

Housing and Commodity Investment Booms in a Small Open-Economy

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ABSTRACT

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.

JEL Classifications: E23, E32, R31

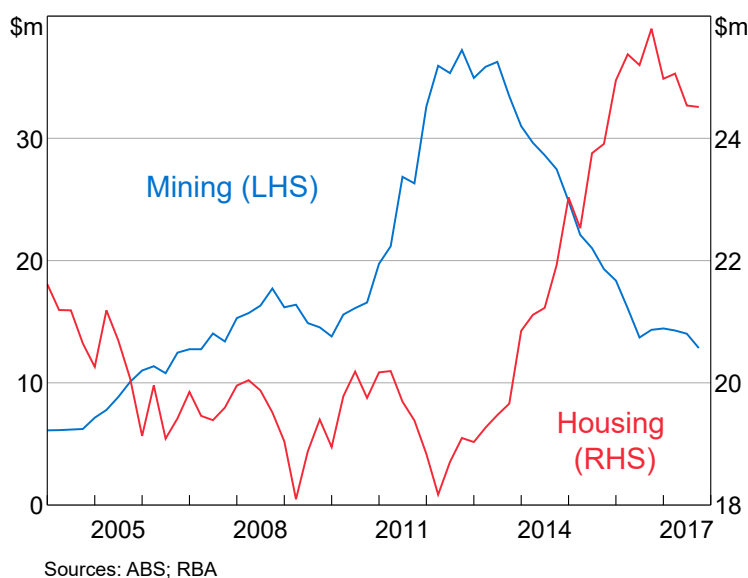
Key Words: housing, DSGE, open economy, monetary policy, residential investment, commodity prices.

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1 INTRODUCTION

Economic activity in the Australian housing market increased substantially from 2011 through 2017, attracting considerable interest from academics and policymakers.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. Concerns which are especially acute given the experience of the United States in the previous decade.²

Figure 1



Sources: ABS; RBA
 Notes: The figure shows mining and housing investment over time in Australia in millions of AUD.

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 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

¹See, for example, Fox and Finlay (2012), RBA (2014), Lim and Tsiaplias (2016), and Shoory et al. (2016).

²See 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.

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 model of Rees, Smith, and Hall (2016) (henceforth RSH). The RSH model is a multisector DSGE model of the Australian economy, which complements the Reserve Bank of Australia's suite of economic models 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 who 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 setup 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. And second, a growing literature casts doubts on the validity of the spender-saver structure because it ignores rental markets. For example, d'Albis and Iliopoulos (2013) show that if a rental market is added to the basic spend-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 have 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 GDP, inflation, and consumption. In particular, the RSH model ascribes as much of 50% 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%.

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 one half percentage point to GDP growth and one 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 in Norway or Canada, which have had similar experiences in recent years.³

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 to 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.

2 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

³See 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 model formally and by explaining dynamic and steady state implications of our housing modelling assumptions for interpreting the data.

2.1 RSH OVERVIEW

The small open economy of RSH 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.

2.2 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 also 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 the way that other assets are held (e.g. Nakajima and Telyukova 2013 or Sinai and Souleles 2005). The tax treatment of housing is also distinct from 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 papers 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 and 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% in Australia. The average housing share of nominal gross value added from 1993 to 2016 is around 16%. 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.

2.3 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,

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

subject to the budget constraint:

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

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:

$$H_t = [h_{n,t}^{1+\sigma} + h_{m,t}^{1+\sigma} + h_{z,t}^{1+\sigma} + h_{d,t}^{1+\sigma}]^{\frac{1}{1+\sigma}} \quad (3)$$

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

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

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

(2013). Workers have heterogeneous skills and firms purchase a bundle of labour from households that includes workers of all types:

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

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 previous period's sectoral wage growth $\Pi_{j,t-1}^w$, and steady-state sectoral wage growth $\Pi_{j,ss}^w$. 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

2.4 SECTORAL PRODUCTION

2.4.1 INTERMEDIATE MONOPOLISTICALLY COMPETITIVE GOODS AND SERVICES PRODUCERS

In the three monopolistically competitive producing sectors (non-tradeable excluding housing, the non-resource tradeable, and the housing sector), 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:

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

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

⁵We 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: $\frac{1}{2} \left(\frac{I_{j,t}}{I_{j,t-1}} - \mu \right)^2 \Theta_j$.

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 interest 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 following 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:

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

where $\epsilon_{\pi_j,t}$ 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 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.

2.4.2 IMPORTS, RESOURCES, AND FINAL GOODS SECTOR

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

⁷Despite 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.

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:

$$MC_{f,t}(x) = \epsilon_{\pi_f,t} \frac{S_t P_{f,t}^*}{P_{f,t}} \quad (11)$$

where $\epsilon_{\pi_f,t}$ 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:

$$Y_{z,t}(x) = a_{z,t} (M_t h_{z,t}(x))^{\alpha_z} (M_t L_t)^{\alpha_L} (K_{z,t}(x))^{1-\alpha_z-\alpha_L} \quad (12)$$

where the stationary sector-specific technology shock takes on 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:

$$\Delta_{z,t} = P_{z,t} Y_{z,t} - W_{z,t} h_{z,t} - R_{z,t} K_{z,t} - R_{L,t} L \quad (13)$$

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:

$$P_{z,t} = (S_t P_{z,t}^*)^{1/2} (P_{z,t-1})^{1/2} \quad (14)$$

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:

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

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

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

2.5 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:

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

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

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

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:

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

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 $\epsilon_{r,t}$ is a monetary policy shock.

2.6 MARKET CLEARING AND THE CURRENT ACCOUNT

The goods market clearing conditions are:

$$Y_{m,t} = Y_{m,t}^{dom} + Y_{m,t}^{ex} \quad (20)$$

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

$$DFD_t = C_t + G_t + \sum_{j=n,m,d,z} I_{j,t} \quad (22)$$

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, the government or invested.

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

$$\frac{S_t B_t^*}{R_t^* \Psi_t} = S_t B_{t-1}^* + NX_t \quad (23)$$

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:

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

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:

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

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

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

2.7 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:

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

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

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

$$r_t^* = \rho_{r^*} r_{t-1}^* + (1 - \rho_{r^*})(\phi_{\pi^*} \pi_t^* + \phi_{dy^*}(y_t^* - y_{t-1}^*)) + \epsilon_{r^*,t} \quad (30)$$

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, $\epsilon_{r^*,t}$, 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:

$$p_{z,t}^* = (1 - \rho_z) p_z^* + \rho_z p_{z,t-1}^* + \theta_{zy} \xi_{y^*,t} + \epsilon_{p_z^*,t} \quad (31)$$

where $p_z^* = \ln(P_{z,t}^*/P_t^*)$ is the relative price of the resource good in terms of the foreign currency.

2.8 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:

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

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

where Λ_t is the shadow price of consumption and $\Lambda_{j,t}^k$ 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' behavior 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.

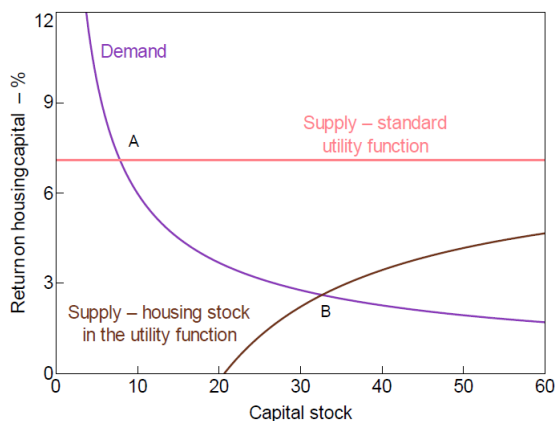
The second impact of including housing stock in the utility function is on the steady state implied relationships of the model. The steady state relationships are primarily used to pin down the share of economic activity allocated to each sector, which allows us to relate sectoral values to aggregate 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,

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

Figure 2: Factor market: housing capital



Notes: 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.

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, which give 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:

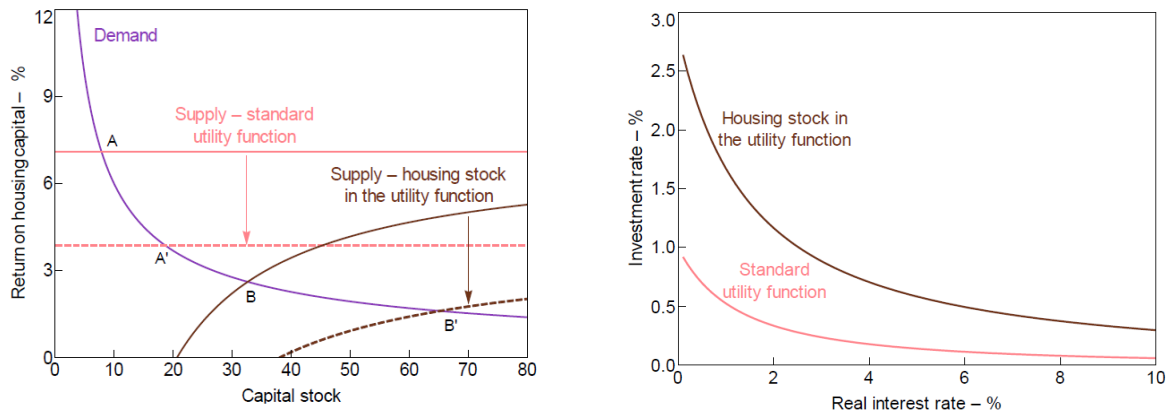
$$r_{d,ss} = \frac{\mu}{\beta} - 1 + \delta_d + \frac{A_d \mu^2}{(b_d - \mu) K_{d,ss} \lambda_{d,ss}^k} \quad (35)$$

where $\lambda_{d,ss}^k$ is the steady state shadow price of housing capital (i.e. the Lagrange multiplier associated with housing capital from the household's constrained optimisation problem).⁹ Equation (35) implies an upward sloping relationship (gross steady state productivity growth is assumed greater than one and habit persistence is less than one), which is depicted in Figure 2. Intuitively, the supply curve slopes upward 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.

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

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

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 $\lambda_d = 1$.

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.

3 ESTIMATION

We take 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

3.1 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

¹⁰We 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.

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

3.2 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 calibrated to be 10% 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

¹¹The 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).

¹²Unless 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% nominal steady state interest rate.

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

¹⁴We have tried a number of different measurement error specifications, including moving average unit root

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
\bar{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 multisector 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
Public demand	22.7	22.5
Production as a share of nominal GVA^(a)		
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^(a)		
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

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

3.3 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 United States 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

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 bring to multisector models.

¹⁵To 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 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%.

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 (x 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

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

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 are 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 and Rees 2008).¹⁶

As in RSH, rather than estimating the price adjustment costs, about which we have no strong prior beliefs, we directly estimate the slopes of the Phillips curves. Each slope is just a monotonic transformation of the adjustment cost parameters.¹⁷ We, however, use different priors to 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

¹⁶We 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.

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

Table 4: Parameter estimates - domestic block

Parameter	Prior distributions			Posterior distributions				Parameter	Prior distributions			Posterior distributions			
	Shape	Mean	Std dev	Mode	Mean	5-%ile	95-%ile		Shape	Mean	Std dev	Mode	Mean	5-%ile	95-%ile
Habit persistence and investment adjustment costs								Sector Wage Phillips Curves							
b	Beta	0.50	0.20	0.90	0.90	0.85	0.94	κ_{w_n}	Gamma	50.00	30.00	0.15	0.20	0.09	0.31
b_d	Beta	0.20	0.10	0.19	0.22	0.04	0.40	κ_{w_m}	Gamma	50.00	30.00	0.11	0.15	0.07	0.23
Φ_d	Normal	3.00	1.50	3.36	3.73	2.35	5.16	κ_{w_z}	Gamma	50.00	30.00	0.12	0.14	0.07	0.20
$\Phi_{n,m,z}$	Normal	20.00	2.50	10.76	11.21	7.15	14.91	κ_{w_d}	Gamma	50.00	30.00	0.16	0.20	0.11	0.28
Monetary policy and UIP								Shock persistence							
ρ_r	Beta	0.90	0.03	0.86	0.86	0.83	0.88	χ_{w_n}	Beta	0.30	0.15	0.11	0.16	0.02	0.29
ϕ_π	Normal	1.50	0.10	1.54	1.55	1.40	1.71	χ_{w_m}	Beta	0.30	0.15	0.20	0.24	0.08	0.39
ϕ_{dy}	Normal	0.20	0.03	0.21	0.21	0.17	0.26	χ_{w_z}	Beta	0.30	0.15	0.27	0.29	0.11	0.46
ϕ_q	Normal	0.00	0.05	0.00	0.00	-0.03	0.03	χ_{w_d}	Beta	0.30	0.15	0.10	0.12	0.02	0.22
Θ_{ψ}	Beta	0.50	0.15	0.07	0.08	0.03	0.13	ρ_g	Beta	0.5	0.2	0.75	0.69	0.46	0.93
Sector Phillips curves								ρ_{ξ_c}							
κ_{π_n}	Gamma	8.00	2.00	2.93	3.39	1.82	4.76	ρ_{ξ_H}	Beta	0.5	0.2	0.92	0.9	0.84	0.97
κ_{π_m}	Gamma	10.00	2.50	9.15	9.21	5.40	13.43	$\rho_{\xi K_d}$	Beta	0.5	0.2	0.5	0.52	0.19	0.84
$\kappa_{\pi_m^*}$	Gamma	10.00	2.50	4.74	5.16	3.04	7.16	ρ_Γ	Beta	0.5	0.2	0.55	0.52	0.38	0.66
κ_{π_d}	Gamma	1.00	0.30	0.13	0.16	0.09	0.24	ρ_{Γ_d}	Beta	0.5	0.2	0.6	0.57	0.42	0.73
κ_{π_f}	Gamma	10.00	2.50	2.04	2.19	1.37	2.92	ρ_Φ	Beta	0.5	0.08	0.78	0.77	0.72	0.81
χ_n	Beta	0.30	0.15	0.28	0.29	0.11	0.45	ρ_{a_n}	Beta	0.5	0.2	0.75	0.73	0.63	0.83
χ_m	Beta	0.30	0.15	0.16	0.19	0.04	0.33	ρ_{a_m}	Beta	0.5	0.2	0.98	0.95	0.91	1
χ_m^*	Beta	0.30	0.15	0.08	0.12	0.02	0.21	ρ_{a_z}	Beta	0.5	0.2	0.93	0.92	0.85	0.98
χ_d	Beta	0.30	0.15	0.63	0.61	0.45	0.76	ρ_{a_d}	Beta	0.5	0.2	0.75	0.71	0.62	0.81
χ_f	Beta	0.30	0.15	0.15	0.19	0.04	0.32								

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.

industries, revealing no significant differences in wage setting across the intermediate industries.

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 does 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.

3.4 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 through 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 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.

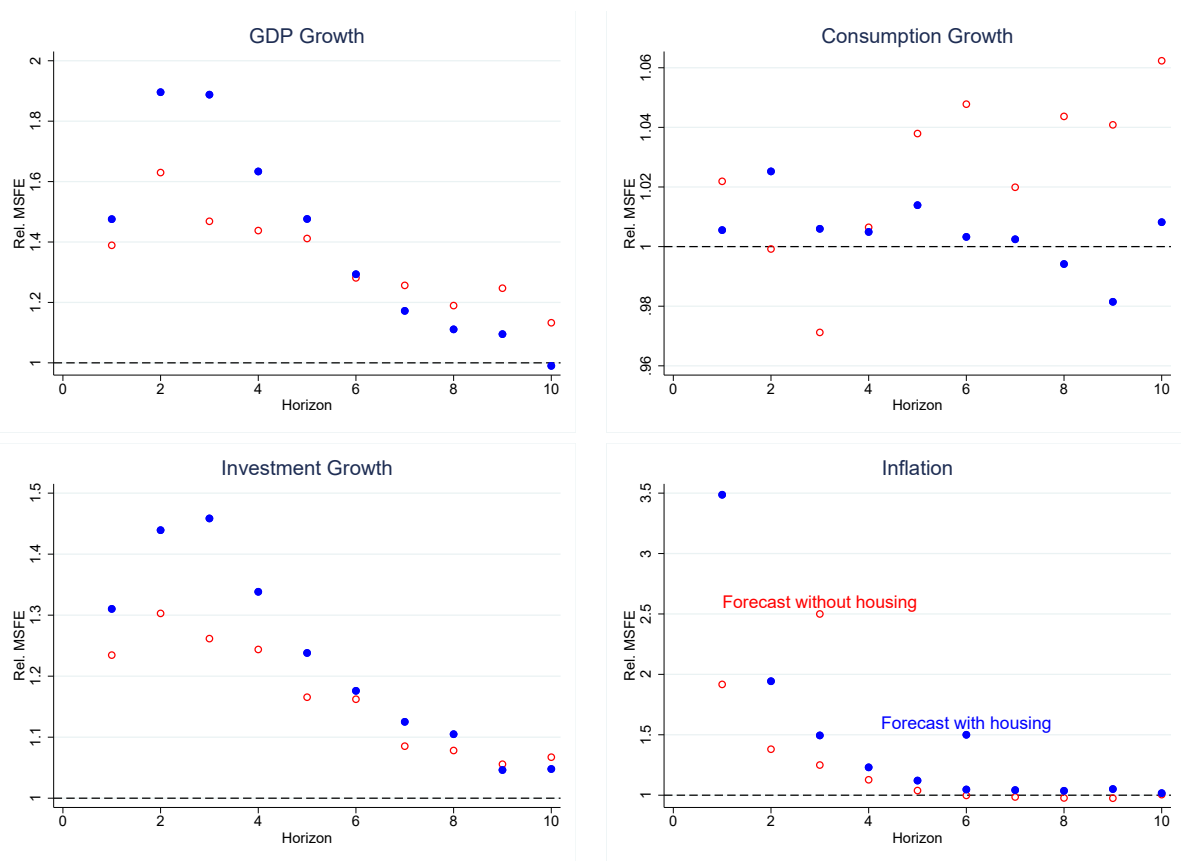
Figure 4 shows the mean squared forecast errors (MSFE) of the model with and without housing relative to the AR(1) forecasts for forecasts between one and ten quarters ahead. With

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 (x 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 (x 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 (x 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

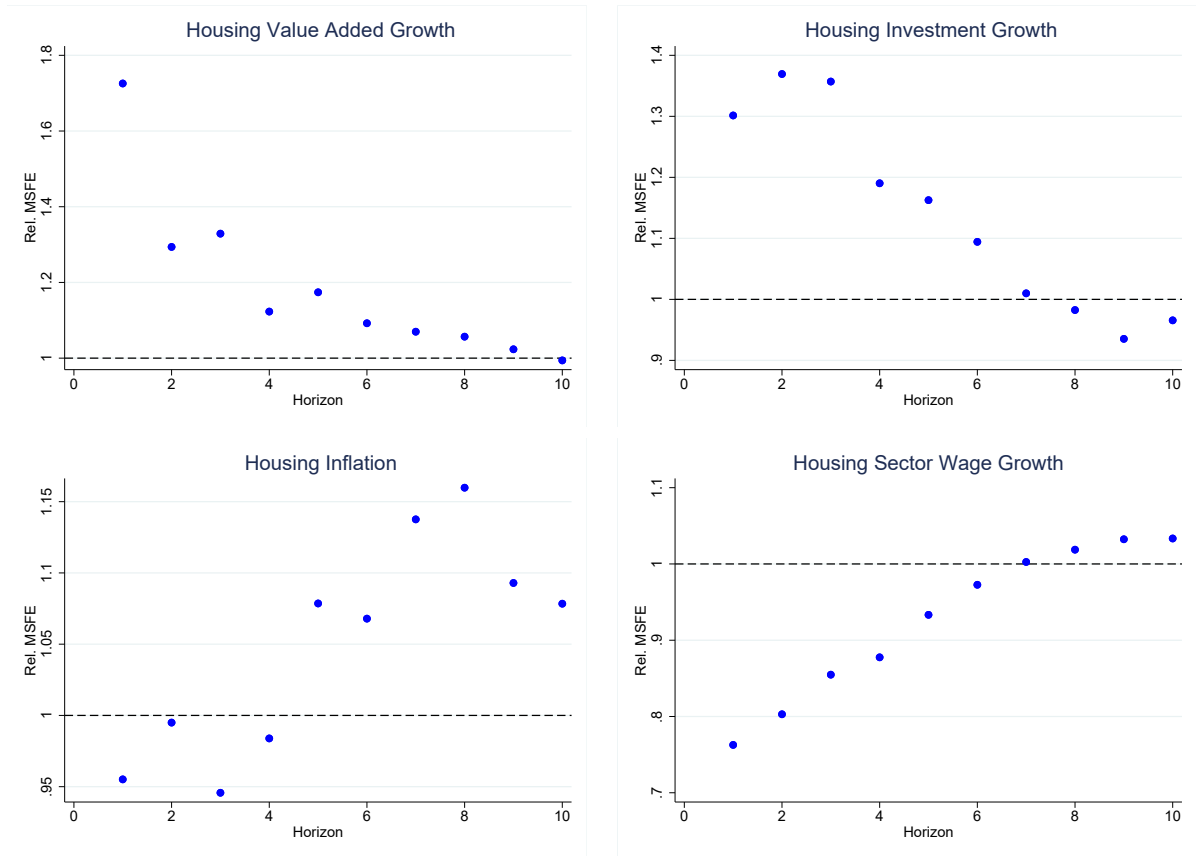
Notes: Estimates of the standard deviations of the exogenous domestic shock processes. We set the world economy parameters to the mean values of the posterior distribution for estimation.

Figure 4: Out-of-sample forecast comparison



Notes: 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.

Figure 5: Forecast comparison for housing sector variables

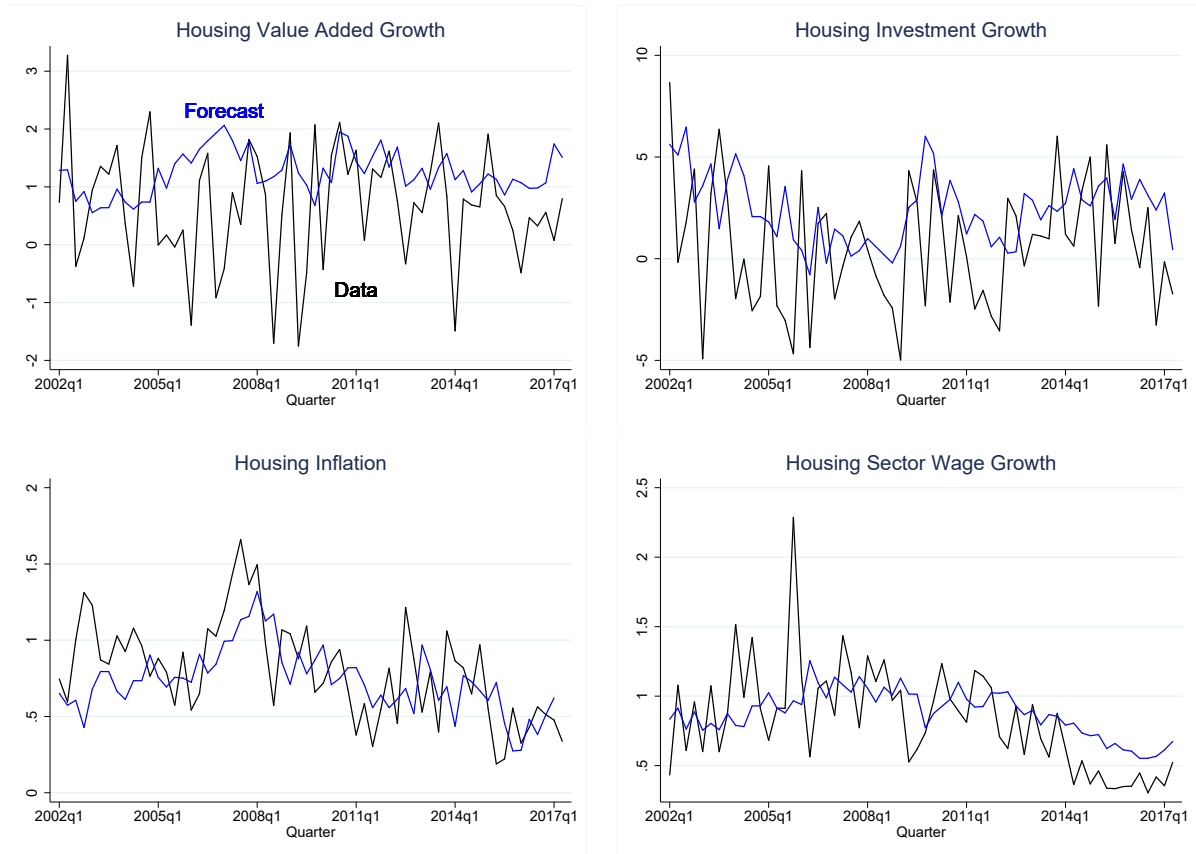


Notes: Out-of-sample comparison of mean squared forecast error (MSFE) for the model with housing displayed relative to the MSFE of an AR(1) model forecast for different horizons.

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 and 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. 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.

Figure 6: Forecast comparison for housing sector variables to data



Notes: Out-of-sample comparison of the one-quarter horizon forecasts from the model with housing to the actual data.

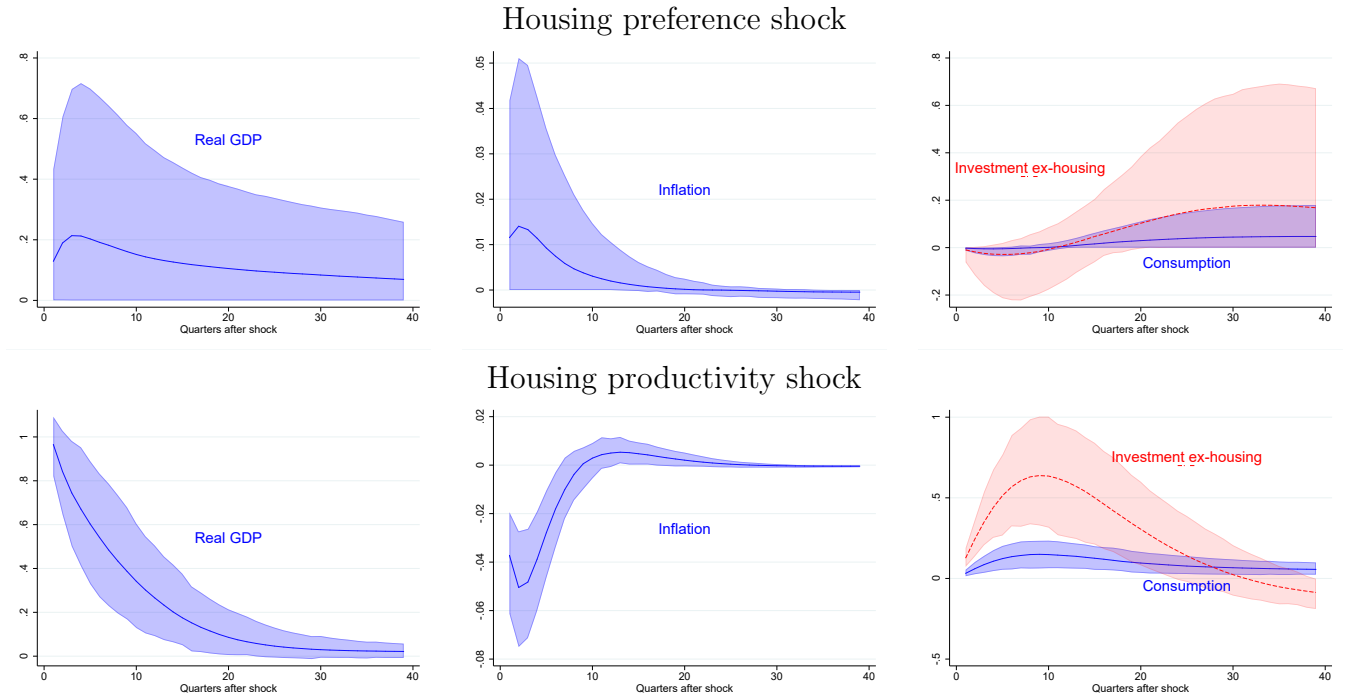
4 TRANSMISSION OF SHOCKS

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.

4.1 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 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.

Figure 7: Housing sector shocks



Notes: 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.

The latter relationship is not present in Iacoviello and Neri but is argued to be necessary to match United States 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 stylized facts. Looking at consumption, the median response to the housing preference shock is strictly positive, which is consistent with the collateral constraints case of Iacoviello and Neri. The response of investment ex-housing, though, is only weakly consistent with the second stylized 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%. The shock causes consumption and investment ex-housing to rise and it is mildly deflationary, which is consistent with the third stylized fact.

4.2 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.

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											
Nontraded	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 add 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 markup shocks.

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

economy-wide measures of inflation.

4.3 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 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

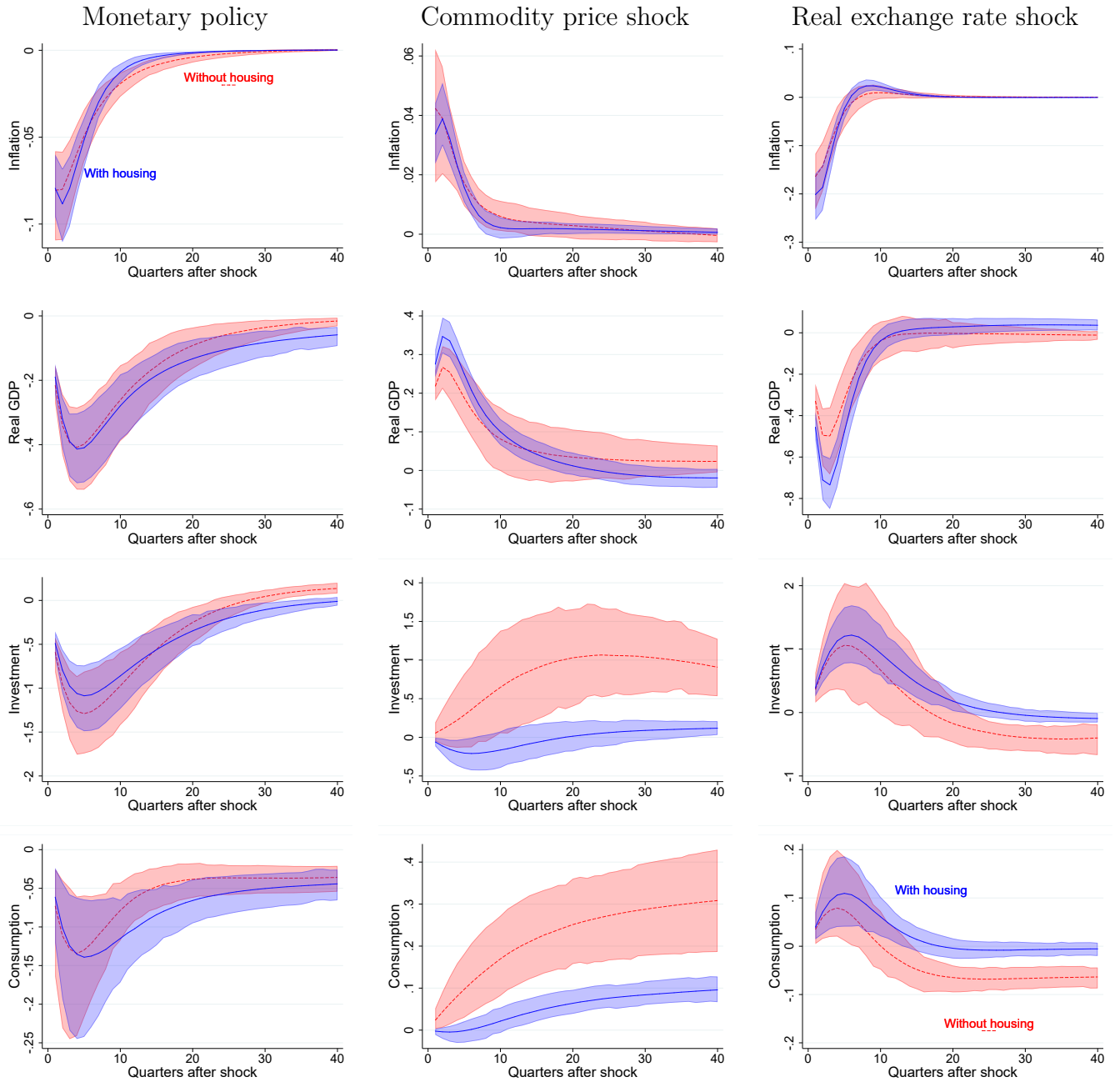
5 COMMODITY PRICES AND HOUSING INVESTMENT

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

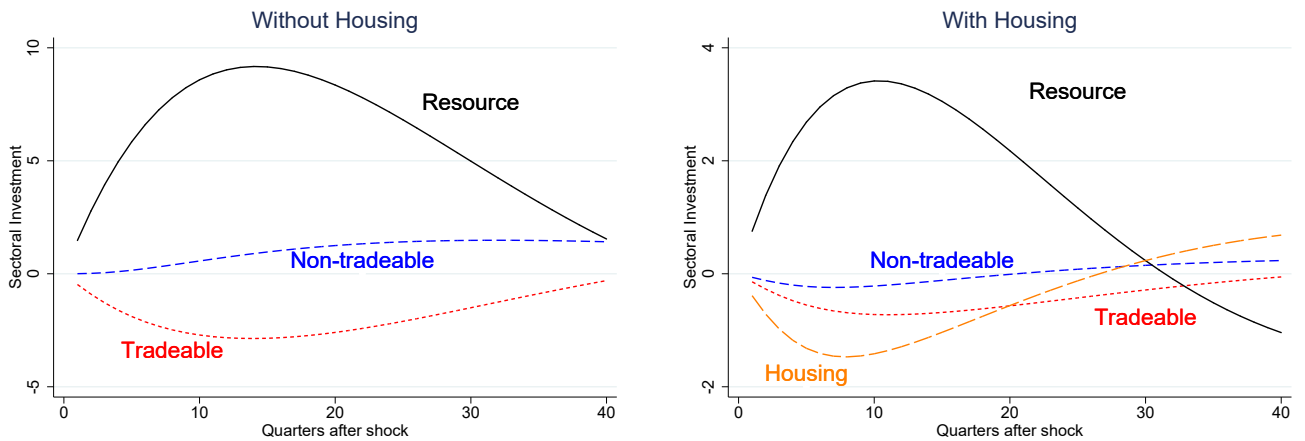
¹⁸The similar impact on GDP in the two models is explained by the different predicted behaviour for net exports. The value added in the resource sector rises by much more in the model with housing in response to commodity shocks. This causes GDP to rise even though consumption and investment do not respond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

Figure 8: Transmission of shocks



Notes: Bayesian impulse responses to a 100 basis point monetary policy shock, 10% increase in commodity prices, and a 10% appreciation of the real exchange rate.

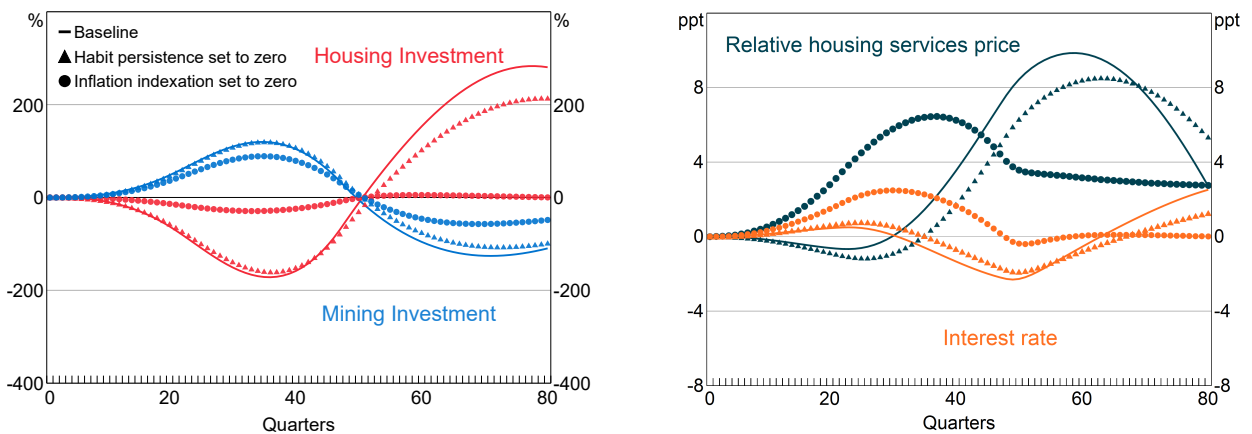
Figure 9: Sector specific investment responses to commodity prices



Notes: Bayesian impulse responses to a 10% increase in commodity prices for sector specific investment.

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 are plotted along with response of housing service prices and the interest rate. Consistent with Figure 1 in the introduction, 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 - 2011 followed by the peak housing investment sometime in 2017 - 2018.

Figure 10: Housing investment booms



Notes: The 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.

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 price 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.

5.1 HISTORICAL DECOMPOSITION OF HOUSING INVESTMENT

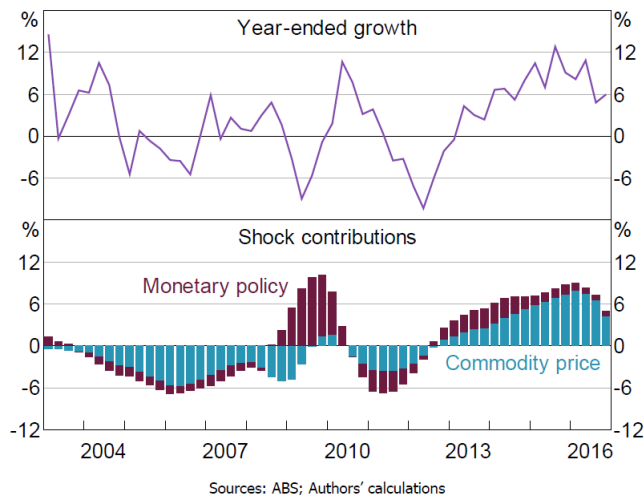
This relatively sensitive relationship between housing investment and foreign shocks is also clearly seen in the variance decomposition implied by the estimated model. Table 6 shows that housing investment is the second most foreign affected investment series after the resource sector, with just over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

Figure 11: Historical decomposition of shocks



Notes: Historical decomposition of the shocks using the estimated parameter values of the model given in Section 3 set to their posterior means.

as less investment removes housing supply from the market and supports prices. The large effect on GDP growth coupled with the stabilizing effects on inflation underscore the unique role housing investment can play as a propagator of shocks to overall macroeconomic dynamics in Australia.

6 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 multisector 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 most affected sector to 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 lasts 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.

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 (ex. 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 (ex. 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

Notes: 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 3 and 4. The relevant parameter estimates obtained are shown in Table 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	5-%ile	95-%ile		Shape	Mean	Std dev	Mode	Mean	5-%ile	95-%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
Monetary policy and UIP								Shock persistence							
ρ_r	Beta	0.9	0.03	0.84	0.82	0.79	0.85	ω_{w_z}	Beta	0.3	0.15	0.96	0.96	0.95	0.97
ϕ_π	Normal	1.5	0.1	1.55	1.56	1.40	1.72	χ_{w_m}	Beta	0.3	0.15	0.16	0.32	0.05	0.55
ϕ_{dy}	Normal	0.2	0.03	0.42	0.45	0.30	0.63	χ_{w_z}	Beta	0.3	0.15	0.31	0.32	0.11	0.52
ϕ_q	Normal	0	0.05	0.01	0.01	-0.03	0.04	χ_{w_d}	Beta	0.3	0.15	0.27	0.28	0.10	0.46
Θ_Ψ	Beta	0.5	0.15	0.21	0.25	0.15	0.35	ρ_g	Beta	0.5	0.2	0.71	0.66	0.43	0.92
Sector Phillips curves								ρ_{ξ_c}							
ω_{π_n}	Beta	0.66	0.1	0.79	0.90	0.66	0.85	ρ_{ξ_H}	Beta	0.5	0.2	0.35	0.45	0.18	0.71
ω_{π_m}	Beta	0.66	0.1	0.80	0.84	0.75	0.92	ρ_{Γ}	Beta	0.5	0.2	0.77	0.56	0.18	0.91
ω_{π_n}	Beta	0.66	0.1	0.89	0.88	0.84	0.94	ρ_Φ	Beta	0.5	0.08	0.78	0.71	0.56	0.85
ω_{π_f}	Beta	0.66	0.1	0.90	0.90	0.86	0.85	ρ_{a_n}	Beta	0.5	0.2	0.82	0.88	0.70	1.00
χ_n	Beta	0.3	0.15	0.07	0.09	0.02	0.16	ρ_{a_m}	Beta	0.5	0.2	0.35	0.69	0.28	0.98
								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 Phillips curve.

Table B2: Parameter estimates - domestic block shocks for model without housing

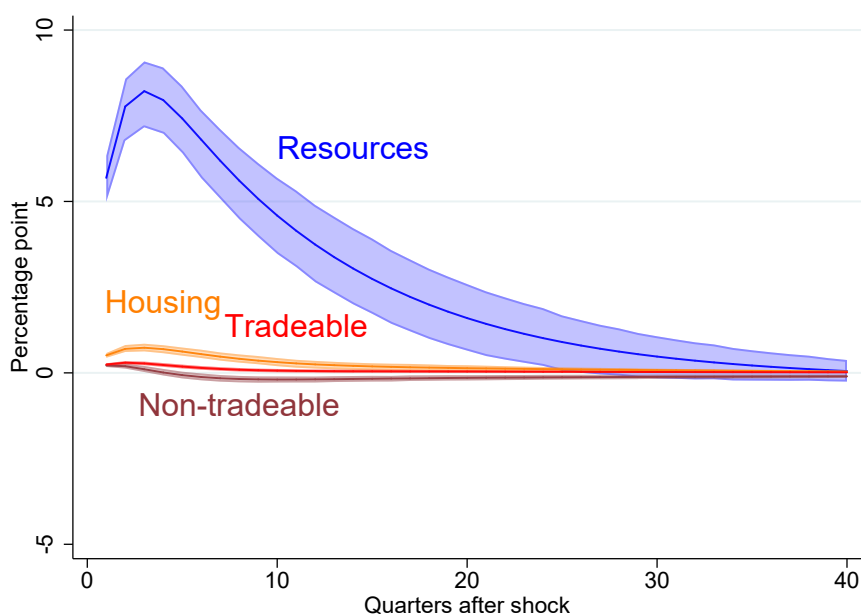
Parameter	Prior distributions			Posterior distributions			
	Shape	Mean	Std dev	Mode	Mean	5th %ile	95th %ile
Policy and preferences (x 100)							
σ_g	Gamma	1.00	0.80	1.28	1.29	1.08	1.50
σ_{ξ_C}	Gamma	1.00	0.80	3.71	3.22	1.64	4.67
σ_{ξ_H}	Gamma	1.00	0.80	3.43	2.18	0.05	4.27
σ_r	Gamma	0.15	0.10	0.11	0.12	0.10	0.13
σ_Ψ	Gamma	0.50	0.40	0.59	0.73	0.41	1.03
Production (x 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 (x 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
σ_{π_n}	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 prices shocks may operate through when crowding out housing investment is through 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 rises sharply in the resource sector (peaking at about 8% more hours worked in the sector compared to steady state) and rises 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 shock drawing workers into the labour force in all sectors of the economy.

Figure C1: Labour supply response for commodity price shock



Notes: Sectoral labour supply responses to a 10% commodity price shock.

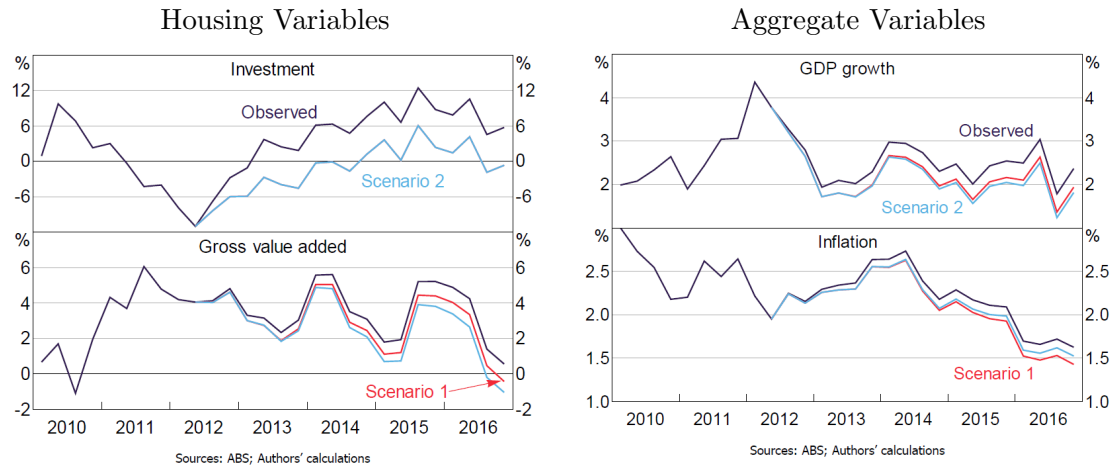
APPENDIX D: COUNTERFACTUAL SCENARIO

To quantify the extent to which housing investment “filled the hole” left by mining investment, we explore some counterfactual scenarios. There is not a unique way to quantify spillovers from one sector to another in a general equilibrium model. Housing prices and quantities 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 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 what actually occurred while leaving all other shocks the same. The housing investment shock is used in this case because it only directly impacts

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 2003 and the second quarter 2012 through the end of 2016. We use the housing investment and technology shocks to construct the counterfactual.

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 scenario 1. 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 housing investment is the same in scenarios 1 and 2).

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.

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