary policy is tightened, thus making it harder for the central bank to achieve its objective.

We propose here a simplified approach that resolves the problems relating to both the treatment of capital gains and interest rates. The expected real return on real estate (g_t) equals the expected return on governments bonds (r_t), minus the expected rate of inflation (π_t), plus a risk premium (γ_t^b).

$$g_t = r_t - \pi_t + \gamma_t^b. \tag{4}$$

If we substitute (4) into (2), we obtain that

$$u_t = \delta_t + \omega_t + \gamma_t - \gamma_t^b. \tag{5}$$

Now we have two risk premiums. The first, γ_t, captures the risk difference between owning and renting. It is generally assumed to be positive, since house prices tend to be more volatile than rents. For example, Himmelberg, Mayer and Sinai (2005) drawing on previous studies, set it to 2 percent. The second, γ_t^b, captures the risk difference between owning bonds and real estate, which should also be positive since house prices tend to be more volatile than interest rates. These risk premiums should tend to move in the same direction over time. For example, if the perceived volatility of house prices increases, then both should rise.

Our simplifying assumptions are that the depreciation rate, the running and average transaction costs, and the difference between the two risk premiums remain constant over time. In other words, (5) reduces to

$$u_t = \delta + \omega + k, \tag{6}$$

where $k = \gamma_t - \gamma_t^b$. With these assumptions it follows that u_t no longer varies over time. This in turn implies that u_t drops out of the user cost price index, which now becomes simply a house price index P_t/P_{t-1}.

In the case, as in the US, where owner-occupiers can tax deduct mortgage interest payments, the situation is slightly more complicated. Now the original user cost equation is rewritten as follows (see Poertba, 1984, and Himmelberg, Mayer and Sinai, 2005):

$$u_t = r_t - \tau_t r_t^m + \delta_t + \omega_t + \gamma_t - \pi_t - g_t, \tag{7}$$

where τ_t is the marginal tax rate and r_t^m is the mortgage interest rate. In this case, the expected capital gain equation from (4) is modified as follows:

$$g_t = r_t - \tau_t r_t^m - \pi_t + \gamma_t^b. \tag{8}$$

The risk premium of owning rather than renting, γ_t, is smaller when mortgage interest payments can be deducted. Assuming now that $k = \gamma_t - (\gamma_t^b - \tau_t r_t^m)$, the user cost formula again reduces to (6).

An alternative derivation of this simple user cost method is to exclude capital gains and risk premiums and fix the real interest rate. This is the approach taken by Sweden since 2017, although the Swedish method differs in some other important ways from the simplified user cost method outlined here (see section 4.4).

Our simple user cost method has a number of advantages. First, the interest rate cancels out of the user cost formula. Hence contractionary monetary policies will not immediately push up inflation. Second, the capital gain term also cancels out, and hence the inclusion of OOH will not have a destabilizing effect on the CPI. Third, since the user cost price index now reduces to a house price index, it will make the CPI more responsive to developments in the housing market than it would be under the rental equivalence method. We discuss these issues further in section 5.

4 Empirical Strategy

4.1 The data set

It is important to check how the various methods discussed above perform on real data. We focus here on Sydney, Australia over the period 2004 to 2014. There are two reasons why we chose Sydney. First, the Australian Bureau of Statistics (ABS) computes a CPI specifically for Sydney, and it provides results at a sufficiently disaggregated level that it is possible to remove OOH from the CPI. Second, we have access to micro-level housing data for Sydney that allows us to experiment with alternative treatments of OOH. The micro-level dataset was purchased from Australian Property Monitors (APM) (see `http://apm.com.au`). We have 340 362 actual transaction prices for houses sold and 215 408 for units sold. The data set also includes 311 105 asking rents for houses and 479 211 asking rents for units (the rents are quoted in Australian dollars – AUD – per week).

For each price and rent observation we have information on the following characteristics: exact date of sale (or posting of the asking rent), land area, number of bedrooms, number of bathrooms, exact address, postcode identifier, and exact longitude and latitude. Properties with land areas greater than 10 000 square meters, or more than 6 bedrooms or bathrooms were deleted (since a significant number of these outliers contain data entry errors). Above that, observations with unrealistic price or rent information such as a weekly rent of 1 Australian dollar or observations with missing price or rent information or locational characteristics were deleted as well. Properties that are not located in one of Sydney's 16 Residex regions were also excluded. Summary statistics are provided in Appendix C, Table C1.

The data set has some gaps. There are, in particular, many observations lacking the number of bed- or bathrooms. To fill up these gaps we exploit the fact that some properties appear multiple times in the data sets, as they are both sold and rented, or sold or rented more than once.[16] The empirical analysis is then performed on all directly observed or successfully refilled observations.

4.2 Construction of hedonic price and rent indexes

We use hedonic quantile regression models to impute prices and rents for individual dwellings. A quantile approach ensures that predictions for each property are tailored to its part of the price or rent distribution. The prediction procedure consists of five steps which are described in Appendix B.

Sample means for OOH sales and rental prices are shown in Table C2 in Appendix C. Separate mean prices and rents are calculated for houses and units. The whole market mean is then a weighted average of the house and unit means. The weights were obtained from estimates of the total stock of houses and units in Sydney, by counting the total number of

[16]The algorithm applied in this paper is similar to the ones used in Waltl (2016, 2018), but extended to cross-refilling between sales and rental observations, and reconstruction of the variable land area.

distinct sales (i.e., excluding repeats) – see explanations in Appendix C for further details.

Price and rent indexes are shown in Figure I and Table C3 in Appendix C. These indexes are constructed using the Törnqvist-type hedonic double imputation formula in (9), which is the geometric mean of (10) and (11). The Paasche-type index in (10) focuses on the properties sold in period $t+1$. Hedonic models are used to predict prices for all these properties in both periods t and $t+1$. For example, $\hat{p}_{t+1,h}(z_{t+1,h})$ denotes the predicted price in period $t+1$ of a property h actually sold in period $t+1$, while $\hat{p}_{t,h}(z_{t+1,h})$ denotes the same property's predicted price in period t. These predicted prices are then fed into a standard geometric-Paasche price index formula. The Laspeyres-type index in (11) takes an analogous approach, except that it now focuses on the properties actually sold in period t. Double imputation (i.e., imputing both the numerator and denominator for each price relative) tends to reduce omitted variables bias when the levels of the omitted variables are reasonably stable over time, as is typically the case for housing data (see for example de Haan 2004, and Hill and Melser 2008).

$$\text{Törnqvist-Type Imputation}: \ P^{TI}_{t,t+1} = \sqrt{P^{PI}_{t,t+1} \times P^{LI}_{t,t+1}} \tag{9}$$

$$\text{Paasche-Type Imputation}: \ P^{PI}_{t,t+1} = \prod_{h=1}^{H_{t+1}} \left[\left(\frac{\hat{p}_{t+1,h}(z_{t+1,h})}{\hat{p}_{t,h}(z_{t+1,h})} \right)^{1/H_{t+1}} \right] \tag{10}$$

$$\text{Laspeyres-Type Imputation}: \ P^{LI}_{t,t+1} = \prod_{h=1}^{H_{t}} \left[\left(\frac{\hat{p}_{t+1,h}(z_{t,h})}{\hat{p}_{t,h}(z_{t,h})} \right)^{1/H_{t}} \right] \tag{11}$$

The overall price (rent) index is then obtained by chaining the bilateral comparisons between adjacent periods.

Insert Figure I Here

The predicted prices in (10) and (11) are obtained from quantile regression models as described in Appendix B.

4.3 Estimating the components of the user cost of OOH

Recapping, the components of user cost as stated in (2) are as follows:

$$u_t = r_t + \delta_t + \omega_t + \gamma_t - \pi_t - g_t.$$

We consider two approaches to the estimation of u_t. First, we take our simplified user cost method discussed in section 3, and set the parameter k in (6) equal to zero. In this case, the user cost formula reduces to the following:

$$u_t = \delta + \omega.$$

Henceforth we refer to this case as $u(f)$, where f indicates that the per dollar user cost is fixed over time.

The crucial assumption with u(f) is that the gap between the two risk premiums, denoted by k in (6), stays constant. A higher level of k increases the OOH expenditure share, but, as long as it is fixed, does not affect the OOH price index. Even with $k = 0$, the average OOH expenditure share for Sydney over our sample period is 18.4 percent (see Table I). This is because the level of house prices, $\bar{P}$, is very high. In most countries, k would need to be set to a positive value to obtain similar OOH expenditure shares.

Since structures depreciate while land does not, the depreciation rate, δ, for the whole property should be lower than for the structure. We set depreciation $\delta = 1.1$ percent. This is the rate estimated by Stapledon (2007) for Sydney and used by Fox and Tulip (2014).

Fox and Tulip (2014) estimate running costs in the Australian context of 1.2 percent (see their Table A1, p. 29).[17] The main components of transaction costs are stamp duty and real estate agent commissions. Average transaction costs are obtained by amortizing the total amount over a ten year period. Again these estimates are obtained from Table A1 in Fox and Tulip (2014). Fox and Tulip estimate average transaction costs to equal 0.7 percent. Combining these components yields a total estimate of 1.9 percent for the combination of running and transaction costs, ω.

When we do not assume that the difference between the risk premiums is constant, we need to select values for r_t, γ_t, π_t, and g_t. Here we draw again on Fox and Tulip (2014) and Hill and Syed (2016). We set r_t as the 10-year interest rate on Australian government bonds (Source: Reserve Bank of Australia). This bond rate ranged between a minimum value of 2.89 percent

[17] Fox and Tulip include repair costs as part of running costs. In our setup, we exclude repair costs from running costs since they are included in gross depreciation.

in 2012 and a maximum value of 6.59 percent in 2008. We set the risk premium, γ_t, to zero. The expected rate of inflation π_t is assumed to be 2.5 percent. This is very close to the average rate of inflation for Sydney over the 2004-2014 period, which equaled 2.6 percent. It is also the middle of the Reserve Bank of Australia's inflation target (which is 2-3 percent).

g is the expected real capital gain. We set the expected real capital gain in year t equal to the geometric average of the real capital gain over the preceding x years. We consider three different values of x (i.e., 0, 10, and 30 years). The first of these (x=0) corresponds to when capital gains are excluded. For cases where $x > 0$, the expected real capital gain in year t is calculated as follows:

$$\text{Expected real capital gain}_t = \left(\frac{EHPI_t/CPI_t}{EHPI_{t-x}/CPI_{t-x}} \right)^{1/x} - 1.$$

Here $EHPI_t$ is the level of the Established House Price Index and CPI_t is the level of the consumer price index for Sydney in year t. Both the EHPI and CPI are computed by the Australian Bureau of Statistics (ABS).[18] We refer to the three resulting approaches as $u(0)$, $u(10)$ and $u(30)$.

Annualized expected real capital gains based on extrapolating over 10 and 30 year horizons are shown in Table C4 in Appendix C.[19]

4.4 The impact of OOH on the CPI

Here we compare the impact of eight different treatments of OOH on the Sydney CPI. The methods are listed below.

[18]The Established House Price Index (EHPI) is computed using the stratified-median approach, which may fail to fully adjust for quality changes over time. Given the EHPI is probably the most widely followed house price index for Sydney, it nevertheless is a useful benchmark for describing expectations of capital gains. The EHPI only goes back to 1986. To obtain prices back to 1974 (for the cases where x=30), the EHPI was spliced together with an index calculated by Abelson and Chung (2005).

[19]Diewert (2009), citing evidence on the length of housing booms and busts from Girouard et al. (2006), argues that a longer time horizon (e.g., 30 years) is more plausible in terms of how market participants form their expectations (see also Bracke, 2013). Also shown in Table C4 are the implied values of the per dollar user cost u_t.

(i) User cost excluding real capital gains: $u(0)$

(ii) User cost with expected real capital gains extrapolated from the previous 10 years: $u(10)$

(iii) User cost with expected real capital gains extrapolated from the previous 30 years: $u(30)$

(iv) Simplified user cost: $u(f)$

(v) Rental equivalence

(vi) Acquisitions (Australia)

(vii) Acquisitions (Europe)

(viii) Excluding OOH

Average OOH expenditure shares are shown in Table I.[20] The derivations of these shares are explained in Appendix C.

Insert Table I Here

$u(0)$, the user cost approach excluding capital gains, has the largest OOH expenditure shares in Table I. u(0), rental equivalence, and $u(f)$ generate higher OOH expenditure shares than $u(10)$, $u(30)$, and the acquisitions method.[21] Coefficients of variation (CV) are included in Table I so that the volatility of the OOH weights over time can be compared. The CV of the OOH shares under rental equivalence and $u(f)$ are much lower than for $u(0)$, $u(10)$ and $u(30)$.

The impact of each approach to including OOH on the Sydney CPI is shown in Table II. The methodology we used for removing OOH from the CPI and then re-inserting it is explain in Appendix C. According to the official CPI – computed using the acquisitions method – the average annual inflation rate over our sample period is 2.70 percent. When OOH is completely excluded from the CPI, the average annual inflation rate is slightly lower at 2.63 percent. Hence the impact of OOH on the CPI is minimal, when the Australian version of the acquisitions approach is used. It pushes up the average by only 0.07 percentage points, even though the Sydney housing market experienced a significant boom during this period. This is because

[20] Estimates of OOH expenditure in Australian dollars are provided in Appendix C, Table C2.

[21] The $u(10)$ and $u(30)$ expenditure shares are lower because of the high level of expected capital gains arising from the boom that ended in 2004. Indeed, the u(10) expenditure shares would be negative in 2004 and 2005 if we did not impose a non-negativity constraint. The acquisitions expenditure shares are low because they exclude land values. Also, the acquisitions shares are constant since they are all taken from the same household expenditure survey.

the house price index used by the Australian version of the acquisitions approach focuses on building material costs only, and it is land prices that have risen in Sydney. The Eurostat version of the acquisitions method is slightly more responsive to OOH, generating an average annual inflation rate of 2.86 percent. The effect of housing on the CPI is still muted since the acquisitions OOH expenditure share in Table I is low.

Insert Table II Here

Of particular interest in Table II are the user cost results for $u(0)$, $u(10)$, and $u(30)$. $u(10)$ fails disastrously, generating a completely implausible CPI of 38 percent in 2012-13. It is instructive to consider how such a result can arise. It is caused by a combination of three events that happened in 2012-13 that acted to re-enforce each other. First, the interest rate rose by 0.55 percentage points. Second, the expected capital gain based on a 10-year horizon fell from 2.17 to 0.71 percent.[22] These two events combined to cause a large increase in the per dollar user cost from 2012 in 2013. Third, house prices rose by 10.5 percent from 2012 to 2013 (see Figure I and Table C3 in Appendix C). Putting these factors together, the user cost, $P_t u_t$, almost tripled from 2012 to 2013. At the same time, the unusually large value of $P_t u_t$ in 2013 ensured that the huge increase in the user cost price index got a relatively high weight in the CPI formula.

Lengthening the expectation formation horizon from 10 to 30 years, or excluding capital gains produces more plausible results. However, u(30) and u(0) still generate erratic fluctuations in the CPI, as indicated by the large coefficients of variation of the annual inflation rates (see the final row of Table II). The results for u(0) demonstrate that excluding capital gains is not enough to prevent implausible swings in the CPI. This is because the interest rate over our sample period, as shown in Table C4 in Appendix C, is subject to some substantial movements. Most notable is the 2.16 percentage point cut in interest rates in 2012. This caused a large fall in u, and hence in the user cost price index $(P_{12}u_{12})/(P_{11}u_{11})$. This explains why CPI inflation according to u(0) in 2011-2012 was -6.7 percent, even though over the same period the CPI excluding housing was positive and house prices were rising.

[22]This was because house prices rose much more in 2001-02 (the year dropping out of the expectation formation horizon) than in 2011-12 (the new year being added).

These results demonstrate why countries have been reluctant to use the user cost method. To put it bluntly, the user cost methods u(0), u(10) and u(30) are not fit for purpose. The countries – Canada, Sweden and Iceland – that use the user cost method prevent erratic fluctuations in the CPI by using some form of smoothing.

Iceland smooths less than Sweden and Canada. It distinguishes between the cost of capital on the debt and equity components of owner-occupied-housing wealth, and then uses a current mortgage interest rate for the former, but a fixed real rate for the latter (see Hardarson, 2018). Sweden, in 2017, switched its main inflation measure from CPI to CPIF, where CPIF fixes the interest rate in the user cost formula (see Sveriges Riksbank, 2017). In this regard, the treatment of OOH in CPIF is quite similar to our preferred measure, $u(f)$. However, Sweden in practice mixes the user cost and rental equivalence methods, since OOH expenditures for apartments are estimated using rental equivalence. A pure user cost method is only applied to houses. Canada smooths the impact of interest rate changes by taking a five-year moving average (see Sabourin and Duguay, 2015), and includes only the debt component of housing wealth in the OOH expenditure share (see Hardarson, 2018). Sweden and Canada take smoothing a step further. Rather than using the actual change in house prices in the OOH price index, both use a 25 year moving average of house price changes (see Sveriges Riksbank, 2016, and Soumare, 2017). While this additional step doubtless stabilizes the CPI, it also undermines its market relevance.

None of the criticisms of $u(0)$, $u(10)$ and $u(30)$, however, apply to our simplified user cost method, $u(f)$. It brings in house prices in a way that does not destabilize the CPI: The coefficient of variation of the annual inflation rates is almost the same as when OOH is excluded from the CPI. Also, with u(f), changes in interest rates do not cause adverse shocks to the CPI. Nor is there any need for the complicated "fixes" that Sweden and Canada use to stabilize their CPIs.

We find that $u(f)$ generates an average annual inflation rate of 3.05 percent. Hence, on average, including OOH using $u(f)$ pushes up the CPI by 0.42 percentage points per year, as compared with excluding OOH.[23] Looking at the average difference, however, masks some

[23]Rental equivalence generates an even higher average CPI of 3.28 percent. This is due to the rental index

important features of the results. Referring to Table II, in three of the years in our sample (2005-06, 2007-8 and 2010-11), the inclusion of OOH using $u(f)$ actually lowers the CPI. There are three years in which house prices rise strongly in our data sample (2009-10, 2012-13, and 2013-14 – see Figure I). For the first two of these years, $u(f)$ pushes up the CPI by about 1.5 percentage points. In 2013-14, $u(f)$ pushes up the CPI by 2.6 percentage points. Hence a central bank using $u(f)$ in its target CPI would respond with a strongly contractionary monetary policy during a housing boom like that experienced by Sydney in the last years of our sample.

5 Some Implications for Monetary Policy

5.1 The impact of excluding OOH on the CPI during housing booms

The impact on the CPI of excluding OOH depends on how fast real house prices are rising. We can check this for 14 OECD countries using data provided by Knoll, Schularick and Steger (2017). The results for the periods 1950-2012, 1980-2012, and 2000-2012 are presented in Table III. In every country in each of these periods (with one minor exception) real house prices rose.

Insert Table III Here

To assess the average impact on the CPI of excluding OOH for different rates of real house price appreciation, we undertake a simulation calibrated to our Australian data set. The simulation exercise is explained in Appendix C. We consider real appreciation rates of house prices in the range of -1 to 6 percent per year. Varying the rate of real appreciation of house prices λ in this range generates the results shown in Table IV. Table IV illustrates that excluding OOH generates a downward bias in the CPI, as compared with when OOH is included using our preferred user cost method u(f), whenever real house prices rise (i.e., $\lambda > 0$). When real house prices rise by 1 percent per year, including OOH using u(f) would increase the CPI by

rising faster than the house price index over our sample period as shown in Table C3 and Figure I. Rents were catching up with the housing boom that ended in 2004. Also, the rental index in Table C3 is based on current market rents. A rental index constructed from surveys of existing renters would not have risen as fast. Hence we would not normally expect the CPI generated by $u(f)$ to be lower than the one generated by rental equivalence.

0.17 percentage points per year. When real house prices rise by 4 percent per year, including OOH raises the CPI by 0.80 percentage points per year.

Insert Table IV Here

Given that real appreciation rates for housing of about 4 percentage points per year for sustained periods are not unusual in Table III, the results in Table IV indicate that excluding OOH may be causing a systematic downward bias in the CPI of about 0.8 percentage points per year. During boom periods, like in Sydney from 2013-14, the bias could be much larger.

5.2 The disinflation puzzle

In the US, OOH is included in the CPI using the rental equivalence method. In Figure II, the owners equivalent rent (OER) index, used to measure the change in the price of OOH, is graphed against the S&P Core Logic Case-Shiller index. As can be seen in Figure II, the OER completely misses the boom and bust in the US housing market. This example clearly illustrates the main problem with the rental equivalence method: it fails to reflect the underlying realities of the housing market.[24]

Insert Figure II Here

In light of Figure II, it can be seen how the use of rental equivalence may have contributed to the relatively accommodative monetary policy in the US in the years preceding the start of the global financial crisis (GFC). We return to this issue in the next section.

Here we focus on the disinflation puzzle. During the GFC, a number of economists expressed puzzlement over why inflation rates in the US did not fall more as unemployment rose from 4 to 10 percent from 2007 to 2010. For example, Williams said the following in a speech in 2010:

> "The surprise [about inflation] is that it's fallen so little, given the depth and duration of the recent downturn." (Williams, 2010, p. 8)

The macroeconomic data during the global financial crisis seemed to be inconsistent with

[24]Admittedly, the rental index would not be so sticky if it focused exclusively on new rental contracts, rather than surveys of existing renters. See Ambrose, Coulson, and Yoshida (2015, 2018) for a detailed discussion of the weaknesses of the existing rental indexes used in the US CPI.

the expectations augmented Phillips curve relationship, which over the period 1960-2007 had worked quite well (see Ball and Mazumder, 2011). The implications are potentially important given the widespread use of the Phillips curve as a tool for describing the macroeconomy and forecasting inflation.

A number of possible explanations have been provided in the literature for this "disinflation puzzle", such as anchoring of inflation expectations (Bernanke, 2010), the impact of nominal price stickiness at low rates of inflation (Ball and Mazumder, 2011), the impact of globalization on inflation (Borio, 2017), or the use of alternative measures of inflation expectations (Coibion and Gorodnichenko, 2015).

Part of the explanation may be the failure of the CPI to properly capture the impact of OOH. Figure III graphs the US CPI in its current form against an alternative CPI that includes OOH using our preferred $u(f)$ method.[25]

Insert Figure III Here

As can be seen from Figure III, when OOH is included using $u(f)$, the CPI turns strongly negative starting in November 2008, reaching its low point of -5.3 percent in July 2009. At a stroke, the disinflation puzzle ceases to be such a puzzle.

It is difficult to say what would have happened next after 2009 if OOH was included in the CPI using $u(f)$, since the change in measured inflation would have affected expected inflation. Hence actual inflation would probably not have rebounded as quickly as the CPI-with-$u(f)$ series in Figure III suggests. The inflation rate staying negative for longer is more consistent with the prevailing wisdom on the Phillips curve, given that unemployment remained significantly above its natural rate through to 2014.

[25] To compute our alternative CPI, we first removed OOH from the US CPI-U (Consumer Price Index for All Urban Consumers). To do this we needed the expenditure share of OOH in CPI-U and the OER index. These data series are available on the Bureau of Labor Statistics (BLS) website. The procedure for removing OOH from CPI-U is similar to that discussed in the Australian context in section 4.5. When reinserting OOH into the CPI with the user cost method, $u(f)$, we compute the per dollar user cost using (6), invoking the assumptions in (2) and (4). Also, crucially, we replace the OER index with the S&P Core Logic Case-Shiller index.

5.3 Inflation targeting and leaning against the wind

Inflation targeting has spread rapidly around the world since its introduction in New Zealand in 1990. Given that real house prices have typically been rising for many decades in the OECD (see Table III), the treatment of OOH in the CPI could potentially have significant implications for monetary policy. Of particular interest in Table III are the Euro area countries and the UK, since the ECB and Bank of England both target the HICP (which excludes OOH). Australia also effectively excludes OOH.

Our results indicate that the exclusion of OOH in these countries is causing a downward bias in the CPI. If this is not factored into the inflation target, the implication is that monetary policy will be too loose. Even in the US, where rental equivalence is used, Figure III indicates that in the years preceding the GFC, the measured rate of inflation was too low. Between January 2003 and January 2006 the US CPI would have been on average 2.2 percentage points higher if OOH had been included in the CPI using $u(f)$ instead of rental equivalence. The use of $u(f)$, by triggering a more robust monetary policy response, could have reduced the extent of the housing boom and the consequent financial crisis.

There has been much debate, particularly since the GFC, over whether an inflation targeting central bank should raise interest rates during a housing boom (i.e., "leaning against the wind"), or focus on just "cleaning" up the mess after a bubble bursts. Cecchetti (2006) and Mishkin (2011) argue that "leaning" is particularly important during housing booms, since such booms are almost invariably credit driven. Any subsequent bust, therefore, could inflict significant damage on the banking sector. Including OOH in the CPI using $u(f)$ would effectively internalize the impact of the housing market directly into the CPI, thus potentially resolving the "lean versus clean" debate, at least as it relates to housing. In other words, there is no longer any need to "lean", when OOH is included in the CPI using $u(f)$.

Most of the participants in the "leaning-cleaning" debate (Cecchetti being an exception) are therefore neglecting an important issue, which is the extent to which the CPI already responds to movements in house prices and hence to what degree an implicit leaning is already happening. Our analysis clearly shows that this fundamentally depends on how OOH is treated in the CPI and hence that the chosen treatment needs to be the actual starting point of any debate over "leaning".

5.4 Secular stagnation and globalization

The natural rate of interest, as defined by Wicksell, is the rate that equates saving and investment at full employment. There is clear evidence that the natural rate has fallen substantially in the last two to three decades (see Rachel and Smith, 2015). This has led to what Summers refers to as secular stagnation:

> Secular stagnation occurs when neutral real interest rates are sufficiently low that they cannot be achieved through conventional central-bank policies. At that point, desired levels of saving exceed desired levels of investment, leading to shortfalls in demand and stunted growth.
>
> This picture fits with much of what we have seen in recent years. Real interest rates are very low, demand has been sluggish, and inflation is low, just as one would expect in the presence of excess saving. Absent many good new investment opportunities, savings have tended to flow into existing assets, causing asset price inflation. (Summers, 2016, p. 3)

Assuming the housing market is one of the asset markets affected, bringing OOH into the CPI using $u(f)$ would provide an upward jolt to measured inflation. To the extent this jolt increased the expected rate of inflation it would act as a stimulus to investment and a disincentive to saving, thus potentially raising the natural rate of interest. Changing the treatment of OOH in the CPI would, therefore, be a useful complement to forward guidance and quantitative easing as policy responses to secular stagnation.

There is also a growing debate over whether globalization is acting to flatten the Phillips curve (see for example, Auer, Borio and Filardo, 2017, Borio, 2017, and Forbes, 2019). In particular, the huge expansion of global value chains has increased competition for both intermediate and final goods, thus weakening the link between inflation and the domestic output gap.

From this perspective, the problem is not so much a negative natural rate of interest, as that central banks are finding it increasingly hard in a globalized economy to control the domestic rate of inflation. In particular, in recent years, many central banks, including the ECB, have struggled to get inflation up to the 2 percent target level. Trying to achieve the target has required them to keep monetary policy very loose, thus potentially triggering housing and other asset market booms.

Again, bringing OOH into the CPI using our preferred user cost method, $u(f)$, may prove useful in this regard. Under the scenario just described, the resulting housing boom would act to push up the CPI towards the target rate of 2 percent, allowing the central bank to tighten monetary policy somewhat and limit the extent of the boom. By implication, the inclusion of OOH in the CPI using $u(f)$ would reduce the extent of the damage arising from a central bank pursuing an inflation target that is inconsistent with developments in the global economy. Inflation would again become more country-specific and more responsive to monetary policy, via the OOH channel.

6 Conclusion

The CPI is sensitive to the treatment of OOH. This is not merely an accounting exercise. Changing the treatment of OOH would affect the expected rate of inflation, the measured level of real interest rates, and hence the behavior of market participants and potentially also of the central bank.

Figure II provides a striking demonstration of the disadvantages of using the rental equivalence method: A housing boom may not even register on the CPI. Attempts to switch from rental equivalence to the user cost method have been hampered by two main problems with the latter. First, the inclusion of an interest rate term in the user cost formula means that the immediate impact of a contractionary monetary policy may be to increase measured inflation. Second, the inclusion of a capital gain term can cause high levels of volatility in the CPI and generate counterintuitive results (see the quote from Goodhart in section 3).

We have, therefore, advocated for a simplified version of the user cost method, $u(f)$, that retains its best features while avoiding the disadvantages. When $u(f)$ is used, the CPI will be responsive to the housing market without becoming excessively volatile. Nor will it jump whenever interest rates are changed. Last but not least, the data requirements for implementing our simplified user cost method are also less onerous than rental equivalence, acquisitions or other user cost methods.

Applying hedonic quantile-regression methods to microdata for Sydney over the years 2004-2014, we have estimated the impact of a number of different treatments of OOH on the CPI. Based on our estimates for Sydney the baseline CPI, excluding OOH, is on average 2.63 percent. When OOH is included using $u(f)$, the average CPI increases to 3.05 percent. However, in 2013-14 when house prices were rising quickly, $u(f)$ increases the CPI by 2.6 percentage points. Similarly large differences would be observed for the US in the years preceding the GFC. From 2003 to 2005, the US CPI would have been on average 2.2 percentage points higher, if OOH had been included in the CPI with $u(f)$ instead of rental equivalence.

The treatment of OOH is relevant to some important debates in macroeconomics. First, inflation in the US did not fall as much as expected during the GFC. This disinflation puzzle can be partly resolved by switching the treatment of OOH in the CPI from rental equivalence to our simplified user cost method, $u(f)$. Second, the debate over using monetary policy to "lean" on asset market bubbles can likewise be largely resolved by changing the way OOH enters the CPI. When our preferred $u(f)$ measure is used, the CPI will automatically lean against the wind. Furthermore, irrespective of one's stance on "leaning", a prerequisite to any debate is to first consider how OOH is currently being treated in the CPI. Third, including OOH in the CPI using $u(f)$ would help in the fight against secular stagnation, and reduce the damage arising from a central bank pursuing an inflation target that is inconsistent with developments in the global economy. Any housing booms created by loose monetary policy would push up the CPI, thus naturally prompting the central bank to raise interest rates.

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Table I: Average Monthly OOH Expenditure Shares: Sydney 2004-2014

	$u(0)$	$u(10)$	$u(30)$	$u(f)$	Rental Equiv.	Acquis.
2004	0.3246	0.0000	0.1870	0.1852	0.1859	0.1198
2005	0.2866	0.0000	0.1402	0.1760	0.1846	0.1198
2006	0.3071	0.0466	0.1737	0.1757	0.1894	0.1198
2007	0.3324	0.0926	0.1947	0.1822	0.2010	0.1198
2008	0.3354	0.1395	0.2016	0.1760	0.2132	0.1198
2009	0.3034	0.1614	0.1797	0.1775	0.2109	0.1198
2010	0.3100	0.1276	0.1826	0.1879	0.2186	0.1198
2011	0.2969	0.1102	0.1849	0.1829	0.2235	0.1198
2012	0.2050	0.0890	0.0528	0.1812	0.2247	0.1198
2013	0.2414	0.2078	0.0676	0.1911	0.2230	0.1198
2014	0.2686	0.2359	0.0547	0.2077	0.2215	0.1198
Average	0.2920	0.1101	0.1472	0.1840	0.2087	0.1198
CV	0.1370	0.6931	0.4024	0.0510	0.0758	0.0000

Notes: u(x) denotes the user cost method with expected capital gains extrapolated based on the preceding x years, u(f) denotes the user cost method where it is assumed that the parameter k in (6) equals zero. Rental Equiv. denotes the rental equivalence method. Acquis. denotes the acquisitions method.

Table II: CPI Annual Inflation for Sydney

	u(0)	u(10)	u(30)	u(f)	Rental Equiv	Acq(AUS)	Acq(EUR)	OOH Excl.
2004-05	-2.293%	2.215%	-1.823%	1.304%	2.298%	2.463%	1.820%	2.215%
2005-06	6.189%	3.961%	8.528%	3.449%	4.179%	3.846%	3.791%	4.146%
2006-07	5.398%	11.739%	4.405%	2.296%	3.166%	1.736%	2.078%	1.744%
2007-08	4.748%	12.828%	5.217%	3.491%	6.331%	4.323%	3.869%	4.269%
2008-09	-2.067%	4.892%	-0.717%	1.956%	1.300%	1.309%	1.600%	1.041%
2009-10	4.234%	-0.189%	3.436%	4.389%	4.060%	2.906%	3.609%	2.845%
2010-11	2.269%	2.153%	4.310%	3.380%	4.398%	3.766%	3.604%	3.800%
2011-12	-6.652%	-0.542%	-2.748%	1.297%	1.671%	1.310%	1.313%	1.266%
2012-13	8.496%	38.796%	4.571%	3.854%	2.585%	2.587%	3.149%	2.396%
2013-14	7.412%	7.387%	1.536%	5.128%	2.831%	2.813%	3.761%	2.538%
Average	2.773%	8.324%	2.672%	3.054%	3.282%	2.706%	2.859%	2.630%
CV	1.771	1.398	1.326	0.424	0.432	0.370	0.361	0.413

Notes: u(0) denotes the user cost method with capital gains excluded. u(x) denote the user cost method with expected capital gains extrapolated based on the preceding x years, u(f) denotes the user cost method where it is assumed that the real interest rate and real expected capital gain are equal. Rent Eq. denotes the rental equivalence method. Acq(AUS) and Acq(EUR) denote respectively the Australian and Eurostat versions of the acquisitions method. OOH Excl. denotes the CPI with OOH excluded.

Table III: Average Annual Increase in Real House Prices

	1950-2012	1980-2012	2000-2012
Australia	2.35%	2.94%	4.45%
Belgium	2.45%	2.03%	3.69%
Canada	2.71%	2.42%	5.00%
Switzerland	1.00%	1.20%	3.67%
Denmark	1.75%	1.12%	1.32%
Finland	3.31%	2.45%	2.70%
France	5.08%	2.05%	4.78%
Great Britain	2.28%	2.78%	3.22%
Netherlands	2.61%	1.69%	-0.01%
Norway	2.39%	4.17%	5.51%
Sweden	1.51%	2.16%	5.12%
USA	0.30%	0.28%	0.01%

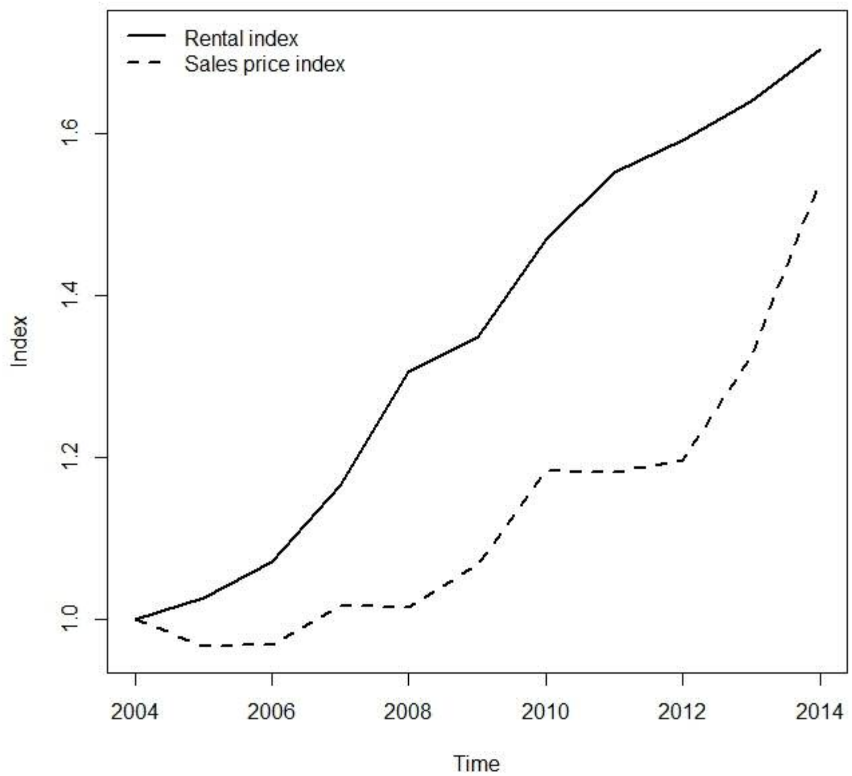
Source: Knoll, Schularick and Steger (2017), online additional materials “Data Set” available on the American Economic Review website.

Table IV: Impact of Including OOH in the CPI Using u(f)

	1 year Difference	10 year Difference
λ=-1%	-0.157%	-1.558%
λ=0%	0.000%	0.000%
λ=1%	0.171%	1.727%
λ=2%	0.358%	3.636%
λ=3%	0.560%	5.746%
λ=4%	0.779%	8.074%
λ=5%	1.016%	10.639%
λ=6%	1.271%	13.462%

Notes: λ denotes the rate at which real house prices are rising. The "Difference" here measures the impact of including OOH in the CPI using the user cost method, $u(f)$. For example, when $\lambda = 3\%$, it follows that the CPI is 0.56 percentage points higher under the $u(f)$ method than if OOH is excluded from the CPI.

Figure I: Rental and Sales Price Indexes for Sydney



Notes: Results are based on the chained Törnqvist price index formula. We use imputed prices and rents from conditional quantile models (see Appendix B).

Figure II: The Owners Equivalent Rent and CoreLogic SPCS indexes

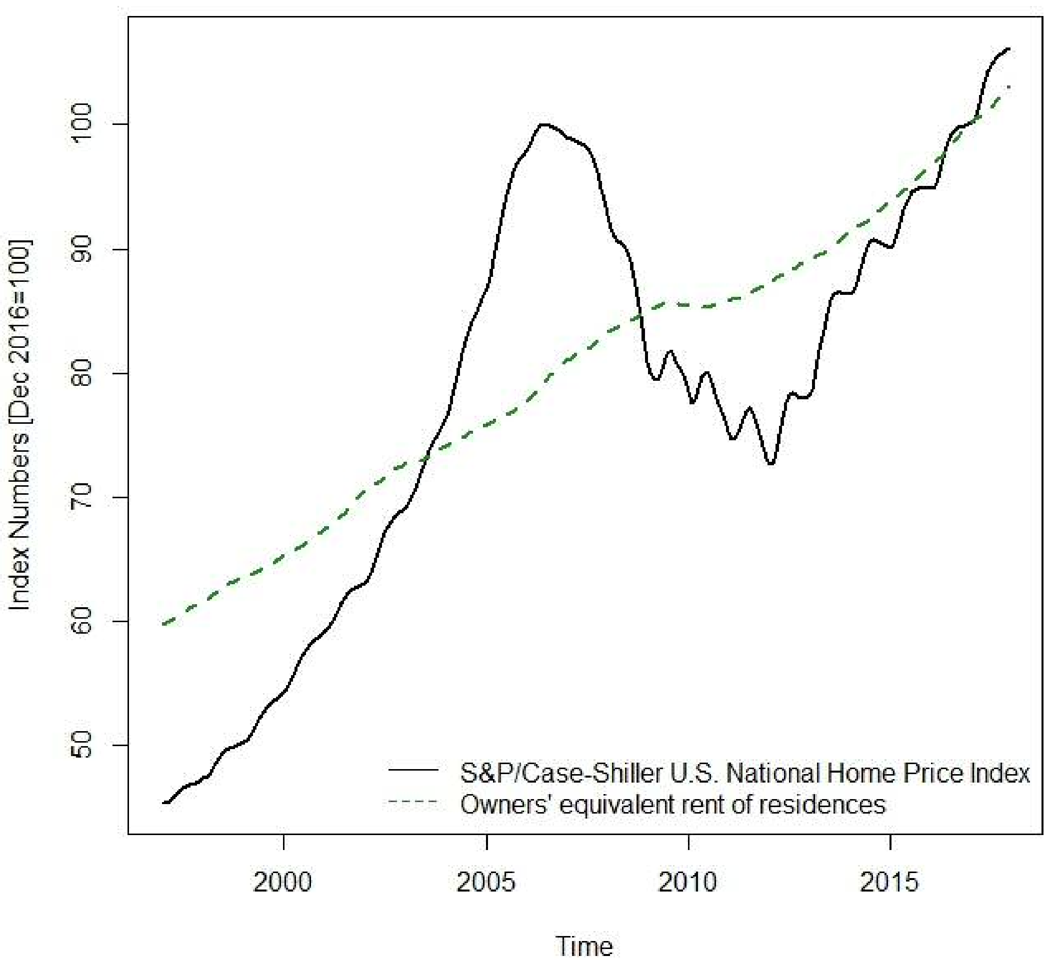
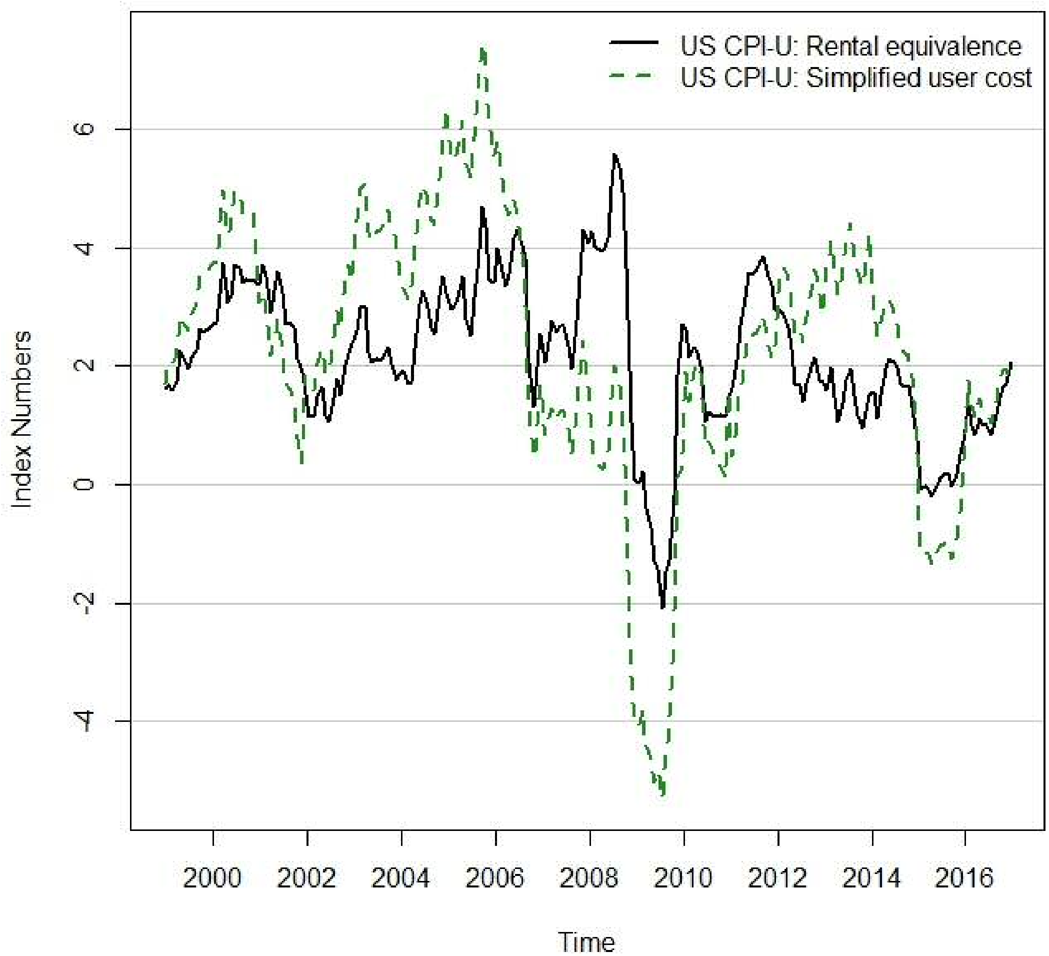


Figure III: The Impact of Changing the Treatment of OOH on the US CPI



Notes: CPI is the official CPI. CPI_u(f) is an alternative version of the CPI that include owner occupied housing (OOH) using the u(f) user cost method.

Appendix: For Online Publication

A The Treatment of Capital Gains in the User Cost of OOH: A Cause of Downward Bias in the CPI?

A.1 A thought experiment

Suppose house prices rise and then return back to their original level. Suppose further that during this process everything else in the economy – prices and expenditure on all goods and services and all the components of user cost except capital gains – remains fixed. Here we explore the impact of such a scenario on the CPI when OOH is included using the user cost method with capital gains calculated ex post or by extrapolating from past performance in the previous period. From an axiomatic perspective the CPI, in this case, should return to its original value. We show that this does not happen.

A.2 The three period case

The Laspeyres price index formula can be written as follows:

$$\text{Laspeyres}: \quad CPI_{12}^{L} = \sum_{n=1}^{N} s_{1n}\left(\frac{p_{2n}}{p_{1n}}\right), \quad CPI_{23}^{L} = \sum_{n=1}^{N} s_{2n}\left(\frac{p_{3n}}{p_{2n}}\right),$$

where s_{1n} and s_{2n} are the expenditure share of heading n in periods 1 and 2 respectively. Here heading 1 is OOH. All other headings are combined and denoted by heading 2.

We now make four assumptions.

(i) The expenditure on heading 2 (i.e., all other expenditure) remains constant and takes the value z.

(ii) The fraction of households that are owner-occupiers – denoted by α – remains constant over time. For example if $\alpha = 0.6$ this means that 60 percent of households are owner-occupiers.

(iii) Let P_t and P_{t+1} denote the average house price in periods t and $t+1$ respectively. It is assumed that the house price index between periods t and $t+1$ can be written as the ratio of the average house prices in the two periods. Hence the house price index takes the following form: P_{t+1}/P_t.

(iv) The price of housing in period 3 is the same as in period 1 (i.e., $P_1 = P_3$). Defining μ as the growth rate of prices from period 1 to 2, it therefore follows that

$$\frac{P_2}{P_1} = 1 + \mu, \quad \text{and} \quad \frac{P_3}{P_2} = \frac{1}{1+\mu}.$$

We assume that $\mu > 0$.

OOH expenditure per owner-occupying household under the user cost approach in period t is given by $P_t u_t$. It follows from assumptions (i) and (ii) that the expenditure shares for owner occupied housing (OOH) and everything else in periods 1, 2 and 3 are:

$$\begin{aligned}
\text{Period 1}: \quad s_{11} &= \frac{\alpha P_1 u_1}{\alpha P_1 u_1 + z}, \quad s_{12} = \frac{z}{\alpha P_1 u_1 + z}, \\
\text{Period 2}: \quad s_{21} &= \frac{\alpha P_2 u_2}{\alpha P_2 u_2 + z}, \quad s_{22} = \frac{z}{\alpha P_2 u_2 + z}, \\
\text{Period 3}: \quad s_{31} &= \frac{\alpha P_3 u_3}{\alpha P_3 u_3 + z}, \quad s_{33} = \frac{z}{\alpha P_3 u_3 + z},
\end{aligned}$$

where recapping, α denotes the proportion of households that are owner-occupiers, and z denotes non-housing expenditure. Given these expenditure shares and assumptions (iii) and (iv), the Laspeyres formula reduces to

$$\begin{aligned}
CPI^L_{12} &= \left(\frac{\alpha P_1 u_1}{\alpha P_1 u_1 + z}\right)\left(\frac{P_2 u_2}{P_1 u_1}\right) + \frac{z}{\alpha P_1 u_1 + z} = \frac{\alpha P_2 u_2 + z}{\alpha P_1 u_1 + z}, \\
CPI^L_{23} &= \left(\frac{\alpha P_2 u_2}{\alpha P_2 u_2 + z}\right)\left(\frac{P_1 u_3}{P_2 u_2}\right) + \frac{z}{\alpha P_2 u_2 + z} = \frac{\alpha P_1 u_3 + z^*}{\alpha P_2 u_2 + z^*}.
\end{aligned}$$

Now we take the product of CPI^L_{12} and CPI^L_{23}:

$$CPI^L_{12} \times CPI^L_{23} = \left(\frac{\alpha P_1 u_3 + z}{\alpha P_1 u_1 + z}\right) \tag{12}$$

The implied quantities for housing q^h_t and other consumption q^o_t are calculated as follows:

$$q^h_t = \frac{\alpha P_t u_t}{P_t u_t} = \alpha, \quad q^o_t = \frac{z}{1} = z.$$

Given that both quantities do not vary over time, it follows that the data are consistent with the Leontief aggregation conditions, and hence Paasche, Laspeyres and Fisher indexes are all the same.

Case 1: Capital gains are included ex post

The user cost of OOH when capital gains are included ex post is as follows:

$$\begin{aligned}
u_1 &= k - \left(\frac{P_2 - P_1}{P_1}\right) = k - \mu, \\
u_2 &= k - \left(\frac{P_1 - P_2}{P_2}\right) = k + \frac{\mu}{1+\mu}, \\
u_3 &= k,
\end{aligned}$$

where $k = r + \delta + \omega + \gamma - \pi$ (i.e., all the other components of user cost) is assumed to remain fixed. Hence all changes in u are caused by the treatment of capital gains. Since $u_3 > u_1$, it follows from (12) that

$$CPI^L_{12} \times CPI^L_{23} < 1.$$

Case 2: Expected capital gains are extrapolated from performance in the previous period

When capital gains are extrapolated from past performance, u_1, u_2 and u_3 take the following values:

$$\begin{aligned}
u_1 &= k, \\
u_2 &= k - \left(\frac{P_2 - P_1}{P_1}\right) = k - \mu, \\
u_3 &= k - \left(\frac{P_1 - P_2}{P_2}\right) = k + \frac{\mu}{1+\mu}.
\end{aligned}$$

Again, $u_3 > u_1$, and hence it follows from (12) that

$$CPI^L_{12} \times CPI^L_{23} < 1.$$

A.3 The general multi-period case

Suppose now we generalize this example to an arbitrary number of periods. Starting from period 1, house prices rise for M consecutive periods at the rate μ, after which prices then fall for M consecutive periods at the rate μ returning to their original value in period $1 + 2M$. Hence prices peak in period $M + 1$. More precisely, for periods $t = 1, \ldots, M$ we have that $P_{t+1}/P_t = 1 + \mu$, while for periods $t = M + 1, \ldots, 2M$ we have that $P_{t+1}/P_t = 1/(1 + \mu)$.

It now follows that chained Laspeyres price indexes can be written as follows:

$$\prod_{t=1}^{2M} CPI^L_{t,t+1} = \prod_{t=1}^{2M} \left(\frac{P_{t+1}u_{t+1} + z}{P_t u_t + z}\right) = \left(\frac{P_1 u_{2M+1} + z}{P_1 u_1 + z}\right). \tag{13}$$

Case 1: Capital gains are included ex post

When capital gains are included ex post the user cost of OOH in each period is as follows:

$$u_t = \begin{cases} k - \mu, & \text{for } 1 \leq t \leq M, \\ k + \frac{\mu}{1+\mu}, & \text{for } M+1 \leq t \leq 2M, \\ k, & \text{for } t = 2M+1. \end{cases}$$

Since $u_{2M+1} > u_1$, it follows from (13) that

$$\prod_{t=1}^{2M} CPI^L_{t,t+1} < 1.$$

Case 2: Expected capital gains are extrapolated from performance in the previous period

In this case the per period user costs are as follows:

$$u_t = \begin{cases} k, & \text{for } t = 1, \\ k - \mu < k, & \text{for } 2 \leq t \leq M+1, \\ k + \frac{\mu}{1+\mu} > k, & \text{for } M+2 \leq t \leq 2M+1. \end{cases}$$

Given again that $u_{2M+1} > u_1$, it follows from (13) that

$$\prod_{t=1}^{2M} CPI^L_{t,t+1} < 1.$$

Conclusion: In all cases considered above, a chained Laspeyres (or Paasche or Fisher) index has a downward bias.

A key issue when expected capital gains are derived from the past performance of the housing market is the time horizon over which expectations are formed. Here we have considered the case where market participants extrapolate performance from the previous period. As the performance time horizon over which expectations are extrapolated gets longer, the extent of the downward bias problem diminishes.

B Imputing Prices and Rents using Quantile Regression

Step 1: Estimating quantile regression models. In the first step hedonic models are estimated. For each year from 2004 to 2014, there are two types of quantile regression models:

one based on rental observations and one based on sold properties. All models have the following structure:

$$Q_\vartheta(\log p|X) = \beta_0 + \beta_1 \log(area) + \sum_{j=2}^{4} \beta_j^{bed} \mathbb{1}_{\{j\}}(bed) + \sum_{j=2}^{4} \beta_j^{bath} \mathbb{1}_{\{j\}}(bath) + f(long, lat), \quad (14)$$

where p denotes either the transaction price or the observed rent, X a matrix containing all covariates as well as an intercept, and $\vartheta \in (0, 1)$ a specific quantile level. Due to a lack of sufficient observations with five or six bed- or bathrooms, the four, five and six rooms are merged to a single category. The function $f(long, lat)$ denotes a smoothly estimated geographical spline measuring locational effects on a grid spanned by longitudes and latitudes.[26]

Models are ultimately estimated for nine different quantile levels $\vartheta \in \{0.1, 0.2, \ldots, 0.9\}$. Hence, there are 11 (years) $\times$ 9 (quantile levels) $\times$ 2 (type: sale / rent) $\times$ 2 (type: house / unit) $=$ 396 models. In the following, we refer to a model for rental (R) - or sales (S) - observations in year t and quantile level ϑ by $mod(R, t, \vartheta)$ or $mod(S, t, \vartheta)$.

Step 2: Allocating dwellings to segments. This step ensures that there is a unique price (rent) for each observation per year. Each observation is allocated to a unique price segment indicating its position in the price or rent distribution.

For instance, let $z^R_{t,h}$ denote a dwelling rented in year t, $p^R_{t,h}$ its observed rent, and $x^R_{t,h}$ its set of characteristics. To assign it to an appropriate segment, we impute rents based on its characteristics $x^R_{t,h}$ using models for period t and *all* quantile levels yielding nine different prices:

$$\begin{aligned}
mod(R, t, 0.1) &\longrightarrow \hat{p}^R_{t,h}(\vartheta = 0.1), \\
mod(R, t, 0.2) &\longrightarrow \hat{p}^R_{t,h}(\vartheta = 0.2), \\
&\vdots \\
mod(R, t, 0.9) &\longrightarrow \hat{p}^R_{t,h}(\vartheta = 0.9).
\end{aligned}$$

[26] Locational splines have been used previously by Hill and Scholz (2018) for hedonic imputation house price indexes. Waltl (2016) adapted this approach to quantile indexes. We follow this method and apply penalized quantile regression models in combination with the triogram method developed by Hansen et al. (1998) and Koenker and Mizera (2004). The smoothing parameter is chosen using an adapted Schwartz Information Criterion as suggested by Koenker et al. (1994).

Imputed rents are then compared to the observed rent. The model generating an imputed rent closest to the observed rent is the most appropriate for a particular observation. Observation $z^r_{t,h}$ is assigned to price segment ϑ^* given by

$$\vartheta^* = \arg\min_{\vartheta} \left| \hat{p}^R_{t,h}(\vartheta) - p^R_{t,h} \right| .$$

The segment is then treated like an additional characteristic of each observation indicated by $z^R_{t,h}(\vartheta^*)$ (see Davino et al., 2013, section 4.2.2).

Step 3: Imputing prices and rents. In the third step, prices and rents are imputed for each observation appearing at least once in the data set. Prices and rents are imputed for these observations in every time period.[27] For instance, for observation $z^R_{t,h}(\vartheta^*)$, which was originally observed in period t, a rent and a price for period s is obtained by evaluating models $mod(R, s, \vartheta^*)$ and $mod(S, s, \vartheta^*)$ for the set of characteristics $x^R_{t,h}$.

Implicitly we assume that segments are comparable between rented and sold houses in the sense that a house that belongs to a top segment in the sales distribution would also belong to a top segment in the rents distribution and vice versa. As we rely on nine quantile levels only, this is not a very restrictive assumption.

The main advantage of using quantile regression models to impute prices and rents is that observed prices are more reliably replicated than in linear models. With linear models (or

[27] Imputing prices or rents requires a locational spline $f_t(long, lat)$ specific to a particular period to be evaluated. Its support is the convex hull of all locational coordinates of dwellings appearing in period t. Locational effects are obtained for each triangle created from the coordinates using a Delaunay triangulation (see Hansen et al., 1998, and Koenker and Mizera, 2004). It is therefore not possible to directly impute a locational effect for coordinates falling outside the convex hull (see illustration on the right). One could include additional dummy vertices into the Delauny triangulation to increase the support, however this would lead to unfavorable extrapolation which is why we exclude observations that fall outside the intersection of *all* convex hulls (Table C1 reports the number of exclusions).

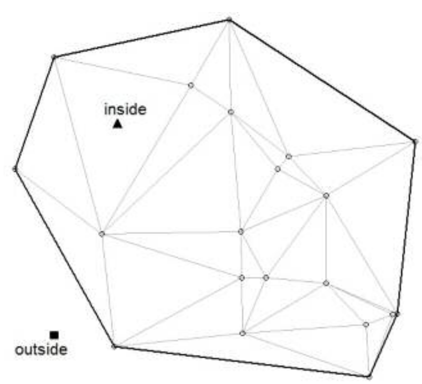
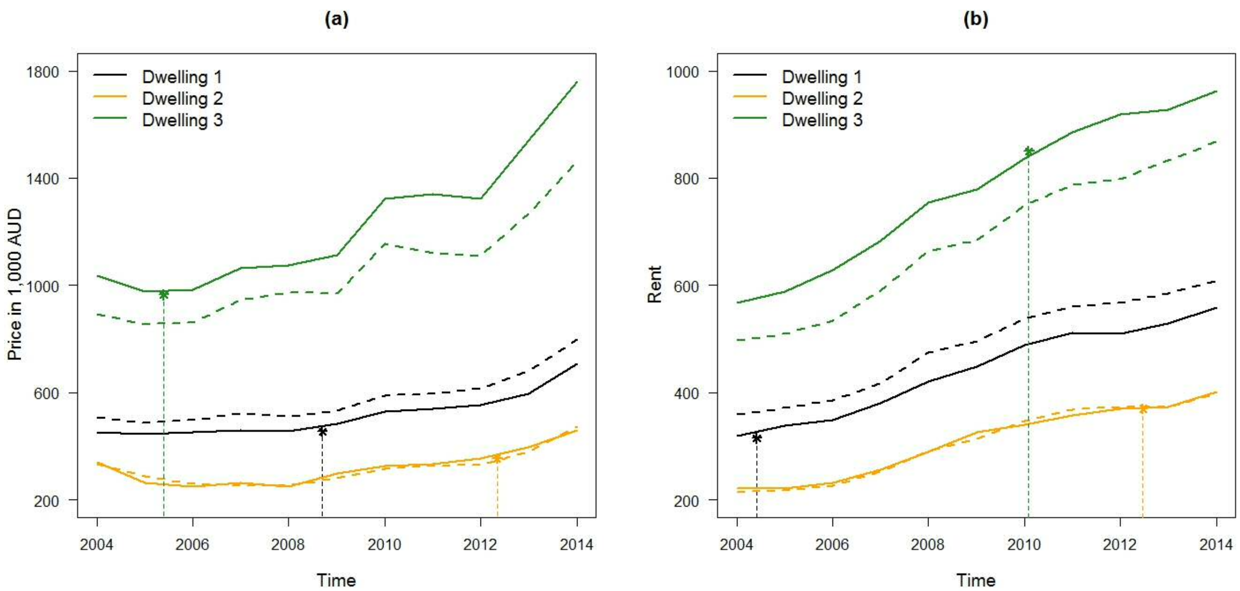


Figure B1: Examples of imputed prices and rents.



Notes: The figure plots the temporal development of imputed prices, panel (a), and imputed weekly rents, panel (b), for three houses that were sold and rented some time within the period of observation. The solid lines depict imputed values from conditional quantile models, the dashed lines imputed values from conditional mean models and the stars indicate observed prices and rents. Dwelling 1 is located in the suburban region *Penrith-Windsor*, has four bedrooms and two bathrooms, a land area of $550m^2$ and was assigned to segment 2. Dwelling 2 is located in the metropolitan region *Fairfield-Liverpool*, has three bedrooms and one bathroom, a land area of $612m^2$ and was assigned to segment 5. Dwelling 3 is located in the inner-city region *Inner West*, has three bedrooms and two bathrooms, a land area of $491m^2$ and was assigned to segment 8. Sales prices are measured in 1,000 Australian dollar (AUD) units.

generalized linear models), evaluating the model for a specific set of characteristics x would yield an estimate of the *conditional mean* price, $\widehat{\mathbb{E}(\log p|x)}$. Imputed prices and rents are much more strongly clustered around the mean than they would be in reality. Quantile regression, by estimating conditional quantile prices $\widehat{Q_\vartheta(\log p|x)}$, reconstructs observed price and rent distributions much more realistically. Figure B1 illustrates this point by depicting imputed prices and rents together with their observed counterparts for three selected dwellings. Observed prices match very well with imputations from conditional quantile models whereas imputations from conditional mean models do not perform as well.[28] Dwelling 1 in Figure B1 was assigned to

[28]Penalized least squares is used to estimate conditional mean models with specification (14) separately for

segment 2, i.e., a low price segment and the conditional mean model overestimates its price and rent. Dwelling 2 is assigned to segment 5, the median segment, and in this case the conditional mean model predicts its price and rent well. Dwelling 3 is assigned to segment 8, a high price segment. With a conditional mean model its price and rent are underestimated.

With the quantile model, average absolute deviations over all observations are very small (numbers refer to houses/units):

$$\frac{1}{n_R}\sum_{h=1}^{n_R}\left|\frac{\hat{p}_h^R - p_h^R}{p_h^R}\right| = 3.7\% \ / \ 2.9\% \quad \text{and} \quad \frac{1}{n_S}\sum_{h=1}^{n_S}\left|\frac{\hat{p}_h^S - p_h^S}{p_h^S}\right| = 3.4\% \ / \ 4.0\%,$$

where n_R and n_S denotes the number of rental and sales observations. The success of reconstructing observed prices is remarkable. When using a conditional mean model instead of conditional quantile models, average absolute prediction errors are much larger:

$$\frac{1}{n_R}\sum_{h=1}^{n_R}\left|\frac{\tilde{p}_h^R - p_h^R}{p_h^R}\right| = 13.6\% \ / \ 13.2\% \quad \text{and} \quad \frac{1}{n_S}\sum_{h=1}^{n_S}\left|\frac{\tilde{p}_h^S - p_h^S}{p_h^S}\right| = 13.8\% \ / \ 15.8\%.$$

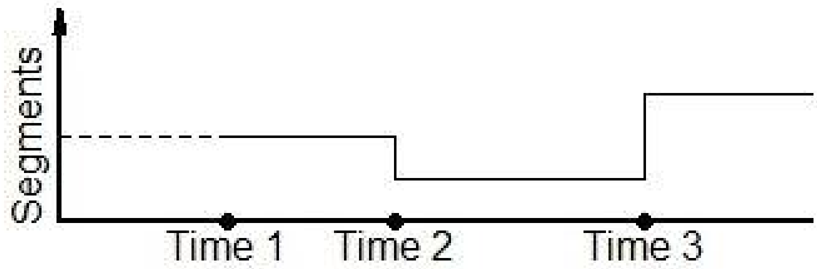
Step 4: Adjusting imputations for dwellings appearing multiple times in the data set. In this step, adjustments are made for repeated observations. There are many dwellings that appear more than once in the data set either as rental or sales observations. We find that 55.8% (40.2%) of all houses (units) are observed once, 23.2% (24.5%) appear twice and 21.0% (35.3%) at least three times. It happens regularly that a property is assigned to different price segments over time. Reasons for changes include renovation, depreciation of the structure or changes in locational amenities.[29] Figure B2 illustrates a possible path: The dwelling appears first in the data set at time 1 and is then assigned to a medium segment. The structure depreciates over time such that it is assigned to a low price segment when it re-appears at time 2. The dwelling undergoes renovation and appears on the market again at time 3 and is then assigned to a high price segment. To obtain unique imputed prices and rents per year, we allow changes in the allocation to segments and use the respective imputed prices and rents. For the illustrated path in Figure B2 this implies that the dwelling is assigned to the medium

each year. The locational spline is based on *thin plate regression splines* (see Hill and Scholz 2018). The predicted prices and rents from these models are denoted by $\tilde{p}_h^S$ and $\tilde{p}_h^R$, respectively.

[29] Of course, measurement errors as well as errors resulting from differences between segments according to the price and rent distribution may also lead to changes in the segment allocation.

segment in the time interval [2004; time 2), to the low segment in [time 2; time 3) and to the high segment in [time 3; 2014].

Figure B2: Illustration of temporal changes in the segment allocation.



Step 5: Identification of owner occupied and rented dwellings. Generally, we assume that dwellings that are sold are owner occupied and those that are rented are not. The allocation of a specific dwelling may – as with step 4 – change over time. If a dwelling was sold at time 1, rented at time 2 and again sold at time 3, we allocate the dwelling to the OOH sample in [2004, time 2) and [time 3, 2014]. In the interval [time 2, time 3) it is assigned to the rental sample.

C Additional Derivations and Tables

C.1 Derivation of expenditure shares

The 16th series of the Australian CPI uses expenditure weights derived from the 2009-2010 household expenditure survey (see Australian Bureau of Statistics, 2011). Average expenditures ($y_{t,n}$) in Australian dollars for each component n of the CPI are provided for Sydney for the June quarter 2011 (here denoted by t). Corresponding average expenditures ($y_{s,n}$) for heading n in other quarters s can be obtained as follows:

$$y_{s,n} = y_{t,n} \times \left(\frac{p_{s,n}}{p_{t,n}} \right),$$

where $p_{t,n}$ is the price index for heading n in the CPI in quarter t.

From (3), average household expenditure on OOH according to the user cost method requires estimates of the value of the average dwelling $\bar{P}_t$ (see Table C2), the per dollar user cost u_t (see Table C4), and an estimate of the share of households that are owner occupiers (i.e., H_t^{OOH}/H_t). In Sydney about two-thirds of households are owner-occupiers and one-third are renters (Australian Bureau of Statistics, Census of Population and Housing). It follows that $\bar{P}_t u_t$ should be multiplied by 2/3 to make the user cost expenditure share representative of the whole population of households. Combining these estimates generates the average (user cost) OOH expenditure shares in Table I.

Similarly, from (1), to compute average household expenditure on OOH according to the rental equivalence method, what is needed is estimates of the average rent $\bar{R}_t$ (see Table C2), and an estimate of H_t^{OOH}/H_t.

The OOH expenditure share under the acquisitions approach is derived from the 2009-2010 household expenditure survey. For this reason it stays fixed throughout our sample period.[30]

C.2 Removing OOH from the CPI and then re-inserting it using a different method

The 16th series of the Australian CPI is computed using a Laspeyres-type price index formula as follows:[31]

$$\frac{CPI_{t+1}}{CPI_t} = \sum_{n=1}^{N} \left[s_{b,n} \left(\frac{p_{t+1,n}}{p_{t,n}} \right) \right],$$

where CPI_{t+1}/CPI_t is the change in the CPI from period t to $t+1$, $s_{b,n}$ denotes the expenditure weight for heading n in the base period which here is June 2011.

Under the acquisitions approach, OOH consists of three headings:

New dwelling purchase of owner occupiers,

Maintenance and repair of the dwelling,

Property rates and charges.

[30] The previous survey was undertaken in 2003-2004. We could have combined the weights from the two surveys in some way. But we decided simply to use the most recent weights for the whole sample.

[31] More precisely, when the weights are fixed, this price index formula is referred to as a Young index (see chapter 1 of the Consumer Price Index Manual 2004).

Here we will classify these headings for notational convenience as $N-2$, $N-1$, and N. To determine the impact on the CPI of switching from acquisitions to user cost or rental equivalence, it is necessary to separate the OOH components of the CPI from the rest of it, as follows:

$$\begin{aligned}\frac{CPI_{t+1}}{CPI_t}\bigg| OOH &= \left(\frac{1}{\sum_{n=1}^{N-3} s_{b,n}}\right)\sum_{n=1}^{N-3}\left[s_{b,n}\left(\frac{p_{t+1,n}}{p_{t,n}}\right)\right] \\ &= \left(\frac{1}{\sum_{n=1}^{N-3} s_{b,n}}\right)\left[\frac{CPI_{t+1}}{CPI_t} - s_{b,N-2}\left(\frac{p_{t+1,N-2}}{p_{t,N-2}}\right)\right. \\ &\quad \left. - s_{b,N-1}\left(\frac{p_{t+1,N-1}}{p_{t,N-1}}\right) - s_{b,N}\left(\frac{p_{t+1,N}}{p_{t,N}}\right)\right].\end{aligned}$$

Our variants on the official CPI are then calculated as follows:

$$\frac{CPI^*_{t+1}}{CPI^*_t} = \left(\frac{1-s^*_{t,N+1}}{\sum_{n=1}^{N-3} s_{b,n}}\right)\sum_{n=1}^{N-3}\left[s_{b,n}\left(\frac{p_{t+1,n}}{p_{t,n}}\right)\right] + s^*_{t,N+1}\left(\frac{p^*_{t+1,N+1}}{p^*_{t,N+1}}\right),$$

where $s^*_{t,N+1}$ and $p^*_{t+1,N+1}/p^*_{t,N+1}$ are expenditure shares and price relatives for OOH obtained using either rental equivalence or user cost. It should be noted that in the case of rental equivalence and user cost, OOH is represented by a single heading here denoted by $N+1$, while under acquisitions it is represented by the three headings $N-2$, $N-1$, and N.

In addition to the official Australian acquisitions method, we provide results computed using the Eurostat version of acquisitions. The Australian and Eurostat methods use the same expenditure shares. They differ in the price index used for the heading *New dwelling purchase of owner occupiers*. As was explained in section 2.1, the Australian index uses a cost index of residential construction building materials. The Eurostat-type index uses an actual house price index. Ideally this index should cover only newly built dwellings. We are unable to do this for Sydney since in our data set we cannot distinguish new from existing dwellings.

C.3 Simulating the impact of OOH on the CPI at different rates of real house price appreciation

A faster appreciation in house prices affects both the OOH price index and expenditure share. To determine the effect on the CPI it is first useful to separate the CPI into its OOH and non-OOH (denoted by C) components as follows:

$$CPI_{t,t+1} = s_{t,C}\left(\frac{p_{t+1,C}}{p_{t,C}}\right) + s_{t,OOH}\left(\frac{p_{t+1,OOH}}{p_{t,OOH}}\right), \tag{15}$$

where $s_{t,C}$ and $s_{t,OOH}$ again denote expenditure shares. Next we set $p_{t+1,OOH}/p_{t,OOH} = (1 + \lambda)(p_{t+1,C}/p_{t,C})$, where λ denotes the rate of real house price appreciation. The expenditure shares of non-OOH $s_{t,C}$ and OOH $s_{t,OOH}$ are:

$$s_{t,C} = \frac{z_t}{k\bar{P}_t u + z_t}, \quad s_{t,OOH} = \frac{k\bar{P}_t u}{k\bar{P}_t u + z_t},$$

where z_t is per capita non-OOH expenditure in period t, k is the proportion of households that are owner-occupiers, and $k\bar{P}_t u$ is per capita expenditure on OOH. Per dollar user cost u is computed according to u(f). Assuming that the share of owner occupiers k in the population remains fixed, and that the average price $\bar{P}_t$ rises at the same rate as the house price index, yields the following:

$$\bar{P}_{t+1} = \bar{P}_t \left(\frac{p_{t+1,OOH}}{p_{t,OOH}} \right). \tag{16}$$

Similarly, z_t is assumed to rise at the average annual rate of growth of per capita nominal GDP:

$$z_{t+1} = (1 + rgdp) \left(\frac{p_{t+1,C}}{p_{t,C}} \right) z_t, \tag{17}$$

where $rgdp$ is the real growth rate of per capita GDP. We take the 2004 to 2014 period in Australia as our benchmark, and set z_{04}, so that $s_{04,OOH} = 0.185$, and $\bar{P} = \$600\,000$. These approximate the values for Sydney in 2004. The value of u is set to 0.03, as specified for $u(f)$ in section 4.3. Each period, $\bar{P}$ and z are then updated according to (16) and (17). $rgdp$ is set equal to the average annual growth rate of real per capita GDP over the period 2004-2014 in Australia.

C.4 Additional tables

Table C1: Summary Statistics

HOUSES			UNITS		
Weekly rents in AUD and **sales prices** in thousand AUD					
Median	470	650	Median	410	444
Mean	569	826	Mean	450	520
[Q1; Q3]	[360; 650]	[450; 950]	[Q1; Q3]	[330;525]	[336; 590]
Land area in m^2					
Median	573	590	Median	1,191	1,397
Mean	657	636	Mean	1,783	2,024
[Q1; Q3]	[404; 715]	[465; 721]	[Q1; Q3]	[697; 2 155]	[804; 2 543]
Number of bedrooms in %					
1	2.35	0.31	1	28.50	20.27
2	16.23	8.75	2	60.33	63.39
3	51.57	45.62	3	10.43	14.78
4+	29.85	45.32	4+	0.74	1.56
Number of bathrooms in %					
1	60.30	44.27	1	77.17	66.72
2	31.31	39.53	2	21.94	31.71
3	7.23	13.61	3	0.85	1.48
4+	1.16	2.59	4+	0.05	0.10
Number of observations					
All	330 102	427 211		521 518	343 437
− incomplete	20 884	105 053		49 623	165 077
+ reconstructed	2 456	19 044		8 688	37 788
− convex hull	569	840		5	0
Final	311 105	340 362		480 578	216 148
in % of all	94.3%	79.7%		92.2%	62.9%

Notes: The numbers in the Table refer to rental (left columns) and sales data (right columns). *All* refers to all observations (after deletions as described above) and *final* to the final number of observations. Observations that are not located in the intersection of locational convex hulls are excluded (see footnote 27). Total distinct house sales= 281 458; Total distinct unit sales=167 905; Total distinct house rentals:=177 023; Total distinct unit rentals:=237 887.

Table C2: Average Imputed Prices and Rents in Australian Dollars

	OOH			Rents (weekly)		
Year	Houses	Units	Total	Houses	Units	Total
2004	707 196	439 876	607 312	393.1	319.3	350.8
2005	685 918	436 526	592 732	404.9	328.4	361.0
2006	695 589	437 966	599 328	422.6	344.2	377.6
2007	742 069	454 911	634 772	459.4	376.8	412.0
2008	738 305	457 780	633 487	517.9	420.5	462.1
2009	762 267	478 329	656 173	514.5	432.2	467.3
2010	840 667	531 912	725 300	562.5	461.1	504.4
2011	830 637	542 368	722 925	595.4	489.2	534.5
2012	830 048	553 450	726 697	607.3	502.2	547.0
2013	920 854	605 285	802 941	622.3	515.0	560.8
2014	1 069 613	689 015	927 402	642.9	530.5	578.5

Notes: The table reports the mean sales price for OOH and the mean weekly rent separately for houses, units, and the total market (i.e., houses and units combined). Results are obtained from imputations based on conditional quantile models (see Appendix B).

Table C3: Price and Rent Indexes

	PRICE INDEXES			**RENT INDEXES**		
	Houses	Units	Total	Houses	Units	Total
2004	1.000	1.000	1.000	1.000	1.000	1.000
2005	0.964	0.987	0.973	1.026	1.027	1.027
2006	0.968	0.985	0.975	1.071	1.071	1.071
2007	1.022	1.022	1.022	1.163	1.175	1.170
2008	1.008	1.044	1.022	1.377	1.312	1.340
2009	1.071	1.109	1.086	1.392	1.353	1.370
2010	1.198	1.232	1.212	1.540	1.452	1.488
2011	1.208	1.265	1.231	1.642	1.546	1.586
2012	1.223	1.287	1.248	1.692	1.594	1.634
2013	1.362	1.402	1.379	1.753	1.642	1.687
2014	1.600	1.588	1.598	1.828	1.697	1.750
Average Rise Per Year	5.005%	4.834%	4.949%	6.325%	5.474%	5.818%

Notes: Results are based on the Törnqvist price index formula. We use imputed prices and rents from conditional quantile models (see Appendix B). The overall price (rent) indexes are computed by taking weighted geometric means of the house and unit price (rent) relatives, with the weights each period determined by the number of house and unit transactions in that same period.

Table C4: Expected Real Capital Gains and Per Dollar User Costs: Sydney 2004-2014

	$g(0)$	$g(10)$	$g(30)$	r	$u(0)$	$u(10)$	$u(30)$	u(f)
2004	0.0000	0.0660	0.0331	0.0585	0.0635	0.0000	0.0303	0.0300
2005	0.0000	0.0591	0.0335	0.0514	0.0564	0.0000	0.0229	0.0300
2006	0.0000	0.0555	0.0328	0.0574	0.0624	0.0069	0.0295	0.0300
2007	0.0000	0.0533	0.0345	0.0620	0.0670	0.0138	0.0326	0.0300
2008	0.0000	0.0481	0.0354	0.0659	0.0709	0.0228	0.0355	0.0300
2009	0.0000	0.0338	0.0301	0.0556	0.0606	0.0268	0.0305	0.0300
2010	0.0000	0.0393	0.0293	0.0533	0.0583	0.0190	0.0290	0.0300
2011	0.0000	0.0400	0.0262	0.0516	0.0566	0.0166	0.0304	0.0300
2012	0.0000	0.0217	0.0274	0.0300	0.0350	0.0132	0.0075	0.0300
2013	0.0000	0.0071	0.0312	0.0354	0.0404	0.0333	0.0092	0.0300
2014	0.0000	0.0067	0.0354	0.0370	0.0420	0.0353	0.0066	0.0300
Average	0.0000	0.0391	0.0317	0.0507	0.0557	0.0171	0.0240	0.0300

Notes: In the per dollar user cost formula we hold depreciation fixed at $\delta = 0.011$, running and average transaction costs fixed at $\omega = 0.019$, and expected inflation fixed at $\pi = 0.025$. r is the yield on 10-year government bonds. $g(x)$ is the expected real capital gain and $u(x)$ the per dollar user cost obtained by extrapolating expectations of capital gains over an x year time horizon. The per dollar user cost is calculated using the formula in (2). u(f) sets the per dollar user cost equal to the sum of depreciation and average transaction and running costs, which do not vary over time.

Table C5: Average Monthly OOH Expenditures in Dollars: Sydney 2004-2014

	$u(0)$	$u(10)$	$u(30)$	$u(f)$	Rental Equiv.	Acquis.
2004	2 140.9	0.0	1 024.2	1 012.2	1 016.9	606.2
2005	1 857.4	0.0	754.2	987.9	1 046.6	629.4
2006	2 077.0	229.0	984.8	998.9	1 094.7	637.8
2007	2 364.4	484.8	1 147.8	1 058.0	1 194.4	646.2
2008	2 494.1	801.3	1 248.2	1 055.8	1 339.4	672.6
2009	2 207.9	975.8	1 110.6	1 093.6	1 354.7	689.9
2010	2 348.2	764.6	1 167.5	1 208.8	1 462.1	711.2
2011	2 273.2	666.7	1 220.9	1 204.9	1 549.4	732.7
2012	1 411.0	534.9	304.8	1 211.2	1 585.8	744.9
2013	1 802.2	1485.4	410.4	1 338.2	1 625.6	770.8
2014	2 165.2	1820.0	341.3	2 545.7	1 676.8	802.3
Average	2 103.8	705.7	883.2	1 155.9	1 358.8	694.9
CV	0.147	0.806	0.416	0.147	0.178	0.091

Notes: u(x) denotes the user cost method with expected capital gains extrapolated based on the preceding x years, u(f) denotes the user cost method where it is assumed that the parameter k in (6) equals zero. Rental Equiv. denotes the rental equivalence method. Acquis. denotes the acquisitions method.

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