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Monetary Policy, Hot Housing Markets And Leverage*

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Working Paper

Abstract

Expansionary monetary policy can increase household leverage by stimulating housing liquidity. Low mortgage rates encourage buyers to enter the housing market, raising the speed at which properties can be sold. Because lenders can resell seized foreclosure inventory at lower cost in such a hot housing market, ex-ante they are comfortable financing a larger fraction of the house purchase. Consistent with this mechanism, this study documents empirically that both the housing sales rate and loan-to-value ratios increase after expansionary monetary policy. Calibrating a New Keynesian macroeconomic model to fit the response of housing liquidity to monetary policy, the interaction between credit frictions and housing market search frictions generates endogenous movements in the loan-to-value ratio which amplify the economy's response to monetary policy.

Key Words: Monetary Policy; Housing Market; Credit Frictions; Search Frictions

JEL Codes: E32; E44; E52; R21

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The conventional story of the housing channel of monetary policy transmission focuses on housing transaction prices. Lower short-term policy rates feed through to mortgage rates, raising house prices to equilibrate demand and supply. As the transaction price of housing collateral rises, lenders allow credit-constrained consumers to borrow more. This stimulates aggregate demand and the macroeconomy.

But this story neglects two additional key features of the effect of monetary policy on the housing market. First, this study shows that borrowers' access to credit expands by more than house prices following expansionary monetary policy. That is, mortgage loan-to-value ratios increase after a monetary loosening. Second, a temporary 1% fall in the federal funds rate, in addition to raising transaction prices by 3% on impact, also raises the monthly rate at which housing is sold by 20%. The sales volumes response of the housing market is much more pronounced than the usually empasized price response.

Motivated by these two empirical findings, this paper explores whether housing liquidity dynamics can explain the rise in loan-to-value ratios following monetary policy expansions. Intuitively, lenders value property collateral primarily for its resale value in case of default. This liquidation value depends on both (i) costs associated with carrying the property from moment of foreclosure until a buyer is found and (ii) the eventual transaction price at which the house is resold to a new household. Following expansionary monetary policy, a higher housing sales rate lowers the carrying cost on foreclosures - therefore raising housing liquidation values and housing debt capacity by more than recorded housing transaction prices. This offers a theory for how loose monetary policy can cause a rise in the leverage ratios that lenders are willing to accept.

Both partial and general equilibrium exercises suggest that this new monetary policy transmission channel can quantitatively account for easing credit standards following an easing of monetary policy conditions. This study presents a New Keynesian macroeconomic model augmented with credit frictions and housing market search frictions. The new transmission channel explored in this paper emerges naturally through the interaction between these two frictions. Calibrating the model to fit the empirical response of housing liquidity to monetary policy, simulations generate a plausible endogenous loan-to-value response that can be compared to empirical impulse responses. This loan-to-value ratio response amplifies the initial impact of the policy shock on the model economy.

In establishing these results, this paper uncovers a more general mechanism through which any shock to housing liquidity, stemming from housing demand or supply, can generate endogenous changes in leverage: lenders feel more comfortable lending because seized property collateral can be resold more easily in hot markets and vice versa. Furthermore, the paper develops a tractable Dynamic Stochastic General Equilibrium model with both search frictions in the housing market as well as credit-constrained agents. This allows examination of the interaction between asset market search frictions and credit frictions in a medium-scale macroeconomic framework. Finally, this analysis offers a novel approach towards calibrating the housing market search frictions technology. In the labour markets literature, search friction technology parameters can be estimated directly, since both the number of workers searching for work (the unemployed) as well as job vacancies are recorded. In the housing market however, while measures of for-sale housing are available, the mass of searching house buyers is not. Instead this study proposes an indirect calibration approach using perturbations from monetary policy shocks.

This paper expands on the growing literature that explores the macroeconomic implications of credit frictions. In the spirit of Shleifer and Vishny (1992) and Kiyotaki and Moore (1997), agents have to offer collateral in order to access loans. Specifically, this paper builds on work by Iacoviello (2005) and Iacoviello and Neri (2010) in which consumers borrow against housing. However, while existing work emphasizes the feedback from asset prices to credit access (keeping borrowing margins fixed), this paper focuses on the amplifying role of time-varying borrowing margins. By emphasizing the substantial time-variation in housing transaction volumes and loan-to-value ratios, this study suggests that an exclusive focus on asset prices may substantially underestimate the response of overall asset debt capacity to monetary policy.

In this sense, this study complements other current work studying procyclical borrowing margins.[1] Eisfeldt (2004) and Kurlat (2009) develop a theory of borrowing margins based on the greater severity of asymmetric information problems during downturns. Geanakoplos (2009) shows that disagreement between optimists and pessimists can cause leverage to rise during asset booms.[2] Relative to this literature, this paper identifies the collateral sales rate as key contributing factor to borrowing margins in the housing market. Furthermore, this paper speaks directly to the popular notion that loose monetary policy causes loose credit conditions.

Finally, this paper is heavily indebted to the literature on markets with search frictions. Specifically, in terms of formalization and notation, this study borrows from the labour markets search frictions survey in Pissarides (2000). The idea that housing market search frictions are important for the evolution of house prices and transaction volume has been explored, among other contributions, in Wheaton (1990), Williams (1995), Krainer (2001), Albrecht et al. (2007), Novy-Marx (2009), Piazzesi and Schneider (2009) and Ngai and Tenreyro (2009). This paper applies these insights to study the interaction between search frictions in the housing market and access to mortgage finance.[3]

Section 1 documents the response of the macroeconomy and the housing market to monetary policy shocks. Section 2 proposes a simple accounting exercise to explore whether housing liquidity dynamics can explain the response of loan-to-value ratios to monetary policy. Section 3 integrates this mechanism in a New Keynesian general equilibrium model with borrowing constraints. Section 4 explores the general equilibrium properties of the housing liquidity channel of monetary policy at the heart of this paper. Section 5 offers concluding comments.

[1]The Costly-State-Verification models of Bernanke and Gertler (1989) and Bernanke, Gertler and Gilchrist (1999) also introduce time-varying leverage in a macroeconomic general equilibrium model, though this is not their focus. Because the setup implies a positive relation between credit spreads and leverage, their finding that spreads fall after expansionary monetary policy implies that leverage should fall. Linking their setup with the search frictions theory of asset liquidation values developed in this study appears a fruitful area for further research.

[2]Simsek (2012) refines this work further, distinguishing between belief disagreement on the upside or downside of risk. In a related line of research, Brunnermeier and Pedersen (2009) and Adrian and Shin (2010) link borrowing margins to collateral asset return volatility.

[3]Parallel to the writing of this paper, Hedlund (2014) explores a framework with housing search frictions and credit frictions in which illiquidity of housing raises default probabilities during recessions. Rachedi (2014) uses the housing market setup in this paper to explore the impact of uncertainty shocks.

1 Motivating Empirical Evidence

Documenting the reduced form dynamic response of the macroeconomy and the housing market to monetary policy shocks, this section establishes the key facts that frame and discipline the argument developed in this paper. To overcome endogeneity of the monetary policy stance, this study adopts the methodology of Romer and Romer (2004).[4] Naive causal interpretation of the correlation between the monetary policy stance and the state of the real economy would conclude that expansionary monetary policy causes economic contractions. However, this neglects that the central bank policy rate responds endogenously to economic conditions, lowering rates in times of crisis precisely in order to counteract shocks from other sectors of the economy. Therefore, to identify exogenous shocks to monetary policy, Romer and Romer (2004) regress the historical intended federal funds rate on contemporaneous forecasts of the future macroeconomic state. They interpret the resulting estimated functional relationship as an estimate of the central bank policy response function. The historical deviation of the actual federal funds rate from the policy rule (labelled f_t) therefore identifies movements in monetary policy that are not a response to macroeconomic fundamentals.[5] Specifically, to analyse the dynamic impact of monetary policy shock f_t on an economic variable of interest x_t, Romer and Romer (2004) propose the single-equation regression model 1.1. Monthly dummies ($D_t(k)$ for dummy month k) are used as seasonal controls. Wherever not otherwise stated, the availability of the Romer and Romer (2004) shock series constrains the sample period considered in the regression to the interval 1969-1996.

$$\Delta log(x_t) = a_0 + \sum_{k=1}^{11} a_k D_t(k) + \sum_{l=1}^{L_x} b_l \Delta log(x_{t-l}) + \sum_{l=1}^{L_f} c_l \Delta f_{t-l} + \epsilon_t \tag{1.1}$$

Figure 1 plots the eight monthly US time series considered in this analysis: the federal funds rate, industrial production, employment (non-construction), the Consumer

[4] Appendix A shows that results are qualitatively similar using an alternative monetary policy identification strategy, namely recursive Vector-Autoregressions.

[5] Romer and Romer (2004) have generously made this data series available on their website `http://elsa.berkeley.edu/users/cromer/Shocks/RomerandRomerDataAppendix.xls` at time of writing.

Price Index (CPI), the effective mortgage rate, real house prices, the monthly housing sales rate and the loan-to-value ratio. The effective mortgage rate is the average effective interest rate on single-family mortgages collected by the Federal Housing Finance Agency (FHFA). The real house price is the Freddie-Mac House price index normalized by the CPI. The monthly housing sales rate is proxied using the ratio of new houses sold to new houses for-sale. This data is provided by the U.S. Census Bureau. The loan-to-value ratio is the average loan-to-value ratio on single-family mortgages collected by the FHFA. As a crucial variable in the analysis of this study, note that the housing sales rate is highly cyclical (and seasonal). Furthermore, in any given month, the number of for-sale properties far exceeds the number of houses actually sold. Given an average sales rate of 17.7% (implying an average time-to-sale of 5.7 months), the time series reaches a minimum value of 7% and a maximum value of 33%.[6]

[Figure 1 about here.]

Figure 2 uses the Romer and Romer (2004) approach to estimate the dynamic response of these eight variables to a one standard deviation monetary policy shock.[7] The effective federal funds rate falls by 100 basis points within two months, recovers and then overshoots after two years - reflecting the systematic response of the Federal Reserve to rising inflation. The macroeconomic response to monetary policy is substantial. Output rises to peak at 3% (relative to its trend value) after two years. The aggregate price level responds sluggishly at first, but inflation decidedly gains momentum as the economy reaches the two year mark.[8] Turning to the housing market, as documented in Iacoviello

[6]The procyclicality of housing transaction volumes has been previously highlighted. See for example Stein (1995) for US data and Andrew and Meen (2003) for the UK economy.

[7]Following Romer and Romer (2004), confidence intervals are computed through Monte-Carlo simulations. 10000 regression coefficients and associated impulse responses are drawn from a multivariate normal distribution with mean at the point estimates and estimated variance-covariance matrix. The month k standard error is then computed as the standard deviation across impulse response function values at month k. The regressions include 36 lags of the dependent variable and 48 lags of the Romer and Romer (2004) shock series.

[8]These macro impulse responses follow closely the results in Romer and Romer (2004). Specifically, relative to traditional recursive identification schemes, the real effect of monetary policy is stronger and the price level effect is more delayed.

(2005), house prices rise substantially after a fall in the federal funds rate - reaching a peak at 3% relative to steady state after 2 years.

Two additional crucial observations from figure 2 motivate the housing liquidity channel of monetary policy explored in this paper. First, the price response of housing pales in comparison with the response of the housing sales rate: the latter jumps by 20% immediately following the policy shock (from a long term average of 17.7% to 21.2%). Only over time, as house prices pick up, does this increase in transactions recede.[9] Second, the loan-to-value ratio on issued mortgages increases relative to trend in the two years following an expansionary monetary policy shock. Classic macroeconomic general equilibrium models assume fixed leverage ratios in response to monetary policy.

[Figure 2 about here.]

2 Partial Equilibrium Accounting Exercise

This section proposes a partial equilibrium accounting exercise to explore whether the housing liquidity response to monetary policy can help explain the response of mortgage loan-to-value ratios. This takes the housing liquidity dynamics estimated in section 1 as given - and then explores whether feeding these impulse responses in a simple modelling framework can replicate the empirical dynamics of loan-to-value ratios.

A link between loan-to-value ratios and housing liquidity emerges naturally under the plausible assumptions that (i) mortgage credit access is tied to the liquidation value that lenders assign to vacant property collateral in case of foreclosure and (ii) liquidation values depend on the speed at which properties can be resold. Specifically, denote the liquidation value of vacant property collateral by $q_{v,t}$. Given foreclosure, the bank pays per-period holding costs c_h on the vacant property, such as maintenance costs and property tax, until a buyer for the property is found with per-period sales probability $P_{s,t}$. The house is then sold at market price $q_{m,t}$ and the seller pays a one-off proportional fixed sales cost

[9] Previous studies that look at the response of housing market variables to monetary policy on the price and volume dimension confirm these empirical results (see Hort (2000) for Swedish data).

F_s, reflecting for example real estate agent fees. Denoting the seller stochastic discount factor with Q_t, the housing liquidation value is therefore given by present value equation 2.1.

$$q_{v,t} = E_t(Q_{t+1}(-c_h + P_{s,t+1}q_{m,t+1}(1 - F_s) + (1 - P_{s,t+1})q_{v,t+1})) \tag{2.1}$$

Given that debt capacity is linked to liquidation value, the loan-to-value ratios that lenders will accept on property collateral are linked to the ratio between housing liquidation value $q_{v,t}$ and the regular house purchase price $q_{m,t}$. Dividing equation 2.1 by current transaction prices yields expression 2.2. Note that the liquidation value $q_{v,t}$ can also be interpreted as the fire-sale price at which housing can be sold instantly on the market (to any speculator). Any intermediary will be willing to buy the house at liquidation value, since the implied fire-sale discount relative to regular transaction price compensates for expected holding costs until the house can be resold to a buyer household. Equation 2.2 therefore naturally generates a link between loan-to-value ratio, fire-sale discounts and the housing sales rate.

$$LTV_t \approx \underbrace{\frac{q_{v,t}}{q_{m,t}}}_{\text{Fire-sale discount}} = E_t\left(Q_{t+1}\frac{q_{m,t+1}}{q_{m,t}}\left(-\frac{c_h}{q_{m,t+1}} + \underbrace{P_{s,t+1}}_{\text{Sales rate}}(1 - F_s - \frac{q_{v,t+1}}{q_{m,t+1}}) + \frac{q_{v,t+1}}{q_{m,t+1}}\right)\right) \tag{2.2}$$

To make equation 2.1 operational, this section requires an expression that identifies the seller discount factor Q_{t+1} empirically. The study therefore makes the assumption that banks price the risk-free asset with return $R_{f,t}$, yielding equilibrium expression 2.3. Equations 2.1 and 2.3 represent basic accounting equations that will hold in a large class of general equilibrium settings. For example, they will be derived as outcomes of optimizing behaviour in the macroeconomic model of section 3. Key however is that these two expressions in themselves impose sufficient structure to infer from the impulse responses in section 1 how housing debt capacity responds to monetary policy.

$$1 = R_{f,t} E_t(Q_{t+1}) \tag{2.3}$$

Using first order approximations around the non-stochastic steady state, iterating 2.1 forward, imposing a no-bubble condition and using 2.3 to substitute out the discount factor, yields expression 2.4 (see appendix B).[10] This equation is key to the quantitative exercise in this section. Given a calibration for ρ_1, ρ_2 and ρ_3, it backs out the liquidation value banks assign to housing collateral given the expected path of the risk-free rate, the housing sales rate and housing transaction prices generated in section 1. From ρ_1, note that the sensitivity of housing liquidation values to the housing sales rate depends on the difference between this steady state fire-sale discount $1 - (q_v^*/q_m^*)$ and the one-off cost of making the sale F_s. Approximately, this difference represents how much of the steady state fire-sale discount is explained by expected holding costs driving the search process. If expected holding costs are important, then the fire-sale discount also becomes more sensitive to fluctuations in the sales rate around steady state.

$$\hat{q}_{v,t} = \underbrace{\rho_1 \sum_{j=0}^{\infty} \rho_3^j E_t(\hat{p}_{s,t+1+j})}_{\text{Sales rate component}} + \underbrace{\rho_2 \sum_{j=0}^{\infty} \rho_3^j E_t(\hat{q}_{m,t+1+j})}_{\text{Price component}} + \underbrace{- \sum_{j=0}^{\infty} \rho_3^j E_t(\hat{r}_{f,t+1+j})}_{\text{Discount factor component}} \tag{2.4}$$

$$\text{where } \rho_1 = \frac{Q^*((1 - F_s) - (q_v^*/q_m^*))P_s^*}{(q_v^*/q_m^*)} \tag{2.5}$$

$$\rho_2 = \frac{Q^* P_s^* (1 - F_s)}{(q_v^*/q_m^*)} \tag{2.6}$$

$$\rho_3 = Q^*(1 - P_s^*) \tag{2.7}$$

To calibrate expression 2.4 at monthly frequency, set the yearly steady state risk-free rate to 4%. To gauge the size of the steady state fire-sale discount in the housing market, this study uses evidence from existing empirical studies. Mayer (1998) finds that

[10] Terms with star superscript denote steady state values and terms with hat accent denote (log) deviations from steady state.

housing sales at auctions in the 1980s (generally associated with foreclosure events) sell at discounts of up to 9% in Los Angeles (boom market) and 9-21% in Dallas (oil bust). In a study of the Massachusetts housing market, Campbell, Giglio and Pathak (2009) estimate foreclosure-related price discounts of 27% of house value. Taking orientation around these numbers, this paper assumes an average fire-sale discount of 15% as a baseline scenario. This calibration has a second convenient interpretation, since it also fits with general priors on steady state loan-to-value ratios of 85% (see Iacoviello and Neri (2010) for example).

It is generally difficult to pin down what fraction of the fire-sale discount on housing is explained by expected holding costs during time-to-sale and what fraction is explained by the one-off seller transaction costs once a buyer household is found. At the same time, as the expression for ρ_1 demonstrates, exactly this calibration decision is crucial in determining how sensitive housing liquidation values are to the housing sales rate. This study therefore takes a conservative baseline approach. It formulates a lower bound on the size of expected holding costs and shows that, even given this conservative choice, the housing liquidity channel is a potent factor in the valuation of vacant for-sale housing. Specifically, as in Poterba (1991), this study assumes yearly holding costs of a vacant property equal yearly property tax and maintenance costs at 2% and 3.9% of house price respectively ($c_h = m + \tau$).[11] Through expression 2.1, this implies one-off seller transaction costs of around 10% of the steady state regular house price.

[Figure 3 about here.]

Figure 3 combines the calibrated version of equation 2.4 with the empirical impulse responses of house prices, housing sales rate and the discount factor from section 1 to generate a simulated response of the ratio between liquidation values and house prices to

[11] In fact, Poterba (1991) suggests that ownership risk substantially drives up the holding costs of property. Effectively, owning a vacant house creates exposure to future house price fluctuations. Adding a yearly 4% risk premium to property holding costs, Poterba (1991) therefore estimates that overall yearly holding costs for housing are about 10%. This higher holding cost would increase the sensitivity of loan-to-value ratios in the housing search frictions framework beyond the baseline results reported in this study.

a loosening of monetary policy. The increase in simulated liquidation values beyond house prices can broadly explain the peak magnitude by which empirical loan-to-value ratios are found to respond in section 1. The decomposition of the simulated liquidation value response in figure 4 furthermore shows that much of the initial response of liquidation values can be traced back to the strong increase of empirical housing sales rates following monetary policy expansions.

Interestingly, this search-theoretic lens also predicts that loan-to-value ratios temporarily fall below steady state as the expansionary monetary policy shock dies out - a fact consistent with the dynamic regressions in section 1. Effectively, since the search framework acknowledges that selling collateral takes time, lenders become forward-looking and become concerned about future price developments. Besides the sales rate, equation 2.2 therefore suggests that loan-to-value ratios will be higher when house prices are forecasted to appreciate. It follows that, as the policy shock dies out and the initial housing sales rate reverts to steady state after a year, the expectation of a slow reversion of temporarily high house prices back towards steady state will temporarily depress loan-to-value ratios.

[Figure 4 about here.]

Overall, the quantitative exercise of this section suggests that housing liquidity and price dynamics, combined with a search friction theory of liquidation values, can indeed explain why loan-to-value ratios increase on impact after expansionary monetary policy.[12] However, this exercise does not offer a story for why the housing market responds to central bank action through both the house price and the sales rate margin. It does not explicitly spell out how this collateral liquidity effect translates into expanding consumer credit and output growth. It does not estimate the contribution of this housing liquidity channel of monetary policy to the overall macroeconomic effect of central bank action.

[12] As with the other housing market variables in section 1, the empirical loan-to-value lags behind the monetary policy shock and the simulated response of the ratio between liquidation values and house prices. While outside the scope of this paper, this may reflect lags in the adjustment of house purchase contract terms to market conditions. It also reflects that the terms of house purchases are often negotiated months before a mortgage is closed and recorded.

Section 3 develops a structural macroeconomic model that attempts to address these issues.

3 A Macroeconomic General Equilibrium Model

This section introduces housing market search frictions into a stylized Dynamic Stochastic General Equilibrium model with credit-constrained entrepreneurs. In this setup, the housing sales rate naturally manifests itself as a determinant of housing fire-sale discounts and of household borrowing margins, yielding a housing liquidity channel of monetary policy transmission to the real economy.

The economy consists of four agent types. Patient (p) consumer households consume, work, occupy housing and trade in a range of financial assets. Impatient (ip) entrepreneur households also consume, occupy housing and trade in a range of financial assets. However, in addition, they operate wholesale firms on their properties to produce intermediate goods. In equilibrium, impatient households will demand to borrow from the patient, creating a role for credit markets. Retail firms transform intermediates production into final goods that are sold to consumers under monopolistic competition with Calvo-style price adjustment rigidities. Finally, a central bank regulates nominal interest rates according to a Taylor-type monetary policy rule.

As shown in figure 5, each period t consists of four phases. In the first phase, aggregate shock innovations to the economy are observed. In the second phase, a fraction of occupied housing becomes unsuitable for the current occupiers and effectively becomes vacant. The household may have to move town because of a new job opportunity. A growing family may require a house with more room for their children. A retired couple may wish to trade down into a smaller housing unit with wheelchair access. In the third phase, the housing, goods, labour, equity and debt markets open. Key is that households engage in a costly and time intensive search process to find a suitable new home. In the fourth phase, debtor households can make an offer to renegotiate debt (in the spirit of Hart and

Moore (1994) and Kiyotaki and Moore (1997)). The creditor has the choice of accepting or rejecting the proposal. This renegotiation threat makes the collateral constraint of debt contracts relevant in equilibrium.

[Figure 5 about here.]

3.1 Households

Type $i = \{p, ip\}$ households value consumption c_t^i and fit-for-occupation (matched) housing h_t^i. Patient consumers experience disutility from providing labour effort l_t^i. Assuming that within-type households insure each other against idiosyncratic shocks through informal and formal financial contracts, all within-type households face identical decision problems. For analytical tractability, the setup can therefore be thought of as consisting of one patient and one impatient representative household.[13] This paper assumes an expected utility objective function 3.1 for both types of households, with log utility in consumption and housing as well as general CRRA utility in leisure.[14]

$$\sum_{s=0}(\beta^i)^{t+s}E_t(ln(c_{t+s}^i) + jln(h_{t+s}^i) - \chi\frac{(l_{t+s}^i)^{1+\varphi}}{1+\varphi}) \tag{3.1}$$

As a key distinguishing feature between the two consumer types, patient households put greater weight on future felicity ($\beta^p > \beta^{ip}$). In equilibrium, this will generate existence of a debt market in which patient households lend their savings to impatient households.

A fraction z of occupied housing becomes unfit for its current residents in phase 2

[13]The big family assumption is clearly a convenient stylized modelling device (see its explicit use in Merz (1995) and Andolfatto (1996)). However, the notion has roots in reality. Assume a grandfather is bound to a wheelchair and can therefore not climb the stairs of his home. The daughter may have to drive to the grandfather's house after work every day to help him with the household. An office worker may find a new job in a distant city. To avoid the long commute, he may ask friends to stay in their guest room weekdays until his old house can be sold and he can himself settle closer to work. In utility terms, the cost of mismatched housing may well be spread across the extended network of a household.

[14]The log functional restrictions for consumption and housing ensure a stable relation between housing expenditures and consumption even in periods of prolonged house price deviations from steady state (see Davis and Heathcote (2005) and Fisher (2007)).

of period t. For simplicity, assume that owning housing that is unfit yields no utility benefits to its current owner. In this sense, unfit housing becomes effectively vacant. Given new acquisitions of matched housing $a^i_{m,t}$, equation 3.2 denotes the evolution of occupied housing for households of type i.

$$h^i_t = (1-z)h^i_{t-1} + a^i_{m,t} \tag{3.2}$$

To acquire new occupied housing, households search with effort $e^i_t \geq 0$. Denoting by $P_{b,t}$ the probability of finding appropriate housing (per unit of search effort), new acquisitions of matched housing are described by equation 3.3.

$$a^i_{m,t} = P_{b,t} e^i_t \tag{3.3}$$

Housing that becomes vacant is offered for sale to households searching for new homes and has a per-period probability of sale $P_{s,t}$. If an appropriate buyer household is found, the transaction takes place at regular market price $q_{m,t}$. Once the search market closes, a vacant housing spot market opens in which vacant lots can be sold instantly to speculators at fire-sale price $q_{v,t}$. Denoting by $a^i_{v,t}$ net acquisitions of vacant housing in the spot market, equation 3.4 displays the evolution of vacant housing v^i_t held by type i households at the end of period t.[15]

$$v^i_t = (1-P_{s,t})(v^i_{t-1} + zh^i_{t-1}) + a^i_{v,t} \tag{3.4}$$

Transactions on the housing market are costly. In search market transactions that lead to occupation, buyers and sellers incur proportional one-off transaction costs F_b and

[15]The existence of a spot market for vacant housing has two aims. First, conceptually, it offers households the option to sell quickly to a speculator (at a liquidation discount) or to engage in lengthy and costly search for a regular house buyer (and then sell at a higher regular price). In a stylized way, the framework therefore features a trade-off between speed of sale and sale price. In this sense, monetary policy affects the steepness of this trade-off. Second, technically, the vacant housing spot market ensures that vacant housing is priced by those households that put highest value on holding it (the patient households in equilibrium). This will simplify the bargaining game, since all sellers put the same value on owning vacant housing at the end of every period.

F_s. Buyers pay consumption cost κ_b per unit of search effort devoted to finding new housing fit for occupation. At the start of period t, households pay maintenance m and property tax τ on all housing held (vacant as well as occupied). Equity in retail firms held o^i_t (normalized to net supply measure 1) trades on a spot market at price $q_{o,t}$. Given retail firm dividends $\Pi_{r,t}$, equity holdings yield $\Pi_{r,t}o^i_{t-1}$ in period t. Denote by $\Pi^i_{w,t}$ profits from wholesale production activity which derive entirely to the impatient entrepreneur. Denoting the nominal return on debt by R_{t-1} and denoting inflation by $\pi_t = p_t/p_{t-1}$, the real yield on debt b^i_t is R_{t-1}/π_t. Given wage w_t for the patient consumer household, equation 3.5 denotes the consumer budget constraint.

$$
\begin{aligned}
& c^i_t + \frac{R_{t-1}b^i_{t-1}}{\pi_t} + q_{o,t}\Delta o^i_t - (w^i_t l^i_t + b^i_t + o^i_{t-1}\Pi_{r,t} + \Pi^i_{w,t}) \qquad (3.5)\\
= & \underbrace{q_{m,t}(1-F_s)P_{s,t}(v^i_{t-1} + z h^i_{t-1})}_{\text{Revenue from housing sales to new occupiers}} - \underbrace{(q_{v,t}a^i_{v,t} + q_{m,t}(1+F_b)a^i_{m,t})}_{\text{Cost of property purchases}}\\
- & \underbrace{\kappa_b e^i_t}_{\text{Cost of search effort}} - \underbrace{((m+\tau)(h^i_{t-1} + v^i_{t-1}))}_{\text{Cost of tax and maintenance on housing}}
\end{aligned}
$$

Finally and crucially, the threat of debt renegotiation in phase four of period t imposes a borrowing constraint (as in Kiyotaki and Moore (1997) and Iacoviello (2005)). Effectively, in the spirit of Hart and Moore (1994), borrowers have the option to repudiate the debt contract. In that case, the lender takes control of the housing collateral underlying the contract. The borrower makes a take-it-or-leave-it alternative loan repayment offer to keep the house. The lender can either accept this alternative offer or he can move the house into his foreclosure inventory. To prevent renegotiation, lenders ex-ante keep the loan small enough relative to the liquidation value they assign to collateral. They can then credibly commit to not accepting renegotiation offers. Equation 3.6 denotes the resulting size limit on debt contracts.

$$E_t(Q^{i'}_{t+1}\frac{R_t}{\pi_{t+1}})b^i_t \leq q_{v,t}h^i_t \tag{3.6}$$

3.2 Search And Matching In The Housing Market

The search market for fit-for-occupation housing borrows from the labour market formalization summarized in Pissarides (2000). Assume a Cobb-Douglas matching function M_t that determines the mass of matches between buyers and sellers as a function of aggregate buyer search effort e_t and vacant housing, the old stock v_{t-1} carried over from the last period and newly vacated housing zh_{t-1}. Variables without superscript are used here to denote the respective aggregates across agent types.

$$M_t = e_t^{1-\gamma}(v_{t-1} + zh_{t-1})^{\gamma} \tag{3.7}$$

Defining market tightness θ_t as the ratio of search effort over vacant housing, this yields closed-form solutions for the matching probabilities of buyers and sellers.

$$P_{b,t} = \frac{M_t}{e_t} = \theta_t^{-\gamma}$$
$$P_{s,t} = \frac{M_t}{v_{t-1} + zh_{t-1}} = \theta_t^{1-\gamma}$$

The search literature commonly determines transaction prices once a match between buyer and seller is found using Nash bargaining. In the Nash bargaining solution, the house price $q^N_{m,t}$ effectively divides the economic surplus from transferring a house to a new occupying household (as opposed to the outside option of not executing the transaction) proportionally according to relative bargaining power. Since sellers can sell on the vacant housing spot market if they cannot sell on the search market, the outside option of sellers (of either consumer type) equals the vacant housing liquidation price $q_{v,t}$

in equilibrium. Denoting by ω the share of the total transaction surplus accruing to the seller (the bargaining weight) and by V_t^f the fundamental valuation that households assign to fit-for-occupation housing, this implies a unique per-period Nash bargained price determined by equation 3.8 (irrespective of which consumer type is buyer or seller in a specific negotiation).[16]

$$q_{m,t}^N(1-F_s) - q_{v,t} = \omega(V_t^f - q_{v,t} - (F_s + F_b)q_{m,t}^N) \tag{3.8}$$

From the empirical results in section 1, it appears that house prices are sluggish. The model therefore assumes that house prices have a backward-looking component (encompassing flexible price Nash-bargaining as a special case). Specifically, assume that the average house transaction price in period t is determined as weighted average of the average transaction price in the preceding period and the current price outcome from Nash bargaining ($q_{m,t}^N$). In calibration of the model, the sluggishness parameter s of this pricing equation is set to match the impulse response function of the housing market to monetary policy (with $s = 1$ yielding fully flexible Nash-bargained house prices).[17]

$$q_{m,t} = sq_{m,t}^N + (1-s)q_{m,t-1} \tag{3.9}$$

3.3 Firms, Policy & The Shock Process

Impatient households use their occupied property, together with hired labour from the patient consumer, to produce intermediate inputs. Output is sold to retailers in a perfectly

[16] In the neighbourhood of the steady state, fundamental valuation of a matched property will be equalized across household types (see below). In introducing notation in this section, I anticipate this result.

[17] A simple story justifying pricing rule 3.9 goes as follows. Assume that the economy consists of a large number of regions (and, implicitly, that search effort cannot be directed at specific regions). In a given region, the transaction price is determined with reference to the previous period transaction price with probability $1-s$. With probability s, the transaction price is determined by the outcome $q_{m,t}^N$ of Nash bargaining between buyer and seller (defined further below). It follows that a region features the Nash bargaining price of k periods ago with probability $(1-s)^k s$. If transactions occur whenever buyers find an appropriate vacant property, it follows that the average transaction price is given as the weighted average of past Nash bargaining prices: $q_{m,t} = sq_{m,t}^N + (1-s)sq_{m,t-1}^N + s(1-s)^2 q_{m,t-2}^N + ...$ Writing this expression recursively yields equation 3.9 (as a natural analogue to Calvo-pricing in firm price-setting).

competitive market at price p_t. Denoting by x_t the retailer mark-up on prices, equation 3.10 denotes the problem of the wholesale firm. The parameter α sets the equilibrium fraction of income going to labour.

$$Max\frac{1}{x_t}A((l_t^p)^{\alpha}(h_{t-1}^{ip})^{\mu} - w_t l_t^p \tag{3.10}$$

Following the New Keynesian literature, retail firms differentiate output by type j and set prices $p_t(j)$ in a monopolistically competitive environment subject to Calvo-pricing. A fraction ϑ of firms can adjust prices in period t. Consumers aggregate output y_t subject to a Dixit-Stiglitz technology with parameter λ_f. The optimisation problem for those retail firms that can adjust prices is therefore given by expression 3.11.[18] Profits from market power are rebated to the consumer through lump-sum per period dividends $\Pi_{r,t}$.

$$Max_{p_t(j)}\sum_{s=0}(\vartheta\beta^p)^s\frac{c_t^p}{c_{t+s}^p}\frac{p_t}{p_{t+s}}(p_t(j) - p_{t+s})y_{t+s}(j) \tag{3.11}$$

$$\text{s.t.}y_{t+s}(j) = (\frac{p_{t+s}}{p_t(j)})^{\frac{\lambda_f}{\lambda_f-1}}y_{t+s} \tag{3.12}$$

The central bank sets interest rates according to a Taylor-type interest rate rule for monetary policy subject to autoregressive monetary policy shock m_t. Effectively, the central bank raises the interest rate in response to widening of the output gap as well as rising inflation.

$$R_t = (R^*)^{r_r}(\pi_{t-1}^{1+r_\pi}(\frac{Y_{t-1}}{Y^*})^{r_Y})^{1-r_r}m_t \tag{3.13}$$

$$log(m_t) = \rho_m log(m_{t-1}) + \epsilon_t \tag{3.14}$$

[18]The assumption that firms use the discounting factor of the patient consumer to evaluate future profits is subsequently validated, as in the neighbourhood of the steady state only patient households will hold firm equity.

3.4 Equilibrium

To recapitulate, it is useful to define formally an equilibrium in this environment. An equilibrium is an allocation of prices (R_t, w_t, $q_{m,t}$, $q_{v,t}$, p_t, $q_{o,t}$,$p_t(j)$) and quantities ($a^i_{m,t}$, $a^i_{v,t}$, c^i_t, h^i_t, v^i_t, e^i_t, l^p_t, o^i_t, b^i_t, $y_t(j)$) such that households maximimize utility, firms maximize profits, the search and matching market for foreclosed housing follow the dynamics set out in subsection 3.2, monetary policy follows the prescribed Taylor rule and all remaining markets clear given any history of shock realizations.

4 Model Results

The full first order conditions linked to the solution of the model presented in section 3 are described in appendix C. This section highlights the key properties of this solution. The main features of the steady state and some dynamic properties can be discussed analytically. The model is then calibrated to match the monetary policy impulse response functions of section 1. This allows counterfactual simulations to quantitatively evaluate the significance of the liquidity effect for monetary policy transmission to mortgage lending and the real economy.

4.1 Analytical Implications

This subsection proceeds to describe analytically the key features of the model steady state as well as several properties of the model dynamics around this steady state.

4.1.1 Steady State

Since the remainder of the paper will be concerned with local perturbations around the steady state, it is useful to start by specifying the salient properties of this steady state through a series of statements. The main text offers the key intuition behind each statement. Analytical proofs can be found in appendix D.

Implication 4.1. *In any non-stochastic steady state, the impatient consumer is borrowing-constrained and the patient consumer is not.*

A simple contradiction argument offers an intuitive interpretation. Conjecture a steady state in which the impatient consumer is not borrowing-constrained. For the bonds market to clear, steady state bond interest rates must be such that the impatient consumer is indifferent between borrowing and saving. But then the patient consumer must have unbounded demand for saving. The bond market cannot be in equilibrium.

This explains why the assumed heterogeneity in consumer discount rates ensures an operational (non-trivial) steady state credit market in the model. Moreover, for small perturbations of the model economy, it follows that the response of impatient households is limited by a binding credit constraint, while the patient consumer is unconstrained.

Implication 4.2. *In any non-stochastic steady state:*

- *Patient and impatient households are committing search effort to finding new housing for occupation* ($e_t^i > 0 \ \forall \ i = p, ip$)*.*
- *Patient and impatient households assign the same fundamental value to occupied housing* ($V_{f,t}^p = V_{f,t}^{ip}$)*.*

Again a contradiction argument is enlightening. Suppose consumer type i did not search for newly occupied housing in steady state. Remember now that a fraction of existing matched housing becomes vacant in every period, cost of searching and purchasing new housing for occupation is finite and marginal utility of occupied housing nears infinity as the occupied housing stock approaches 0. The supposition therefore implies that the consumer's marginal valuation of housing exceeds the cost of purchasing new housing for occupation in finite time. At that point, not searching for housing cannot be optimal for the consumer. Both consumer types searching must be part of any steady state solution.

Suppose now that both consumer types search for appropriate housing in steady state, but the fundamental valuation of housing differs by type. Since both types must then (weakly) prefer searching to not searching, the type with higher fundamental valuation must strictly prefer searching. Optimally, the high fundamental valuation type should therefore raise search effort, increasing housing market tightness and search costs for both types until the lower valuation type is persuaded to stop searching. This contradicts a steady state in which both consumer types search actively for housing fit for occupation.

Implication 4.3. *In any non-stochastic steady state:*

- *The patient consumer holds all equity and vacant housing.*
- *The patient consumer (the marginal buyer), prices equity and after-search vacant housing.*

Intuitively, the patient consumer requires a lower rate of return to hold assets until the next period. The patient consumer therefore prices equity and vacant housing down to the level at which the impatient consumer leaves these markets. It follows that patient households hold all assets in steady state (as well as for small deviations around the steady state).

Jointly, statements 4.2 and 4.3 lead to a key representational simplification of the model: in every period there exists a unique Nash-bargained transaction price for housing. To understand why this is surprising, note that the Nash-bargained price depends on the payoffs and outside options of buyer and seller involved in a transaction. It follows that a model with two consumer types generally exhibits four different Nash bargained house prices (a price when the buyer is patient and the seller is patient, a price when the buyer is patient and the seller is impatient and so on).

In this specific modelling setup however, a unique Nash-bargained transaction price emerges. Why? Notice implication 4.3 implies that the seller outside option does not depend on seller type. Because of the spot market in vacant housing, the outside option of both types equals the liquidation value of housing for a patient consumer. Because implication 4.2 shows that the buyer pay-off is independent of type, it therefore follows that, in this framework, the Nash-bargained price of all four buyer-seller type encounters is identical. While this setup is presumably not crucial (in a qualitative sense) for the main conclusions developed in this paper, it substantially increases transparency of model output as well as the calibration procedure. Implication 4.4 summarizes this argument.

Implication 4.4. *In any non-stochastic steady state:*

- *Patient and impatient households face the same outside option during negotiations to sell a vacant house to a new occupant (the vacant house price).*
- *Patient and impatient households face the same gain from successfully concluding negotiations to buy a vacant house for occupation (see fundamental value result for implication 4.2).*
- *By implication, all period t matches lead to a transaction at the same price $q_{m,t}$ (irrespective of buyer and seller types involved).*

4.1.2 Why Does Expansionary Monetary Policy Raise Housing Liquidity?

The interaction between housing market search frictions and house price Nash-bargaining offers a natural explanation for the section 1 finding that monetary policy stimulates housing liquidity. The argument relies on two steps. First, notice that the consumer optimality condition for buyer search effort e_t implies free entry condition 4.1:[19] In equilibrium, the net gain from purchasing a unit of housing equals the expected search costs from buying that unit. Second (and abstracting from house price rigidities), Nash bargaining in prices implies that the buyer surplus from moving into a vacant house is proportional to the economic surplus accruing from the household-property match.

[19]The free entry condition is already simplified taking into account local properties around the steady state summarized in implication 4.2.

$$
\underbrace{\frac{\kappa_b}{\theta_t^{-\gamma}}}_{\text{Expected cost of buyer search}} = \underbrace{V_t^f - q_{m,t}(1+F_b)}_{\text{Buyer surplus}} \tag{4.1}
$$

$$
= (1-\omega)\underbrace{\left(V_t^f - q_{v,t} - (F_s + F_b)q_{m,t}\right)}_{\text{Total match surplus}}
$$

In combination, these two steps offer a story for the link between monetary policy and housing market liquidity. Temporary low interest rates raise the present value (in consumption terms) of the current and future flow of housing services to an occcupier household. This drives up the economic surplus from a match between household and property and, through Nash bargaining, the buyer payoff from purchasing a home. In equilibrium, more buyers enter the housing market, driving up search costs to the point that search costs equalize expected benefits from locating a house. From a seller perspective, in a market crowded with potential buyers, the rate at which vacant housing can be resold to new occupiers rises.[20]

4.1.3 Why Does Higher Housing Liquidity Raise Consumer Credit Access?

The solution to the consumer utility maximisation problem 3.1 naturally generates the equilibrium valuation of vacant property 2.1 derived intuitively in section 2. In turn, rewriting the impatient consumer credit constraint (that binds around the steady state according to implication 4.1), the fire sale discount emerges as a crucial determinant of the loan-to-value ratio. The security offered to lenders by housing collateral depends inherently on the costs associated with liquidating that collateral in case of default. When liquidation costs are high because fire-sale discounts are large, then banks tighten credit

[20]Two additional comments are useful at this point. First, key to this result is that buyers have bargaining power. This ensures that house prices rise by less than the change in fundamental housing value following a fall in interest rates. It follows that the sensitivity of housing liquidity to monetary policy rises in buyer bargaining power. Second, notice house price rigidities mean that house prices respond even more sluggishly to monetary policy than under Nash bargaining. Following the intuition in the main text, this makes buyer surplus and housing liquidity even more sensitive to changes in the policy rate.

access.

$$LTV_t = \frac{b_t^{ip}}{q_{m,t} h_t^{ip}} = \underbrace{\frac{1}{E_t(Q_{t+1}^p \frac{R_t}{\pi_{t+1}})}}_{\text{Inverse bond return}} \underbrace{\frac{q_{v,t}}{q_{m,t}}}_{\text{Fire-sale discount}} \tag{4.2}$$

Equations 2.2 and 4.2 therefore offer a natural argument suggesting that the housing sales rate response to monetary policy matters for the overall transmission process. By raising housing liquidity, monetary policy relaxes consumer credit constraints over and above the rise in regular book value of the housing stock.

4.1.4 Why are Backward-Looking House Prices needed to generate large Housing Liquidity Responses to Monetary Policy?

Notice that the Nash bargaining price implies that buyer and seller surplus from matching a vacant house to a new household are positively related (see equation 4.3). Combined with buyer free entry and a Cobb-Douglas matching technology, this generates a mechanism significantly dampening housing liquidity fluctuations.

Intuitively, buyers take advantage of low housing sale rates to drive down Nash-bargained prices in negotiations (since the seller surplus from a transaction rises). In turn, this raises the ex-ante incentive to search for housing. The number of buyers in the housing market rises, housing liquidity rises and the original fall in house prices is dampened.

$$\omega \underbrace{(V_t^f - (1+F_b) q_{m,t}^N)}_{\text{Buyer surplus from match}} = (1-\omega) \underbrace{(q_{m,t}^N (1-F_s) - q_{v,t})}_{\text{Seller surplus from match}} \tag{4.3}$$

As will be seen in the calibration of the subsequent section, the model therefore strongly suggests that house prices do not follow Nash-bargaining. Instead, house prices have a backward looking component. Buyers cannot instantly take advantage of the bad bargaining position of house sellers in illiquid property markets. In equilibrium, this amplifies the role of housing liquidity fluctuations.

4.2 Calibration

The quarterly calibration of the model follows a two-step procedure. Wherever possible, this study uses reference parameters from the literature.

As in Iacoviello (2005), set the yearly discount factors of patient and impatient households to 0.99 and 0.98. This reflects estimates on the range of discount factors across the US population found in the micro studies of Lawrance (1991), Carroll and Samwick (1997) and Samwick (1998). Set labour market parameter $\chi_l = 1$ and housing preference parameter $\chi_h = 0.15$ to ensure a steady state housing-GDP ratio of 1.5. Normalize productivity factor $A = 1$ and the total housing supply $\bar{H}$ to 1. Set the monetary policy response to output gap and inflation as in the baseline model of Iacoviello (2005) ($r_r = 0.73$, $r_y = 0$ and $r_\pi = 0.27$). Following convention, set labour wage elasticity to $\varphi = 0.01$ and steady state mark-up $X^* = 1.05$.

As in Ngai and Tenreyro (2009), set the rate at which housing is unmatched z to 2.78% for consistency with an average stay in a house of 9 years, following the median duration of stay in a house according to the American Housing Survey 1993-2005. Matching a steady state time-on-market for vacant housing of 5.7 months and a fire-sale discount of 15%, set m, τ and F_s following the calibration approach in section 2. Set κ_b to ensure a steady state monthly sales rate of 20%. Given lack of other information, assume buyer fixed costs are equal to the seller's ($F_b = F_s$). Some evidence in favour of such equal sharing of costs comes from Levitt and Syverson (2008). They report that real estate agents on buyer and seller side generally charge each about 3% of house price for their services.

The housing search friction parameter γ, the house seller bargaining weight ω, the house price persistence parameters s, monetary policy shock persistence parameter ρ_m, the Calvo pricing persistence parameter ϑ and the weight of property in the production function μ are set to minimize the squared distance between model and empirical impulse responses to an annualized 100 basis points shock to monetary policy ($e_m = -0.025$). Specifically, set target moments as first quarter and fourth quarter responses of house price and housing sales rate. Additionally, set parameters to ensure that peak model and empirical response of output coincide. Finally, the calibration targets the five-year price response to the monetary shock. Formally, denoting by u and u^{emp} the model and empirical peak response of variable x (in log-dev. from steady state) respectively, model parameters are chosen according to optimality criterion 4.5.

$$u = \begin{bmatrix} \hat{P}_{s,1} \\ \hat{P}_{s,4} \\ \hat{q}_{m,1} \\ \hat{q}_{m,4} \\ \hat{y}_1 \\ \hat{p}_{20} \end{bmatrix} \tag{4.4}$$

$$Min_{\omega,\gamma,s,\rho_m}(\frac{u-u^{emp}}{u^{emp}})'(\frac{u-u^{emp}}{u^{emp}}) \tag{4.5}$$

The resulting calibration suggests setting $\gamma = 0.79$, $\omega = 0.4$, $s = 0.2$, $\rho_m = 0.8$, $\vartheta = 0.53$ and $\mu = 0.09$. Notably, this implies significant persistence in both house prices and monetary policy shocks. Price rigidities are somewhat weaker than in standard calibrations.[21] Table 1 summarizes the baseline calibration.

[Table 1 about here.]

4.3 Model Simulations

Figure 6 plots the impulse response functions of the calibrated DSGE model to a 100 basis points annualized monetary policy shock.[22] As in the standard New Keynesian framework, expansionary monetary policy lowers interest rates and encourages consump-

[21] Typical DSGE models assume that 75% of firms cannot re-adjust prices in a given quarter, compared to roughly 50% in the baseline calibration of this paper. Intuitively, the calibration yields relatively high pricing flexibility because it aims to match the significant empirical medium-term price response implied by Romer and Romer (2004).

[22] For comparison with the graphs in previous sections, the sales rate response from the quarterly DSGE simulations is expressed in monthly terms.

tion relative to saving. Given price rigidities, firms respond to higher demand by raising production and employment. As prices gradually adjust, this gives rise to a prolonged period of inflation - to which monetary policy endogenously responds by raising the policy rate. As monetary policy eventually fully feeds through into the price level, the real economy reverts to steady state.

In addition to the standard forces of the New-Keynesian framework, lower interest rates also raise the present value of housing services. This encourages more buyers to search for housing and raises the rate at which property can be sold. In turn, this raises the loan-to-value ratio at which impatient entrepreneus can borrow. Both rising loan-to-value ratios as well as higher transaction prices of housing allow an expansion of entrepreneurial activity and output, reinforcing the expansionary impact of a decline in policy rates.

For comparison, figure 6 also plots the empirical impulse response functions estimated in section 1. In line with other basic New Keynesian models, the simulations fail to account for the lag and persistence with which monetary policy affects the economy. Output and prices respond much faster in the simulations than in the empirical impulse response functions.[23] As a result, monetary policy is also endogenously tightened faster in the simulations. In addition, the employment response in the model is significantly stronger than empirical evidence suggests. However, as already suggested by the partial equilibrium exercise in section 2, the model does well in capturing the magnitude of the loan-to-value response, given the calibrated response of the housing sales rate. The calibrated backward-looking component of house prices ensures a hump-shape response, as in the data.

[Figure 6 about here.]

To evaluate the contribution of the endogenous leverage margin of this model to

[23] Christiano, Eichenbaum and Evans (2005) propose several additions to the baseline model that generate additional persistence in output and inflation impulse response functions. This paper refrains from introducing these additions in order to focus attention on the core features driving the housing liquidity channel of monetary policy.

macroeconomic transmission of monetary policy, consider a counterfactual scenario in which lenders are only allowed to raise loan amounts in line with house transaction price q_m: modified borrowing constraint 4.6 holds. Effectively, this rule blends out the housing liquidity effect, since a direct link between transaction prices and the borrowing limit is artificially imposed.

$$E_t(Q^i_{t+1}\frac{R_t}{\pi_{t+1}})b^i_t \leq \frac{q^*_v}{q^*_m}q_{m,t}h^i_t \tag{4.6}$$

Figure 7 plots the cumulative difference between the monetary policy impulse responses of the baseline and the counterfactual fixed-leverage scenario. This shows that the endogenous leverage extension of the DSGE model significantly amplifies the impact of monetary policy on credit access of entrepreneurs. Entrepreneurs expand the use of property in their business. The resulting quasi-productivity shock implies that the same output can be produced with less labour. Given the price rigidities faced by firms in the short-run, at the margin, they respond to higher productivity by reducing employment. Nonetheless, on impact, the endogenous leverage margin overall ampifies the expansionary impact of monetary policy.

As the economy recovers towards steady state, a channel that was already discussed in the partial equilibrium exercise of section 2 emerges in figure 7. The housing sales rate quickly reverts to steady state and a prolonged period of declining house prices sets in. This depresses the loan-to-value ratios that lenders, concerned about future collateral liquidation values, are willing to accept (see equation 2.2). While higher housing sale rates immediately after the monetary policy shock generate a positive quasi-productivity shock, the expectation of house price declines back to steady state generates a persistent negative quasi-productivity shock in the medium run.

[Figure 7 about here.]

4.4 Sensitivity of Results

Figure 8 evaluates how the GDP impact of this endogenous leverage ratio mechanism varies with alternative parameter choices - thereby also yielding additional intuition into the workings of the model.

This exercise highlights the quantitative importance of backward-looking house prices. Increasing the house price flexibility parameter s from 0.2 in the baseline to 0.95, effectively allowing house prices to follow the Nash bargaining solution, the macro contribution of the housing liquidity mechanism becomes negligible. This confirms the intuition discussed in subsection 4.1.4 and the importance of trying to match the empirical hump-shaped response of house prices to monetary policy shocks. In contrast, lowering the house price flexibility parameter s further from 0.2 to 0.05 has very limited impact.

Equally, figure 8 shows that the endogenous leverage mechanism gains in strength as monetary policy shocks become more persistent. The graph considers varying the persistence paramater ρ_m from 0.8 in the baseline to 0.95 and to 0.05. The mechanism also strengthens if property plays a more important role in production. The graph shows alternative simulations in which the housing share in output μ is changed from 0.09 in the baseline to 0.2 and to 0.05.[24]

Finally, this parameter sensitivity exercise reveals the non-linear link between the impact of endogenous leverage ratios and Calvo price rigidities in this environment. In effect, very low price rigidities (setting φ to 0.05 instead of 0.53) lead to a strong response of inflation and hence monetary policy - reducing the output impact of endogenous leverage. High price rigities (setting φ to 0.75 as in many standard New Keynesian macro models) limits the ability of firms to convert higher credit access, and hence access to property, into higher sales of output.

[Figure 8 about here.]

[24] The simulations become unstable for values of μ above 0.2.

5 Concluding Discussion

This paper shows that expansionary monetary policy can increase household leverage by stimulating housing liquidity. When lenders evaluate the security provided by property collateral, they plausibly not only take into account the eventual resale price of the house in case of default, but also the substantial carrying costs they face until an appropriate counterparty is found. Based on the empirical finding that a fall in interest rates substantially lowers the time-to-sale of housing, simulations show that this housing liquidity effect can play an important quantitative role (distinct from the standard house price effect) in the transmission of monetary policy to household credit access and the macroeconomy.

This mechanism implies a potential trade-off between price stabilization and financial stability objectives. In the face of a demand-slump, central banks face a trade-off between boosting demand through expansionary monetary policy and increasing financial risk by encouraging private sector leverage. As seen in Mian, Sufi and Trebbi (2011), private sector leverage can, in turn, make the economy more sensitive to other shocks.

The notion that asset debt capacity depends on the severity of resale market search frictions and fire-sale discounts offers a promising and tractable approach towards understanding fluctuations in leverage beyond the mortgage market. For example, the ability of the financial sector to sustain high leverage ratios may depend on the liquidity of securities markets that provide the collateral for short-term wholesale funding of these institutions. Applying this search-theoretic approach to procyclical borrowing margins in over-the-counter financial asset markets is a fascinating topic for further research.

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A Alternative Empirical Identification Strategy

This paper identifies empirical monetary policy shocks using the Romer and Romer (2004) narrative approach. In this appendix, we show that results are qualitatively robust to using an alternative empirical approach based on recursive Vector-Autoregressions.

The specification broadly follows Christiano, Eichenbaum and Evans (2005). Intuitively, monetary policy shocks are identified through the assumption that output and price level do not respond contemporaneously to monetary policy. The VAR includes a constant, a linear trend and seasonal dummies. Confidence intervals are computed at the 90% significance level.

Figure 9 confirms the standard finding that the recursive identification scheme identifies shocks with smaller amplitude on the real economy and faster price transmission than under the Romer and Romer (2004) methodology. Confirming the results of the main text, housing liquidity and mortgage loan-to-value ratios increase following expansionary monetary policy.

[Figure 9 about here.]

B Derivation of the Log-Linearization in Section 2

Taking a first order (log) Taylor approximation of equation 2.1 yields equation B.1.

$$q_v^* \hat{q}_{v,t} = q_v^* \hat{Q}_{t+1} + [Q^*(q_m^*(1-F_s) - q_v^*)] P_s^* \hat{P}_{s,t+1} + [Q^* P_s^*(1-F_s)] q_m^* \hat{q}_{m,t+1} + Q^* q_v^*(1-P_s^*) \hat{q}_{v,t+1} \tag{B.1}$$

Defining $\rho_1 = \frac{Q^*(q_m^*(1-F_s)-q_v^*)P_s^*}{q_v^*}$, $\rho_2 = \frac{Q^* P_s^* q_m^*(1-F_s)}{q_v^*}$ and $\rho_3 = Q^*(1-P_s^*)$ we can rewrite this as equation B.2.

$$\hat{q}_{v,t} = E_t(\hat{Q}_{t+1} + \rho_1 \hat{P}_{s,t+1} + \rho_2 \hat{q}_{m,t+1} + \rho_3 \hat{q}_{v,t+1}) \tag{B.2}$$

Log-linearization of expression 2.3 yields expression B.3. Inserting B.3 in B.2 and iterating forward yields expression 2.4 in the main text.

$$E_t(\hat{Q}_{t+1}) = -\hat{r}_{f,t+1} \tag{B.3}$$

C The First Order Conditions of the Model

Consider the consumer problem described in section 3. The associated first order conditions are key drivers of the macroeconomic mechanism behind this paper. First, for notation, it is useful to introduce the shadow price of vacant housing before search in period t ($q_{vb,t}$). Irrespective of consumer type, this is given by:

$$q_{vb,t} = -m - \tau + P_{s,t} q_{m,t} + (1 - P_s(\theta_t)) q_{v,t} \tag{C.1}$$

Second, for any type i, either the price of a vacancy at the end of period t equals the present discounted value of a vacancy at the start of period $t+1$, or no vacant property is held by that type at the end of period t.

$$q_{v,t} \geq E_t(Q^i_{t+1} q_{vb,t+1});\ v^i_t \geq 0;\ (q_{v,t} - E_t(Q^i_{t+1} q_{vb,t+1})) v^i_t = 0 \tag{C.2}$$

Third, the fundamental (shadow) value of occupied housing V^f_t equals its current consumption-equivalent service value, its present discounted future value (either as matched house or as newly unmatched house), the value of property in production for the impatient entrepreneur-households, as well as its value as collateral asset to access debt finance (where the Lagrangian λ_t denotes the consumption-equivalent value of collateral).

$$V^{f,p}_t = j \frac{c^i_t}{h^i_t} + E_t(Q^i_{t+1}(-m - \tau + z q_{vb,t+1} + (1 - z) V^{f,i}_{t+1})) + \lambda^i_t \frac{1}{E_t(Q^i_{t+1} \frac{R_t}{\pi_{t+1}})} q_{v,t} \tag{C.3}$$

$$V_t^{f,ip} = j\frac{c_t^i}{h_t^i} + E_t(Q_{t+1}^i(-m-\tau+\mu\frac{y_{t+1}}{h_{t+1}} + zq_{vb,t+1} + (1-z)V_{t+1}^{f,i})) + \lambda_t^i \frac{1}{E_t(Q_{t+1}^i \frac{R_t}{\pi_{t+1}})} q_{v,t} \quad \text{(C.4)}$$

Fourth, consumers undertake search effort for housing up to the point where marginal benefit equals marginal cost. In effect, this links equilibrium sales probability to the difference between fundamental housing value and the current bargained transaction price when housing fit for occupation is found.[25] Note that, if both patient and impatient consumers have put effort into search, then in equilibrium the free entry condition must equalize perceived fundamental value across types. As will be shown, this condition will hold in the neighbourhood of the deterministic steady state.

$$V_t^{f,i} \leq \frac{\kappa_b}{P_{b,t}} + q_{m,t}(1+F_b); e_t^i \geq 0; (V_t^{f,i} - (\frac{\kappa_b}{P_{b,t}} + q_{m,t}(1+F_b)))e_t^i = 0 \quad \text{(C.5)}$$

Fifth, the Euler equation ensures consumption is optimally allocated across time, given rates of return available and the borrowing constraint.

$$1 = E_t(Q_{t+1}^i \frac{R_t}{\pi_{t+1}}) + \lambda_t^i \quad \text{(C.6)}$$

Sixth, in equilibrium, either the stock price equals the present discounted value of future dividend and capital gain for consumer type i, or no equity is held by that subgroup of the population.

$$q_{o,t} \geq E_t(Q_{t+1}^i(q_{o,t+1} + \Pi_{t+1})); \; o_t \geq 0; \; (q_{o,t} - (E_t(Q_{t+1}^i(q_{o,t+1} + \Pi_{t+1}))))o_t = 0 \quad \text{(C.7)}$$

Seventh, the intratemporal labour-consumption first order condition ensures workers

[25] Note this condition offers an analogue to the free entry condition for vacancy posting in the labour market search literature (see Pissarides (2000)).

optimally trade-off the utility cost of providing additional labour against the consumption gains from greater labour income.

$$\frac{w_t}{c_t^i} = \chi(l_t^i)^\eta \tag{C.8}$$

Eighth, the Lagrangian for the borrowing constraint is zero if the borrowing constraint does not bind:

$$E_t(Q_{t+1}^i \frac{R_t}{\pi_{t+1}})b_t^i \leq q_{v,t}h_t^i;\ \lambda_t \geq 0;\ (E_t(Q_{t+1}^i \frac{R_t}{\pi_{t+1}})b_t^i - q_{v,t}h_t^i)\lambda_t = 0 \tag{C.9}$$

The first order conditions of the wholesale producer and retailer follow the standard textbook.

D Characterizing the Steady State of the Model

This section describes the steady state (the deterministic solution of the model in a setting without stochastic shocks) of section 3 in a series of propositions. Denote steady state variables by a star subscript.

Proposition 1. *In any steady state of the model, the patient consumer is not credit constrained.*

Proof of proposition 1: Assume the patient consumer is credit constrained. Then we have $(b^p)^* > 0$ and, using C.9, the shadow value of funds is strictly positive for patient consumers ($(\lambda^p)^* > 0$). Note now by the bond market clearing this implies $(b^{ip})^* = -(b^p)^* < 0$ and, using C.9, the shadow value of funds for the impatient must be zero ($(\lambda^{ip})^* = 0$). Subtract now the Euler equations C.6 of the two types to get:

$$0 = (\beta^p - \beta^{ip})R^* + (\lambda^p)^* \tag{D.1}$$

Since $R^* > 0$ in a well-defined steady state, this implies $\beta^{ip} > \beta^p$. This contradicts the definition of patient and impatient consumers ($\beta^{ip} < \beta^p$).

Proposition 2. *In any steady state of the model, the impatient consumer is credit constrained.*

Proof of proposition 2: Assume the impatient consumer is not credit constrained in steady state. Since we have established that the patient consumer must not be credit constrained in steady state, by equation C.9, the shadow value of funds is zero for both types: $\lambda^{ip} = \lambda^{p} = 0$. Using equation C.6 this implies $1 = \beta^{p} R^{*}$ and $1 = \beta^{ip} R^{*}$. Subtracting these two statements yields $0 = (\beta^{p} - \beta^{ip}) R^{*}$. Since $R^{*} > 0$ in a well-defined steady state, this implies $\beta^{p} = \beta^{ip}$. But this contradicts the assumption that there is a patient and impatient consumer type ($\beta^{p} > \beta^{ip}$).

Proposition 3. *In any steady state of the model, both consumer types search for new housing for occupation.*

Proof of proposition 3: Assume consumer of type i did not search in steady state $(e^{i})^{*} = 0$. By the dynamic equation for occupied housing held by type i consumers 3.2, this implies that the consumer does not occupy any housing in steady state ($(h^{i})^{*} = 0$). But then the fundamental value of housing is undefined, since the fundamental housing value equation implies $lim_{(h^{i})^{*} \downarrow 0} (V^{i,f})^{*} = +\infty$. The first order condition C.5 ($(V^{i,f})^{*} \leq \frac{\kappa_b}{Pr_b(\theta_t)} + q_{m,t}(1 + F_b)$) cannot hold.

Proposition 4. *In any steady state of the model, both consumer types occupy housing.*

Proof of proposition 4: The proof for this statement follows straightforwardly combining proposition 3 and the equation for housing dynamics 3.2.

Proposition 5. *In any steady state of the model, both consumer types have the same fundamental valuation of housing.*

Proof of proposition 5: Since $(e^{i})^{*} > 0$ for both types, free entry condition C.5 implies that $(V^{i,f})^{*} = \frac{\kappa_b}{Pr_b(\theta_t)} + q_{m,t}(1 + F_b)$. Subtracting the statement across types yields: $(V^{p,f})^{*} = (V^{ip,f})^{*}$.

Proposition 6. *In any steady state of the model, the patient agent holds all firm equity.*

Proof of proposition 6: At least one consumer type must hold all equity, since the equity market clears in equilibrium and equity is in positive supply. Assume now that both types hold equity in steady state. Then first order condition C.7 implies: $(q_o)^* = \beta_i((q_o)^* + \Pi^*)$. Subtracting this equation by consumer type yields: $0 = (\beta_p - \beta_{ip})((q_o)^* + \Pi^*)$. Since $((q_o)^* + \Pi^*) > 0$ in a well-defined steady state, this implies $\beta_p = \beta_{ip}$. But this contradicts the assumption that there is a patient and impatient consumer type ($\beta_p > \beta_{ip}$).

Proposition 7. *In any steady state of the model, the patient agent holds all end-of-period vacant property and physical capital.*

Proof of proposition 7: The proof of this proposition follows directly the pattern of the argument for proposition 6.

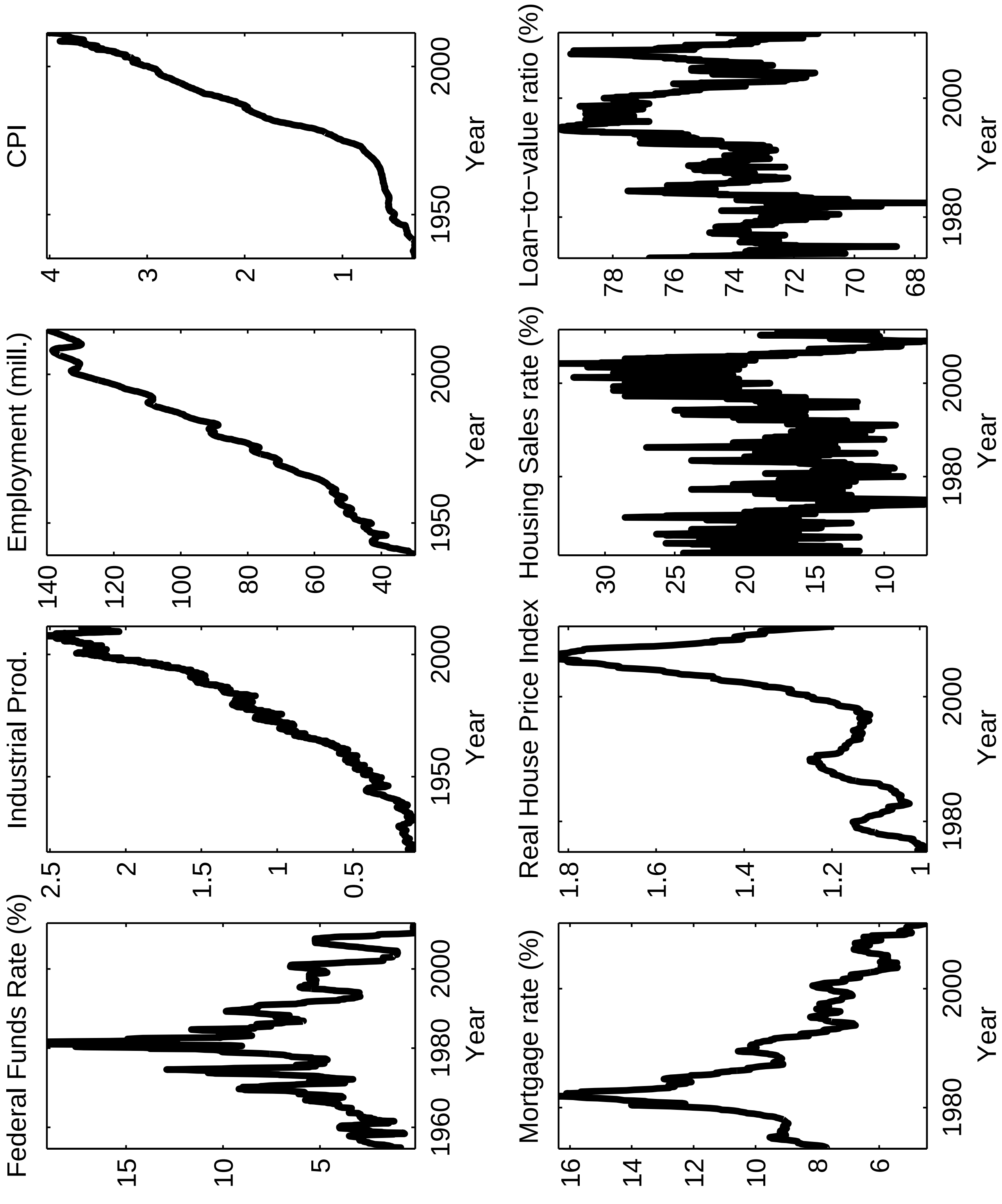

Figure 1: Raw time series

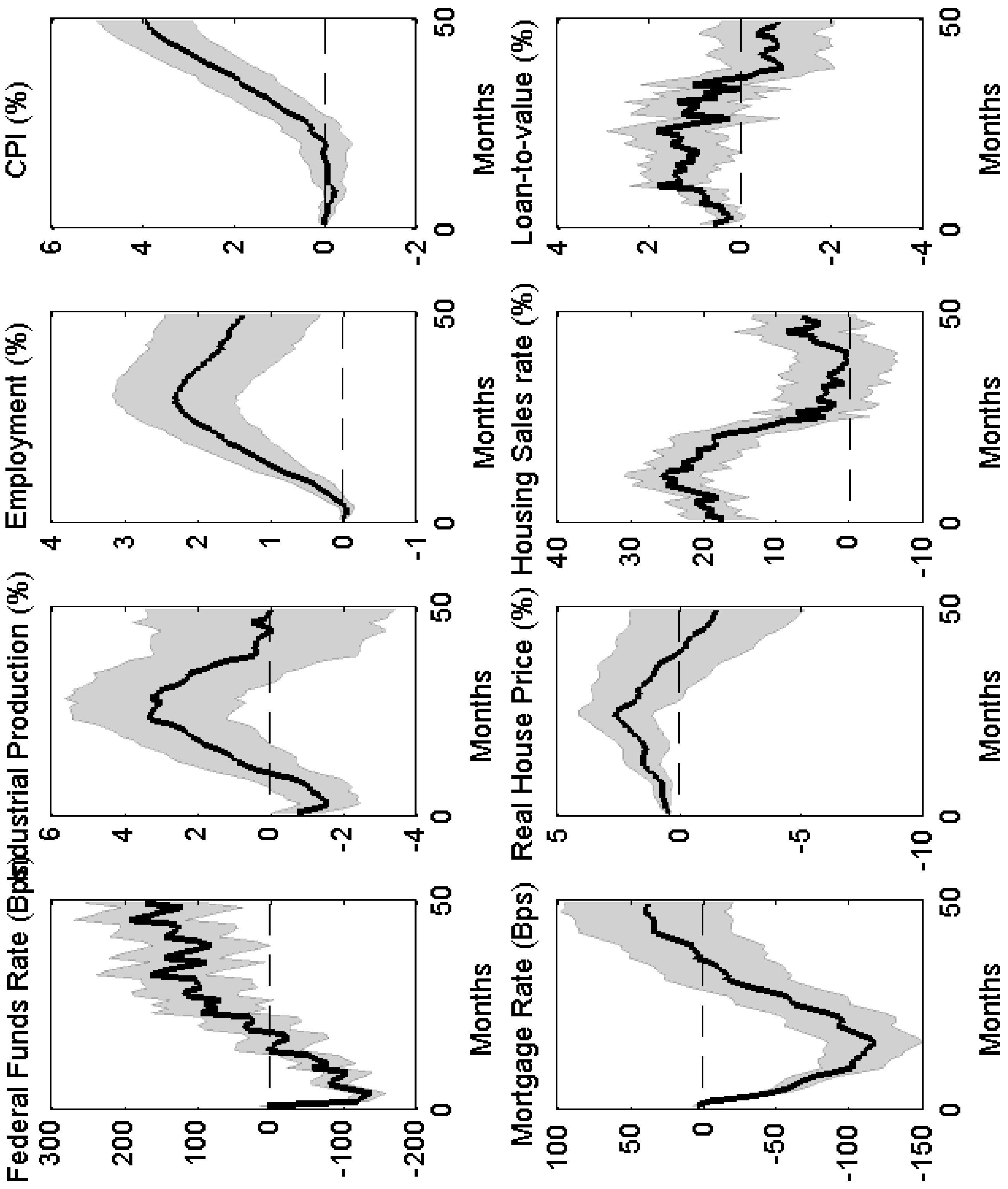

Figure 2: Empirical macroeconomic response to monetary policy changes (Romer and Romer (2004) shocks; in log dev. from trend; 95% confidence intervals)

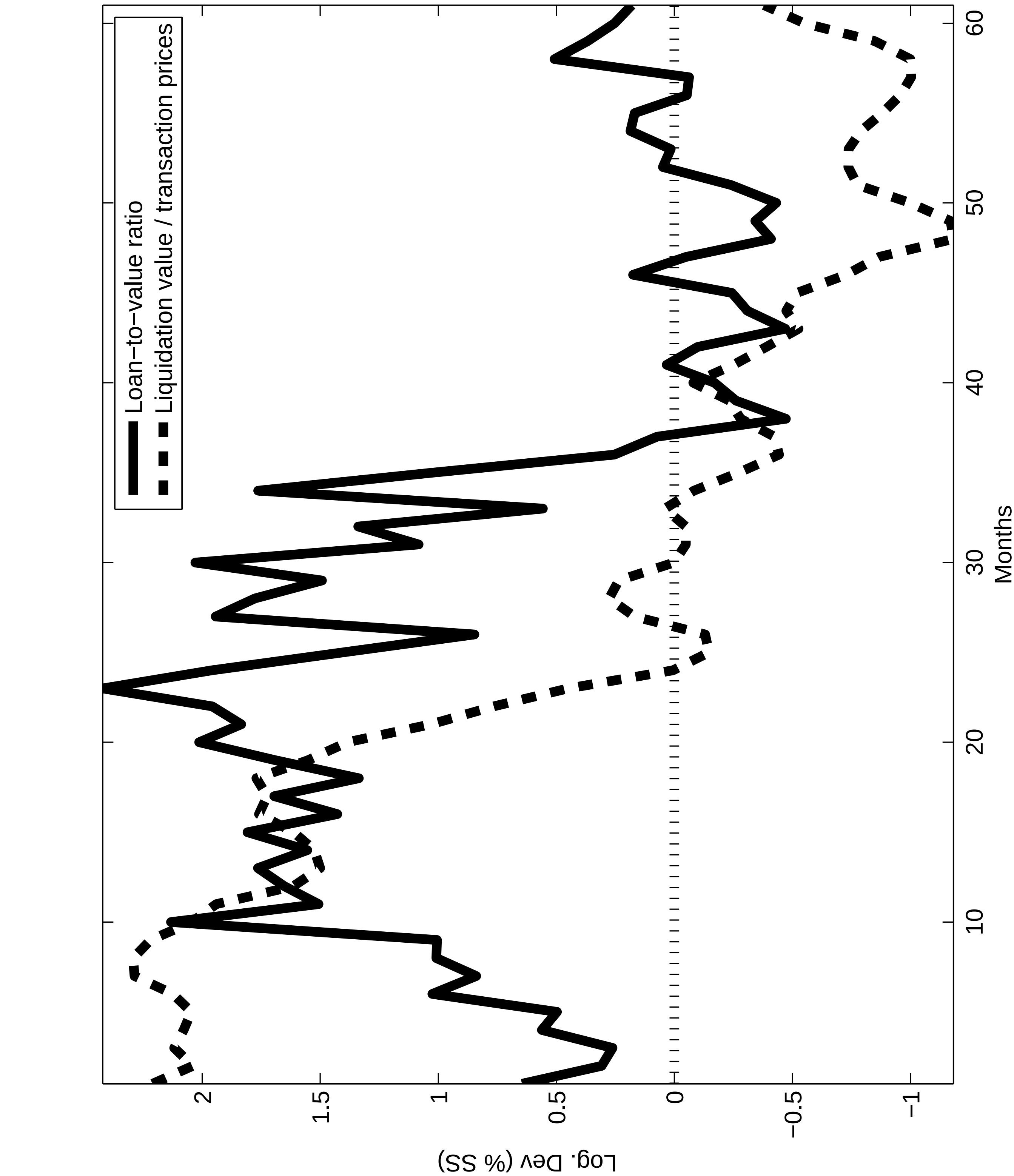

Figure 3: Response of the simulated liquidation value to temporary 1% exogenous fall in federal funds rate

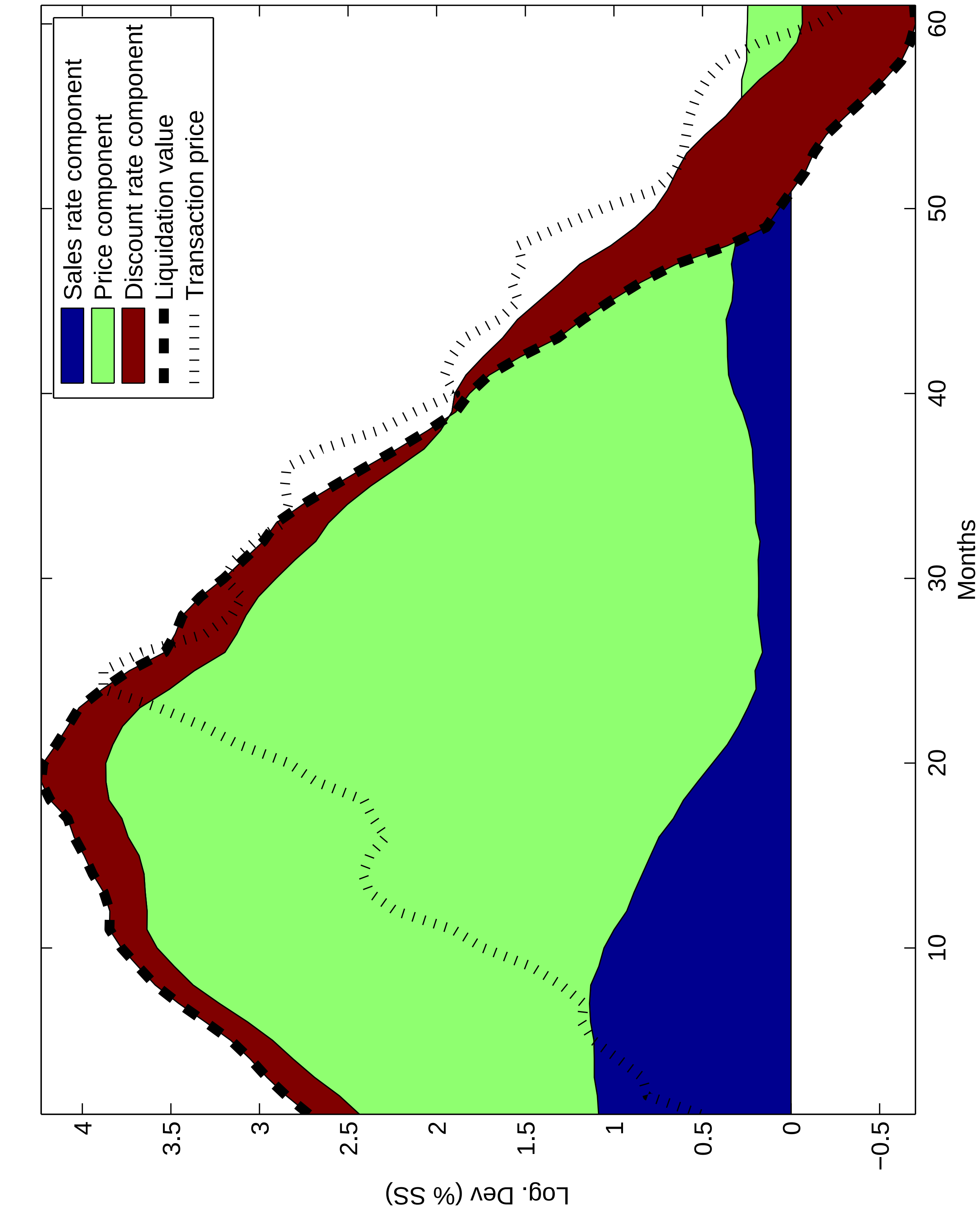

Figure 4: Response of the simulated liquidation value to temporary 1% exogenous fall in federal funds rate

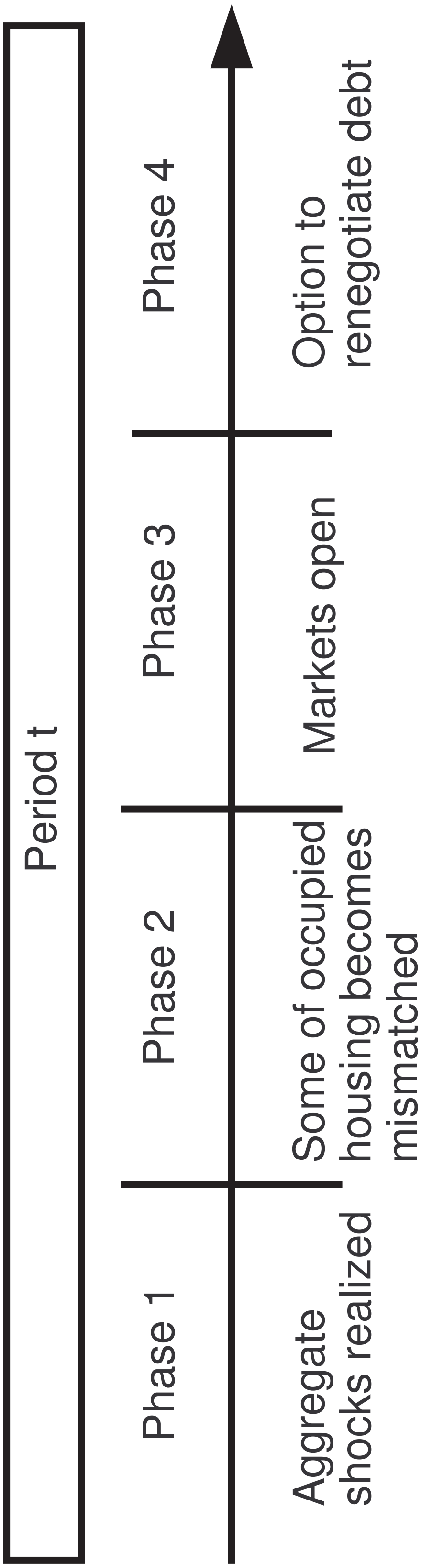

Figure 5: Period t in the DSGE model consists of four distinct phases

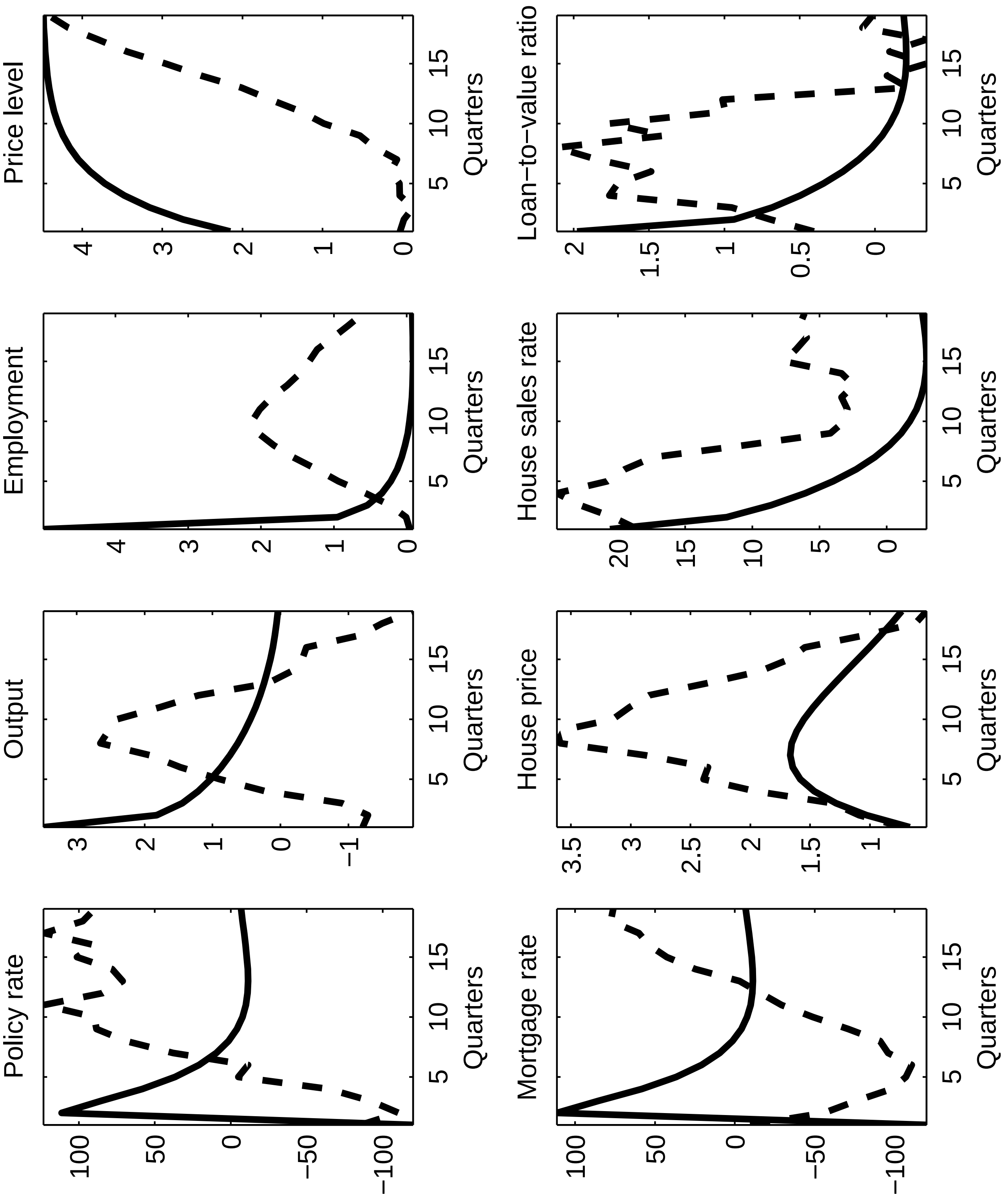

Figure 6: Baseline impulse response functions of the DSGE model (continuous line) and the empirical dynamic regressions from section 1 (dashed line) (% dev. from steady state)

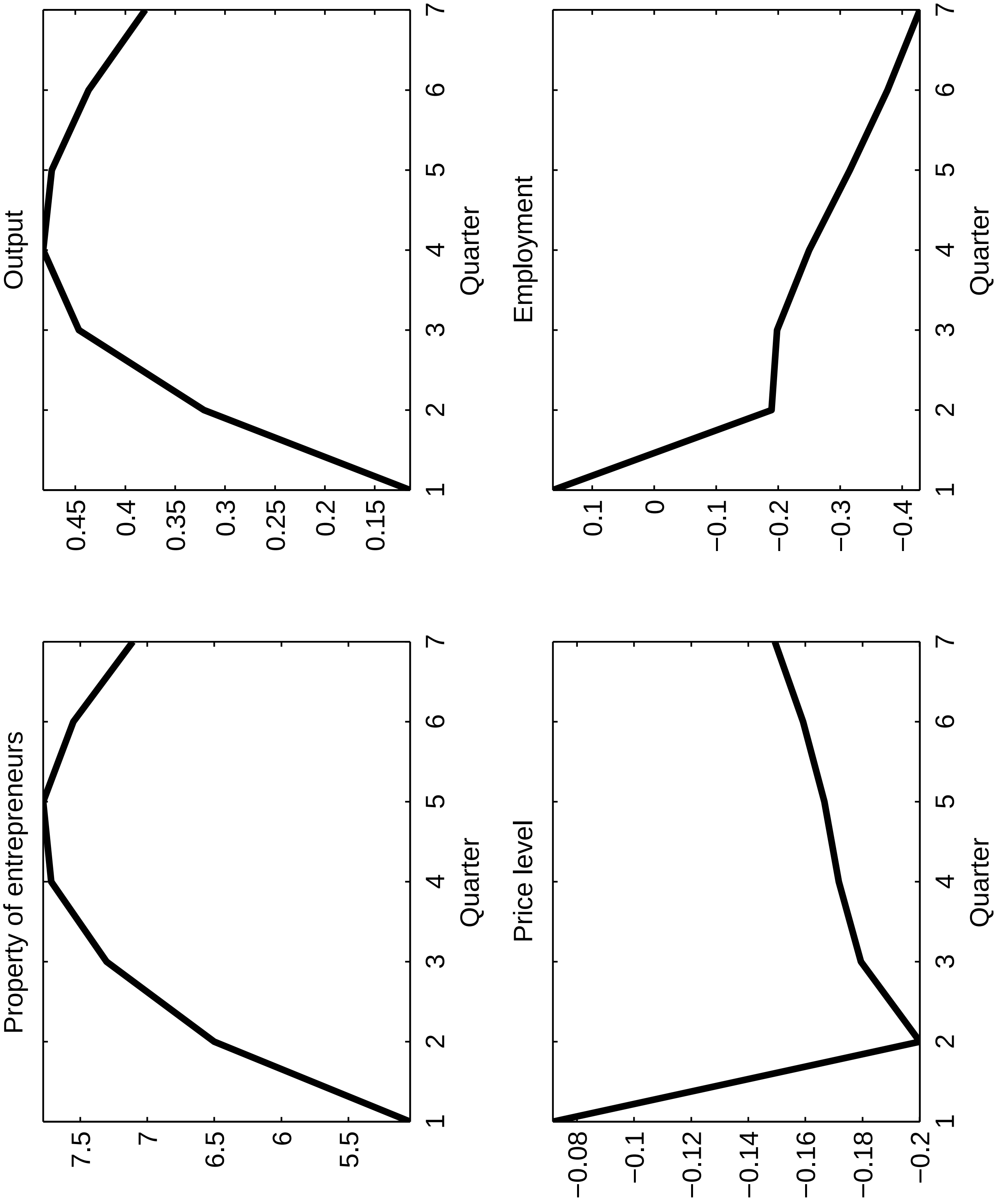

Figure 7: Difference between baseline model and counterfactual fixed-leverage scenario (cum. % dev. from steady state)

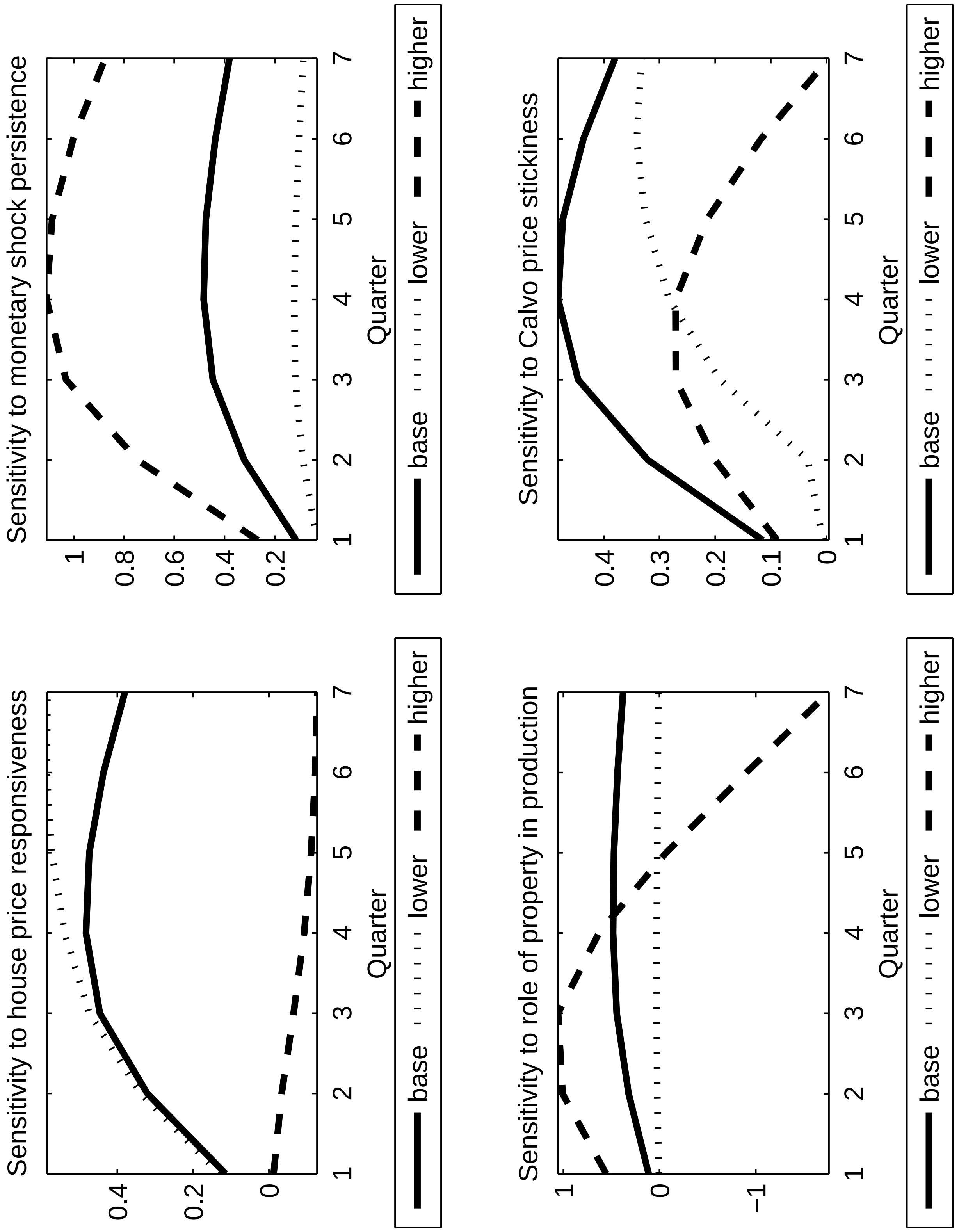

Figure 8: Sensitivity of GDP impact of the endogenous leverage ratio (cum. % dev. from steady state)

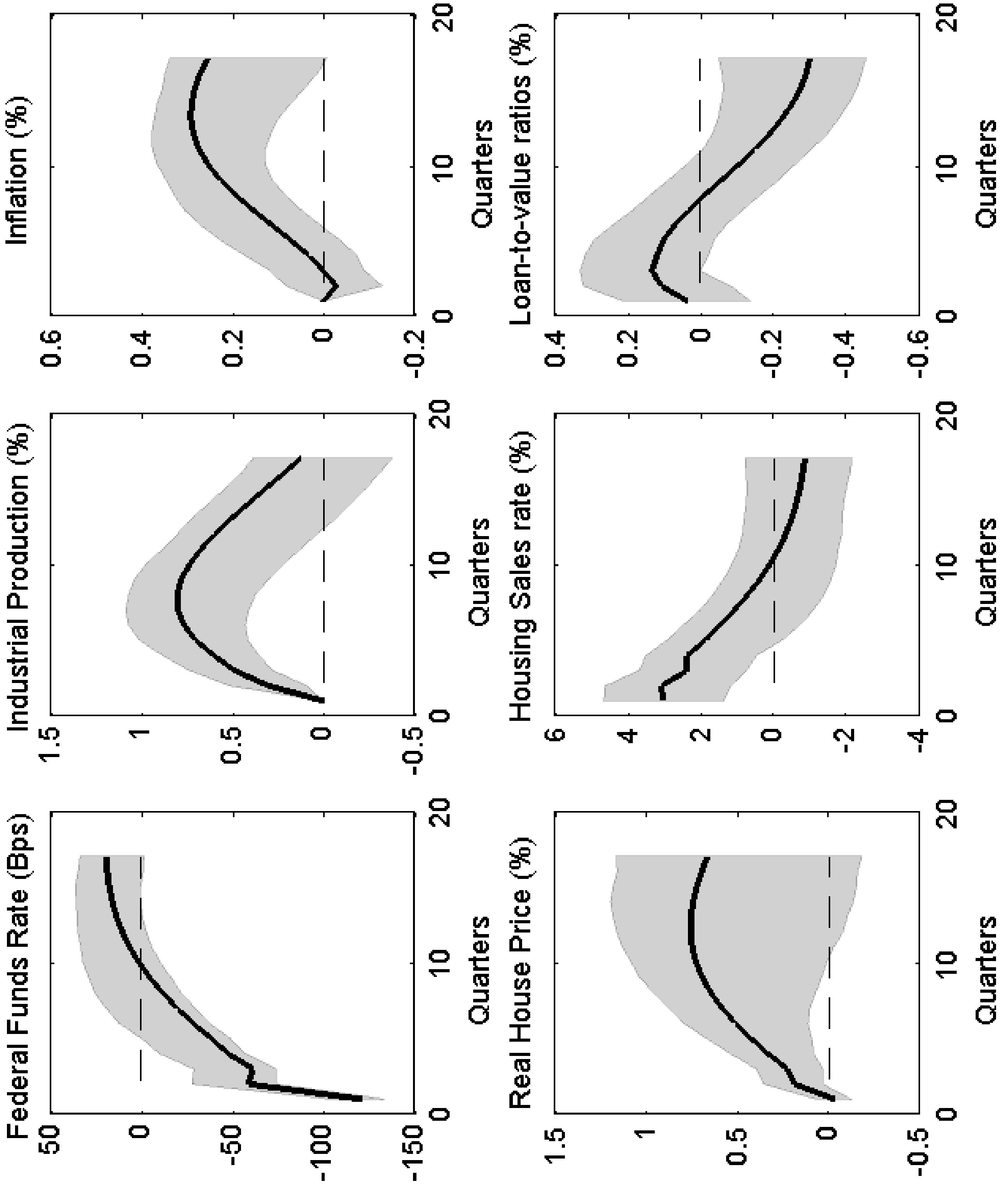

Figure 9: Empirical macroeconomic response to monetary policy changes (Recursive VAR identification; in log dev. from trend; 90% confidence intervals)

Parameter	Value	Target
Consumer preferences		
β_p	0.99	Iacoviello (05)
β_{ip}	0.98	Iacoviello (05)
χ_h	0.15	$\frac{q_m^* h^*}{y^*} = 6$ (Iacoviello (05))
χ_l	1	Iacoviello (05)
φ	0.01	Iacoviello (05)
Production technology		
α	0.7	Labour income share of 70%
ϑ	0.53	match IRFs
λ_f	1.15	Iacoviello (05)
μ	0.09	match IRFs
Housing search market		
z	0.0278	av. ownership 9 yrs (Ngai & Tenreyro (09))
κ_b	1.57	satisfy buyer free entry
F_s	0.1	$\frac{V_s^*}{q_m^*} = 0.85$ (emp. fire-sale discount)
F_b	0.1	$F_b = F_s$
$\frac{m}{q_m^*}$	0.04/4	Poterba (91)
$\frac{\tau}{q_m^*}$	0.02/4	Poterba (91)
ω	0.4	match IRFs
γ	0.79	match IRFs
s	0.2	match IRFs
Policy		
r_y	0.0	Iacoviello (05)
r_π	0.27	Iacoviello (05)
r_r	0.73	Iacoviello (05)
ρ_m	0.8	match IRFs
$\epsilon_{1,m}$	-0.025	100 Basis Points shock to annual policy rate

Table 1: Calibration for baseline DSGE