ECONOMIC RECORD

ECONOMIC RECORD, VOL. 97, NO. 317, JUNE, 2021, 212–242

Housing and Commodity Investment Booms in a Small Open Economy

CHRISTOPHER G. GIBBS
University of Sydney, Camperdown, NSW, Australia

JONATHAN HAMBUR
Department of Treasury, Australia, Sydney, NSW, Australia

GABRIELA NODARI
Reserve Bank of Australia, Sydney, NSW, Australia
NodariG@rba.gov.au

We add a housing sector to the Reserve Bank of Australia's small open-economy model to explore the effect of commodity price shocks on housing investment. The model predicts that housing investment booms may follow commodity booms. Commodity booms have a persistent effect on housing services price inflation and they 'crowd out' housing investment. When the commodity boom ends, the combination of higher prices and falling interest rates induces a significant housing investment response. The model attributes a significant share of the recent increase in housing investment in Australia directly to falling commodity prices.

I. Introduction

Economic activity in the Australian housing market increased substantially from 2011 to 2017, attracting considerable interest from academics and policy-makers.[1] Housing investment, for example, has grown by more than 30 per cent over this period. This dramatic rise in economic activity has coincided with a dramatic fall in mining investment in Australia associated with the downswing in global commodity prices (Figure 1). On the one hand, the rise in housing investment has partly filled the hole left by falling mining investment. On the other hand, it has raised concerns about high housing investment and prices in a low interest rate environment. Such concerns are especially acute given the experience of the United States in the previous decade.[2]

Housing investment and prices have been shown to play a considerable role in macroeconomic fluctuations. For example, Iacoviello and Neri (2010) show, using a multi-sector estimated dynamic stochastic general equilibrium (DSGE) model, that shocks emanating from the housing market have significant effects on the real economy, especially on consumption. Liu, Wang, and Zha (2013) extend this result to business investment. Muellbauer (2015) cites evidence from several model-based and econometric studies to argue that housing is also a significant determinant of inflation in the United States.

Likewise, in open-economy settings, there is growing evidence of an empirical link between current account deficits, the terms of trade and

The authors would like to thank Daniel Rees, Tim Robinson, Gian-piero Lovicu, Jarkko Jääskelä, John Simon, participants of the Sydney Macro Reading Group Workshop and seminar participants at the Australian Treasury and the Australian National University for helpful comments. The views expressed in this paper are those of the authors and do not necessarily reflect the views of the Reserve Bank of Australia or Treasury. The authors are solely responsible for any errors.

JEL classifications: E23, E32, R31

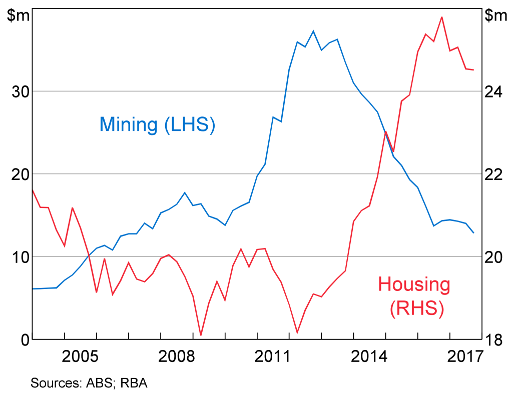
Correspondence: Gabriela Nodari, Reserve Bank of Australia, 65 Martin Place, Sydney, New South Wales, 2000, Australia. E-mail: NodariG@rba.gov.au

[1] See, for example, Fox and Finlay (2012), Reserve Bank of Australia (2014), Lim and Tsiaplias (2016), and Shoory *et al*. (2016).

[2] See Kulish and Rees (2017) for an overview of the size and scope of the recent mining boom in Australia. See Lowe (2015) for a discussion on the transition of the Australian economy away from the mining boom.

doi: 10.1111/1475-4932.12590

Figure 1
Mining and Housing Investment in Millions of Australian Dollars, Australia, 2004–17. [Colour figure can be viewed at wileyonlinelibrary.com]



housing investment. Ferrero (2015) argues, using a calibrated DSGE model, that the interaction of housing sector shocks and international investment flows can simultaneously explain the US housing boom and the current account. Meanwhile, Sá, Towbin, and Wieladek (2014) and Corrigan (2017) use cross-country data to demonstrate the important role of external non-monetary shocks on the housing market. However, little work has tried to formally model the relationship between housing investment and external non-monetary forces in Australia, such as sustained increases in global commodity prices, in an open-economy setting, a gap which this paper seeks to fill.

To study the link between commodity booms and housing investment, we modify the Rees–-Smith–Hall (RSH) model (Rees, Smith, and Hall, 2016). The RSH model is a multi-sector DSGE model of the Australian economy, which complements the suite of economic models of the Reserve Bank of Australia (RBA) and is used as an analytical tool to conduct scenario analysis. We leave the key features of the RSH model intact but incorporate a standalone housing sector into the existing framework. Like most housing model specifications, households are assumed to have preferences over a basket of consumption goods and over holdings of the housing stock. However, in a departure from many of the models in this literature, we maintain a single representative household which owns the housing stock and consumes the stream of services produced by the housing service sector rather than assuming a two-agent spender–saver structure, where home ownership is mediated through financial markets.

We adopt this set-up for two reasons. First, we wish to keep the model as close to the original RSH specification as possible to draw precise comparisons between the two models. Second, a growing literature casts doubts on the validity of the spender–saver structure because it ignores rental markets. For example, d'Albis and Iliopulos (2013) show that if a rental market is added to the basic spender–saver model, then the constrained households never choose to own housing. Likewise, Kaplan, Mitman, and Violante (2017) also show that when renting is an option for households the existence of credit constraints has little explanatory power over house prices and investment dynamics. We show that our single-agent specification is able to replicate the basic dynamic relationships highlighted by Iacoviello and Neri (2010) and Liu, Wang, and Zha (2013) without assuming collateral constraints or a detailed debt market. We also conduct a pseudo out-of-sample forecasting exercise to show that the model well captures aggregate and sectoral dynamics relative to a simple univariate benchmark and the RSH model. Therefore, although we abstract from many features of the housing market, we are still able to capture the relevant dynamic relationships present in macroeconomic data.

We estimate the model on Australian data using standard Bayesian techniques. We compare the estimated impulse response functions, out-of-sample forecasts, and variance decomposition of our model to those arising from RSH. We find that the introduction of the housing sector has the largest impact on how the model attributes the impact of foreign shocks. We find marked reductions in the reliance on commodity shocks to explain aggregate dynamics across the key aggregate variables such as gross domestic product (GDP), inflation and consumption. In particular, the RSH model ascribes as much of 50 per cent of the movements in aggregate consumption to commodity and foreign-related shocks over the 1992–2017 period. The model with a housing sector puts that number at around 10 per cent.

The different interpretation of the data between the two models can be directly attributed to the role that housing consumption and investment play as an endogenous propagator of shocks. In the RSH model, aggregate investment responds strongly to increases in commodity prices. But adding housing to the model significantly dampens this effect because housing investment tends to be crowded out by mining investment. The sensitivity of the housing sector to these external factors as an offsetting force means that the movements in other sectors of the economy must be determined by domestic developments. Therefore, although the economy in general is less driven by external developments, the housing sector is an important source of the transmission of these shocks when they occur.

In fact, by decomposing recent data using the model, we find that housing investment in Australia has been significantly driven by shocks in global commodity prices over recent years. We find that housing investment played a large role in driving growth and inflation over this period, adding a half percentage point to GDP growth and a quarter percentage point to inflation in year-ended terms. The model suggests that commodity booms significantly depress housing investment but elevate housing service prices. The effect on prices is estimated to be very persistent, leaving housing services prices elevated even as commodity prices fall. Elevated housing service prices and falling interest rates, in response to retreating commodity prices, induce a significant increase in housing investment, which generates a housing investment boom as mining busts.

The key estimated parameters that drive these dynamics in the model are those of the housing sector Phillips curve. The estimates suggest that prices in the housing sector are both less affected by real activity and much more persistent than prices in other sectors. Therefore, short-lived but large shocks that affect housing sector inflation can have very persistent effects that over time are seemingly divorced from current fundamentals. In the Australian case, large commodity price shocks that drove the mining investment boom provided the impulse for the persistent increase in housing-services-related inflation. When commodity prices fell along with interest rates, the stage was set for a housing boom. This dynamic may go some way in explaining similar housing investment dynamics observed in other commodity-dependent small open economies, such as Norway and Canada, which have had similar experiences in recent years.[3]

[3] See Geng, Henn, and Zhang (2017) for details on Norway's recent housing investment boom and Corrigan (2017) for an empirical study of 14 OECD countries.

The remainder of the paper proceeds as follows. Section 2 describes the model and intuition for the housing sector. Section 3 describes the estimation and calibration of the model. Section 4 compares the variance decompositions and key impulse responses of the model with housing to RSH and Iacoviello-type models. Section 5 explores the quantitative importance of commodity prices movements to housing investment and discusses the key mechanism that underlies the two booms. Section 6 concludes.

II. The Model

We start by providing a brief overview of the structure of the RSH model. We then describe in words how we modify the model to include a housing sector. We finish this section by describing the model formally and by explaining dynamic and steady-state implications of our housing modelling assumptions for interpreting the data.

RSH Overview

The RSH small open economy of consists of households and firms that produce and consume in five distinct sectors. There are four intermediate goods- and services-producing sectors: resource (mining), non-resource tradeable (manufacturing and agriculture), non-tradeable, and imports. The resource sector is modelled as perfectly competitive and takes the world price of the resource good as given. The remaining sectors are monopolistically competitive. Price changes for monopolistically competitive firms are subject to Rotemberg (1982) style price adjustment costs. Wages in all domestic production sectors face similar adjustment costs. Intermediate goods and services, produced domestically and imported from abroad, are combined into final goods by the fifth sector, a perfectly competitive final goods sector, which provides final goods for household and government consumption as well as business investment.

Households derive utility from consumption of the composite final good and derive disutility from labour supplied to firms in the three domestic intermediate production sectors. Households earn wages from labour supplied, rents from their ownership of capital, and dividends from ownership of firms. Households may also purchase domestic and foreign nominal bonds.

Monetary policy in the model follows a Taylor-type rule that responds more than one-for-one to changes in inflation and positively to changes in real GDP growth. Fiscal policy is assumed passive with lump-sum taxation.

The world economy is modelled as a two-sector closed-economy version of the model just described, and also features price stickiness. It purchases resources and tradeable goods from Australia, and sells tradeable goods to Australia.

Adding a Housing Sector

We add a housing sector to the model by splitting the non-tradeable sector of RSH into a housing services sector and a non-tradeable ex-housing sector. This brings the total number of intermediate goods and service sectors to five. The housing services sector combines labour and housing-specific capital supplied by households together with resource goods to produce housing services in a monopolistically competitive market. The housing services are sold to final goods producers who construct a market basket of goods that the households consume subject to constant elasticity of substitution production technology. The demand for housing services, therefore, comes from households' consumption of the composite consumption good in the economy, which aligns both the price level and consumption variables in the model well with the actual construction of the Consumer Price Index and measures of consumption used to calculate GDP.

In addition, we assume that households have direct utility over the housing stock, which is represented by housing-specific capital. We make this additional assumption because households, the government, and banks tend to treat housing assets differently from other real assets. For example, home ownership – in Australia and in many other developed countries – makes up a disproportionate share of household wealth, and households typically dissave their housing wealth in retirement at rates below what the classical life-cycle model would predict (Skinner, 1996). Households also tend not to use their housing wealth to respond to income shocks in the same way as they do with other assets, which suggests that housing is not accumulated for precautionary savings motives to smooth consumption in the way that other assets are held (e.g. Sinai & Souleles, 2005; Nakajima & Telyukova, 2013). The tax treatment of housing is also distinct from that of other assets in that it does not factor in means-testing for pensions and there are capital gains exemptions. Similarly, banks often give preferential treatment to housing assets as collateral. We do not model in detail all these differences between housing capital and other sector-specific capital. Rather, we include housing capital in the utility as a short-hand way to capture the peculiarities related to housing. One question this paper answers is whether this short-cut delivers plausible dynamics when taken to the data, which we answer in the affirmative.

Because households gain utility from holding housing stock, housing investment becomes more responsive to changes in the real interest rate than investment in other sectors, which is consistent with empirical evidence (e.g. Lawson & Rees, 2008). Including the housing stock in the utility function also generates a positive correlation between real housing wealth (measured by the housing stock) and consumption. This is qualitatively similar to the housing wealth effects documented empirically in Australia by Dvornak and Kohler (2007), Gillitzer and Wang (2016), and May, Nodari, and Rees (2020), and to the effect of housing collateral constraints when housing debt is considered as in the models of Iacoviello (2005) and Iacoviello and Neri (2010).

The housing price of interest in our model also differs from that of the Iacoviello-type models referenced above. In our framework, the relevant price in the housing market is the service flow value of housing, which reflects rents, new construction costs, and real estate services. Many papers in this literature focus on the quantity and price of trading the existing housing stock, not housing services, where the latter is the relevant concept for measuring GDP and inflation. The current weight of the housing services component of the CPI basket is about 23 per cent in Australia. The average housing share of nominal gross value added (GVA) from 1993 to 2016 is around 16 per cent. So, the choices of which housing prices and services to model are not trivial with respect to matching macro variables. Our housing market assumptions make the model definitions of these variable consistent with the actual variables we are attempting to explain.

The Household's Decision Problem

We assume that there is a continuum of identical households indexed by i and distributed uniformly on the unit interval. The household's decision problem is to choose consumption, $C_t(i)$, hours worked, $H_t(i)$, and the level of the housing stock, $K_{d,t}(i)$, to maximise expected utility,

$$\mathbb{E}_t\sum_{t=0}^{\infty}\beta^t\left\{\zeta_{C,t}\ln(C_t(i)-bC_{t-1}(i))+A_d\zeta_{K_d,t}\ln(K_{d,t}(i)-b_dK_{d,t-1}(i))-A_H\zeta_{H,t}\frac{H_t(i)^{1+\eta}}{1+\eta}\right\}, \tag{1}$$

subject to the budget constraint.

$$\begin{aligned}P_t\left(\sum_{j=n,m,z,d}I_{j,t}(i)\right)+\frac{B_t(i)}{R_t}+\frac{B_t(i)^*S_t}{R^*\Psi_t}+C_t(i)\leq&\sum_{j=n,m,z,d}\left(h_{j,t}(i)W_{j,t}(i)+K_{j,t}(i)R_{j,}t\right)\\&+L(i)R_{L,t}+B_{t-1}(i)++\Delta_t(i)+S_tB^*_{t-1}(i)-T_t(i)\\&-\sum_{j=1}^{J}\frac{\tau_{w,j}}{2}\left(\frac{W_{j,t}(i)}{W_{j,t-1}(i)(\prod^w_{j,ss})^{1-\chi j}(\prod^w_{j,t-1})^{\chi j}}-1\right)^2W_{j,t}h_{j,t}.\end{aligned} \tag{2}$$

Households' preferences are subject to three autoregressive preference shocks (ζ_t) and exhibit habit persistence in both the level of consumption, b, and the level of the housing stock, b_d. A_d and A_H are normalising constants used to pin down the steady state of the model for estimation. Total hours worked H_t is an index composed of the hours allocated by households to each different production sector:

$$H_t=\left[h^{1+\sigma}_{n,t}+h^{1+\sigma}_{m,t}+h^{1+\sigma}_{z,t}+h^{1+\sigma}_{d,t}\right]^{\frac{1}{1+\sigma}}. \tag{3}$$

The four domestic production sectors of the economy are denoted $j=\{n,m,z,d\}$, where n is non-tradeable excluding housing, m is non-resource tradeable, z is resources, and d is the housing (dwelling) sector. In the budget constraint, $h_{j,t}(i)$ and $W_{j,t}(i)$ denote hours worked and the nominal wage of household i in sector j; $h_{j,t}$ and $W_{j,t}$ are average hours and wages in sector j, respectively; $\tau_{w,j}$ is the wage adjustment cost in sector j; $I_{j,t}(i)$ and $K_{j,t}(i)$ are investment and capital, respectively, of household i in sector j; L is land; $\Delta_t(i)$ and $T_t(i)$ are dividends and lump-sum taxes; P_t is the price level; S_t is the nominal exchange rate; Ψ_t is a risk premium shock that is a function of foreign assets, which is how we close the open-economy aspect of the model; $B_t(i)$ is the amount household i has invested in one-period risk-free nominal bonds; R_t is the nominal interest rate factor; and starred variables denote foreign quantities.[4]

[4] We follow RSH and assume that the risk premium shock, Ψ_t, depends on the stock of foreign debt outstanding such that $\Psi_t=\exp\left(-\iota\frac{B^*_tS_t}{P_tY_t}+v_t\right)$, where v_t follows an autoregressive process.

The household consumes a composite consumption good that is a constant elasticity of substitution (CES) aggregate of all intermediate goods, including housing services. Therefore, housing-related quantities enter the utility function in two different ways. One can think of this as separating the household's need to consume housing services from their preference for holding housing assets.

The final term of the budget constraint captures Rotemberg (1982) style wage adjustment costs with indexation, which we use to introduce wage stickiness into the model. The specification follows Burgess, Fernandez-Corugedo, Groth, Harrison, Monti, Theodoridis, and Waldron (2013). Workers have heterogeneous skills and firms purchase a bundle of labour from households that includes workers of all types:

$$h_{j,t}=\left(\int_0^1\left(h_{j,t}(i)\right)^{\frac{\theta^{w,j}-1}{\theta^{w,j}}}d_i\right)^{\frac{\theta^{w,j}}{\theta^{w,j}-1}}. \tag{4}$$

Workers, therefore, have some bargaining power over their wages and take into consideration overall demand for labour and average wages in the market when negotiating. In addition, wage changes may be indexed to a combination of the previous period's sectoral wage growth $\Pi^w_{j,t-1}$, and steady-state sectoral wage growth $\Pi^w_{j,ss}$. The parameter $\theta^{w,j}$ determines the degree of substitutability among differentiated labour inputs in sector j.

Households are homogeneous, so individual consumption and saving decisions mirror the aggregated decisions. The aggregate capital stock of each sector in the economy evolves according to the following law of motion:

$$K_{j,t+1} = (1-\delta_j)K_{j,t} + \Gamma_t\left[1 - F\left(\frac{I_{j,t}}{I_{j,t-1}}\right)\right]I_{j,t} \quad (5)$$

where δ_j is the depreciation rate of capital in sector j, $F(\cdot)$ is the capital adjustment cost, and Γ_t is an autoregressive investment adjustment cost shock.[5]

Sectoral Production

Intermediate monopolistically competitive goods and services producers

In the three monopolistically competitive producing sectors (non-tradeable excluding housing, non-resource tradeable, and housing), we assume that there is a continuum of firms, indexed by x, that produce different intermediate goods using three factors: capital, labour, and the resource good. The firms sell their output to a wholesaler, who combines the differentiated intermediate goods into a homogeneous good for sale in the final goods and services sector using a CES production technology,

$$Y_{j,t} = \left[\int_0^1 Y_{j,t}(x)^{\frac{\theta^{\pi,j}-1}{\theta^{\pi,j}}}\mathrm{d}x\right]^{\frac{\theta^{\pi,j}}{\theta^{\pi,j}-1}}, \quad (6)$$

where $Y_{j,t}(x)$ is output of firm x and $\theta^{\pi,j}$ governs the degree of substitutability among the different intermediate goods in sector j. The demand for each firm's output is given by

$$Y_{j,t}(x) = \left(\frac{P_{j,t}(x)}{P_{j,t}}\right)^{-\theta^{\pi,j}} Y_{j,t}. \quad (7)$$

Given the demand, the firm must choose the amount of capital and labour to hire, the price of their product, and the amount of resources to use in production. These decisions are the same across the three intermediate domestic goods-producing sectors with the exception of the tradeable sector, where firms additionally must choose how much to export and at what price. The decision in this case mirrors the decision for the domestic market. Therefore, in the interests of space, we present only the decision problem for firms selling in the domestic market.[6]

Each intermediate firm produces a unique variety of goods and services using the production function

$$Y_{j,t}(x) = a_{j,t}(M_t h_{j,t}(x))^{\alpha_j}(K_{j,t}(x))^{\gamma_j}(Z_{j,t}(x))^{1-\alpha_j-\gamma_j}, \quad (8)$$

where $Z_{j,t}(x)$ is the resource good used in production by the x th firm, $a_{j,t}$ is a sector-specific autoregressive technology shock, and M_t is an aggregate permanent labour-augmenting technology shock that follows a random walk with drift.[7] A firm's objective is to choose a sequence of factor inputs and prices to maximise the expected discounted value of profits, subject to demand for $Y_{j,t}(x)$, where a firm's real profit in period t is given by

$$\Delta_{j,t}(x) = \left(\frac{P_{j,t}(x) - MC_{j,t}(x)}{P_t}\right)Y_{j,t}(x) - \frac{\tau^{\pi,j}}{2}\left[\frac{P_{j,t}(x)}{\pi_{j,t-1}^{\chi_j}\Pi_j^{1-\chi_j}P_{j,t-1}(x)} - 1\right]^2 \frac{P_{j,t}Y_{j,t}}{P_t}. \quad (9)$$

The firm's pricing decision is subject to a quadratic price adjustment cost, which is scaled by $\tau^{\pi,j}$. In addition, firms may index their price to a combination of $\pi_{j,t-1}$ and Π_j, which are the previous period's sector-specific inflation rate and the steady-state sectoral inflation rate, respectively.

The $MC_{j,t}(x)$ term is the marginal costs for firm x in sector j, which take the form.

$$MC_{j,t}(x) = \frac{\varepsilon_{\pi_j,t}}{a_{j,t}}\left[\frac{W_{j,t}}{\alpha_j M_t}\right]^{\alpha_j}\left[\frac{R_{j,t}}{\gamma_j}\right]^{\gamma_j}\left[\frac{P_{z,t}}{1-\alpha_j-\gamma_j}\right]^{1-\alpha_j-\gamma_j}, \quad (10)$$

where $\varepsilon_{\pi_j,t}$ is a white noise mark-up shock and $P_{z,t}$ is the domestic nominal price of commodities.

In the case of housing services production, the intermediate producers can be thought of as

[5] We assume that F is a function of the steady-state growth rate of labour-augmenting productivity, μ, such that $F(\mu) = F'(\mu) = 0$ and $F''(\mu) > 0$. In practice, we adopt the following function form: $\frac{1}{2}\left(\frac{I_{j,t}}{I_{j,t-1}} - \mu\right)^2\Theta_j$.

[6] For a detailed description of each individual sector we direct the interested reader to RSH.

[7] Despite land being included in the model as part of the mining production function, we do not include land as a factor of production for the housing sector. Instead, to retain a close link to the original model and to the production of other non-tradeable goods, we choose the same functional form for the production function as that of the non-tradeable sector. Considering a fixed factor here is an interesting area to explore in future iterations of the model.

professional property developers and managers. These developer/managers rent housing stock from households and combine it with labour and resources inputs to produce housing services. The housing services are then sold to the final goods producers to be combined with all other intermediates, which in turn are sold on to households as part of the CES consumption bundle. The price for housing services, therefore, reflects a composite of rents, new dwelling prices and real estate services, which are the main housing components that are included in the CPI.

Imports, resources, and final goods sector

Imports. Firms in the imports sector, f, import differentiated goods and services from overseas, which they sell to wholesalers. The marginal cost of importing goods and services by firm x is given by

$$MC_{f,t}(x) = \varepsilon_{\pi_f,t}\frac{S_t P^*_{f,t}}{P_{f,t}}, \tag{11}$$

where $\varepsilon_{\pi_f,t}$ is a white noise mark-up shock. The firms seek to maximise expected profits by choosing a sequence of prices and the amount of goods and services to import, subject to demand for $Y_{f,t}(x)$ and quadratic price adjustment costs as in Equation (10).

Resources sector. The resources sector is perfectly competitive and produces a homogeneous resource good. The resource good production function is given by

$$Y_{z,t}(x) = a_{z,t}(M_t h_{z,t}(x))^{\alpha_z}(M_t L_t)^{\alpha_L}(K_{z,t}(x))^{1-\alpha_z-\alpha_L},$$

where the stationary sector-specific technology shock takes the same functional form as in the other sectors. The resource firms take the price as given and choose capital and labour to maximise profit, which is given by

$$\Delta_{z,t} = P_{z,t}Y_{z,t} - W_{z,t}h_{z,t} - R_{z,t}K_{z,t} - R_{L,t}L. \tag{13}$$

Following RSH, we assume that the law of one price holds for resources in the long run. However, we allow for a delay in the short-term pass-through of global resource price movements to the domestic price. This assumption captures the fact that a fraction of the resources exported from Australia are priced using contracts, which are only revised periodically, and that firms often hedge their foreign currency exposures. Therefore, the domestic price is assumed to follow

$$P_{z,t} = \left(S_t P^*_{z,t}\right)^{1/2}(P_{z,t-1})^{1/2}, \tag{14}$$

where $P^*_{z,t}$ denotes the price in foreign currency terms, and S_t is the nominal exchange rate.

Final goods sector. The final goods sector purchases the homogenous composite goods from the wholesalers and assembles them into final goods giving rise to domestic final demand:

$$DFD_t = \left[\omega_n^{\frac{1}{\zeta}}Y_{n,t}^{\frac{\zeta-1}{\zeta}} + \omega_m^{\frac{1}{\zeta}}\left(Y_{m,t}^{\mathrm{dom}}\right)^{\frac{\zeta-1}{\zeta}} + \omega_d^{\frac{1}{\zeta}}Y_{d,t}^{\frac{\zeta-1}{\zeta}} + \omega_f^{\frac{1}{\zeta}}Y_{f,t}^{\frac{\zeta-1}{\zeta}}\right]^{\frac{\zeta}{\zeta-1}}, \tag{15}$$

where $\omega_n + \omega_m + \omega_d + \omega_f = 1$ governs the shares of each sector's output in the final domestic good and $Y^{\mathrm{dom}}_{m,t}$ stands for tradeable goods sold domestically. Profit maximisation by the final goods producers implies the following aggregate price index:

$$P_t = \left[\omega_n P_{n,t}^{1-\zeta} + \omega_m P_{m,t}^{1-\zeta} + \omega_d P_{d,t}^{1-\zeta} + \omega_f P_{f,t}^{1-\zeta}\right]^{\frac{1}{1-\zeta}}. \tag{16}$$

Fiscal and Monetary Policy

Following RSH, fiscal policy is assumed to be passive. The government issues bonds and raises lump-sum taxes for expenditures. The government's budget constraint is given by

$$P_t G_t + B_{t-1} = T_t + \frac{B_t}{R_t}. \tag{17}$$

Public demand, G_t, is assumed exogenous and takes the form

$$\ln\left[\frac{G_t}{M_t}\right] = (1-\rho_t)\ln(g) + \rho_g \ln\left[\frac{G_{t-1}}{M_{t-1}}\right] + \varepsilon_{g,t}, \tag{18}$$

where g determines the public demand steady-state share of GDP. The lump-sum taxes assumption implies that Ricardian equivalence holds in the model, meaning that the timing of taxation does not affect households' and firms' decisions. In addition, we assume that government debt is held in zero net supply.

Monetary policy is assumed to be active and follows a Taylor-type rule. Therefore, short-term nominal interest rates are set according to

$$\ln\left(\frac{R_t}{R}\right) = \rho_r \ln\left(\frac{R_{t-1}}{R}\right) + (1-\rho_r)\left[\phi_\pi \ln\left(\frac{\pi_t}{\Pi}\right) + \phi_{dy}\ln\left(\frac{Y_t^{va}}{Y_{t-2}^{va}}\right) + \phi_q \ln\left(\frac{Q_t}{Q_{t-1}}\right)\right] + \varepsilon_{r,t} \tag{19}$$

where π_t is the CPI inflation rate, Y_t^{va} is real GDP (value added measure), Q_t is the real exchange rate, ρ_r governs the degree of interest rate smoothing, and $\varepsilon_{r,t}$ is a monetary policy shock.

Market Clearing and the Current Account

The goods market clearing conditions are:

$$Y_{m,t} = Y_{m,t}^{dom} + Y_{m,t}^{ex}, \tag{20}$$

$$Y_{z,t} = Y_{z,t}^{ex} + Z_{n,t} + Z_{m,t} + Z_{d,t}, \tag{21}$$

$$DFD_t = C_t + G_t + \sum_{j=n,m,d,z} I_{j,t}. \tag{22}$$

The first condition requires all tradeable goods and services produced to be sold domestically (dom) or abroad (ex). The second condition requires all resource goods produced to be sold abroad or to the three intermediate production sectors. The third condition says that all final goods must be sold to consumers, sold to the government or invested.

The net foreign asset position of the economy is given by the current account:

$$\frac{S_t B_t^*}{R_t^* \Psi_t} = S_t B_{t-1}^* + NX_t, \tag{23}$$

where NX_t is nominal net exports. Net exports in this case are equal to the sum of the exported traded goods and the traded resources, less imports:

$$NX_t = S_t P_{m,t}^* Y_{m,t}^{ex} + P_{z,t} Y_{z,t}^{ex} - S_t P_{f,t}^* Y_{f,t}. \tag{24}$$

In addition, the non-tradeable, tradeable and housing sectors all use resources as inputs. This introduces a wedge between the production and the value added in these sectors. Therefore, the relevant concept of GDP requires a value-added computation. Following RSH, we do this calculation by subtracting out the value of the resource input in each intermediate sector using steady-state prices P_j such that $Y_{j,t}^{va} = Y_{j,t} - (P_z/P_j)Z_{j,t}$. Therefore, real GDP is defined as.

$$Y_t^{va} = \left(\frac{P_n}{P}\right)Y_{n,t}^{va} + \left(\frac{P_m}{P}\right)Y_{m,t}^{va} + \left(\frac{P_d}{P}\right)Y_{d,t}^{va} + \left(\frac{P_z}{P}\right)Y_{z,t}^{va}. \tag{25}$$

Finally, the following uncovered interest rate parity (UIP) condition holds in the log-linearised model:

$$r_t - r_t^* - \Psi_t = (1-\Phi_\Psi)[\mathbb{E}_t q_{t+1} - q_t + \mathbb{E}_t \pi_{t+1} - \mathbb{E}_t \pi_{t+1}^*] - \Phi_\Psi[q_t - q_{t-1} + \pi_t - \pi_t^*]. \tag{26}$$

The Foreign Economy

The foreign economy is modelled as a standard closed-economy sticky-price model. The log-linearised equations of this model are given by:

$$(\mu - b^*)(\mu - \beta b^*)\lambda_t^* = (\mu - b^*)(\mu \xi_{y^*,t} - b^* \beta \mathbb{E}_t \xi_{y^*,t-1}) - (\mu^2 + \beta (b^*)^2) y_t^* + \mu b^* (y_{t-1}^* + \beta \mathbb{E}_t y_{t+1}^* - \mu_t + \beta \mathbb{E}_t \mu_{t+1}), \tag{27}$$

$$\lambda_t^* = r_t^* + \mathbb{E}_t \lambda_{t+1}^* - \mathbb{E}_t \mu_{t+1} - \mathbb{E}_t \pi_{t+1}^*, \tag{28}$$

$$\pi_t * = (1 + \chi^* \beta)^{-1}\left(\beta \mathbb{E}_t \pi_{t+1}^* + \chi^* \pi_{t-1}^* + \kappa^* y_t^*\right) + e_{\pi^*,t}, \tag{29}$$

$$r^* = \rho_{r^*} r_{t-1}^* + \left(1 - \rho_{r^*})(\phi_{\pi^*}\pi_t^* + \phi_{dy^*}(y_t^* - y_{t-1}^*)\right) + \varepsilon_{r^*,t}, \tag{30}$$

where Equations (27) and (28) together form the IS relationship, Equation (29) is the Phillips curve, and Equation (30) is the monetary policy rule. The foreign demand shock, $\xi_{y^*,t}$, the foreign interest rate shock, $\varepsilon_{r^*,t}$, and the foreign mark-up shock, $e_{\pi^*,t}$, are assumed to follow autoregressive processes, while the remaining shocks are assumed to be white noise.

Commodity prices are assumed to follow an exogenous autoregressive process, which depends on its own shock and on the foreign demand shock:

$$p^*_{z,t} = (1-\rho_z)p^*_z + \rho_z p^*_{z,t-1} + \theta_{zy}\xi_{y^*,t} + \varepsilon_{p^*_z,t}, \quad (31)$$

where $p^*_z = \ln(P^*_{z,t}/P^*_t)$ is the relative price of the resource good in terms of the foreign currency.

Understanding Housing Capital Stock in the Utility Function

Adding housing stock to the utility function has two impacts on the predictions of the model. First, it affects the household's first-order condition with respect to its choice of housing capital ($K_{d,t}$) relative to the first-order condition for its choice of capital ($K_{j\neq d,t}$) in the other sectors:

$$\text{Non}-\text{housing}(K_{j\neq d,t}) : \beta\Lambda_{t+1}R_{j,t+1} = \beta(\delta_j - 1)\Lambda^k_{j,t+1} + \Lambda^k_{j,t}, \quad (32)$$

$$\text{Housing}(K_{d,t}) : \frac{\beta A_d \zeta_{K_d,t+1}}{K_{d,t+1} - b_d K_{d,t}} + \beta\Lambda_{t+1}R_{d,t+1} = \beta(\delta_d - 1)\Lambda^k_{d,t+1} + \Lambda_{k,d,t}, \quad (33)$$

where Λ_t is the shadow price of consumption and $\Lambda^k_{j,t}$ is the shadow price of capital. When log-linearised, this specification introduces an additional lag in housing capital and a housing preference shock, which allows for a richer set of dynamics in housing investment than in the other sectors. Note that if b_d and A_d are set to zero, the two equations are the same. Hence the investment decision would be identical in all sectors, which, as discussed in Section 2.2, is inconsistent with the known difference in households' behaviour towards housing assets for a myriad of reasons. Nonetheless, the two parameters enter multiplicatively in the log-linearised equations and b_d is estimated so the model allows the data to dictate to what degree these assumptions matter.

The second impact of including housing stock in the utility function is on the steady-state implied relationships of the model. The steady-state relationships are primarily used to pin down the share of economic activity allocated to each sector, which allows us to relate sectoral values to aggregate values in the model. With the exception of the two parameters b_d and A_d, all new parameters relating to the housing sector most significantly affect the model through pinning down these steady-state shares. To build intuition for how these assumptions affect the steady state, we present some partial equilibrium analysis focusing specifically on how these assumptions generate an increased housing investment share in steady state.

The housing capital factor markets in the model are perfectly competitive and can be illustrated using supply and demand schedules. The suppliers of the housing stock in this economy are the households. The demand for the housing stock comes from the firms in the housing services sector. These firms combine the housing stock with labour and resource goods to produce housing services, which are sold to the final goods producers and then on to households for consumption.

To understand the effect of our preference assumption on this market, we compare the market with and without housing stock in the utility function. In the case without housing stock in the utility function, the steady-state supply of capital is a fixed share of household saving that is determined by its return,

$$r_{j,\text{ss}} = \frac{\mu}{\beta} - 1 + \delta_j, \quad (34)$$

where μ is the steady-state labour-augmenting productivity growth rate.[8] We represent this relationship as a perfectly elastic supply schedule (the horizontal line in Figure 2). The demand for capital comes from the marginal productivity of capital implied by the production technology. The production technology is Cobb–Douglas in all sectors, so there are diminishing returns to capital, giving rise to the standard downward sloping demand schedule (Figure 2).

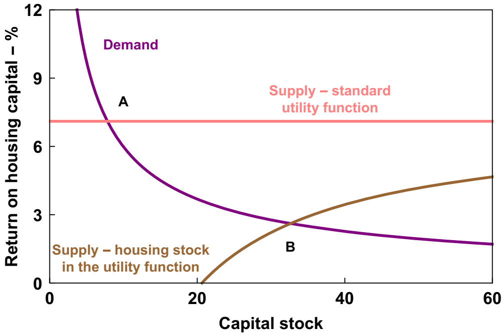
When we include the housing stock in the utility function, the household's supply schedule for housing capital is changed. Since households derive utility from the housing capital stock, they invest more in this sector. In doing so, they weigh the utility they get from housing capital stock along with the utility of consumption, which gives rise to the following supply schedule:

$$r_{d,\text{ss}} = \frac{\mu}{\beta} - 1 + \delta_d + \frac{A_d\mu^2}{(b_d - \mu)K_{d,\text{ss}}\lambda^k_{d,\text{ss}}}, \quad (35)$$

where $\lambda^k_{d,\text{ss}}$ is the steady-state shadow price of housing capital (i.e. the Lagrange multiplier associated with housing capital from the household's

[8] Equation (34) is obtained by looking at the steady-state relationship implied by Equation (32).

FIGURE 2
Factor Market: Housing Capital. Note: Steady-state supply and demand schedules for the housing factor market when the housing stock is included in the utility function and when it is not. [Colour figure can be viewed at wileyonlinelibrary.com]



constrained optimisation problem).[9] Equation (35) implies an upward-sloping relationship (gross steady-state productivity growth is assumed greater than 1 and habit persistence is less than 1), which is depicted in Figure 2. Intuitively, the supply curve slopes upwards because capital in the utility function is subject to diminishing returns. To offset the diminishing utility of larger holdings of capital, a higher rate of return is required. Despite diminishing returns in marginal utility, the steady-state rate of return of housing capital is lower for this calibration, while the steady-state level of housing is higher (point B instead of point A in Figure 2) because of the added utility benefit. This higher steady-state level of housing is a robust feature of the model, which helps it to match the data in steady state, where housing capital makes up a much larger share of the total capital stock than is justified by returns when housing is not included in the utility function.

The differences in the supply curves imply different responses of housing investment to changes in steady-state real interest rates. Figure 3 shows the predicted change in the capital stock for a decrease in the real interest rate due to an increase in the household discount factor on the left, and investment as a function the real interest rate on the right. A fall in the steady-state real interest rate shifts the supply curve for the housing capital stock to the right. This shift results in a higher steady-state quantity of housing and pushes down the rate of return. Due to the different curvatures of the supply schedules, and the different initial conditions, the increase in housing is much larger in the case where the housing stock is included in the utility function, while the effect on the return is smaller (with the economy moving from point B to B′ in Figure 3 instead of from point A to A′). Therefore, *ceteris paribus*, the same fall in interest rates generates a larger investment response when the housing stock is included in the household utility function, compared to the case when it is not included.

III. Estimation

We apply the model to the data using a mix of calibration and estimation. Komunjer and Ng (2011) show that not all parameters of medium- and large-scale DSGE models are identified. Therefore, we choose to calibrate parameters in the model that are known to be weakly identified and those which are most important for determining the steady state of the model. We estimate the remaining parameters that mostly govern dynamics using standard Bayesian techniques.[10]

Data

We estimate the model using 26 macroeconomic data series. Of these, 22 series are Australia-specific. The series and their sources are reported in Appendix A. To capture the housing sector, we consider four measures of activity: housing sector value added; the housing-related components of the CPI; a housing sector wage index; and dwelling investment. We use data from the March quarter of 1992 to the December quarter of 2016 for all series but the wage price indices, which are only available starting in the December quarter of 1997. We supplement these data with information on import volumes, public demand and capital stocks to calibrate the steady state of the model.[11]

[9] Equation (35) is obtained by looking at the steady state implied by Equation (33).

[10] We take a first-order approximation of the households' and firms' first-order conditions, and the capital accumulation equations around their respective steady states. We then use the software package Dynare (Adjemian, Bastani, Juillard, Mihoubi, Perendia, Ratto, and Villemot, 2011) to solve for the rational expectations solution of the model and to estimate parameters. The Dynare's manual can be found here: https://www.dynare.org/manual/

[11] The world economy is summarised by major trading partner (MTP) GDP growth, the trade-weighted MTP inflation rate, the average interest rate in the G3 (United States, euro area, and Japan), and price growth in world commodity prices. The world economy is assumed to be exogenous to Australia and is estimated separately as in Kulish and Rees (2011).

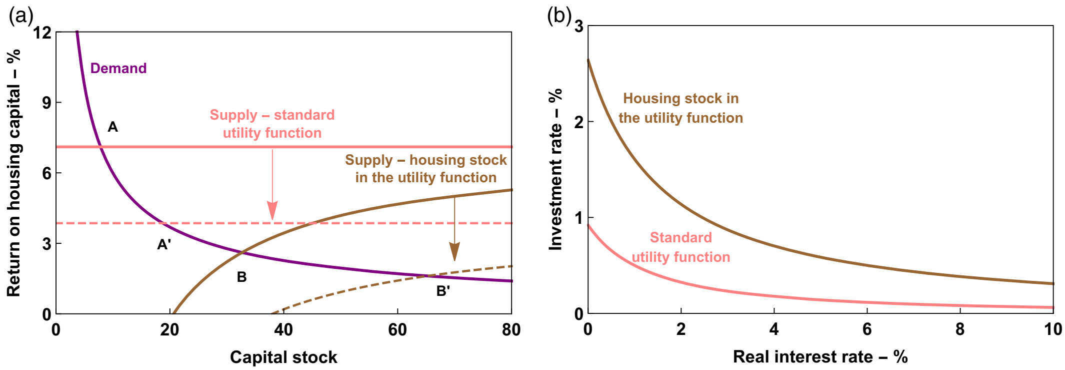


FIGURE 3
Housing Capital Investment Response to a Fall in the Real Interest Rate. Notes: The effect of a fall in the steady-state real interest rate on the housing capital factor market (left) and the relationship between the steady-state real interest rate and housing investment (right). The calibrated parameters for this exercise are $\beta = 0.95$ ($\beta = 0.98$), $\mu = 1.008$, $b_d = 0.15$, $A_d = 0.3$, and $\lambda_d = 1$. [Colour figure can be viewed at wileyonlinelibrary.com]

Calibrated Parameters

Table 1 shows the values chosen for the calibrated parameters of the model. The key calibrated parameters are labour-augmenting productivity growth, the discount factor, parameters of the various sector production functions, the elasticities of substitution between goods, and the consumption shares of the different sectors. These parameter choices follow RSH where possible. The production function parameters are chosen to reflect sectoral income shares observed in the data. We make some minor adjustments to the parameters to hit the steady-state targets.[12]

Table 2 shows the steady-state targets and the model-implied values given the chosen parameters. The model matches the data reasonably well. It does a particularly good job of matching the housing-related quantities, especially the housing capital stock's average proportion of the overall capital stock. To reiterate the role that our preference specification plays, if the assumption that the housing stock is in the utility function is removed, but the same calibration is used, the housing share of the capital stock falls by around 10 percentage points. In other words, housing capital is held in quantities that are not justified by its model-implied returns without this extra assumption, which again reflects the fact that housing capital has special treatment under the law and is held for different reasons by households than other types of capital.

We also include a number of calibrated reconciliation/measurement error terms. Because we use chain volume measures for GDP growth and for the growth in value added in each of the intermediate sectors, the components are additive in levels in the model but are not additive in the data. Similarly, we use trimmed-mean CPI inflation, but headline measures of sectoral inflation. Therefore, to account for these and any other differences between the data and their model counterparts, we include a white noise measurement error term for each observable series, apart from: the nominal and real exchange rates; commodity prices; domestic interest rates; and foreign and domestic aggregate inflation and GDP.[13] The errors are

[12] Unless otherwise noted, we use the same calibrated parameters in the foreign economy as in the domestic economy. For example, the discount rate β is set to the same value in both economies. β is calibrated to $\mu \times \pi \times \left(\frac{1}{1.06}\right)^{1/4}$, where 1.06 corresponds to a 6 per cent nominal steady-state interest rate.

[13] As we include errors in the inflation and GDP components, we do not include them in the aggregates.

Table 1
Calibrated Parameters

Parameter	Description	Value
Technology and policy		
μ	Steady-state labour-augmenting productivity growth	1.008
π	Steady-state inflation rate	1.0062
π^*	Steady-state foreign inflation rate	1.005
ι	Risk premium scale parameter	0.0001
b^x	Controls steady-state trade deficit	0.25
g	Controls share of public demand in GDP	0.6487
Households		
β	Households' discount factor	0.9996
ω_n	Controls share of non-tradeables in domestic final demand	0.397
ω_m	Controls share of non-resource tradeables in domestic final demand	0.1118
ω_d	Controls share of housing in domestic final demand	0.2447
ω_f	Controls share of imports in domestic final demand	0.2465
ζ	Intersectoral elasticity of substitution in domestic final demand	0.8
ξ	Elasticity of substitution between domestic and foreign goods overseas	0.8
η	Labour elasticity	1
σ	Intersectoral labour supply elasticity	1
A_H	Normalising constant for labour in the utility function	4.4177
A_d	Normalising constant for capital in the utility function	0.3
Non-tradeable sector		
α_n	Labour share	0.71
γ_n	Capital share	0.24
θ^{π_n}	Elasticity of substitution between differentiated goods	6
θ^{w_n}	Elasticity of substitution between differentiated labour	0.25
δ_n	Depreciation rate	0.0047
Non-resource tradeable sector		
α_m	Labour share	0.62
γ_m	Capital share	0.32
θ^{π_m}	Elasticity of substitution between differentiated goods	6
θ^{w_m}	Elasticity of substitution between differentiated labour	0.25
δ_m	Depreciation rate	0.0075
ω_m^*	Controls share of non-resource tradeables that are exported	0.6541
Resource sector		
α_z	Labour share	0.2
α_L	Land share	0.5
δ_z	Depreciation rate	0.007
$-p_z^*$	Steady-state foreign-denominated resource price	1
Housing sector		
α_d	Labour share	0.32
γ_d	Capital share	0.64
θ^{π_d}	Elasticity of substitution between differentiated goods	6
θ^{w_d}	Elasticity of substitution between differentiated labour	0.25
δ_d	Depreciation rate	0.0023
Import sector		
θ^f	Elasticity of substitution between differentiated goods	6

Notes: Calibrated parameter values of the multi-sector model. Calibration choices follow RSH where possible. The remaining parameters are set using sectoral data or to hit aggregate targets.

TABLE 2
Calibrated steady-state targets

Variable	Average 1993-2016	Model prediction
Expenditure as a share of GDP		
Consumption	56.9	55.8
Private investment	21.3	22.5
Pubic demand	22.7	22.5
Production as a share of nominal GVA†		
Non-tradeable	47.5	46.2
Tradeable	25.3	24.2
Resource	12.3	11.6
Housing	15.7	18.0
Trade		
Import share of GDP	20.6	20.6
Export share of GDP	19.5	19.6
Resource share of export value	43.4	37.2
Investment as a share of total investment†		
Non-tradeable	29.8	33.4
Tradeable	23.0	23.8
Resource	17.1	15.1
Housing	30.0	27.6
Capital stock		
Housing share of capital stock	37.6	34.1

†Based on the broad definition of resource sector discussed in Rayner and Bishop (2008). Comparison of the model steady states with aggregate targets.

calibrated to be 10 per cent of the observed variance of the variables following RSH. We do not impose any structure on the correlation of these shocks with one another.[14]

Estimated parameters

Table 3 shows the estimated parameter values for the world economy obtained in the first stage of estimation.[15] The parameter estimates are in line with those obtained in the existing literature for estimation on US data, such as An and Schorfheide (2007) or Smets and Wouters (2007). In particular, the Taylor rule coefficients fall within standard ranges found in the literature, the world Phillips curve is estimated to be relatively flat, and output shocks tend to be much larger than inflation shocks.

Tables 4 and 5 show the estimated parameter values for the Australian economy. The estimates of the monetary policy rule are similar to those for the world economy and those from RSH. Australian monetary policy responds aggressively to deviations in inflation from target, and less so to changes in real output. Consistent with RSH, there is no evidence that monetary policy responds to changes in the real exchange rate.

There is evidence of habit persistence in both the consumption of goods and in the holding of the housing stock. The persistence in the housing capital stock indicates whether the additional housing in the utility assumptions is relevant for explaining housing investment dynamics. The parameter estimated for b_d is small, which partly reflects the prior, but it does imply that some additional persistence in housing investment is at least not contradicted by the data. Our priors are informed by earlier studies that have found that housing investment is more sensitive than other sectoral investment is to monetary policy shocks (e.g. Lawson & Rees, 2008).[16]

As in RSH, rather than estimating the price adjustment costs, about which we have no strong

[14] We have tried a number of different measurement error specifications, including moving average unit root processes for key aggregate and foreign variables, white noise errors included on all observables, and the removal of all such error terms from the model. At a minimum, some error terms must be included in the sector-specific level variables in order for the model to be estimated because of the non-additivity of chain volume measures and definitional incongruences between sectoral observables and their model counterparts. However, we find that the precise specification of these terms does not have a significant impact on the inference of estimated parameters once some error is included at the sectoral level. Therefore, we chose the most parsimonious specification. See Liu, Pagan, and Robinson (2018) for in-depth discussion of the issues that measurement error brings to multi-sector models.

[15] To estimate, we choose informative prior distributions for most of the model parameters of interest and use the Metropolis--Hastings algorithm to take draws from the implied joint posterior distributions. We set the world economy parameters to the mean values of the posterior distribution. For estimation, we take 100,000 draws of the posterior distribution and discard the first 20,000. We run multiple chains and assess convergence using the Brooks and Gelman (1998) method included in Dynare. Graphical evidence suggests the number of draws is sufficient to ensure convergence. We obtain an acceptance rate of about 30 per cent.

[16] We do not estimate separate adjustment cost parameters for the non-tradeable, non-resource tradeable and resources sectors because separate investment series for each are not readily available.

TABLE 3
Parameter Estimates: Foreign Block

Parameter	Prior distributions			Posterior distributions			
	Shape	Mean	Std dev.	Mode	Mean	5th %ile	95th %ile
ρ_{ξ^*}	Beta	0.50	0.15	0.94	0.94	0.91	0.97
ρ_{e^*}	Beta	0.50	0.15	0.55	0.53	0.34	0.71
ρ_{r^*}	Beta	0.75	0.10	0.83	0.82	0.77	0.87
ρ_{μ}	Beta	0.40	0.20	0.30	0.33	0.05	0.61
ϕ_{π^*}	Normal	1.50	0.20	1.37	1.41	1.17	1.63
ϕ_{dy^*}	Normal	0.13	0.05	0.23	0.23	0.15	0.30
$\rho_{p_z^*}$	Beta	0.50	0.15	0.94	0.94	0.91	0.97
θ_{zy}	Normal	0.00	0.20	0.12	0.12	−0.19	0.46
χ^*	Beta	0.30	0.15	0.23	0.27	0.09	0.46
κ^*	Gamma	1.00	0.80	0.97	1.52	0.42	2.63
Standard deviations (×100)							
$\sigma_{p_z^*}$	Gamma	0.50	0.40	6.22	6.31	5.59	7.04
σ_{v^*}	Gamma	0.50	0.40	0.97	1.00	0.73	1.30
σ_{r^*}	Gamma	0.50	0.40	0.08	0.08	0.06	0.10
σ_{π^*}	Gamma	0.50	0.40	0.06	0.06	0.05	0.08
σ_{μ}	Gamma	0.50	0.40	0.06	0.13	0.01	0.24

Note: The world economy is assumed to be exogenous to Australia and is estimated separately as in Kulish and Rees (2011).

prior beliefs, we directly estimate the slopes of the Phillips curves. Each slope is just a monotonic transformation of the adjustment cost parameters.[17] However, we use different priors than those used in RSH. We use priors based on micro evidence from Sutton (2017). The estimated slopes reveal much flatter Phillips curve relationships in the housing and non-tradeable sectors than in the non-resource tradeable sector, while the degree of indexation to lagged inflation in these two sectors is higher. In terms of the model, this is consistent with a higher cost to adjusting prices and much higher persistence in prices in these sectors, which, as we will see, plays a significant role in housing investment's response to commodity price changes. We apply the same estimation strategy to the wage Phillips curves, though we use uninformative priors. The slopes of the wage Phillips curves are roughly the same across the sectors and are relatively flat in all cases. The degree of indexation is also similar across industries, revealing no significant differences in wage setting across the intermediate industries.

[17] Specifically: $\kappa_j = \frac{100(\theta^j - 1)}{\tau_j(1+\chi_j\beta)}$ for $j \in \{\pi_n, \pi_m, \pi_z, \pi_d, w_n, w_m, w_z, w_d\}$.

The estimated shock processes all exhibit moderate to high persistence, which is common in these models. There are also a few persistence parameters that appear not to be well identified. For example, the data do not add much to the priors on the autoregressive coefficient on either the housing stock preference shock or the labour supply shock. But we do not find that the model relies on these shocks to explain much of the variation in the data.

Model Fit

To assess the model fit, we turn to an out-of-sample recursive forecasting exercise. We focus on the model's ability to capture movements in the housing sector and for four key macroeconomic variables: real GDP growth, consumption growth, investment growth, and inflation. We begin out-of-sample forecasting in the fourth quarter of 2001 and advance forward with an expanding window up to the fourth quarter of 2016. We re-estimate the model parameters annually in line with the practices of the model's actual use at the RBA.

For general comparisons of the forecasts, we use a simple univariate AR(1) model that is re-estimated every period on the data series of interest. An AR(1) model is typically very hard to

Table 4
Parameter Estimates: Domestic Block

Parameter	Prior distributions: Shape	Prior: Mean	Prior: Std dev.	Posterior distributions: Mode	Posterior: Mean	Posterior: 5th %ile	Posterior: 95th %ile
Habit persistence and investment adjustment costs							
b	Beta	0.50	0.20	0.90	0.90	0.85	0.94
b_d	Beta	0.20	0.10	0.19	0.22	0.04	0.40
Φ_d	Normal	3.00	1.50	3.36	3.73	2.35	5.16
$\Phi_{n,m,z}$	Normal	20.00	2.50	10.76	11.21	7.15	14.91
Monetary policy and UIP							
ρ_r	Beta	0.90	0.03	0.86	0.86	0.83	0.88
ϕ_π	Normal	1.50	0.10	1.54	1.55	1.40	1.71
ϕ_{dy}	Normal	0.20	0.03	0.21	0.21	0.17	0.26
ϕ_q	Normal	0.00	0.05	0.00	0.00	−0.03	0.03
Θ_Ψ	Beta	0.50	0.15	0.07	0.08	0.03	0.13
Sector Phillips curves							
κ_{π_n}	Gamma	8.00	2.00	2.93	3.39	1.82	4.76
κ_{π_m}	Gamma	10.00	2.50	9.15	9.21	5.40	13.43
$\kappa_{\pi_m^*}$	Gamma	10.00	2.50	4.74	5.16	3.04	7.16
κ_{π_d}	Gamma	1.00	0.30	0.13	0.16	0.09	0.24
κ_{π_f}	Gamma	10.00	2.50	2.04	2.19	1.37	2.92
χ_n	Beta	0.30	0.15	0.28	0.29	0.11	0.45
χ_m	Beta	0.30	0.15	0.16	0.19	0.04	0.33
χ_m^*	Beta	0.30	0.15	0.08	0.12	0.02	0.21
χ_d	Beta	0.30	0.15	0.63	0.61	0.45	0.76
χ_f	Beta	0.30	0.15	0.15	0.19	0.04	0.32

Parameter	Prior distributions: Shape	Prior: Mean	Prior: Std dev.	Posterior distributions: Mode	Posterior: Mean	Posterior: 5th %ile	Posterior: 95th %ile
Sector wage Phillips curves							
κ_{w_n}	Gamma	50.00	30.00	0.15	0.20	0.09	0.31
κ_{w_m}	Gamma	50.00	30.00	0.11	0.15	0.07	0.23
κ_{w_z}	Gamma	50.00	30.00	0.12	0.14	0.07	0.20
κ_{w_d}	Gamma	50.00	30.00	0.16	0.20	0.11	0.28
χ_{w_n}	Beta	0.30	0.15	0.11	0.16	0.02	0.29
χ_{w_m}	Beta	0.30	0.15	0.20	0.24	0.08	0.39
χ_{w_z}	Beta	0.30	0.15	0.27	0.29	0.11	0.46
χ_{w_d}	Beta	0.30	0.15	0.10	0.12	0.02	0.22
Shock persistence							
ρ_g	Beta	0.5	0.2	0.75	0.69	0.46	0.93
ρ_{ξ_c}	Beta	0.5	0.2	0.55	0.55	0.36	0.75
ρ_{ξ_H}	Beta	0.5	0.2	0.92	0.9	0.84	0.97
$\rho_{\xi K_d}$	Beta	0.5	0.2	0.5	0.52	0.19	0.84
ρ_Γ	Beta	0.5	0.2	0.55	0.52	0.38	0.66
ρ_{Γ_d}	Beta	0.5	0.2	0.6	0.57	0.42	0.73
ρ_Φ	Beta	0.5	0.08	0.78	0.77	0.72	0.81
ρ_{a_n}	Beta	0.5	0.2	0.75	0.73	0.63	0.83
ρ_{a_m}	Beta	0.5	0.2	0.98	0.95	0.91	1
ρ_{a_z}	Beta	0.5	0.2	0.93	0.92	0.85	0.98
ρ_{a_d}	Beta	0.5	0.2	0.75	0.71	0.62	0.81

Notes: Parameter estimates for the domestic sectors and policy rules of the small open economy. We set the world economy parameters to the mean values of the posterior distribution for estimation. We do not estimate separate adjustment cost parameters for the non-tradeable, non-resource tradeable and resources sectors as separate investment series for each are not readily available.

TABLE 5
Parameter Estimates: Domestic Block Shocks

Parameter	Prior distributions			Posterior distributions			
	Shape	Mean	Std dev.	Mode	Mean	5th %ile	95th %ile
Policy and preferences (×100)							
σ_g	Gamma	1.00	0.80	1.24	1.23	1.04	1.42
σ_{ξ_C}	Gamma	1.00	0.80	4.37	4.56	2.80	6.05
σ_{ξ_H}	Gamma	1.00	0.80	6.01	5.84	3.57	8.20
$\sigma_{\xi K_d}$	Gamma	1.00	0.80	0.36	1.04	0.02	2.16
σ_r	Gamma	0.15	0.10	0.11	0.11	0.10	0.13
σ_Ψ	Gamma	0.50	0.40	0.92	0.99	0.74	1.23
Production (×100)							
σ_Γ	Gamma	2.00	1.50	17.49	19.08	12.95	25.50
σ_{Γ_d}	Gamma	2.00	1.50	6.74	7.84	4.14	11.26
σ_{a_n}	Gamma	1.00	0.80	1.41	1.40	1.20	1.60
σ_{a_m}	Gamma	1.00	0.80	0.57	0.70	0.42	0.98
σ_{a_z}	Gamma	1.00	0.80	1.84	1.87	1.63	2.10
σ_{a_d}	Gamma	1.00	0.80	3.76	3.77	3.23	4.24
Price and wage inflation (×100)							
σ_{π_n}	Gamma	0.50	0.40	0.35	0.36	0.29	0.42
σ_{π_m}	Gamma	0.50	0.40	0.54	0.54	0.44	0.63
$\sigma_{\pi_m^*}$	Gamma	0.50	0.40	2.60	2.62	2.26	3.02
σ_{π_d}	Gamma	0.50	0.40	0.18	0.19	0.16	0.23
σ_{π_f}	Gamma	0.50	0.40	1.12	0.98	0.85	1.17
σ_{w_n}	Gamma	0.15	0.10	0.05	0.05	0.02	0.07
σ_{w_m}	Gamma	0.15	0.10	0.10	0.10	0.08	0.12
σ_{w_z}	Gamma	0.15	0.10	0.19	0.19	0.15	0.24
σ_{w_d}	Gamma	0.15	0.10	0.21	0.22	0.18	0.26

Notes: Estimates of the standard deviations of the exogenous domestic shock processes. We set the world economy parameters to the mean values of the posterior distribution for estimation.

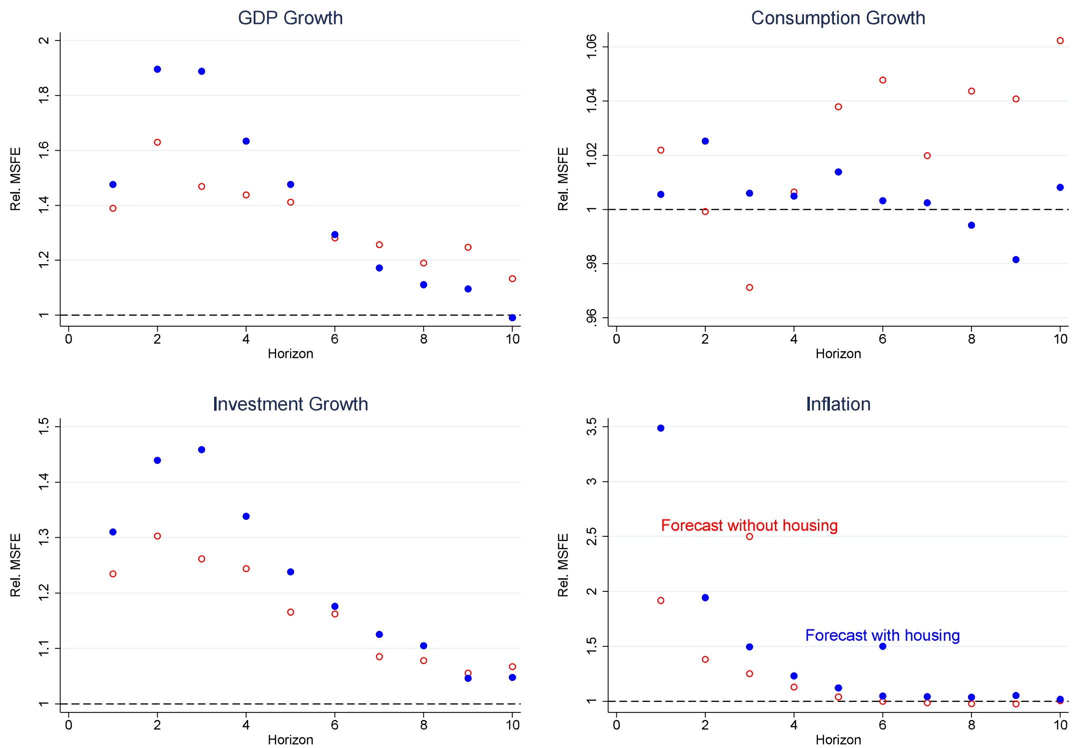
beat, especially in short samples, where larger models tend to overfit the data leading to poor out-of-sample forecast accuracy. Estimating the model every period sets the bar even higher. For the main macro variables, we also compare the model to a version of RSH that includes our sticky wage specification, inflation indexation, and the same foreign economy as the model with housing. This provides a fair horse race between the model with housing and the model without.

Figure 4 shows the mean squared forecast errors of the model with and without housing relative to the AR(1) forecasts for forecasts between one and ten quarters ahead. With the exception of consumption growth, the DSGE models perform worse than the AR(1) model at short horizons and roughly the same at longer horizons. Likewise, the model without housing does better at short horizons but worse at long horizons relative to the model with housing. These forecasting results are in line with the findings in the DSGE forecasting literature (e.g. Del Negro & Schorfheide, 2013). Time series models provide superior forecasts at short horizons but the DSGE performs better at long horizons since it incorporates policy responses and requires that long-run accounting identities must hold. The slightly worse forecasting performance of the larger model with housing is not so surprising since the model is larger, which increases the likelihood of overfitting in short samples. In fact, we find that the poor out-of-sample forecasting performance is largely driven by the early period in the sample, especially with the inflation results. The models are comparable at all horizons post 2008.

Figure 5 shows the results for housing-specific variables. For the real variables, we see a similar pattern to the economy-wide variables with forecast accuracy improving relative to an AR(1) model as the forecast horizon increases. For the nominal variables, though, we see the opposite.

FIGURE 4

Out-of-Sample Forecast Comparison. Note: Out-of-sample comparison of mean squared forecast error (MSFE) for the model with housing to the model without housing displayed relative the MSFE of an AR(1) model forecast. [Colour figure can be viewed at wileyonlinelibrary.com]



Forecast accuracy is greatest at the short horizons. To give a sense of how the forecasts compare with the actual data, Figure 6 shows the one-quarter-ahead model forecasts compared to the actual data. We take from this exercise that the model does a reasonable job of capturing housing sector and aggregate dynamics in that its performance is comparable with what is found with similar models used throughout the literature for this type of analysis.

IV. *Transmission of Shocks*

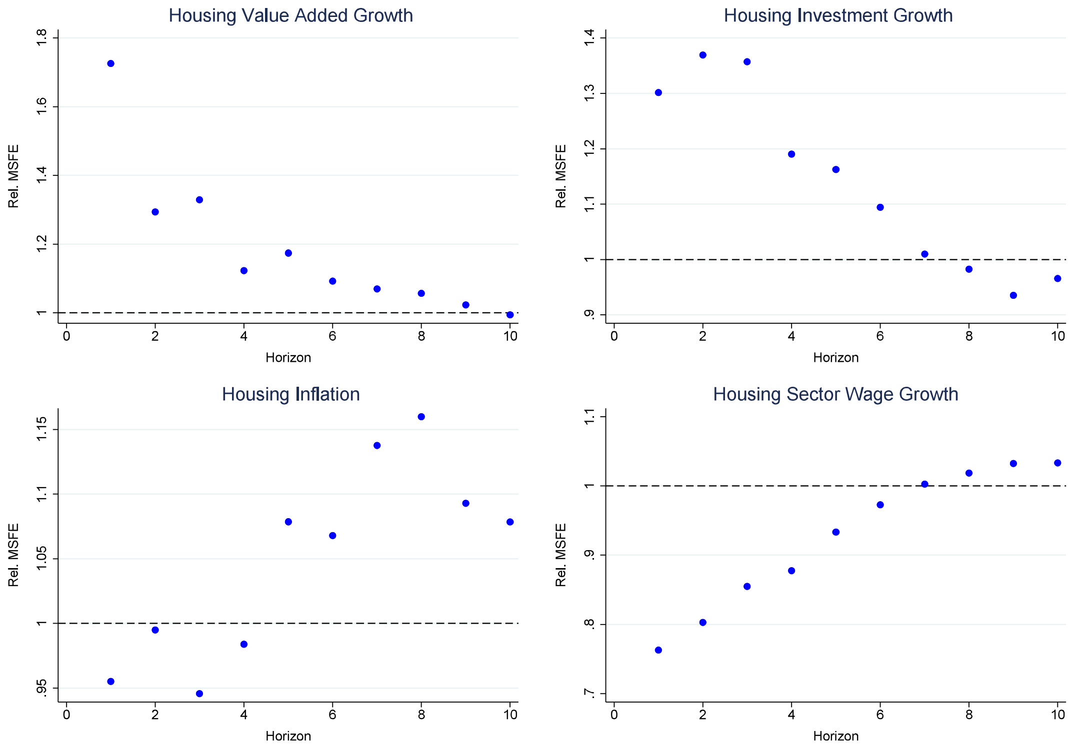
To quantify the role that the housing sector plays in transmitting shocks through the economy, we compare the implied co-movements of macro variables to estimated shocks originating from the housing market in the model to those reported by Iacoviello and Neri (2010) and Liu, Wang, and Zha (2013). We then compare the implied variance decomposition of the model with housing to the modified RSH model of the previous section. Finally, we explore the propagation of the key shocks in the model to highlight the role that housing plays in macroeconomic dynamics in Australia.

Housing as an Exogenous Source of Shocks

There are three main stylized macroeconomic co-movements that come out of the spender–saver DSGE housing literature that we want our model to match. The first is a positive correlation between housing investment and consumption in response to housing preference shocks. Iacoviello and Neri (2010) show that in the absence of constrained mortgaged indebted households their model predicts a counterfactual negative correlation between these two variables. In our model, households are always unconstrained, so it is

FIGURE 5

Forecast Comparison for Housing Sector Variables. Note: Out-of-sample comparison of mean squared forecast error (MSFE) for the model with housing displayed relative the MSFE of an AR(1) model forecast for different horizons. [Colour figure can be viewed at wileyonlinelibrary.com]

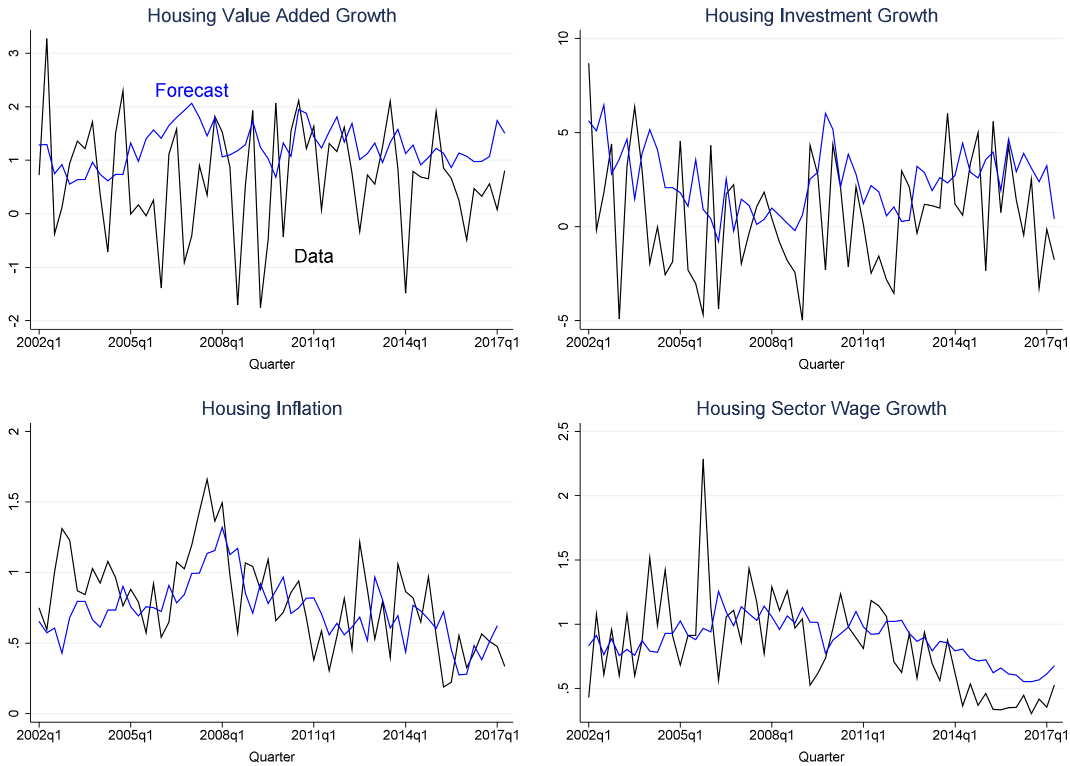


important that the model predicts the positive relationship found in the data. The second is that there is a further positive correlation between consumption and investment in non-housing sectors with respect to housing preference shocks. The latter relationship is not present in Iacoviello and Neri but is argued to be necessary to match US- data during the housing bust by Liu, Wang, and Zha (2013) and which we want our model to match. The final relationship is a positive correlation among non-housing investment and consumption in response to housing sector productivity shocks. Housing productivity shocks make housing services less expensive and free up resources to be used in other sectors, which should generate a positive relationship among non-housing investment and consumption.

Figure 7 shows the response to a housing preference shock that is scaled to produce a 5 per cent increase in housing investment. Consumption and investment have a delayed response that hovers around zero before both turn positive. The overall correlation in the responses is positive across the three variables, which is consistent with the first and second stylised facts. Looking at consumption, the median response to the housing preference shock is strictly positive, which is consistent with the collateral constraints case of iacoviello2010housing. The response of investment ex-housing, though, is only weakly consistent with the second stylised fact at a short horizon.

The second row of plots in Figure 7 show the response of GDP, inflation, consumption, and investment ex-housing to a positive housing productivity shock that raises housing sector value added by 5 per cent. The shock causes consumption and investment ex-housing to rise

FIGURE 6
Forecast Comparison for Housing Sector Variables to Data. Note: Out-of-sample comparison of the one-quarter horizon forecasts from the model with housing to the actual data. [Colour figure can be viewed at wileyonlinelibrary.com]



and it is mildly deflationary, which is consistent with the third stylised fact.

Variance Decomposition

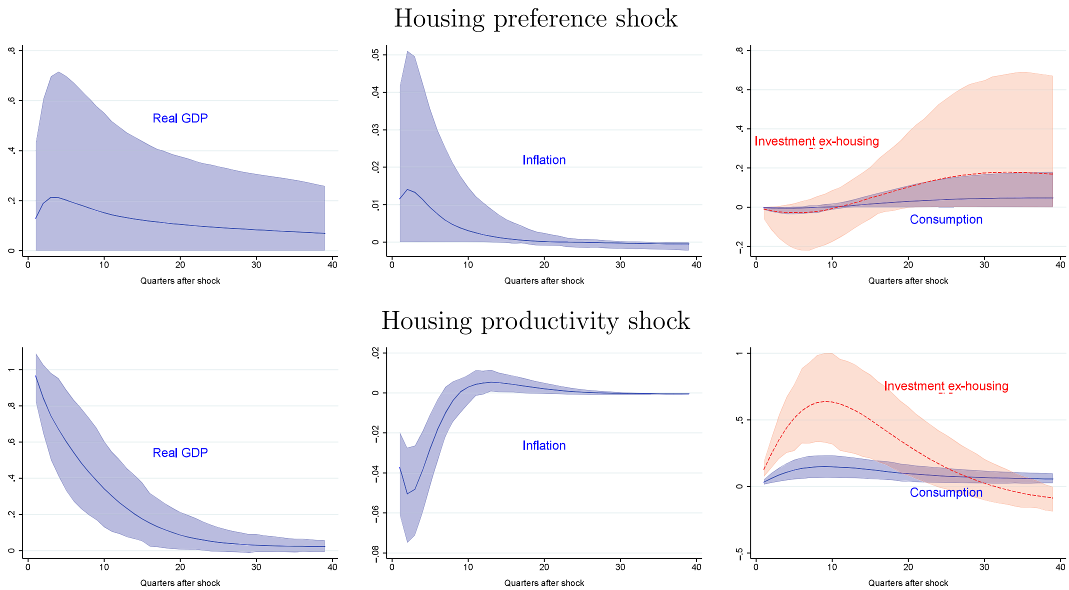
Table 6 reports the variance decomposition for key macro aggregates and sector-specific investment using the RSH model and the model with housing. We aggregate the shocks into foreign and domestic categories and highlight the roles played by three key shocks that are relevant to either commodity prices or housing investment: monetary policy, commodity price shock (commodities), and the risk premium shock (forex) that effectively acts as an exogenous driver of the real exchange rate.

The variance decomposition of the two estimated models reveals that they provide very different interpretations of the key drivers of many macroeconomic variables. For real variables, the model with housing predicts that much more of the variation in the data is explained by domestic shocks rather than foreign shocks. In particular, consumption in the model without housing is largely driven by the commodity price shock, whereas in the model with housing it is largely driven by domestic factors. For the nominal variables, the two models attribute roughly the same split in variation to domestic and foreign shocks. However, foreign exchange movements are much more important in the model with housing than in the model without.

The housing-sector-specific shocks in general do not play an outsized role in driving macroeconomic fluctuations. The proportion of variation in aggregate variables that is ascribed to these shocks is generally less than their sector weights in the economy. For example, as noted

FIGURE 7

Housing Sector Shocks. Note: Bayesian impulse responses to a housing preference shock that raises housing investment by 5% in the first row and a housing productivity shock that raises housing value added by 5% in the second row. [Colour figure can be viewed at wileyonlinelibrary.com]



previously, housing services account for about 23 per cent of CPI inflation but housing shocks only explain 14 per cent of the variation of inflation. Overall, our findings are surprisingly close to those reported by Iacoviello and Neri (2010) for the USA for investment and consumption. But our results differ substantially for inflation. In particular, they find that housing-related shocks explain about 50 per cent of housing investment and 1.3 per cent of consumption, compared to 51.4 per cent and 6.6 per cent in our model. For inflation, though, housing shocks explain less than 1 per cent in their model but 14 per cent in ours. We believe this result reflects the difference in the definition of inflation in their model compared to ours with respect to the contribution of housing services to economy-wide measures of inflation.

Housing as an Endogenous Propagator of Shocks

To explain why the models decompose the data differently, we turn to a comparison of impulse responses. Figure 8 compares the response of real GDP, inflation, investment and consumption in the RSH model to the model with housing for a 100 basis point contractionary monetary policy shock, a 10% commodity price shock, and a 10% appreciation of the real exchange rate. Monetary policy shocks largely affect macro aggregates in the same way in each model, with only a small increase in persistence observed in real variables in the housing model and a slightly muted response for inflation. Larger differences are observed for the real exchange rate shock especially with respect to consumption and investment, with again a more persistent response to the same impulse. But again, the differences between the two models are minor.

The most significant difference arises in the response to the commodity price shocks for investment and consumption. This difference is the principle reason why there is greater reliance on domestic shocks to explain domestic variables in the model with housing. To illustrate the mechanism, Figure 9 shows the sector investment response of the two models to the commodity price shock. In the RSH model, the commodity price shock *crowds in* investment in the non-traded sector, which leads to a large aggregate response. In contrast, with housing in the model a

TABLE 6
Variance Decomposition

	Model without housing					Model with housing					
	Domestic	Foreign	Monetary	Commodities	Forex	Domestic	Foreign	Monetary	Commodities	Forex	Housing sector
Aggregates											
Domestic final demand	59.5	40.5	2.2	33.5	1.4	81.5	18.5	2.0	7.6	2.9	18.7
Nominal GDP	31.3	68.7	2.0	59.3	5.0	61.5	38.5	2.0	30.3	6.7	13.7
GDP	89.9	10.1	4.1	3.8	2.3	92.5	7.5	2.5	2.5	2.9	18.7
Hours worked	79.8	20.2	5.0	10.0	4.8	83.2	16.9	4.0	6.6	9.8	15.0
Consumption	49.6	50.4	0.5	49.2	0.2	88.1	11.9	0.7	9.4	0.4	6.6
Aggregate investment	83.9	16.1	2.4	8.2	1.5	87.1	12.9	1.9	1.9	3.6	23.3
Cash rate	71.5	28.5	27.3	6.3	8.4	70.6	29.4	37.5	3.0	20.5	9.2
CPI inflation	61.8	38.2	6.2	2.6	8.0	56.9	43.1	4.1	2.7	35.4	14.0
Sector-Specific Investment											
Non-traded	75.0	25.0	2.0	15.9	1.7	92.0	8.0	0.8	2.3	1.0	2.7
Traded	71.5	28.5	2.1	22.2	1.2	94.0	6.0	0.8	3.6	0.7	2.9
Resource	33.9	66.1	1.0	61.6	1.0	64.8	35.2	0.7	32.8	0.6	4.4
Housing	–	–	–	–	–	87.9	12.1	0.7	5.0	3.0	51.4

Notes: Variance decompositions from the estimated model with and without housing. Contributions of foreign and domestic shocks are aggregated together and sum to 100 (rounding error may be present). The forex shock is the risk premium shock. The housing sector column also represent an aggregate of all housing shocks, which includes the housing preference, productivity, investment, and price and wage mark-up shocks.

positive commodity price shock *crowds out* housing investment as mining investment rises. The housing sector, therefore, acts as a buffer to these types of shocks. This means that the model with housing cannot rely on the large exogenous impulses coming from commodities prices over the sample of interest to explain domestic co-movements. Much more of the variation in consumption, for example, must be explained by domestic developments.[18]

V. *Commodity Prices and Housing Investment*

The macroeconomic responses to a commodity price shock provide a compelling narrative for why housing booms may follow commodity price booms. Prices in the housing sector remain elevated long after the positive commodity price shock dies out, which leaves housing services prices elevated while at the same time interest rates may be falling. Elevated prices and lower interest rates should generate a significant increase in housing investment.

In fact, if we focus solely on commodity prices, it is possible to generate housing investment dynamics that qualitatively and, to some extent, quantitatively match the dynamics observed in Australia over the last two decades. Figure 10 shows a scenario where commodity price shocks are used to generate a dramatic rise and fall in commodity prices on par with the actual boom experienced in Australia. We simulate a gradual increase in commodity prices, where the commodity price index increases by about 150 per cent above baseline over a period of 5 years, and gradually returns to its baseline level. The response of investment in mining and housing is plotted along with response of housing service prices and the interest rate. Consistent with Figure 1, the booms are offset, with the mining boom followed immediately by the housing boom. We note that the housing services price only falls slightly at the beginning of the boom and peaks well after mining investment has begun to decline. The peaks are offset by about 8 years, which lines up fairly well with the peak of Australian mining investment occurring sometime in 2010–11 followed by the peak housing investment sometime in 2017–18.

The figures also show the key mechanism that drives these dynamics, which is persistence in housing services inflation and, to a smaller extent, habit persistence in utility for the housing stock, which simply implies persistent housing investment in the model. If the indexation of housing services inflation is set to zero, then housing services prices and interest rates move together (dotted line). Therefore, instead of housing service prices rising as the cash rate falls at the end of the commodity price boom, they fall together, which almost eliminates any housing investment response. The other sectors of the economy exhibit far less persistence in inflation and are far less sensitive to movements in the interest rate, which means that they do not respond in nearly as dramatic a fashion in the wake of a commodity boom.

The persistence in housing service inflation that we found using our model, and which drives our conclusion, is also observed in less structured estimation exercises. For example, Saunders and Tulip (2019) find that rents and house prices are significantly explained by their own momentum in an analysis using a semi-structural econometric model. In fact, they note that rents are unusually easy to forecast due to their persistence.

Historical Decomposition of Housing Investment

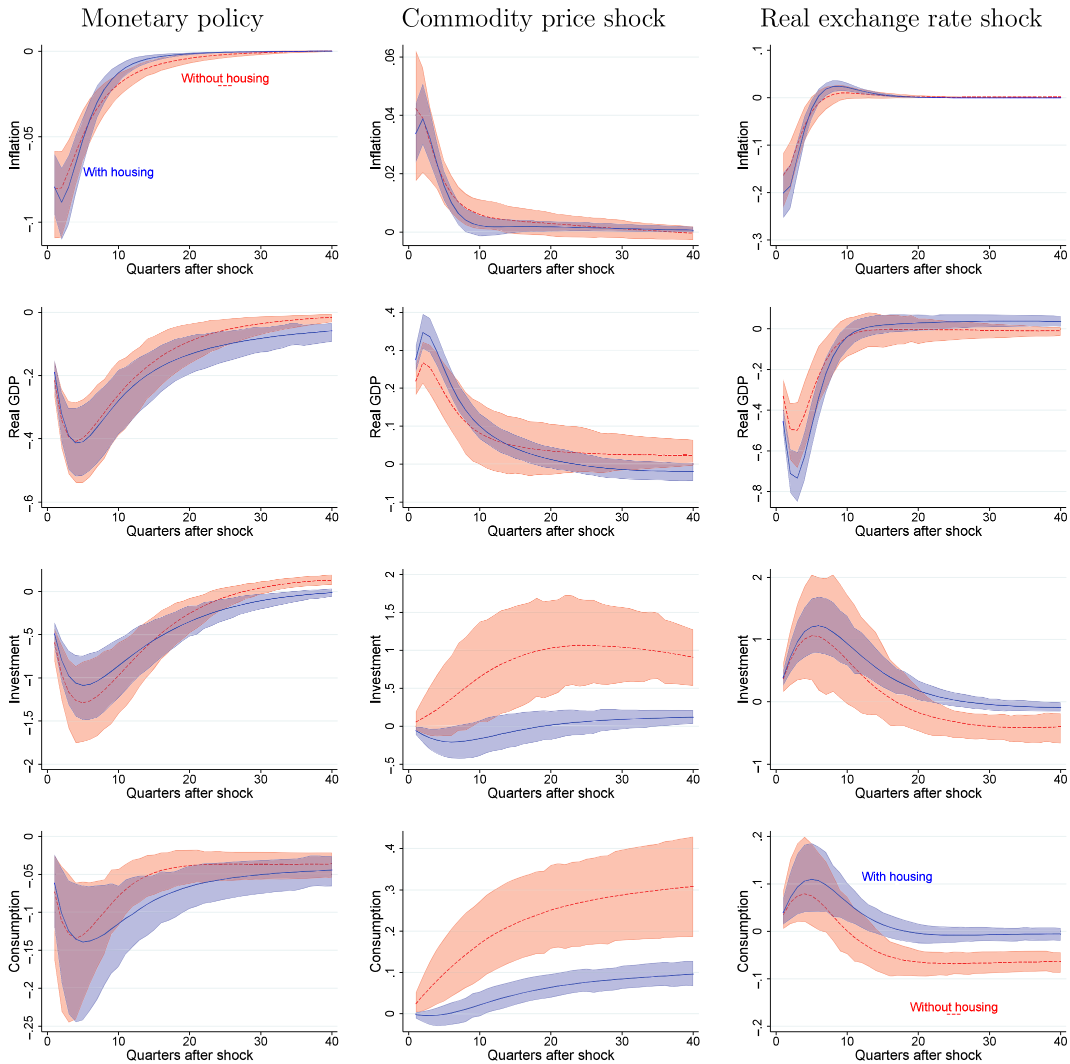
This relatively sensitive relationship between housing investment and foreign shocks is also clearly seen in the variance decomposition implied by the estimated model. Table 6 shows that housing investment is the second most foreign-affected investment series after the resource sector, with just over 12 per cent of its variance explained by foreign shocks. The largest foreign contributor to housing investment is the commodity price shock, which explains 5 per cent of housing investment variation overall.

Figure 11 shows the historical decomposition of housing investment for commodity price and monetary policy shocks over the last decade. As expected, the commodity price shocks consistently weighed on housing investment during the 2000s and continued to do so until the peak of the terms of trade in 2012. More recently, as

[18] The similar impact on GDP in the two models is explained by the different predicted behaviour for net exports. The value added in the resource sector rises by much more in the model with housing in response to commodity shocks. This causes GDP to rise even though consumption and investment do not respond as much in the model with housing. The slightly more persistent responses we see in the model with housing in real variables are also observed when structural vector autoregressions are estimated on sector data that include housing. Results on this finding are shown in Gibbs, Hambur, and Nodari (2018).

FIGURE 8

Transmission of Shocks. Note: Bayesian impulse responses to a 100 basis point monetary policy shock, a 10% increase in commodity prices, and a 10% appreciation of the real exchange rate. [Colour figure can be viewed at wileyonlinelibrary.com]



commodity prices have fallen, the opposite forces have been at work. Although, monetary policy shocks have consistently made positive contributions to housing investment since 2013, they are small compared to the contribution of commodity price shocks. This is also consistent with the relationship explored in the previous section because it implies that the fall in the interest rate is largely an endogenous response to the commodity price shocks.

Aside from commodity price and monetary policy shocks, the model suggests that housing investment shocks have weighed on housing investment over this period. That is, housing

FIGURE 9

Sector-Specific Investment Responses to Commodity Prices. Note: Bayesian impulse responses to a 10% increase in commodity prices for sector-specific investment. [Colour figure can be viewed at wileyonlinelibrary.com]

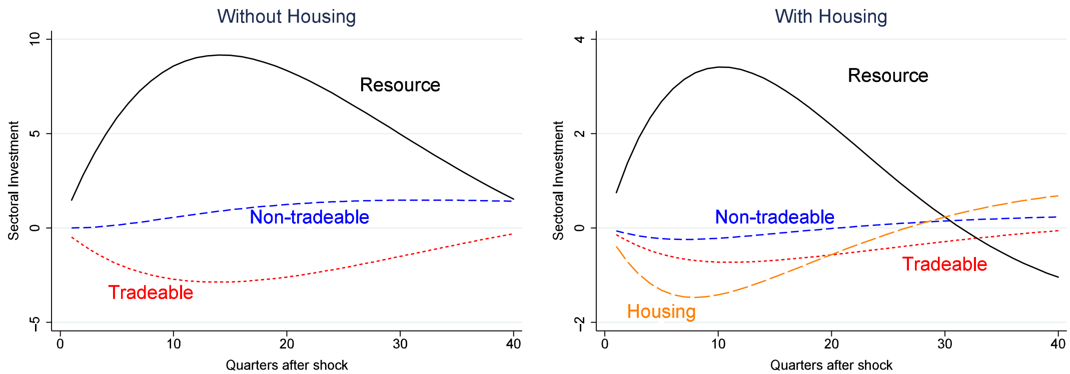
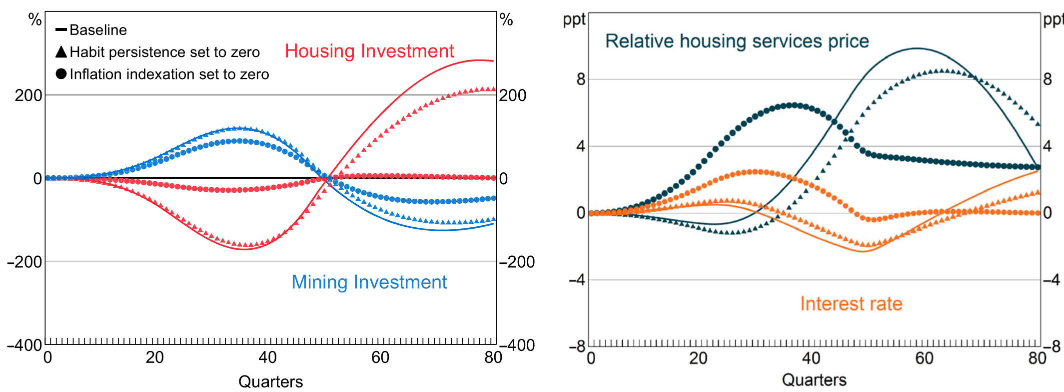


FIGURE 10

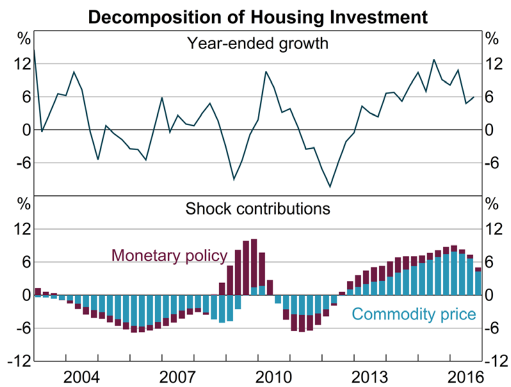
Housing Investment Booms. Notes: This figure shows the housing and mining sector investment responses (right) to a 150 per cent rise in global commodity prices over a five year period. Commodity prices return to the steady state by quarter 50 and remain there for the rest of the simulation. The figure on the left shows the response of housing service prices to the rise in commodity prices and the response of the cash rate. The baseline represents the estimated model with parameters set to their posterior mean. [Colour figure can be viewed at wileyonlinelibrary.com]



investment has been somewhat weaker than the model would predict given the prevailing macroeconomic conditions. Therefore, as opposed to domestic housing shocks acting as key driver of the housing boom as in studies such as Ferrero (2015), these shocks worked against the investment boom in Australia. Two potential explanations for this finding are capacity constraints in the housing construction industry and regulatory tightening in lending standards put in place as prices and investment significantly increased, which muted investment activity.

In Appendix D we use counterfactual scenarios to quantify what would have occurred if these constraints had been even more binding, and curtailed housing investment to continue to grow at its pre-mining boom average. We find under these assumptions that year-ended GDP growth is around one-half of a percentage point lower than when investment is allowed to endogenously respond to the commodity price shocks. Inflation, however, is only slightly lower as less investment removes housing supply from the market and supports prices. The large effect on GDP growth,

FIGURE 11
Historical Decomposition of Shocks. Note: Historical decomposition of the shocks using the estimated parameter values of the model given in Section III set to their posterior means. [Colour figure can be viewed at wileyonlinelibrary.com]



coupled with the stabilizing effects on inflation, underscores the unique role housing investment can play as a propagator of shocks to overall macroeconomic dynamics in Australia.

VI. *Conclusion*

Motivated by the recent increase in housing investment, we extend the DSGE model constructed by RSH to include a standalone housing sector. In doing so, we outline a simple way to incorporate a housing sector into a multi-sector DSGE model that has several appealing features, including its focus on modelling housing services (which have a large weight in GDP and the CPI basket). Moreover, we show that our extended model can qualitatively match a number of the predictions of more complicated models with lending and mortgage markets.

The estimated model shows that the housing sector is surprisingly responsive to foreign shocks. It is the sector most affected by external shocks after the resource sector in terms of investment. The model predicts that housing investment booms are an endogenous response to resource booms. Resource booms cause investment in housing to fall and housing sector prices to rise. The increases in prices are persistent and last well beyond the end of the resource boom. The end of the resource boom is accompanied by falling interest rates, which, in combination with higher housing sector prices, results in a significant increase in housing investment.

REFERENCES

Adjemian, S., Bastani, H., Juillard, M., Mihoubi, F., Perendia, G., Ratto, M. and Villemot, S. (2011): '*Dynare: Reference Manual, Version 4*,' Dynare Working Paper No. 1, CEPREMAP, Paris.

An, S. and Schorfheide, F. (2007), 'Bayesian Analysis of DSGE Models', *Econometric Reviews*, **26** (2–4), 113–72.

Brooks, S.P. and Gelman, A. (1998), 'General methods for monitoring convergence of iterative simulations', *Journal of Computational and Graphical Statistics*, **7**, 434–55.

Burgess, S., Fernandez-Corugedo, E., Groth, C., Harrison, R., Monti, F., Theodoridis, K. and Waldron, M. (2013), '*The Bank of England's Forecasting Platform: COMPASS, MAPS, EASE and the Suite of Models*,' Working Paper No. 471, Bank of England, London.

Corrigan, P. (2017), '*Terms-of-Trade and House Price Fluctuations: A Cross-Country Study*,' Staff Working Paper No. 2017–1, Bank of Canada, Ottawa.

d'Albis, H. and Iliopulos, E. (2013), 'Collateral constraints and rental markets', *Economics Letters*, **121**, 436–9.

Del Negro, M. and Schorfheide, F. (2013), in Elliott, G. and Timmermann, A.A. (eds), *"DSGE model-based forecasting," in Hand-book of Economic Forecasting*. **2A**. Elsevier, Amsterdam; 57–140.

Dvornak, N. and Kohler, M. (2007), 'Housing wealth, stock market wealth and consumption: a panel analysis for Australia', *Economic Record*, **83**, 117–30.

Ferrero, A. (2015), 'House price booms, current account deficits, and low interest rates', *Journal of Money, Credit and Banking*, **47** (S1), 261–93.

Fox, R. and Finlay, R. (2012), 'Dwelling prices and household income,' *Reserve Bank of Australia Bulletin*, (December), 13–22.

Geng, N., Henn, C. and Zhang, Y.S. (2017), 'Are house prices overvalued in Norway?' in '*Norway: Selected Issues*', IMF Country Report No. 17/181, International Monetary Fund, Washington, DC; 4–15.

Gibbs, C.G., Hambur, J. and Nodari, G. (2018), *'DSGE Reno: Adding a Housing Block to a Small Open Economy Model*,' Research Discussion Paper RDP 2018–04. Reserve Bank of Australia, Sydney.

Gillitzer, C. and Wang, J.C. (2016), 'Housing Wealth Effects: Cross-sectional Evidence from New Vehicle Registrations', *Economic Record*, **92**, 30–51.

Iacoviello, M. (2005), 'House prices, borrowing constraints, and monetary policy in the business cycle', *American Economic Review*, **95**, 739–64.

Iacoviello, M. and Neri, S. (2010), 'Housing market spillovers: evidence from an estimated DSGE model', *American Economic Journal: Macroeconomics*, **2**, 125–64.

Kaplan, G., Mitman, K. and Violante, G.L. (2017), '*The housing boom and bust: Model meets evidence*,' NBER Working Paper No. 23694, National Bureau of Economic Research, Cambridge, MA.

Komunjer, I. and Ng, S. (2011), 'Dynamic identification of dynamic stochastic general equilibrium models', *Econometrica*, **79**, 1995–2032.
Kulish, M. and Rees, D. (2011), 'The yield curve in a small open economy', *Journal of International Economics*, **85**, 268–79.
Kulish, M. and Rees, D.M. (2017), 'Unprecedented changes in the terms of trade', *Journal of International Economics*, **108**, 351–67.
Lawson, J. and Rees, D. (2008), '*A sectoral model of the Australian economy*,' Research Discussion Paper RDP 2008–01. Reserve Bank of Australia, Sydney.
Lim, G.C. and Tsiaplias, S. (2016), '*Non-linearities in the Relationship between House Prices and Interest Rates: Implications for Monetary Policy*,' Melbourne Institute Working Paper Series wp2016n02, Melbourne Institute of Applied Economic and Social Research, University of Melbourne.
Liu, X., Pagan, A.R. and Robinson, T. (2018), 'Critically Assessing Estimated DSGE Models: A Case Study of a Multi-sector Model', *Economic Record*, **94**, 349–71.
Liu, Z., Wang, P. and Zha, T. (2013), 'Land-price dynamics and macroeconomic fluctuations', *Econometrica*, **81**, 1147–84.
Lowe, P. (2015), '*Managing Two Transitions*,' Address given at the Corporate Finance Forum, Sydney, 18 May.
May, D., Nodari, G. and Rees, D.M. (2020), 'Wealth and Consumption in Australia', *Australian Economic Review*, **53**, 105–17.
Muellbauer, J. (2015), 'Housing and the macroeconomy: Inflation and the financial accelerator', *Journal of Money, Credit and Banking*, **47** (S1), 51–8.
Nakajima, M. and Telyukova, I.A. (2013), '*Housing in Retirement across Countries*,' CRR WP 2013–18. Center for Retirement Research, Boston College, Chestnut Hill, MA.
Rayner, V. and Bishop, J. (2008), '*Industry Dimensions of the Resource Boom: An Input-Output Analysis*,' Research Discussion Paper RDP 2013–042. Reserve Bank of Australia, Sydney.
Rees, D.M., Smith, P. and Hall, J. (2016), 'A Multi-sector Model of the Australian Economy', *Economic Record*, **92**, 374–408.
Reserve Bank of Australia (2014), '*Box C: The Cycle in Dwelling Investment*,' Statement of Monetary Policy, May, pp 43–45.
Rotemberg, J.J. (1982), 'Sticky Prices in the United States', *Journal of Political Economy*, **90**, 1187–1211.
Sá, F., Towbin, P. and Wieladek, T. (2014), 'Capital inflows, financial structure and housing booms', *Journal of the European Economic Association*, **12**, 522–46.
Saunders, T. and Tulip, P. (2019), '*A Model of the Australian Housing Market*,' Research Discussion Paper RDP 2019–01. Reserve Bank of Australia, Sydney.
Shoory, M. et al. (2016), 'The growth of apartment construction in Australia,' *RBA Bulletin*, (June), 19–26.
Sinai, T. and Souleles, N.S. (2005), 'Owner-occupied housing as a hedge against rentrisk', *Quarterly Journal of Economics*, **120**, 763–89.
Skinner, J.S. (1996), '*Is housing wealth a sideshow?*,' in Advances in the Economics of Aging. University of Chicago Press, Chicago; 241–272.
Smets, F. and Wouters, R. (2007), 'Shocks and frictions in US business cycles: A Bayesian DSGE approach', *American Economic Review*, **97**, 586–606.
Sutton, M. (2017), '*The Average Size and Proportion of Price Changes in the CPI*,' Consumer Price Index, Australia, (September), 12–21.

Appendix A. Data Description

TABLE A1
Data

Series	Dates	Source
Aggregate data		
Gross domestic product	1992q1–2016q4	ABS
Consumption growth	1992q1–2016q4	ABS
Investment growth	1992q1–2016q4	ABS
CPI inflation (trimmed mean)	1992q1–2016q4	ABS, RBA
Cash rate	1992q1–2016q4	RBA
Hours worked growth	1992q1–2016q4	ABS
Nominal TWI growth	1992q1–2016q4	RBA
Foreign aggregate data		
Major trading partner GDP growth	1992q1–2016q4	RBA
Major trading partner CPI inflation	1992q1–2016q4	RBA, authors' calculations
G3 interest rate (average)	1992q1–2016q4	NY Fed, BoJ, ECB
Resource Price Growth	1992q1–2016q4	RBA
Sector: non-tradeable (excl. housing)		
Value added growth	1992q1–2016q4	ABS, RBA, authors' calculations
CPI inflation	1992q1–2016q4	ABS, RBA, authors' calculations
Wage inflation	1997q4–2016q4	ABS, RBA, authors' calculations
Sector: tradeable (excl. resources)		
Value added growth	1992q1–2016q4	ABS, RBA, authors' calculations
CPI inflation	1992q1–2016q4	ABS, RBA, authors' calculations
Wage inflation	1997q4–2016q4	ABS, RBA, authors' calculations
Export growth	1992q1–2016q4	ABS, RBA, authors' calculations
Sector: resources		
Value added growth	1992q1–2016q4	ABS, RBA, authors' calculations
CPI inflation	1992q1–2016q4	ABS, RBA, authors' calculations
Wage inflation	1997q4–2016q4	ABS, RBA, authors' calculations
Export growth	1992q1–2016q4	ABS, RBA, authors' calculations
Sector: housing		
Value added growth	1992q1–2016q4	ABS, RBA, authors' calculations
CPI inflation	1992q1–2016q4	ABS, RBA, authors' calculations
Wage inflation	1997q4–2016q4	ABS, RBA, authors' calculations
Housing investment growth	1992q1–2016q4	ABS, RBA, authors' calculations

Note: Data used for estimating all models discussed in the paper.

Appendix B. Estimated values for model without housing

We estimate a version of the RSH model with the same foreign sector and wage stickiness assumptions as in the model with housing for comparison in Sections III and IV. The relevant parameter estimates obtained are shown in Tables B1 and B2. Calibrated parameters are the same as in Table 1,

TABLE B1
Parameter Estimates: Domestic Block for Model without Housing

Parameter	Prior distributions			Posterior distributions				Parameter	Prior distributions			Posterior distributions			
	Shape	Mean	Std dev.	Mode	Mean	5th %ile	95th %ile		Shape	Mean	Std dev.	Mode	Mean	5th %ile	95th %ile
Habit persistence and investment adjustment costs								*Sector wage Phillips curves*							
b	Beta	0.5	0.2	0.88	0.83	0.73	0.93	ω_{w_n}	Beta	0.3	0.15	0.92	0.83	0.90	0.96
$\Phi_{n,m,z}$	Normal	5	2	5.17	5.05	3.10	6.99	ω_{w_m}	Beta	0.3	0.15	0.92	0.92	0.89	0.95
								ω_{w_z}	Beta	0.3	0.15	0.96	0.96	0.95	0.97
Monetary policy and UIP								χ_{w_m}	Beta	00.3	0.15	0.16	0.32	0.05	00.55
ρ_r	Beta	0.9	0.03	0.84	0.82	0.79	0.85	χ_{w_z}	Beta	0.3	0.15	0.31	0.32	0.11	0.52
ϕ_π	Normal	1.5	0.1	1.55	1.56	1.40	1.72	χ_{w_d}	Beta	0.3	0.15	0.27	0.28	0.10	0.46
ϕ_{dy}	Normal	0.2	0.03	0.42	0.45	0.30	0.63	*Shock persistence*							
ϕ_q	Normal	0	0.05	0.01	0.01	−0.03	0.04	ρ_g	Beta	0.5	0.2	0.71	0.66	0.43	0.92
Θ_Ψ	Beta	0.5	0.15	0.21	0.25	0.15	0.35	ρ_{ξ_c}	Beta	0.5	0.2	0.35	0.45	0.18	0.71
Sector Phillips curves								ρ_{ξ_H}	Beta	00.5	0.2	0.77	0.56	0.18	00.91
ω_{π_n}	Beta	0.66	0.1	0.79	0.90	0.66	0.85	ρ_Γ	Beta	0.5	0.2	0.45	0.43	0.25	0.63
ω_{π_m}	Beta	0.66	0.1	0.80	0.84	0.75	0.92	ρ_Φ	Beta	0.5	0.08	0.78	0.71	0.56	0.85
$\omega_{\pi_m^*}$	Beta	0.66	0.1	0.89	0.88	0.84	0.94	ρ_{a_n}	Beta	0.5	0.2	0.82	0.88	0.70	1.00
ω_{π_f}	Beta	0.66	0.1	0.90	0.90	0.86	0.85	ρ_{a_m}	Beta	0.5	0.2	0.35	0.69	0.28	0.98
χ_n	Beta	0.3	0.15	0.07	0.09	0.02	0.16	ρ_{a_z}	Beta	0.5	0.2	0.95	0.93	0.90	0.97

Notes: Parameter estimates for the domestic sectors and policy rule of the small open economy without housing. We set the world economy parameters to the mean values of the posterior distribution for estimation. We do not estimate separate adjustment cost parameters for the non-tradeable, non-resource tradeable and resources sectors as separate investment series for each are not readily available. In this model we estimate the Calvo parameters (ω) rather than the slope of the Philips curve.

TABLE B2
Parameter Estimates: Domestic Block Shocks for Model without Housing

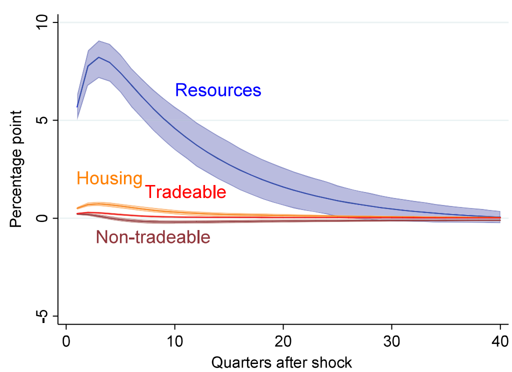
Parameter	Prior distributions			Posterior distributions			
	Shape	Mean	Std dev.	Mode	Mean	5th %ile	95th %ile
Policy and preferences (×100)							
σ_g	Gamma	1.00	0.80	1.28	1.29	1.08	1.50
σ_{ξ_C}	Gamma	1.00	0.80	3.71	3.22	1.64	4.67
σ_{ξ_H}	Gamma	1.00	0.80	3.43	2.18	0.05	4.27
σ_r	Gamma	0.15	0.10	0.11	0.12	0.10	0.13
σ_Ψ	Gamma	0.50	0.40	0.59	0.73	0.41	1.03
Production (×100)							
σ_Γ	Gamma	2.00	1.50	8.30	8.28	4.46	11.98
σ_{a_n}	Gamma	1.00	0.80	0.46	0.47	0.35	0.62
σ_{a_m}	Gamma	1.00	0.80	1.18	1.42	0.91	1.87
σ_{a_z}	Gamma	1.00	0.80	1.83	1.84	1.59	2.06
Price and wage inflation (×100)							
σ_{π_n}	Gamma	0.50	0.40	0.16	0.17	0.12	0.22
σ_{π_m}	Gamma	0.50	0.40	0.48	0.47	0.37	0.57
$\sigma_{\pi_m^*}$	Gamma	0.50	0.40	2.17	2.20	1.83	2.49
σ_{π_f}	Gamma	0.50	0.40	0.59	0.59	0.43	0.74
σ_{w_n}	Gamma	0.15	0.10	0.04	0.06	0.35	0.09
σ_{w_m}	Gamma	0.15	0.10	0.09	0.10	0.07	0.12
σ_{w_z}	Gamma	0.15	0.10	0.22	0.23	0.17	0.27

Notes: Estimates of the standard deviations of the exogenous domestic shock processes. We set the world economy parameters to the mean values of the posterior distribution for estimation.

Appendix C. Labour Supply Responses to Commodity Price Shocks

One channel that commodity price shocks may operate through when crowding out housing investment is labour demand. Figure C1 shows the response in percentage points above steady state in hours worked in each sector to a 10% commodity price shock. Hours worked rise sharply in the resource sector (peaking at about 8 per cent more hours worked in the sector compared to steady state) and rise modestly in all other sectors. Therefore, the model does not predict substitution between these sectors in response to commodity shocks. In the data, we can see that the labour force participation rate rose sharply during the mining boom. The models predictions are thus in line with these shocks drawing workers into the labour force in all sectors of the economy.

FIGURE C1
Labour Supply Response for Commodity Price Shock. [Colour figure can be viewed at wileyonlinelibrary.com]

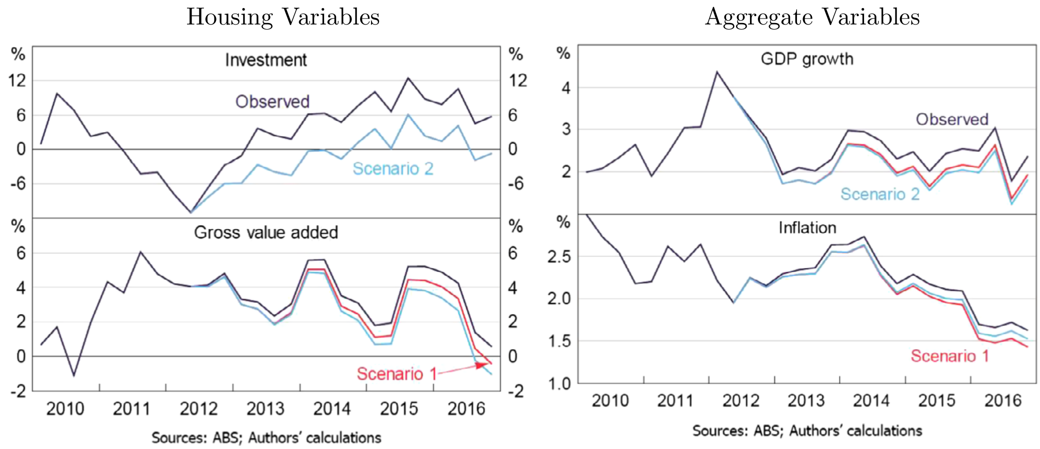


Appendix D. Counterfactual Scenario

To quantify the extent to which housing investment ‘filled the hole’ left by mining investment, we explore some counterfactual scenarios. There is no unique way to quantify spillovers from one sector to another in a general equilibrium model. Housing prices and quantities

Figure D1

Counterfactual Scenario. Notes: Counterfactual scenarios for the path of investment, GDP and inflation. We simulate the model as if housing investment and value added grew at the average rate observed between the first quarter of 2003 and the second quarter 2012 through the end of 2016. We use the housing investment and technology shocks to construct the counterfactual. [Colour figure can be viewed at wileyonlinelibrary.com]



are endogenous variables that respond to many different shocks. However, we are able to construct scenarios where counterfactual shocks occur in the housing market that can offset the usual endogenous response of this sector to the other shocks in the economy. The experiment is not a perfect exercise though because the counterfactual shocks may also affect other decisions in the economy concurrently, such that we are not capturing just the absence of the endogenous response to housing.

With that caveat in mind, we proceed by using housing-specific shocks to construct a counterfactual path for housing investment and value added to answer this question. We assume that these values continued to grow at their mining boom averages, rather than accelerating as observed in the data. For the counterfactual, we define the mining boom as from March quarter 2003 to June quarter 2012. We start by taking the structural shocks estimated using a historical decomposition, discussed previously. With these shocks in hand, we can then look at our counterfactual while incorporating all of the shocks that would have hit the economy over the period.

In the first scenario we lower quarterly housing investment growth by 1.6 percentage points (to its mining boom average) for each quarter in the post-boom period using the housing investment shock. In other words, we use negative housing investment shocks to construct a lower path for housing investment than actually occurred while leaving all other shocks the same. The housing investment shock is used in this case because it only directly impacts housing investment. Most other variables are affected endogenously by the lower rate of housing investment that occurs because of the shock. Essentially, we are using housing investment shocks to offset the usual response of housing investment to negative commodity price shocks, as discussed previously.

In the second scenario we also incorporate housing-sector-specific technology shocks so that quarterly growth in housing sector value added is, on average, 0.2 percentage points below its historical path. As these housing technology shocks weigh on housing investment, the housing investment shocks required to hit our target for housing investment are smaller than in the first scenario. We choose technology shocks as apartments have made up a particularly large portion of recent residential construction (e.g. Shoory *et al*., 2016). To some extent, this can be seen as a positive technology shock, as a given amount of investment produces more dwellings and housing services compared to construction of single-family dwellings. This type of interpretation is supported by the historical decomposition, which shows that improved productivity in the housing services sector has supported value-added growth. The resulting calibrations are shown in the left panel of Figure D1 (note that housing investment is the same in both scenarios).

The right panel of Figure D1 compares the observed growth in GDP and inflation to our scenarios. Under the scenarios, year-ended GDP growth is around one-half of a percentage point lower. Inflation is also somewhat lower; however, disinflationary pressures from softer growth are partly offset by higher inflation in the housing sector due to the smaller and less productive housing stock. Under both scenarios, the cash rate is around 40 basis points lower. Therefore, these scenarios suggest that housing investment activity does appear to have significantly contributed to growth and inflation over this time.