

The Real Price of Housing and Money Supply Shocks: Time Series Evidence and Theoretical Simulations*

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Abstract: I estimate the dynamic response of aggregate owner-occupied housing prices to money supply shocks, and interpret these responses using a dynamic equilibrium model of the housing market that relies on the asset view of housing demand. Money supply shocks are identified empirically from a vector autoregression (VAR) using restrictions that are consistent with a wide class of theoretical models. Using monthly data, I find that money shocks have real effects on the housing market: both real housing prices and housing sales (new starts and existing homes) rise in the short-run in response to positive shocks to the money supply. Simulations of the theoretical model suggest that, for reasonable parameter values, the estimated price responses are generally consistent with the theory.

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1. Introduction

This paper attempts to measure and interpret the dynamic effects of money supply shocks on the aggregate market for owner-occupied housing. This objective is important for at least two reasons: a) to understand how money affects real economic activity, at least in the short-run; and b) to understand the economic behavior that underlies the housing market. I use both time series methods and theoretical simulations to shed light on these issues.

In section 2 of the paper, I use aggregate time series data on the U.S. housing market and the macro economy to estimate the dynamic responses of housing prices and sales to unanticipated money supply shocks. I do so by undertaking a vector autoregression (VAR) analysis of the data in which the restrictions used to identify money supply shocks are weak in the sense of being consistent with a wide range of theoretical macro models. To gauge the sensitivity of the results to these restrictions, I alternatively consider two sets. In the first, I assume that money supply shocks are neutral (i.e., they have no effects on real variables), but only in the long-run. The second set uses a contemporaneous block-recursive structure that relies on informational assumptions regarding central bank behavior. These alternative schemes provide a useful comparison since the former imposes restrictions at an infinite horizon, while the latter imposes restrictions on impact.

I find that money supply shocks have important dynamic effects on the aggregate housing market variables (as well as on aggregate output, prices and interest rates), and that these effects are generally not sensitive to the identification scheme. This evidence supports and supplements other recent studies showing the importance of money supply shocks in explaining short-run economic behavior.¹

The innovation accounting exercise of the VAR analysis estimates the average reaction

¹ Christiano, Eichenbaum and Evans (1999) surveys the recent evidence on the real effects of money supply shocks. Other studies have documented the impact of money on the housing market – e.g. Baffoe-Bonnie (1998) and Dreiman and Follain (2000) – but use different identifying restrictions than I use.

of the housing market variables to money supply shocks without relying on a particular theory of the housing market. The results thus can be interpreted only in general, qualitative terms. However, I am also interested in whether the magnitudes of the estimated effects of money on housing, and the channels through these effects occur, are consistent with the implications of our understanding of housing market behavior. Therefore, in section 3 I provide a more precise interpretation of the time-series evidence within the framework of an equilibrium model of the housing market that views housing as an asset.² The theory focuses on the role of intertemporal optimization, the demand for housing and user cost. To examine the ability of this model to explain the observations obtained from the VAR analysis, I simulate the theoretical model's predicted dynamic responses of real house prices to exogenous money supply shocks (through their estimated effects on interest rates and inflation), and compare this prediction to the actual (i.e., estimated) responses.³ The simulations show that the theoretical model provides a reasonably good match to the data for a plausible set of behavioral parameters, lending credibility to the model as a framework for interpreting the results.

The simulation strategy in this paper is a tractable way to examine how well the standard intertemporal optimization model explains and predicts actual behavior in the aggregate housing market. But since I focus only on responses to money shocks, my strategy does not allow estimation and testing of a fully-specified dynamic, general equilibrium model. While such estimation is necessary to fully understand housing market behavior, it comes with a substantial cost – it requires proper specification of all aspects of relevant economic behavior, a difficult (if not impossible) task in practice. The more modest approach here relies only on plausible assumptions regarding behavior in the face of money supply shocks, and will therefore be more robust than the alternative approach to mis-specification along other dimensions.

² See Poterba (1984) for an early statement of this view.

³ Focusing on dynamic responses rather than other moments to better understand dynamic models has been suggested by Campbell (1994).

Understanding how well the theoretical model predicts house price reactions to money has several benefits. Most obviously, to the extent that the model fits the facts, it can be used to simulate the effects of alternative monetary policies on housing markets. More generally, it can be used as a starting point to justify the use of such models for other policy analysis. For example, Bruce and Holtz-Eakin (1999) examine the implications for tax reform on housing markets within the context of a model very similar to the one used here. Showing that the model does a good job of explaining responses to money supply shocks enhances our confidence that the model can give good answers to questions about tax reform, and other issues. Finally, if the model works for housing markets, it is also likely to work for other markets in durable goods. Thus, the results of this study can potentially shed additional light on more general household consumption behavior.

2. Estimating the dynamic responses to money supply shocks

a. Empirical model and identifying restrictions

In this subsection, I lay out the empirical model and discuss the alternative sets of restrictions used to identify money supply shocks. Let z_t be an $n \times 1$ vector of endogenous random variables at time t , containing housing market variables and other macro variables that aid in the identification of money supply shocks. Assume that z_t is generated by the following linear, dynamic structural model:

$$A_0 z_t = A_1 z_{t-1} + \cdots + A_p z_{t-p} + u_t, \quad (1)$$

where u_t is an $n \times 1$ vector of serially and contemporaneously uncorrelated shocks, each with unit variance. The model is structural in the sense that the equations are explicitly in terms of optimal decision rules and equilibrium conditions. The elements in u_t are exogenous random shocks to these decision rules, reflecting the modeler's inability to specify all factors that determine optimal decisions. One of the equations represents the behavior of the money supply sector; the element in u_t corresponding to this equation is taken to be an

exogenous shock to the money supply process. The implied moving average representation of the structure is:

$$\begin{aligned} z_t &= (D_0 + D_1L + D_2L^2 + \dots)u_t \\ &= D(L)u_t, \end{aligned} \tag{2}$$

where $D(L) = (A_0 - A_1L - \dots - A_pL^p)^{-1}$ and L denotes the lag operator. The coefficient matrices in this representation are dynamic multipliers, which show the equilibrium response of the endogenous variables to impulses in the exogenous shocks.

To estimate these multipliers, first note that the moving average of the model's reduced form is

$$\begin{aligned} z_t &= (I + C_1L + C_2L^2 + \dots)\epsilon_t \\ &= C(L)\epsilon_t, \end{aligned} \tag{3}$$

where $\epsilon_t = D_0u_t$, $C_i = D_iD_0^{-1}$ and

$$E\epsilon_t\epsilon_t' \equiv \Sigma = D_0D_0'. \tag{4}$$

The reduced form parameters $C(L)$ and Σ are directly estimable from the VAR representation of z_t , but (4) is not a unique mapping from structure to reduced form. The typical VAR identification strategy imposes a sufficient number of restrictions on D_0 to identify the structural coefficients from Σ and $C(L)$. This identification strategy is “weak” in the sense that it does not require imposing the restrictions from a fully specified dynamic equilibrium model; e.g. the lag structure in (2) is left unrestricted. My strategy is even weaker. The restrictions I use just-identify only the multipliers corresponding to money supply shocks while the system in (2) as a whole remains underidentified; for a discussion of such partial identification in VARs, see Christiano, Eichenbaum and Evans (1999).

To ensure robustness in the face of weak identifying restrictions, I consider two alternative sets of restrictions. The first set of restrictions relies on the commonly held view that nominal money supply shocks are neutral in the long-run (e.g. Lucas 1996). Let $\tilde{z}'_t = (p_{ht} \ h_t \ r_{mt} \ r_t \ y_t \ m_t \ M_t)$, where p_h is the log of the real house price, h_t is the log of a flow measure of the quantity of houses, r_{mt} is the interest rate on mortgage

loans, r_t is the interest rate on alternative debt securities, y_t is the log of aggregate output, m_t is the log of real money balances and M_t is the log of the nominal stock of money. Output and the price level (the latter of which is implicit from the relationship between real and nominal money balances) are included to refine the identification of money supply shocks based on macroeconomic theory.

Suppose that each of the univariate processes in \tilde{z}_t contains one unit root. Thus, in the structural model in (2), set $z_t = \Delta\tilde{z}_t$, so that the vector process is stationary. In this case,

$$\begin{aligned} \lim_{k \rightarrow \infty} \frac{\partial \tilde{z}_{t+k}}{\partial u_t} &= D_0 + D_1 + D_2 + \dots \\ &= D(1) \end{aligned} \tag{5}$$

is the matrix of infinite horizon multipliers with respect to the levels of the variables. Given the ordering of the variables in \tilde{z}_t , long-run monetary neutrality implies that all elements of the final column of $D(1)$ are zero except for the element in the final row. That is, a shock that has a permanent effect on nominal money but no permanent effect on the real variables in the system is defined to be a money supply shock. Hence, the last equation in (1) and (2) represents money supply behavior by assumption.⁴ It is straightforward to show that although this set of restrictions is not sufficient to fully identify the structural model, it is sufficient to just-identify the responses to money supply shocks (the final columns of D_i) by exploiting the Cholesky factor of the “long-run” covariance matrix, $C(1)\Sigma C(1)'$.⁵

Although long-run neutrality is very plausible and is consistent with almost all views of the role of money in the economy, the use of infinite-horizon restrictions may be highly sensitive to the statistical specification since the sample is finite (Faust and Leeper 1997).

⁴ Note that, though the interest rates in z_t are nominal, their long-run behavior in response to a permanent change in the *level* of the money supply is assumed to be identical to real rate behavior, since such a change in money will not cause a permanent change in the inflation rate.

⁵ See Keating (1996) and Lastrapes (1998, appendix). The use of infinite horizon restrictions to identify VARs was pioneered by Blanchard and Quah (1989) and Shapiro and Watson (1988).

For this reason, I consider an alternative set of identifying restrictions that depends only on contemporaneous relationships and that does not require first-differencing the data. First differencing is overly restrictive if cointegrating relationships exist. Determining the sensitivity of the results to the choice of identification scheme is important since the restrictions are not testable.

For this set of restrictions, let z_t be analogous to \tilde{z}_t in that the variables are in levels, not differences. Partition z_t as $\begin{pmatrix} z_{1t} \\ s_t \\ z_{2t} \end{pmatrix}$, where z_{1t} is a vector containing variables that are restricted not to respond to contemporaneous monetary policy but can contemporaneously affect such policy; let s_t be the monetary policy instrument, so that the equation in the VAR corresponding to s_t represents monetary policy behavior; and let z_{2t} be restricted to have a contemporaneous impact on neither z_{1t} nor s_t . These restrictions imply that D_0 is lower block recursive, taking the partitioned form:

$$D_0 = \frac{\partial z_t}{\partial u_t} = \begin{pmatrix} D_{11} & 0 & 0 \\ D_{21} & D_{22} & 0 \\ D_{31} & D_{32} & D_{33} \end{pmatrix}. \quad (6)$$

As Christiano, Eichenbaum and Evans (1999) show, the zero restrictions in (6) are sufficient to just-identify responses to monetary policy shocks. Identification can be implemented, using (4), by setting D_0 equal to the Cholesky factor of Σ .

Let s_t stand for the federal funds rate, z_{1t} contain output, the price level and a commodity price index, and z_{2t} contain total reserves in the banking system, non-borrowed reserves, the mortgage rate, real house prices and the flow of house sales.⁶ Except for the housing market variables, this system is almost identical to the first benchmark case in Christiano, Eichenbaum and Evans (1999, p. 83) and much of their other work (e.g. Christiano, Eichenbaum and Evans 1996, 1997).⁷ Using the federal funds rate for s_t is

⁶ As is now common, I include commodity prices to control for the possibility that policy makers use information about future inflation in setting policy. See, for example, Eichenbaum (1992).

⁷ They include a measure of the aggregate money stock in z_{2t} ; adding such a measure to my system did not alter the main results of this paper in any important way.

consistent with federal funds rate targeting – under the zero restrictions above, the Fed is assumed to prevent reserve demand and housing market shocks from influencing the federal funds rate in the very short-run. But the model is also consistent with a “Taylor Rule” (Taylor 1993) under which Federal Reserve policy makers set the federal funds rate target as a function of output and prices. Thus, shocks to the funds rate equation are interpreted as exogenous policy shocks. Justification of the other restrictions in (6) can be found in Christiano, Eichenbaum and Evans (1996 and 1999).

b. Data and estimated responses

I apply the estimation strategy discussed above to monthly U.S. data, taken primarily from DRI/Citibase. The following macro variables are used in the system identified with long-run restrictions (with the DRI name in parenthesis): M1 (fzm1), 3-month treasury bill rate (fygm3), industrial production index (ip), producer price index for all commodities (pw), and the 30 year conventional mortgage loan rate (fymcle). Under the short-run identification scheme, the effective fed funds rate (fyff) substitutes for the 3-month t-bill, and M1 is replaced by total reserves adjusted for reserve requirements (fmrria) and nonborrowed reserves plus extended credit (fmrnbc). In addition, the system contains the Commodity Research Bureau Spot Index (psccom). In each system, the producer price index is used to compute real money and real house prices. Two alternative measures of aggregate housing prices and quantities are used. The first is from the Bureau of the Census Current Construction Reports available from DRI: new houses sold (hns) and the median sales price of new houses sold (hnmp). The second set focuses on existing homes: existing single-family home sales and median sales price of existing single-family homes. These data are available from the National Association of Realtors (NAR).⁸

⁸ It is appropriate to focus on national aggregates of the housing market to examine the overall transmission of money shocks to the real economy. However, by focusing on nationwide housing aggregates, I ignore distributional effects of money on housing prices across geographic locations. Since real estate markets are uniquely affected by local conditions, it would be interesting in future research to consider region-specific housing

The data range from January 1963 through August 1999 for all variables except existing home sales and prices, which are available only from January 1968 to April 1999. Figure 1 provides some perspective on the housing market by plotting the time series data on monthly mortgage rates and the alternative measures of real housing prices and quantities. There is an upward trend in all four of the housing market variables, although the growth of existing home sales outpaces the others. The average annual growth rates for new house price, existing house price, new home sales and existing home sales from 1968 to 1999 are, respectively 2.0%, 1.9%, 2.1% and 4.2%. From 1981 to 1999, new house prices rose 3.3% annually, compared to 2.5% for existing home prices. However, given the nearly identical growth over the longer period, this seems more likely to reflect the high volatility and large decrease in new home prices after the credit crunch of 1979 than a shift in trends. There is a clear, though by no means pervasive, tendency for negative comovement between mortgage rates and the housing market variables. The correlation coefficients from 1968 to 1999 between mortgage rates and the housing variables are -0.39 (new houses sold), -0.23 (existing houses sold), -0.36 (price of new homes), and -0.31 (price of existing homes).

As noted above, the variables in the system identified with long-run restrictions are first-differenced; those in the short-run system are not.⁹ In each case, the VAR includes a constant, seasonal dummies and 12 common lags across variables and equations, which is sufficient to eliminate all serial correlation from the errors. The sample range for the VAR estimation is February 1964 to August 1999 for the new house systems, and February 1969 to April 1999 for the existing homes data. Figures 2 through 5 report the estimated dynamic response functions with respect to money supply shocks (the appropriate columns

prices, as in Baffoe-Bonnie (1998) for example.

⁹ First-differencing is appropriate if each variable has one unit root and if the system is not cointegrated. Dickey-Fuller tests for unit roots indicate that each series used on the first-differenced system is consistent with the presence of a single unit root. Furthermore, there is no compelling evidence for the existing of cointegrating relationships in this system according to Johansen's maximum likelihood test with small sample adjustment. Thus, the first-differenced VAR specification is reasonable.

of the D matrices in (2)) for the two identifying strategies and the two measures of the housing market. Standard errors bands indicating the sample precision of the estimates are computed from Monte Carlo simulations with 1000 replications and accompany the point estimates.¹⁰

Figure 2 shows the responses for the long-run restrictions when the housing market is represented by new house sales and median prices. The money supply shock leads to a monotonically increasing nominal stock of money; ultimately, the typical shock causes a permanent rise in nominal money of 0.8%.¹¹ In the short-run, real money balances closely track nominal money, indicating stickiness in the price level (recall that the price level response is simply the difference between the nominal and real money responses). Ultimately, the price level rises to a permanently higher level, causing real money to decline to its restricted steady state response of zero. The inflation response is not shown directly, but can be inferred from the price level response – inflation's response is positive but transitory. Output reacts with a lag, rising above its original steady state by about 0.6% 12 months after the shock, then receding to zero. There is clear evidence of a liquidity effect in the government securities market, with the 3-month t-bill rate falling by around 35 to 45 annualized basis points in the initial periods, which is consistent with many of the previous findings of a liquidity effect (e.g. Lastrapes 1998). These response functions are in line with almost all of the VAR literature on the dynamic effects of money supply (see Christiano, Eichenbaum and Evans 1999).

Now consider the impact on the housing market variables. The 30-year conventional

¹⁰ In a small number of cases (0 to 1%) for the models using long-run neutrality, the largest simulated root of the VAR exceeded one, causing the standard error bands to explode as the forecast horizon increased. Since these explosive draws do not affect the magnitude of the error bands at the short-horizon (the focus of this study), the unstable replications are simply dropped.

¹¹ The proper interpretation of this response function is that, given the exogenous shock and holding other shocks constant, the money stock settles at a new deterministic steady state that is 0.8% higher than its original steady state, in the limit. The steady state need not be constant, only deterministic.

mortgage rate falls in response to the positive money shock, but only with a delay and with a noticeably smaller magnitude when compared with the t-bill rate. In fact, the impact response is essentially zero, while the maximum decline is just over 15 annualized basis points for the four to seven month horizon. Furthermore, whereas the t-bill rate returns to its original steady-state within one year, the mortgage rate takes at least three years to converge. On impact, median house prices rise by 0.1%, then rise to a peak of 0.7% after a year and a half, followed by a monotonic decline to zero. Though positive, the initial response is measured imprecisely according to the standard error bands. The response of new houses sold is much larger than the price response in the short-run: a 2.5% increase at the time of the shock (with a standard error band ranging from 2% to 3%), a quick rise to a peak of 3.5% at three to four months, then a gradual decline. These estimated responses are consistent, at least qualitatively, with a simple story that an increase in the money supply reduces interest rates and thus user costs, increasing the demand for housing.¹²

Figure 3 reports the results using the alternative short-run identification scheme. Whereas the identifying restrictions in Figure 2 are evident at the infinite horizon, the initial zero responses in the first column of Figure 3 indicate the restrictions in this case. Note the similarity between the federal funds response function and the t-bill response in Figure 2. Non-borrowed reserves rise on impact, but total reserves are essentially unchanged (as in Strongin 1995). The output response is smaller for the short-run restrictions than in Figure 2, but the shape is similar. Although the price level response on impact is negative, quantitatively it is small enough to imply price rigidity in the short-run. The mortgage rate again displays a delayed negative response, while housing prices and sales rise in the short-run. The housing price response is essentially the same as for the long-run

¹² As noted in the introduction, Baffoe-Bonnie (1998) also examines the dynamic responses of new house prices and sales to money shocks. His results are ambiguous and difficult to interpret, since he pays very little attention to identifying the exogenous source of money shocks. For example, his discussion on p. 190 seems to suggest that money shocks operate through shifts in the *supply* of housing, not demand, since prices fall and quantity rises. It is also not clear how to interpret his “mortgage rate” shocks.

restrictions, but the peak effect is somewhat smaller. New house sales are about 1 to 1.5% higher over the first 20 months than in the original steady-state; this response is about half the magnitude when long-run restrictions are used. Overall, the dynamic responses for new house prices and sales are robust to the alternative identification strategies.¹³

Since the long-run identifying restrictions underidentify the entire structure, it is not possible to perform a complete variance decomposition of the variables in the system. However, the restrictions are sufficient to identify the importance of money supply shocks relative to all other shocks. Figure 4 reports the relative contribution of money supply shocks to forecast error variance at various horizons for all variables in the VAR. Clearly, money supply shocks account for most of the error variance in the t-bill rate at short horizons, explaining 80% of such variance on impact. Such shocks explain a large portion of mortgage rate variance – 41% at the 8 month horizon. The effect on new houses sold is also large – 17% on impact rising to 46% at 10 months. The maximum contribution to house price variation is about 14% at 20 months. Figure 5 contains the same information for the short-run identification scheme. In general, the contribution of monetary policy shocks identified in this way is smaller for the housing market variables than in the previous case.

Figures 6 and 7 show the results when new house data are replaced with sales and price data for existing owner-occupied homes. Though the responses of the macro variables are similar across systems, there are some important differences for the housing market variables. When long-run monetary neutrality is imposed, the median price of existing homes rises by about 0.4% on impact, then declines; there is much less evidence of a gradual rise in prices over the first year and a half when compared to new homes. At the same time, new house sales show very little response on impact, but rise to close to 2% after 15 months. Thus, when compared to the market for new houses, existing home prices respond quicker, but existing home sales respond slower, to money supply shocks.

¹³ This finding is consistent with McMillin (2001).

The lagged response of existing homes carries through to the short-run identification scheme, but the house price response differs. In particular, its response is small on impact, rises to almost 0.2% and falls quickly to zero (and potentially to a negative range over the long-run). Although the pattern is similar, the existing home price response is less robust to identification than the new home response. Finally, Figures 8 and 9 give the partial variance decomposition for the systems with existing home price and sales data. Only for real house prices for the short-run restriction case is the contribution of money supply shocks trivial.

Neither the Census Bureau nor the NAR house price series control for home quality or size. The estimated price responses above may thus reflect a change in the mix of houses rather than a change in the constant-quality price, which is relevant for the theoretical model in the following section. To determine the sensitivity of my results to this issue, I re-estimate the model using the weighted-repeat sales index constructed by the Office of Federal Housing Enterprise Oversight (see Calhoun 1996, for a technical description). The series is available only at a quarterly frequency, and begins in the first quarter of 1975, so a direct comparison with the previous results is not possible. However, the quarterly response estimates using the OFHEO index (not reported) are very similar to the quarterly responses using the median price series both in shape and magnitude, implying that our results are not sensitive to a potential response in the mix of houses.¹⁴

A separate issue is the stability of the estimates of the VAR. Given the numerous changes in the housing finance system over the sample period, we might not expect the coefficients of the VAR to be stable over time, which could affect the response functions. Indeed, a Chow test suggested a structural break in the VAR around 1980. However, the

¹⁴ The median price series and the OFHEO index have correlation coefficients over 99%; correlations of growth rates exceed 40%. DiPasquale and Somerville (1995) likewise find that the NAR median price series behaves similarly to other constant-quality price indices based on hedonic regression methods. The OFHEO data are available online at <http://www.ofheo.gov/house/download.html>.

response functions for the housing market variables over the period 1980:1 to the end of the sample remain generally similar to those over the full samples implying that the structural changes have not had an important impact on the estimated dynamics reported.

Overall, the evidence presented above is consistent with the hypothesis that on average, money supply shocks are capitalized in aggregate real house prices, albeit perhaps gradually. However, since the results from the identified VAR are reduced form responses to structural shocks, the economic behavior underlying these dynamics cannot be precisely understood. In addition, the response functions are unable to determine whether the relative magnitudes of the responses are consistent with theoretical models of the housing market. In the next section, I develop an equilibrium model of the housing market that focuses on the effects of money on user cost and the demand for housing. I then compare the responses implied by the theory to those estimated from the data to better understand the empirical results.

3. Interpreting the dynamic responses

a. A dynamic equilibrium model of the housing market

The theoretical model relies on the asset view of housing: housing is a durable good, the demand for which reflects both the service flow and asset value of housing units. On the margin, the return from housing must equal the return on alternative assets. This view of housing demand is consistent with more general models of durable goods, as in Obstfeld and Rogoff 1996, pp. 96-98, and Kau and Keenan 1980, and has been used often in policy analysis of housing markets, as in Bruce and Holtz-Eakin (1999), Poterba (1984) and Miles (1994). I develop the model by assuming a representative agent who solves for the optimal time path of consumption of nondurable goods and housing as the sole durable good, and building into the model some of the important institutional features of housing market finance and tax policy. I also assume perfect foresight, as do, for example, Poterba

(1984) and Bruce and Holtz-Eakin (1999).¹⁵

Let the aggregate consumer maximize the intertemporal objective function:

$$V_0 = \sum_{t=0}^{\infty} \left(\frac{1}{1+\rho} \right)^t U(H_t, c_t), \quad (7)$$

where c_t is the quantity of nondurable goods consumption, H_t is the number of housing units (of standardized size and quality), ρ is the personal rate of time preference, and the data frequency is the same as the decision frequency. The consumer's intertemporal budget constraint (in real terms, using nondurables as the numeraire) is

$$A_{t+1} + c_t + p_t H_t [1 + \mu + \tau_p (1 - \tau)] + \left[\frac{1 + (1 - \tau) R_{mt}}{1 + \pi_t} \right] B_{m,t-1} = y_t (1 - \tau) + \left[\frac{1 + (1 - \tau) R_t}{1 + \pi_t} \right] A_t + p_t (1 - \delta) H_{t-1} + B_{mt}, \forall t. \quad (8)$$

The left-hand-side of this constraint defines the uses of funds: the real value of non-mortgage financial assets carried over into the next period (A_{t+1}), current consumption, current purchases of housing stock ($p_t H_t$, where p_t is the real price of the standard unit of housing in terms of nondurables), expenses incurred through home ownership (where μ measures maintenance/repairs/insurance as a fixed proportion of current house value, τ_p is the property tax rate, and τ is the income tax rate), and real expenditures on mortgage principal and interest (where R_{mt} is the nominal yield on mortgage-secured loans, π_t is the rate of nondurables inflation, and $B_{m,t-1}$ is real mortgage debt coming into the period).¹⁶ Note that the uses of funds incorporates income tax deductibility of property taxes and

¹⁵ Miles (1994) generalizes the asset model to allow for the effect of uncertainty on housing demand.

¹⁶ Clearly, the correspondence between the theoretical price and the observed median sales prices used in the data analysis is not exact, since as noted earlier the latter are not adjusted for land values, quality or size. This could affect the interpretation of the empirical results, and lead to poor explanatory power of the model. However, to the extent that the effects of money supply shocks have no systematic effect on house quality and size in aggregate, the observed prices will conform to the theory. The results noted above for the OFHEO constant-quality price index suggest that such effects are likely to be small.

mortgage interest. The right-hand-side defines the sources of funds: real income (y_t) net of income taxes, the current stock of financial assets gross of real interest earnings (R_t is the nominal yield on securities), the value of the housing stock carried over from last period net of depreciation (δ), and new mortgage borrowing. Note that interest income on securities is not tax deductible and that there are no capital gains taxes on the appreciation of housing value.¹⁷

The budget constraint, as it stands, makes no distinction between borrowing through mortgage loans or issuing other securities to finance housing expenditures. If, say, $R < R_m$, then mortgages would not be supplied. To motivate a separate market for mortgage loans in the model, and thus allow yields on the alternative securities to differ, I impose the following mortgage borrowing constraint:

$$B_{mt} = \beta p_t H_t, \tag{9}$$

where β , the loan-to-value ratio, lies between zero and one. That is, the representative consumer is required to finance a given percentage of his house purchase by issuing mortgage debt. This restriction can be weakened by allowing mortgage debt to be less than the right-hand-side of (9), but then some restriction on borrowing from other sources must be imposed. One problem with this strict equality constraint is that mortgage borrowing rises and falls with house prices, *ceteris paribus*. For example, the consumer is forced to pay off principle during periods of declining home values, a condition seldom seen in real housing markets. However, given our focus on the aggregate household at the margin, the binding constraint seems an appropriate approximation.¹⁸

¹⁷ For justification of the latter assumption, see Poterba (1984, p. 734, footnote 10). I also rule out infinite borrowing, so that only the saddlepath is optimal. Miles (1994) goes further by imposing a nonnegativity constraint on securities, so that borrowing with mortgage securities is the only available finance alternative.

¹⁸ Note that I have ignored considerations of the term-structure of mortgage debt. This is tantamount to assuming “adjustable rate mortgages”, or perfect capital markets with no refinancing constraints. The use of 30-year mortgages in the empirical work above can

To solve the model, substitute (9) into (8) to eliminate B_{mt} , then choose c_t , A_{t+1} , and H_t to maximize (7) subject to (8). If λ_t is the multiplier associated with (8) at time t , the Euler equations are:

$$\left(\frac{1}{1+\rho}\right)^t U_c(H_t, c_t) = \lambda_t \quad \forall t \quad (10)$$

$$\frac{\lambda_{t+1}}{\lambda_t} = \frac{1 + \pi_{t+1}}{1 + \tilde{R}_{t+1}} \quad \forall t \quad (11)$$

$$\begin{aligned} & \left(\frac{1}{1+\rho}\right)^t U_H(H_t, c_t) = \\ & \lambda_t p_t (1 + \mu - \beta + \tilde{\tau}_p) + \lambda_{t+1} \left[\left(\frac{1 + \tilde{R}_{m,t+1}}{1 + \pi_{t+1}}\right) \beta p_t - p_{t+1} (1 - \delta) \right] \quad \forall t \end{aligned} \quad (12)$$

where $\tilde{x} = (1 - \tau)x$, and $U_x(\cdot)$ is the partial derivative of $U(\cdot)$ with respect to x . Together, equations (10) and (11) combine to yield the usual tangency condition reflecting the optimal intertemporal tradeoff of consumption (holding the path of housing fixed). Substituting (10) and (11) into (12) to eliminate the multipliers implies

$$\begin{aligned} & \frac{U_H(H_t, c_t)}{U_c(H_t, c_t)} = \\ & p_t \left[(1 - \beta) + (\mu + \tilde{\tau}_p) + \left(\frac{1 + \tilde{R}_{m,t+1}}{1 + \tilde{R}_{t+1}}\right) \beta - \left(\frac{1 - \delta}{1 + \tilde{R}_{t+1}}\right) (1 + \pi_{t+1})(1 + \dot{p}_{t+1}) \right] \\ & = p_t \nu_t \end{aligned} \quad (13)$$

where $\dot{p}_{t+1} \equiv \left(\frac{p_{t+1} - p_t}{p_t}\right)$. Along the optimal path, the marginal rate of substitution between consumption and housing equals the user cost of housing. The latter is the slope of the budget line, which reflects the amount of current nondurable consumption given up (holding future expenditures and asset accumulation fixed) by purchasing one unit of housing, using it, then selling it at the end of the period. The first term in ν , the proportion of house value not financed by mortgage borrowing, is the direct resource cost of buying a

also be justified by appealing to the model as a framework for aggregate behavior, rather than individual. Note also that I do not account for “tilt” due to the effect of inflation on amortized mortgage payments (Kearl 1979).

house. The second term reflects the resources used up by owning the home. The third term reflects the opportunity costs of financing part of the house by mortgage borrowing. And the last term is the real future value of the undepreciated portion of housing, discounted to the current period.¹⁹ With the intertemporal resource constraint (and the restriction on infinite borrowing), (13) determines the optimal time paths of consumption and housing.

Equation (13) expresses the tangency condition for the demand for housing. The model implies two channels through which money supply shocks can affect this demand by way of changes in user cost. The first reflects the relative cost of housing finance by mortgage borrowing. As long as $\beta > 0$, an unanticipated increase in money supply that reduces (after tax) mortgage rates more than rates on alternative assets will reduce user cost and increase housing demand. The second channel reflects the effect of money supply shocks on the real rate of return on housing as an asset. As the (after tax) real rate falls in the face of money supply shocks, the expected future house value is discounted at a lower rate, and is thus worth more in terms of the present value of current consumption than before the shock. Therefore, user cost falls and housing demand rises.

Completing the equilibrium model for the housing market requires adding an equation representing flow housing supply. To this end, assume that

$$H_{t+1} - H_t = \alpha p_t - \delta H_t, \quad \alpha > 0; \quad (14)$$

i.e. housing construction is positively related to the real price of housing (e.g. Miles 1994, equation 2.19 and Poterba 1984, equation 4). The simplicity of this supply relation rules out potentially interesting channels for the effects of money, such as interest rate effects on

¹⁹ (13) is identical to Poterba (1984, p. 732) for $R_m = R$. It is also comparable to Miles (1994, equation 2.8) for the case of perfect foresight and no borrowing constraints on non-mortgage securities. Note that depreciation is explicit in the model and not factored into the real price of housing. That is, aging and depreciation of the housing stock affect the quantity, not the price, of housing. In actual market transactions, depreciation will be reflected in the price. This should be more a problem for existing home data than new home data.

supply and differences in supply elasticities in the short- and long-run. Topel and Rosen (1988) consider a richer model of construction supply.

Equations (13) and (14) determine the partial equilibrium dynamics of the housing market. Under the usual regularity conditions on preferences, the stable saddlepath for the real housing price and the stock of housing is downward sloping. Thus, given the presumption that the housing stock is constant at a point in time, a reduction in user cost that increases the demand for housing once and for all causes the price of housing to rise immediately from the original saddlepath to the new, then gradually fall along this path to a steady-state level higher than its pre-shock value. The stock of housing will gradually rise to a higher steady-state.²⁰

These dynamics imply that the housing price response should peak on impact of the shock to demand, then gradually fall (but remain higher than its original value). This prediction seems to be inconsistent with the empirical price response functions in Figures 2 and 3, which exhibit a hump-shaped pattern for price – an initial positive response, a gradual rise, then fall to the original steady-state. However, the empirical “experiment” does not consider a *permanent* change in housing demand; a money supply shock leads to transitory changes in interest rates and inflation. In terms of the model, then, the demand for housing should rise then fall. In the next subsection, I simulate the model to predict the dynamics of price response given the estimated changes in interest rates and inflation.

b. Simulating the theoretical responses of housing price to money supply shocks

By simulating the theoretical model, I can quantitatively assess the model’s predictions regarding the real housing price response to money supply shocks, as well as determine the relative importance of the distinct channels through which money affects housing demand. To perform the simulation, I make a few important assumptions. First, I assume that interest rates and inflation are exogenous to the housing market, which rules out potentially

²⁰ See Miles, (1994 p. 27) or Poterba (1984, p. 737) for a graphical description of these dynamics.

important feedback from the housing market to financial markets. I also assume that money does not affect the housing market indirectly through its effect on nondurables consumption, which in effect ignores the role of permanent income on housing decisions.²¹ Despite these limitations, these assumptions make the solution tractable and are common in the literature (e.g. Poterba 1984 and Bruce and Holtz-Eakin 1999). Thus, I choose to focus on the interest rate and inflation channels mentioned above. Finally, I impose Cobb-Douglas preferences:

$$U(H, c) = \gamma \log(c) + (1 - \gamma) \log(H). \quad (15)$$

Given these assumptions and calibrated values for the model's parameters, I simulate the *theoretical* response of housing price to the *estimated* dynamic responses of interest rates and inflation to money supply shocks from the VAR reported above.

The solution strategy entails log-linearizing the optimality condition from the consumer's problem and the supply equation, then solving the log-linear system for the equilibrium price (a strategy suggested by Campbell 1994 and others for studying real business cycle theories). The details of the linear approximation and simulation are given in the appendix. As shown there, the log-linear system corresponding to (13), (14) and (15) is

$$\log(p_t) = K_1 - w_1 \log(H_t) + w_2 \log(p_{t+1}) + x_t \quad (16)$$

$$\log(H_{t+1}) = \phi_1 \log(H_t) + (1 - \phi_1) \log(p_t), \quad (17)$$

where $x_t = w_3(\tilde{R}_{t+1} - \tilde{R}_{mt+1}) - w_2(\tilde{R}_{t+1} - \pi_{t+1})$. The parameters w_1 , w_2 , w_3 and ϕ_1 in (16) and (17) are functions of the theoretical parameters as defined in the appendix, and are restricted to lie between 0 and 1. Furthermore, $w_2 = 1 - w_1$. Given the assumption that $\log(c)$ is constant, the only channel through which money supply shocks can affect the housing market in this model is through the effects of such shocks on x_t (i.e. interest

²¹ Since money supply shocks likely have only small effects on *permanent* income, this assumption is presumably innocuous.

rates and inflation). Solving (17) for $\log(H_t)$ and substituting into (16) yields the following second order difference equation in price:

$$\log(p_t) = a_0 \log(p_{t+1}) + a_1 \log(p_{t-1}) + \left[\frac{1}{1 + \phi_1 w_2} \right] (x_t - \phi_1 x_{t-1}), \quad (18)$$

where $a_0 = \frac{w_2}{1 + w_2 \phi_1}$ and $a_1 = \frac{\phi_1 - w_1(1 - \phi_1)}{1 + w_2 \phi_1}$. The stable saddlepath solution is

$$\log(p_t) = \zeta (1 - \lambda_1 L)^{-1} \sum_{i=0}^{\infty} \lambda_2^{-i} v_{t+i}, \quad (19)$$

where $\zeta = (1 - a_0 \lambda_1)^{-1} (1 + \phi_1 - \phi_1 w_1)^{-1} > 0$, $v_{t+i} = x_{t+i} - \phi_1 x_{t+i-1}$, and λ_1 and λ_2 are the roots of the appropriate characteristic equation, as described in the appendix. It is straightforward to show that under the conditions of the log-linearization, λ_1 is less than one in absolute value, while λ_2 is greater than 1. Hence, writing the solution as in (19) (solving the unstable root forward) imposes saddlepath stability, which rules out price bubbles in equilibrium.

Now consider the theory's implications for the dynamic response of housing price to a serially uncorrelated exogenous shock u_t :

$$\frac{\partial \log(p_{t+k})}{\partial u_t} = \zeta \lambda_1^k \sum_{i=0}^{\infty} \lambda_2^{-i} \frac{\partial v_{t+i+k}}{\partial u_t}. \quad (20)$$

If u_t is interpreted as a money supply shock, (20) gives the theoretical impulse responses of housing prices (as a function of k) that are analogous to the estimated responses in the previous section. Given the exogeneity assumption, then, we can simulate the theoretical housing price response by substituting into (20) the estimated responses for interest rates and inflation inferred from the VAR results reported in the figures.²²

²² As noted above, the model has been developed and solved assuming perfect foresight. However, the simulations can easily be interpreted in terms of a model with certainty equivalence, in which future values are replaced by expected values. The estimated response functions for interest rates and inflation can be interpreted as the revision in the *expected* path for those variables in the face of unanticipated shocks to the money supply (Hamilton 1994, pp. 319-20). This is exactly what is implied by a model of dynamic choice under uncertainty (Blanchard and Fischer 1989, pp. 261-64).

Figures 10 (new house prices) and 11 (existing house prices) report the simulated theoretical responses of housing prices to money supply shocks for the systems identified by imposing long-run monetary neutrality. For all simulations reported, w_3 is set equal to 0.69.²³ Changing this value has no important effects on the simulated responses; however, the results are sensitive to variations in w_1 and ϕ_1 . To give a feel for this sensitivity, the simulations are reported for various values of w_1 and ϕ_1 . The parameter w_1 varies between 0.01 and 0.40, while ϕ_1 takes the values 0.8, and 0.9. The shaded area in the figures is the identified response from the VAR, repeated from Figures 2 and 6; each panel corresponds to a different value of w_1 , with the solid curve corresponding to $\phi_1 = 0.8$ and the dashed curve corresponding to $\phi_1 = 0.9$.

According to Figure 10, for new house prices the theoretical model closely mimics the estimated response functions when w_1 is small (around .01) and ϕ_1 is close to 0.8. When $\phi_1 = .9$, the theoretical response underpredicts the actual response, but closely matches the timing of the peak response (at about 15 months).²⁴ As w_1 increases, the simulated response becomes increasingly unable to achieve either the magnitude or the hump-shape of the estimated response, for any value of ϕ_1 .

The simulated responses for existing homes in Figure 11 are similar to those for new homes, showing a more exaggerated hump-shape for $w_1 = 0.01$. This shape, however, is not as pronounced for the actual responses. The simulation for $w_1 = 0.01$ and $\phi_1 = 0.90$ closely tracks the actual response after the 12-month horizon, but underpredicts at smaller horizons. The shape of the simulated response is closer to the actual when $w_1 = 0.05$, but the magnitude is too small.

How important are the two transmission channels of money supply shocks? In Figure

²³ This value corresponds to values of β (the loan-to-value ratio) and $\theta = 1 - \beta + \mu + \tilde{\tau}_p$ of 0.70 and 0.32, respectively. The steady-state rate differential is set to zero.

²⁴ Although only two values of ϕ_1 are shown, as this parameter falls below 0.8, the fit of the predicted response worsens. In particular, the peak of the predicted response occurs well before, and overpredicts the magnitude of, the actual response.

12, I plot for new house prices the predicted price response assuming that money supply shocks have no effect on the real interest rate, which isolates the interest rate differential effect. Likewise, in Figure 13, I assume that money supply shocks have no effect on the interest rate differential and thus isolate real rate effects. As is evident from the figures, the real rate response is most responsible for driving the correspondence between the simulated and estimated responses.

In general, then, the theoretical model provides a useful framework for interpreting the time series evidence when w_1 is small (i.e. w_2 is close to one), and ϕ_1 is relatively large (in the 0.80 to 0.90 range). How reasonable are these parameter values? From equations (17) and (A6) in the appendix, note that ϕ_1 measures the persistence in the housing stock due to depreciation and construction activity. Even if housing construction is very elastic (i.e. α is large), we should expect the housing stock to adjust slowly to shocks since depreciation rates are likely to be small and flow construction small relative to the housing stock. “Small” values for ϕ_1 therefore seem implausible.

To get a feel for the magnitude of w_1 , note from the appendix that this parameter depends on the steady-state values of the real price of housing and the marginal rate of substitution of housing and nondurable consumption. The latter can be interpreted as the relative service flow of housing in terms of nondurables; denote this value in the steady-state as S_0 . As shown by Miles (1984, pp. 31-32) among others, equilibrium price can be interpreted as the discounted value of the service flow. If we assume that the rate of depreciation is small (say zero, so that the service flow is permanent) and the discount rate equals the real interest rate in the steady-state, we have approximately:

$$w_1 = \frac{S_0}{S_0 + (1 - \tilde{r})\frac{S_0}{\tilde{r}}} = \tilde{r}.$$

That is, w_1 should approximately equal the real interest rate. A value of 0.01 is surely reasonable under this approximation.²⁵

²⁵ The logarithmic preferences in (15) are a special case of the CES utility function,

4. Conclusion

This paper provides time-series evidence that aggregate real prices and sales of new and existing owner-occupied homes generally respond in a non-trivial way to properly identified money supply shocks over the short-run. This finding adds to the growing body of work using VAR models that supports the notion that money does indeed have real effects on macroeconomic activity in the short-run (Christiano, Eichenbaum and Evans 1999). My results indicate that transmission through the housing sector is likely to be important.

To better understand the economics of the housing market in the face of money shocks, I compare the empirical responses to those implied by a dynamic model of the housing market in equilibrium, in which money affects the user cost of housing demand primarily through its effect on the real interest rate. For plausible parameter values, the theoretical and actual response functions move closely together. This result is especially powerful since the model makes very simple assumptions about the flow supply of housing, and ignores potentially important issues like risk, land values and other housing characteristics.

These findings suggest that the standard dynamic model of housing, in which the role of housing as an asset is accounted for, is a useful framework for predicting the effects of monetary policy on housing markets. They also provide support for the model, as least as a starting point, for simulating the effects of other types of policies, such as tax reform and interest rate subsidies, on housing markets. Finally, the results potentially have broader implications for other types of durable goods and more general consumption behavior, an issue left for future research.

which is utilized by Bruce and Holtz-Eakin (1999). For this general utility function, w_2 no longer exactly equals $1-w_1$, but does so approximately for reasonable values of substitution elasticity. My results are not sensitive to variations in the elasticity of substitution.

Appendix

In this appendix, I provide details regarding the log-linear approximation to theoretical model of housing price given in (16), as well as the simulation. Consider first the approximation to the Euler equation given by (13) in the text. Using the functional form in (15) and making some obvious approximations for the ratios of gross interest rates, I can rewrite (13) as

$$\left(\frac{1-\gamma}{\gamma}\right)\frac{c_t}{H_t} = p_t[\theta + (1 + \tilde{R}_{mt+1} - \tilde{R}_{t+1})\beta] - p_{t+1}(1 - \delta - \tilde{R}_{t+1} + \pi_{t+1}), \quad (A1)$$

where $\theta = 1 - \beta + \mu + \tilde{\tau}_p$. Solving for p_t and taking logs:

$$\log(p_t) = \log\left[\left(\frac{1-\gamma}{\gamma}\right)\frac{c_t}{H_t} + (1 - \delta - \tilde{r}_{t+1})p_{t+1}\right] - \log[\theta + (1 + \tilde{R}_{mt+1} - \tilde{R}_{t+1})\beta], \quad (A2)$$

where r denotes the ex post real interest rate. Note that, in general, the first order Taylor approximation of $f(y, x) = \log(ay + bx)$ around (y_0, x_0) is

$$f(y, x) \approx \log(ay_0 + bx_0) + \left(\frac{ay_0}{ay_0 + bx_0}\right)[\log(y) - \log(y_0)] + \left(\frac{bx_0}{ay_0 + bx_0}\right)[\log(x) - \log(x_0)].$$

Applying this approximation to each of the log functions in (A2) and collecting all constants (including $\log(c_t)$ which I assume is constant) in K_1 yields (16) in the text, for

$$w_1 = \frac{\left(\frac{1-\gamma}{\gamma}\right)\frac{c_0}{H_0}}{\left(\frac{1-\gamma}{\gamma}\right)\frac{c_0}{H_0} + (1 - \delta - \tilde{r})p_0} \quad (A3)$$

$$w_3 = \frac{(1 + \tilde{R}_{m0} - \tilde{R}_0)\beta}{(1 + \tilde{R}_{m0} - \tilde{R}_0)\beta + \theta}, \quad (A4)$$

and $w_2 = 1 - w_1$. Similarly, taking logs of (14) yields

$$\log(H_{t+1}) = \log[(1 - \delta)H_t + \alpha p_t], \quad (A5)$$

which is approximated as (17) in the text for

$$\phi_1 = \frac{(1 - \delta)H_0}{(1 - \delta)H_0 + \alpha p_0}. \quad (A6)$$

The simulation entails using the estimated dynamic response functions for R , R_m , and π (to money supply shocks) on the right-hand-side of (20), which I repeat here for convenience:

$$\frac{\partial \log(p_{t+k})}{\partial u_t} = \gamma \lambda_1^k \sum_{i=0}^{\infty} \lambda_2^{-i} \frac{\partial v_{t+i+k}}{\partial u_t}$$

$$v_{t+i} = x_{t+i} - \phi_1 x_{t+i-1} \tag{A7}$$

$$x_t = w_3(\tilde{R}_{t+1} - \tilde{R}_{mt+1}) - (1 - w_1)(\tilde{R}_{t+1} - \pi_{t+1}).$$

The upper limit of the summation is infinite in theory; in practice, I set the limit to 250 periods. λ_1 and λ_2 are the roots of the characteristic equation (see, for example, Blanchard and Fischer 1989, pp. 261-66):

$$a_0 \lambda^2 - \lambda + a_1 = 0, \tag{A8}$$

where $a_0 = \frac{w_2}{1+w_2\phi_1}$ and $a_1 = \frac{\phi_1 - w_1(1-\phi_1)}{1+w_2\phi_1}$. These roots depend only on w_1 and ϕ_1 . λ_1 , the stable root, can be positive or negative.²⁶ When the root is positive, the theoretical price converges monotonically to the steady-state. When the root is negative, the price oscillates. For the simulations in which λ_1 is negative, I rule out paths for which the implied housing stock path oscillates. It turns out, however, that the effect on the price path is nil.

²⁶ For example, when $w_1 = 0.01$ and $\phi_1 = 0.8$, $\lambda_1 = 0.79$. For $w_1 = 0.2$ and $\phi_1 = 0.1$, $\lambda_1 = -0.07$.

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Figure 1. Mortgage rates and the housing market.
 Shaded area is the mortgage rate. Solid line is a measure of house price or sales.

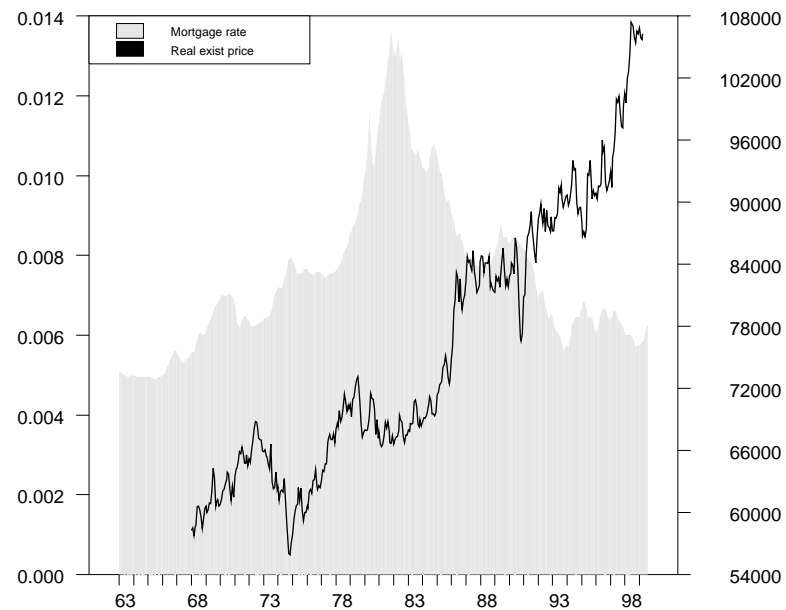
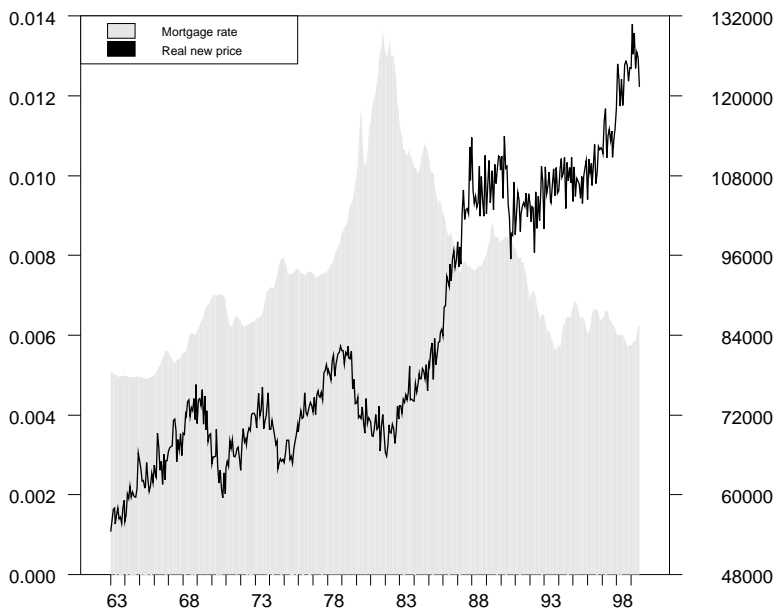
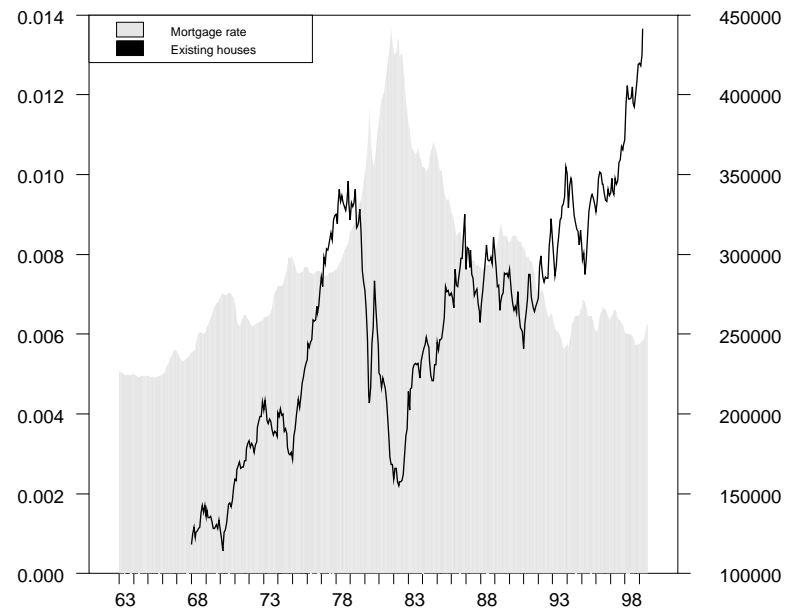
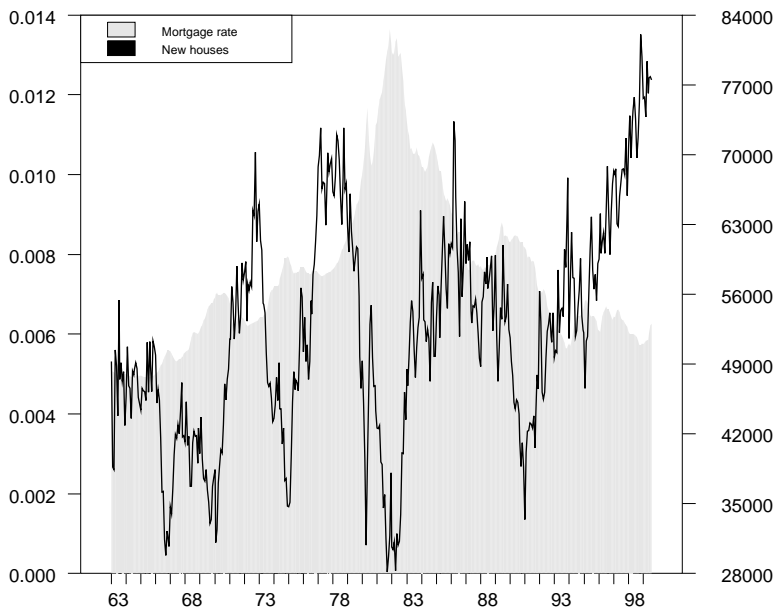


Figure 2. Responses to money supply shocks using new house data with long-run restrictions
Sample range is 64:02 to 99:08

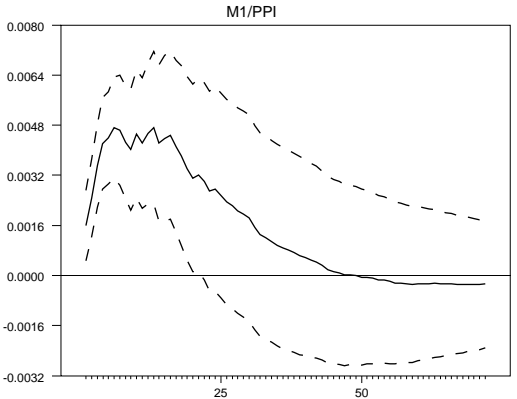
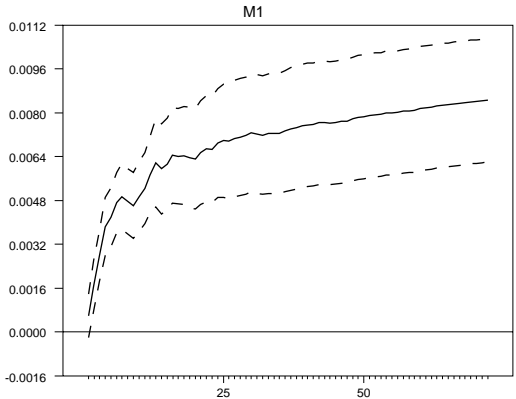
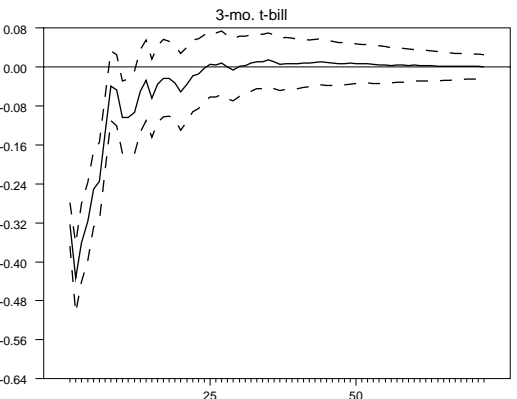
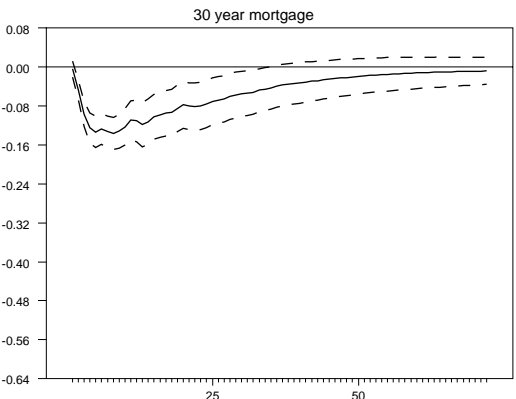
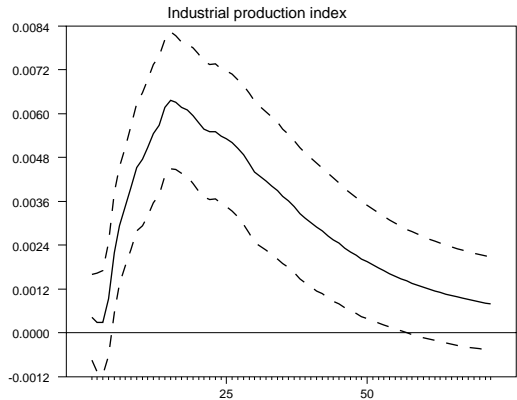
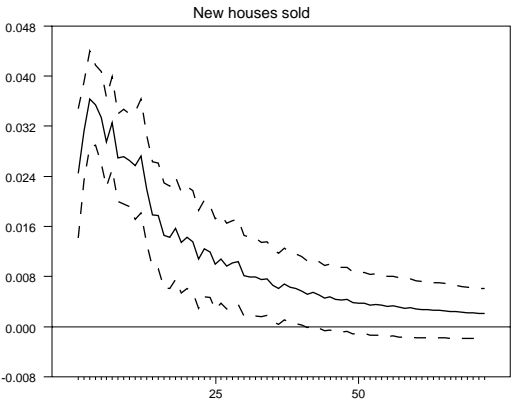
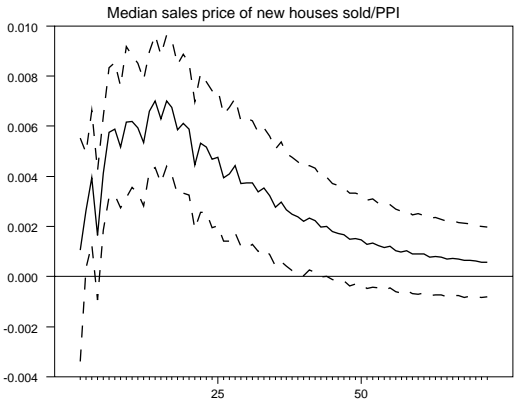


Figure 3. Responses to money supply shocks using new house data with short-run restrictions
Sample range is 64:02 to 99:08

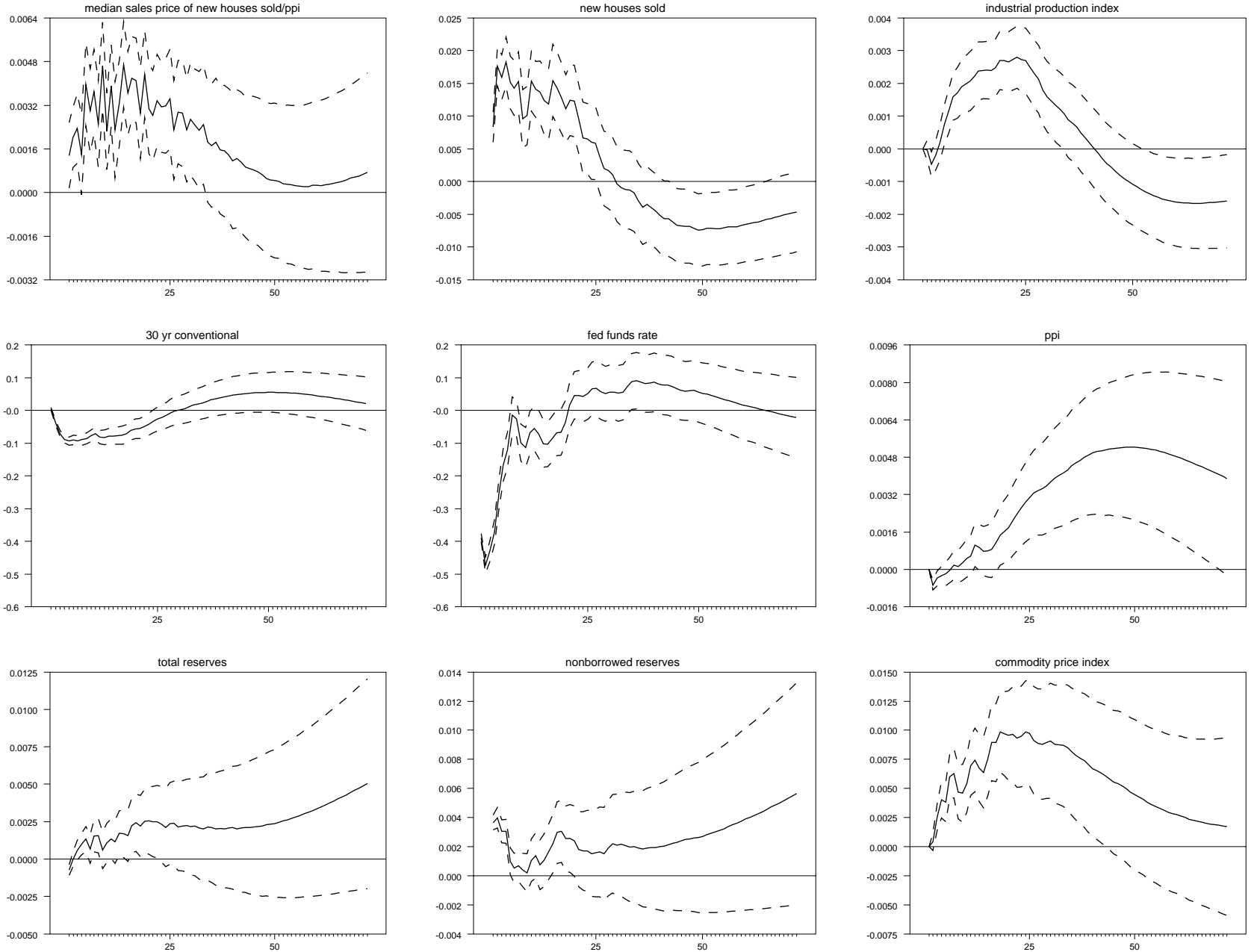


Figure 4. Contribution of money supply shocks to variance using new house data with long-run restrictions
Sample range is 64:02 to 99:08

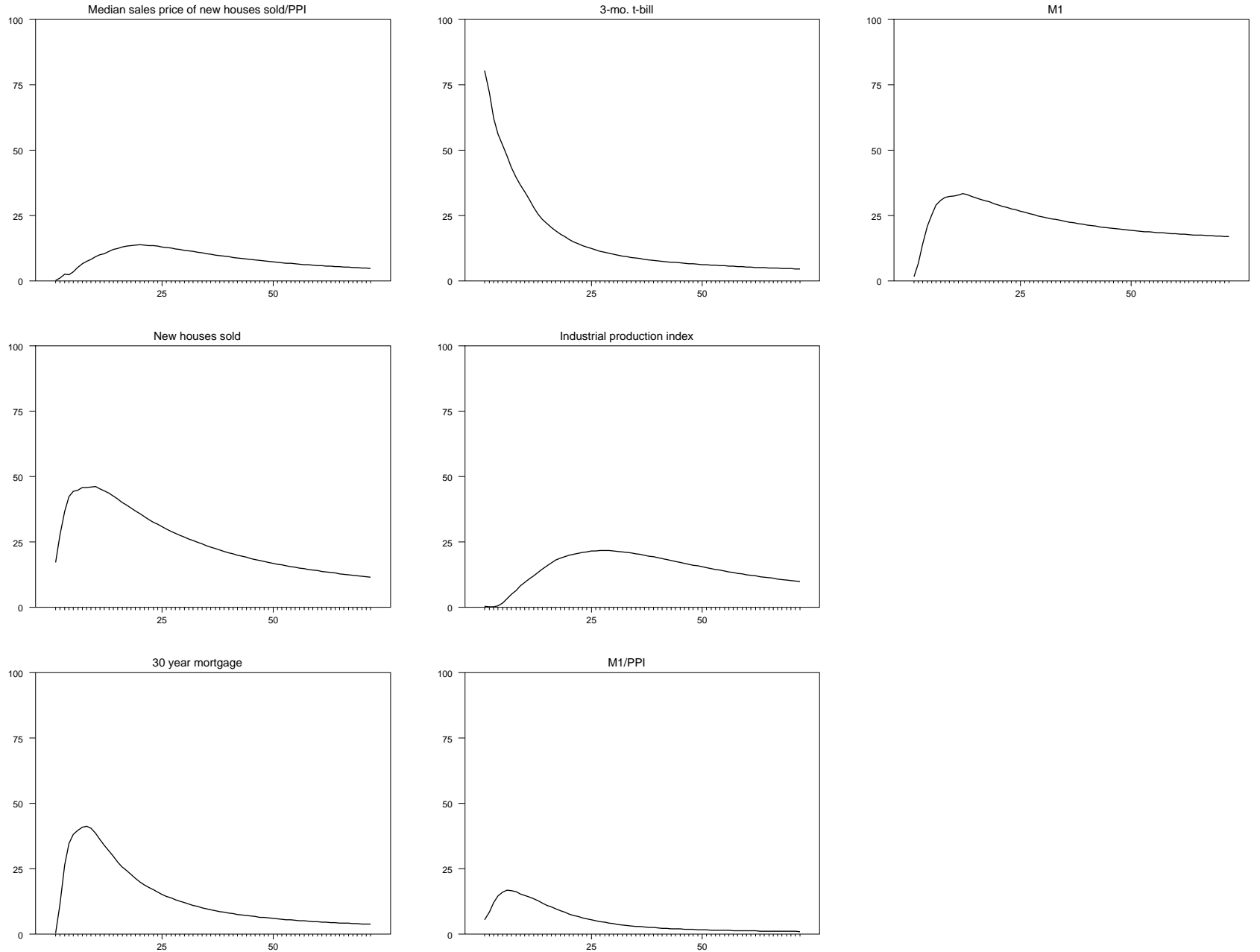


Figure 5. Contribution of money supply shocks to variance using new house data with short-run restrictions
Sample range is 64:02 to 99:08

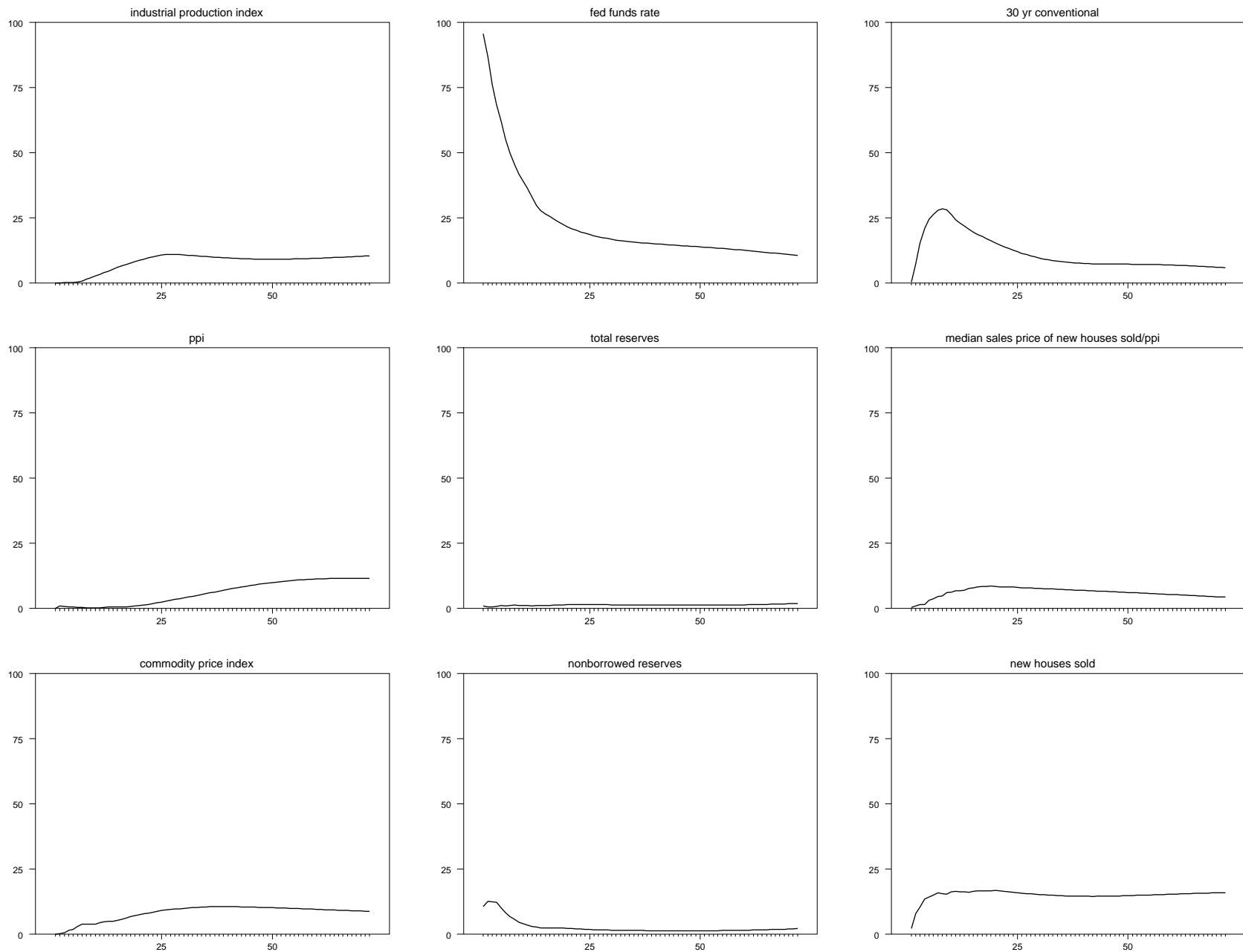


Figure 6. Responses to money supply shocks using existing home data with long-run restrictions
Sample range is 69:02 to 99:04

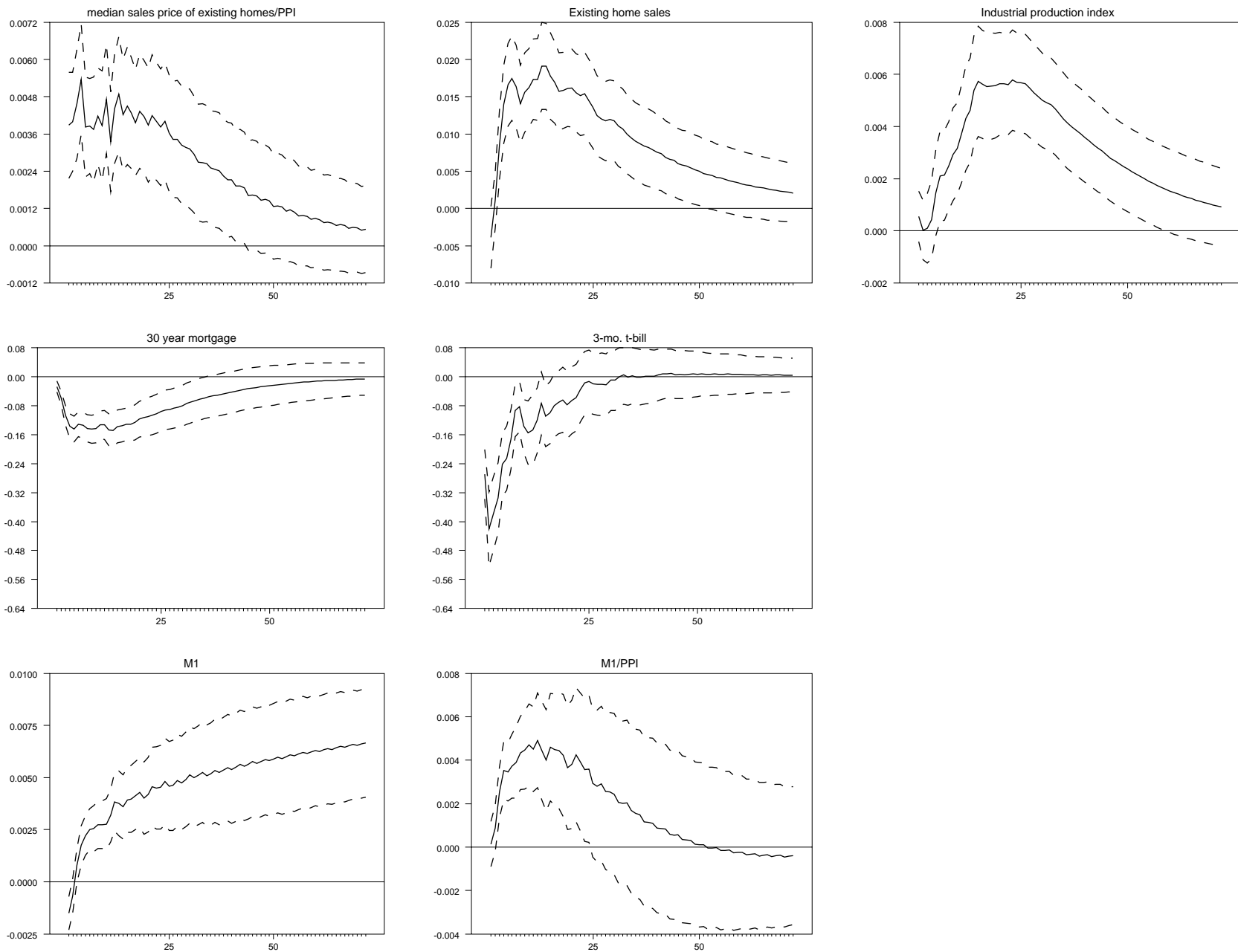


Figure 7. Responses to money supply shocks using existing home data with short-run restrictions
Sample range is 69:02 to 99:04

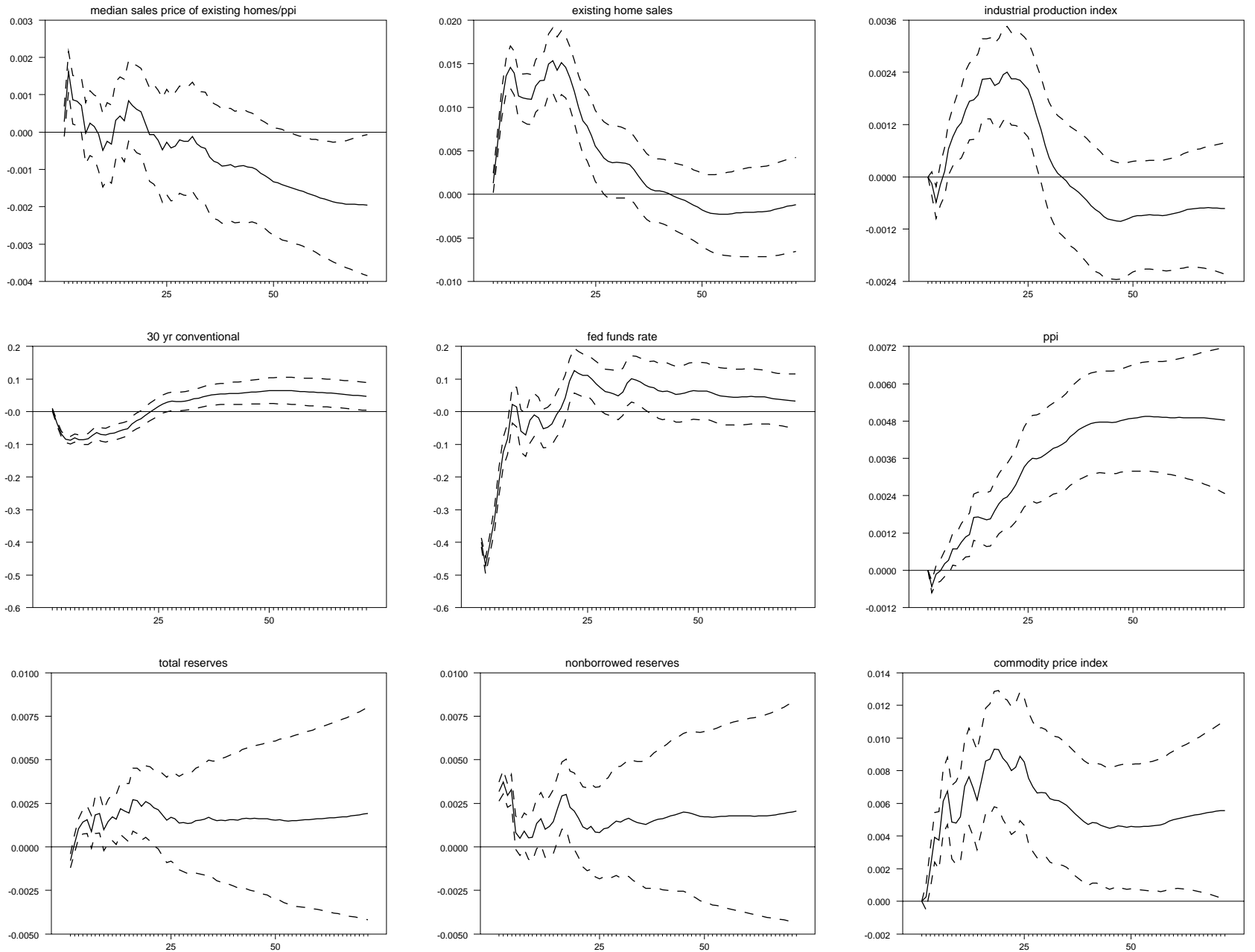


Figure 8. Contribution of money supply shocks to variance using existing home data with long-run restrictions
Sample range is 69:02 to 99:04

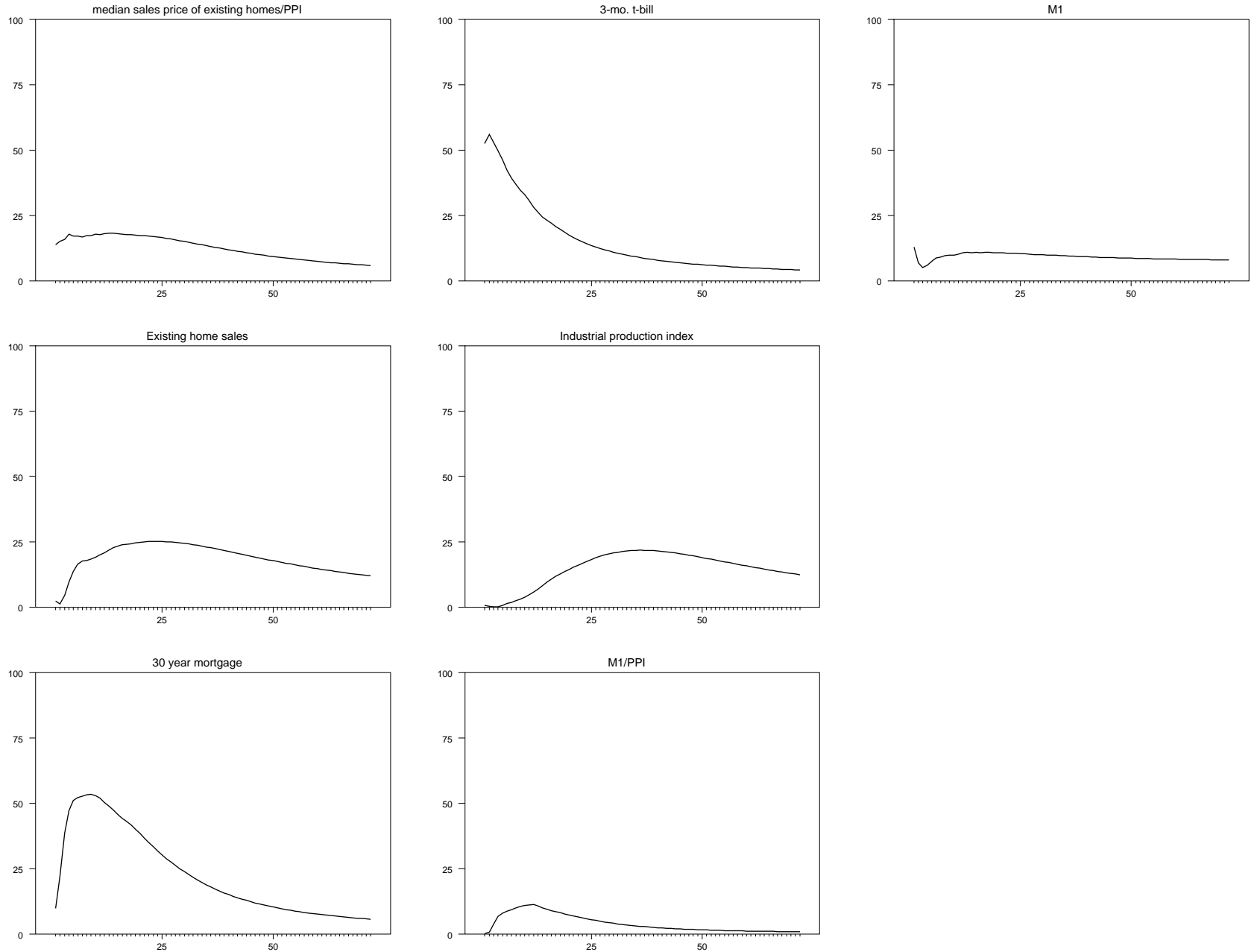


Figure 9. Contribution of money supply shocks to variance using existing home data with short-run restrictions
Sample range is 69:02 to 99:04

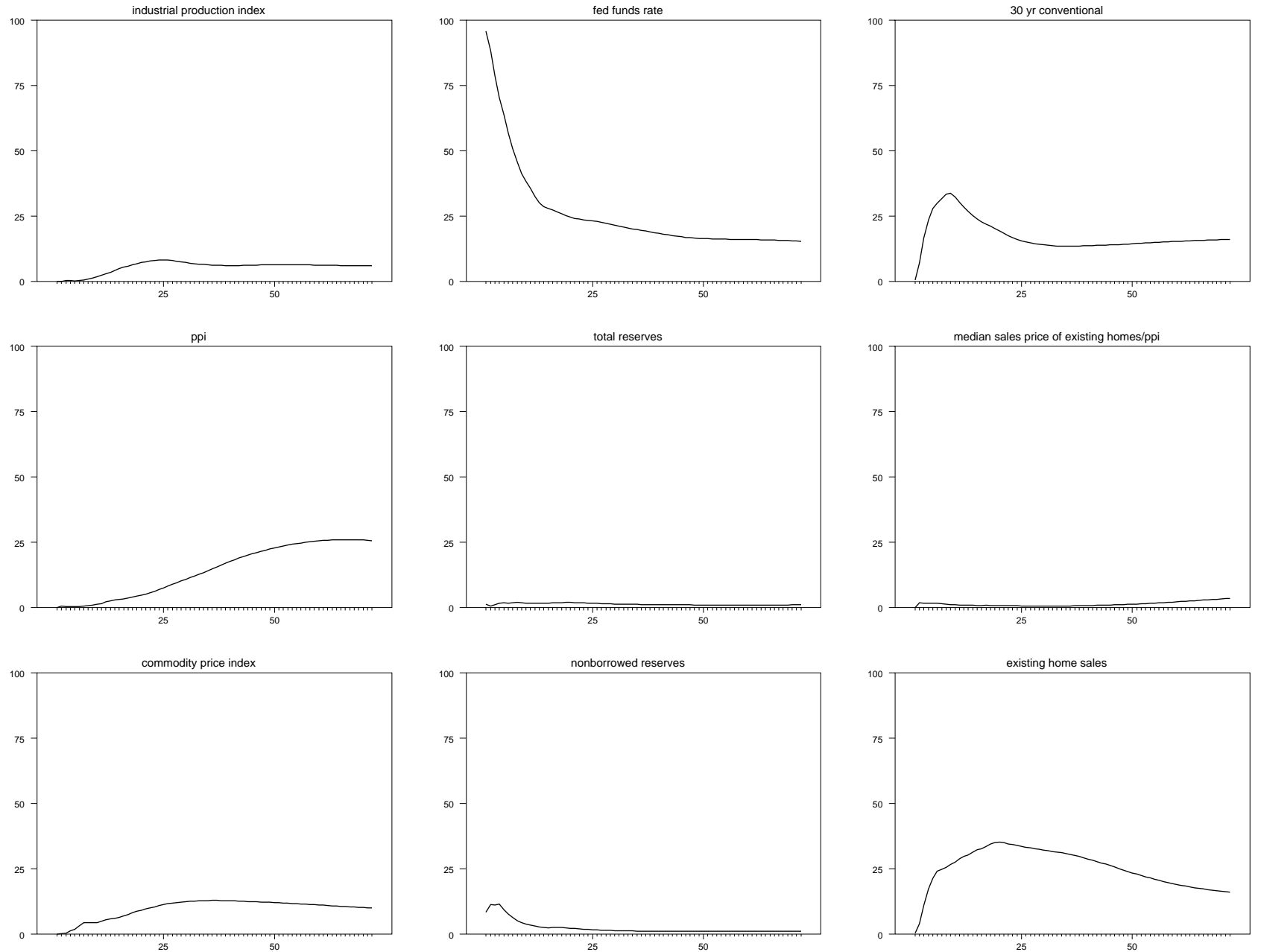


Figure 10. Simulation results for new house prices
Shaded area is response estimated from the data. Solid curve: $\phi_1=0.8$; dashed curve: $\phi_1=0.9$

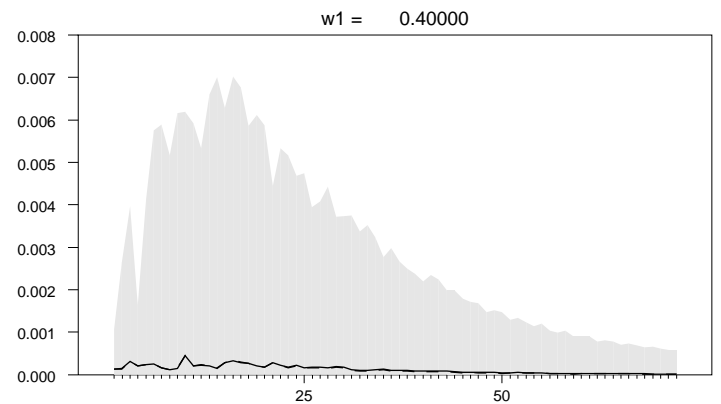
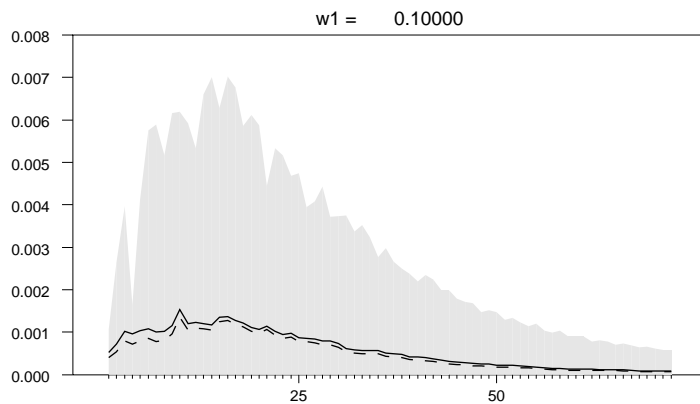
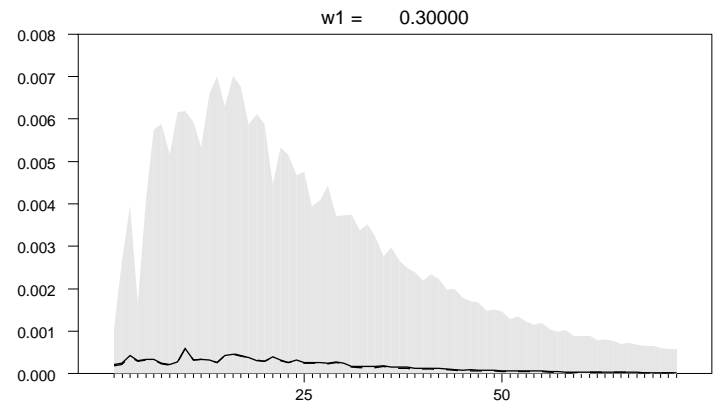
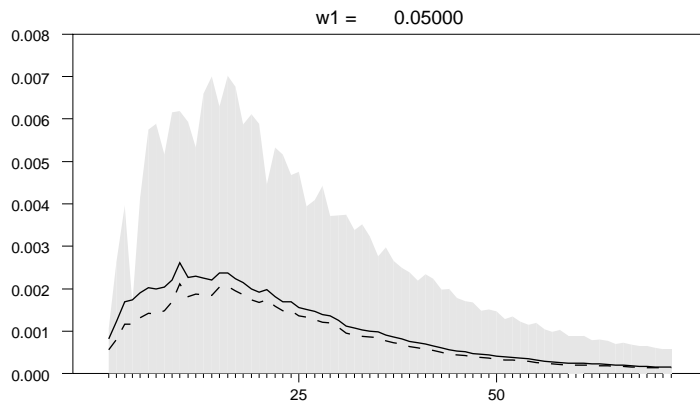
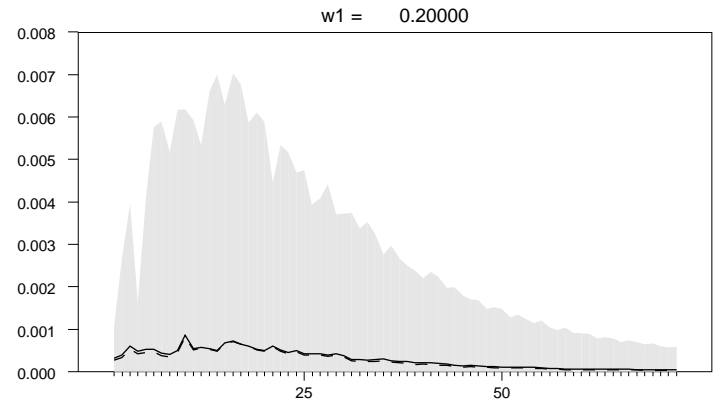
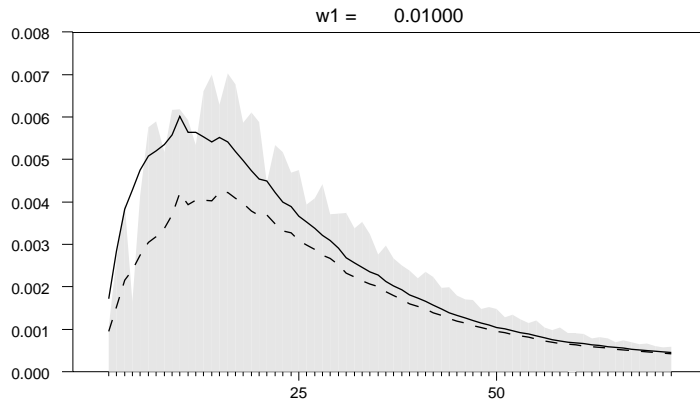


Figure 11. Simulation results for existing house prices
Shaded area is response estimated from the data. Solid curve: $\phi_1=0.8$; dashed curve: $\phi_1=0.9$

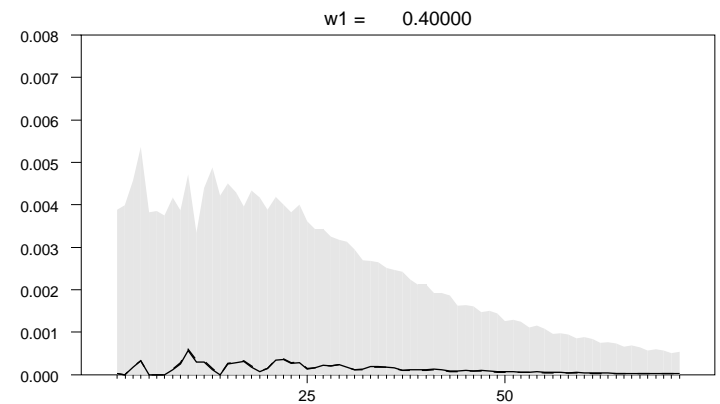
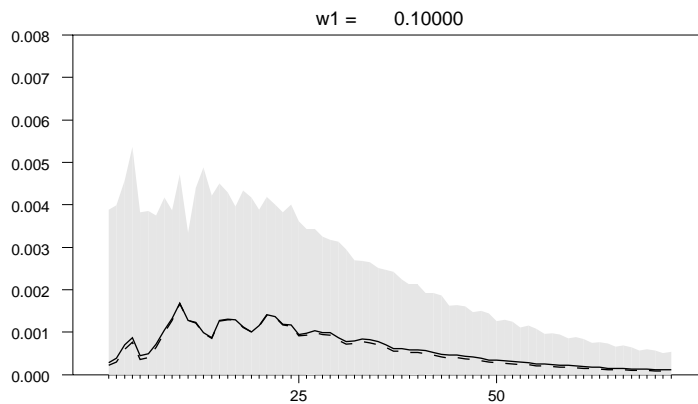
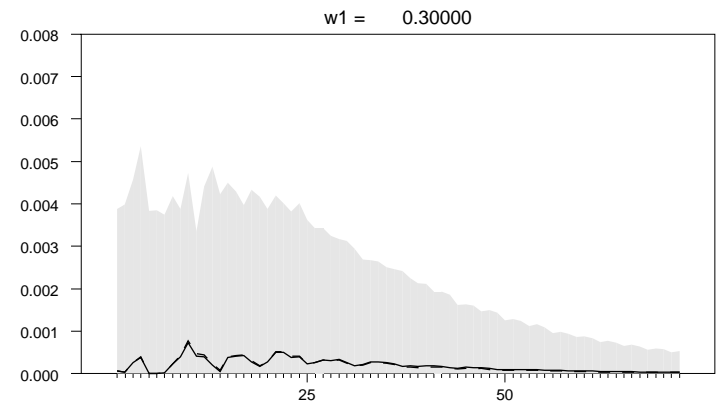
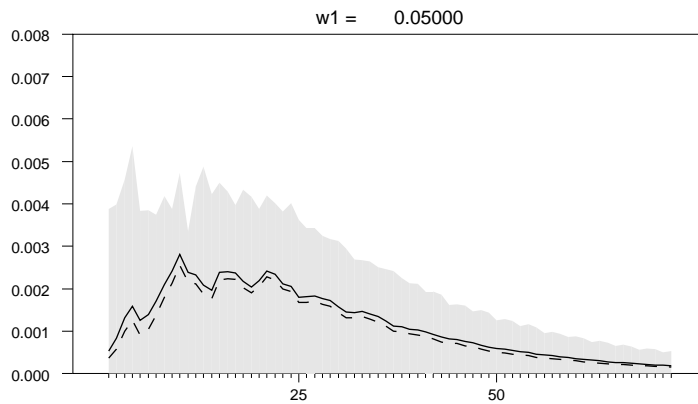
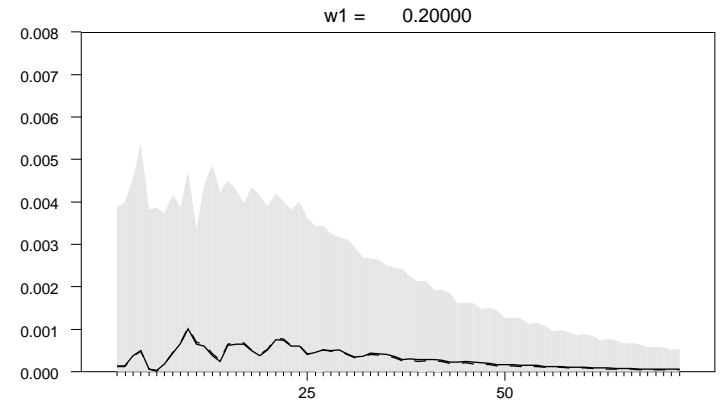
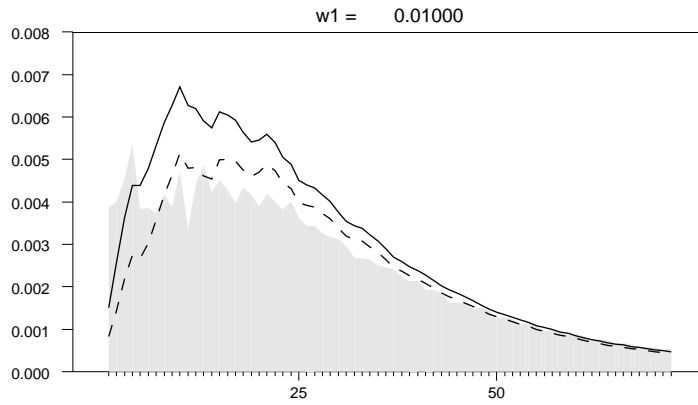


Figure 12. Simulation results for new house prices -- rate differential effect only
Shaded area is response estimated from the data. Solid curve: $\phi_1=0.8$; dashed curve: $\phi_1=0.9$

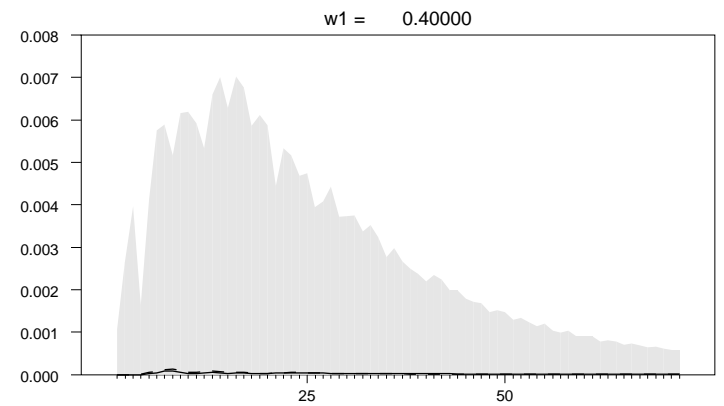
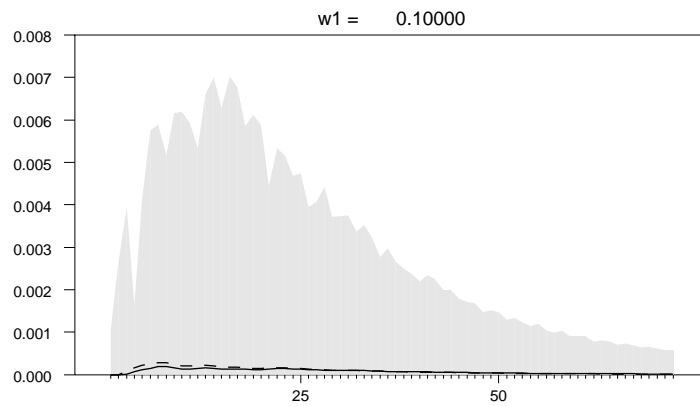
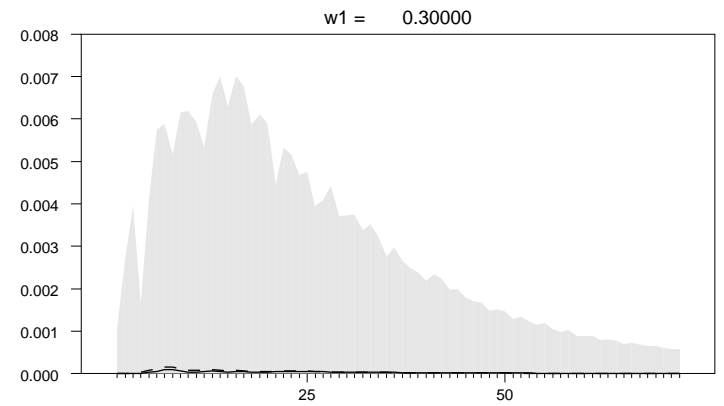
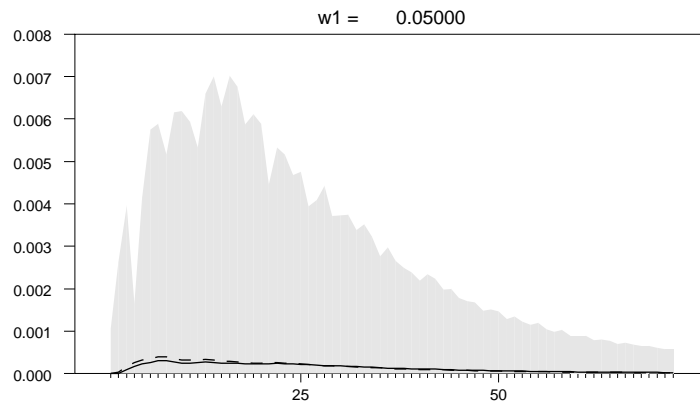
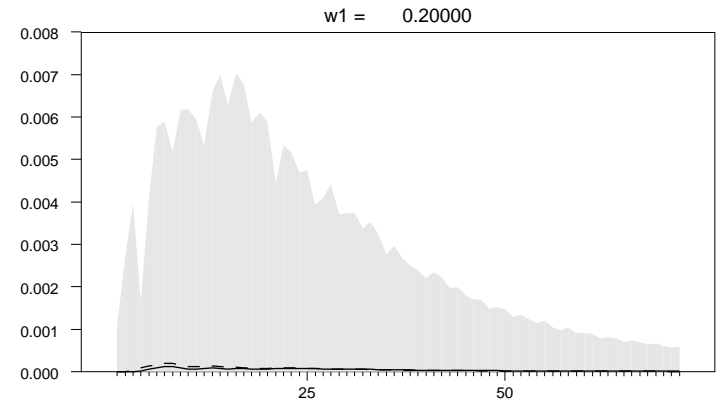
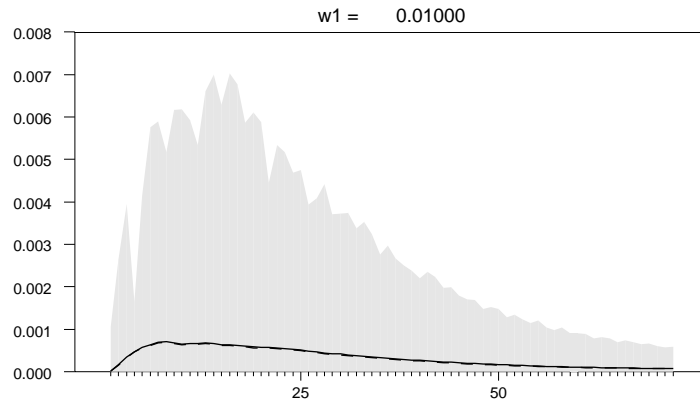


Figure 13. Simulation results for new house prices -- real rate effect only
Shaded area is response estimated from the data. Solid curve: $\phi_1=0.8$; dashed curve: $\phi_1=0.9$

