Appendix D: Robustness Analysis for "Housing Market Spillovers: Evidence from an Estimated DSGE Model"

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1 Overview

This Appendix reports the results of additional robustness exercises that are mentioned in the paper "Housing Market Spillovers: Evidence from an Estimated DSGE Model".

2 Robustness Analysis

2.1 The Role of Shocks and Frictions.

The ability of the various shocks and frictions to match certain moments of the data has been assessed by reestimating the model shutting one or more frictions or shocks off each time. Table D.1a reports the simulated (mean) volatilities of some of the observables used in estimation.[1] Table D.1b reports correlations among selected observables. Table D.2 reports the mode of the posterior distribution of the structural parameters.

Tables D.1a and D.1b report selected standard deviations and correlations for the data and the baseline model in columns (a) and (b). Column (c) reports statistics for the model without capital adjustment costs: this model generates excessive volatilility in business investment and a correlation between consumption and GDP that is far lower than in the data. The model with perfect labor mobility across sectors (column d) underestimates the positive correlation between housing prices and housing investment. The model with fixed capacity utilization (column e) generates excessive volatility of residential investment and house prices, and fails on the correlation between house prices and housing investment. The model with flexible wages and prices (column f) fails to account for the empirical volatilities and the correlations between the real variables (consumption, business and residential investment). Similar considerations apply to the model with flexible wage only (column g) and flexible prices only (column h). Finally, the model without borrowing constrained households (column i) is similar to the baseline model in terms of unconditional moments properties: however, as we already emphasize in the text, it generates a negative comovement between house prices and consumption conditional on a housing demand shock.

Moving to parameter estimates, Table D.2 reports the posterior distribution of the estimated parameters for the alternative model specifications in which real and nominal frictions are shut off one at a time.

The main differences concern the degree of substitutability between hours in the two sectors, the share of unconstrained agents and the parameters measuring the nominal rigidities.

Figures D.1 to D.4 show the estimated impulse responses for the alternative versions of the model. As we argue in the main text, wage rigidity is the most important friction to account for the differential responses of residential and business investment to monetary shocks. In the case of a housing preference shock borrowing constraints, nominal wage rigidity, variable capacity utilisation and imperfect labor mobility are all important elements in enhancing the model's ability to generate an increase in consumption following a shock that increases real house prics.

[1] The statistics are computed using the mode of the posterior distribution of the parameters and drawing 500 time series for each variable.

2.2 The Model with Technology Shocks only

The model has been estimated with only technology shocks. All the variables except residential investment, consumption and business investment have an AR(1) measurement error attached to the corresponding observation equation. Tables D.3 and D.4 report simulated volatilities and correlations of this model.

This model also generates a lower volatility of all the variables. It also produces a very low correlation between real house prices and real residential investment. It also generates a lower correlation between real residential investment and output, and misses the empirical correlation between consumption and housing prices (in the data it is 0.48, in the model it is 0.95).

2.3 The Role of House Price Data

In order to understand the implications of the choice of the data for house prices, we have estimated the model using the OFHEO price index in place of the Census one.[2] We have also estimated the model using both time series under the assumption that each series measures house prices up to some measurement error. In this case we have assumed the following measurement equations:

$$\hat{q}_t^{Census} = \widehat{q}_t + v_t^{Census}$$

$$\hat{q}_t^{OFHEO} = \widehat{q}_t + v_t^{OFHEO}$$

where the two measurement errors v_t^{Census} and v_t^{OFHEO} are assumed to be two mutually independent, serially correlated processes:

$$v_t^{Census} = \rho_C v_{t-1}^{Census} + \epsilon_t^{Census}$$

$$v_t^{OFHEO} = \rho_O v_{t-1}^{OFHEO} + \epsilon_t^{OFHEO}$$

and $\widehat{q}_t$ denotes the model counterpart of log real house prices, in deviation from the linear trend.

Figures D.5 and D.6 compare the impulse responses to housing preference (Figure D.5) and monetary policy (Figure D.6) shocks computed using the mode of the posterior distribution of the parameters obtained using the Census, the OFHEO and both indices. The implications for the results in the paper are evaluated in terms of parameters estimates, impulse responses and historical decompositions of real house prices. Figures D.5 and D.6 show that the three sets of impulse responses are virtually identical.

A comparison of the contribution of monetary policy to the historical decomposition of real house prices shows that the effects of changes in the nominal interest rate have had similar consequences on house prices, either measured by the Census or the OFHEO indices. Table D.5 shows that the mode of the parameters estimated using the two house price data, both separately and at the same time do not differ substantially.

2.4 The Role of Heterogeneous Household Preferences

We have estimated a version of our model where we constrain the preference parameters to be the same across the two types of agents. The results are reported in Table D.6 and are quantitatively similar to those reported in the paper.

[2] The Census series starts in 1965. The OFHEO series is only available from 1970. To ensure compatibility across the two sets of estimates, we extrapolate the OFHEO series backwards for the years 1965-1969 using the growth rate of the Census series during the same period.

Concerning the effects of a positive housing preference shock, the model in which constrained and unconstrained agents have identical preferences (except for the discount factor) suggests a larger elasticity of real consumption to real house prices. The response on impact is twice the one in the model with heterogeneous households' preferences.

With respect to the effects of an expansionary monetary policy shock, the model with identical preferences suggests a larger response of residential investment.

3 Some Additional Checks

3.1 What is the Role of Measurement Error?

In the baseline model, we allow for (iid) measurement error only in wages and hours of the construction sector. We have estimated two alternative versions of the model with different assumption regarding measurement error: (1) a version of our model where we allow for measurement error also in wages and hours in the non-housing sector; (2) a version of our model where we allow for measurement error in all time series. We found no major differences across models for the estimates of the key model parameters. The main discrepancy between our benchmark model and the versions with measurement error arises when we compare monetary shocks between the model with measurement error only for the housing labor market with the model with measurement error in all variables. Allowing for measurement error in all variables reduces the contribution of monetary policy shocks to business fluctuations. In practice, the model assigns a good deal of the fluctuations in interest rates to "noise", rather than random changes in the monetary policy rule. For this reason, the standard deviation of the monetary shocks is found to be smaller (it falls from around 0.3 percent to 0.1 percent), so that monetary shocks play a smaller role in the historical decomposition. Figure D.10 plots the impulse responses to a monetary shock in the three models. The response in the model with measurement error for all variables are a scaled-down version of those of the benchmark model.

3.2 What do Credit Shocks do?

As a further check, we have estimated our model by allowing m to change over time. We have treated m_t as an observable random variable that follows an AR(1) process of the form $\log m_t = (1-\rho_m)\log \overline{m} + \rho_m \log m_{t-1} + \varepsilon_{mt}$, where ε_{mt} is an i.i.d disturbance with standard deviation σ_m. We have then constructed a time series for m_t[3] using as a proxy household leverage, constructed as the ratio of outstanding home mortgages over holdings of residential real estate.[4] The implied series is plotted in Figure D.11 together with the real house price series used in estimation.[5] As the figure shows, the run-up in house prices since the late 1990s is roughly concomitant with an increase in leverage of the household sector. However, household leverage fell in the 1970s (when house prices also rose dramatically) and did not change much between 1997 and 2001 (at the beginning of the housing boom). Our estimates (including the results from the historical decomposition) for this

[3] We have normalized $\overline{m} = 0.85$ as in our benchmark model.

[4] The series are from the Flows of Funds. Home mortgages are in line 32 of Table B.100 - series FL153165105.Q -. Residential real estate holdings are in line 4 of Table B.100 - series FL155035015.Q -.

[5] We set the average loan-to-value ratio $\overline{m}$ to 0.85, and feed into the model the demeaned series for leverage plotted in Figure 2. Therefore, we do not use information on average leverage as an input in estimation. The reason why we do so is because in the data many households have a mortgage but behave as unconstrained households, smoothing consumption through other means (for instance, they might own equity and a mortgage at the same time, or they borrow less than the maximum amount).

version of the model are essentially unchanged from the baseline, with the only exception that we now estimate two additional parameters, ρ_m and σ_m. Their estimated values are respectively 0.994 and 0.0049.

A persistent shock to m_t leads to a protracted increase in debt, housing prices and investment, and consumption. However, the quantitative effects are small, and insufficient to generate large fluctuations in house prices. A one standard-deviation shock (impulse responses are plotted in Figure D.12) changes leverage by 50 basis points (from, say, 0.85 to 0.855) and, while it affects debt substantially (because it creates a large transfer of housing stock from lenders to borrowers), it produces a modest effect on house prices (house prices increase by less than 0.05 percent). Most of the effects of the leverage shock involve reallocation of the housing stock from one class of agents to another, but their effect on housing prices is limited.

To gain insight into why changes in m have little effect on prices, one can study the two key equations that determine the equilibrium behavior of housing demand (equations $A.2$ and $A.3$ in appendix B of the paper). After rearranging, these two equations can be combined to write the two relative housing demand equations as:

$$\underbrace{\frac{u_{h,t}}{u_{c,t}}}_{\text{MRS b/w housing and consumption}} = \underbrace{q_t - E_t\left(\frac{1}{RR_t} q_{t+1}(1-\delta_h)\right)}_{\text{user cost of housing for unconstrained agents}}$$

$$\underbrace{\frac{u_{h',t}}{u_{c',t}}}_{\text{MRS b/w housing and consumption}} = \underbrace{q_t - E_t\left(\frac{\beta' G_C u_{c',t+1}}{u_{c',t}} q_{t+1}(1-\delta_h) + \left(\frac{1}{RR_t} - \frac{\beta' G_C u_{c',t+1}}{u_{c',t}}\right) m_t q_{t+1}\right)}_{\text{user cost of housing for constrained agents}}$$

For changes in leverage to significantly affect housing demand and prices, it must be that they significantly alter the user cost (the right-hand side of the equations above). For unconstrained agents, changes in m do not affect their housing demand. For constrained agents, an increase in m lowers the user cost, with an effect that grows with gap between the stochastic discount factor (the term $1/RR_t - \beta' G_C u_{c',t+1}/u_{c',t}$) of the two groups. But, from a quantitative standpoint, this effect of changes in m is not large enough to generate large increases in asset prices.

4 Estimated Shocks and Newspaper Accounts

We have conducted a search of newspapers' articles for the period 1965-2006 trying to relate, from an informal standpoint, our estimated shocks to contemporary accounts of developments in the housing market at the time. Commentators' accounts in general agree with us that house prices are driven by a large variety of factors, such as inflation, technology, monetary policy. They also seem to refer from time to time to mysterious changes in housing demand that they could not immediately attribute to changes in fundamentals. Below, we report some examples:

For Housing preference shocks

- A positive housing shock in January 1970: "Privacy is another important factor for the buyer in today's market. With the increasing pressures of crowded living, more and more people are searching for solitude" [Anonymous (1970, January 18). "As Tastes Change, So Does Broker's Pitch: Brokers Attuned to Tastes," *New York Times.*]

- In 1975, a positive housing demand shock coming to an end: "People have been buying a lot more house than necessary... They've had empty living rooms with plastic covers on the furniture while they were using the family room..." [Lindsey, Robert (1975, December 7). "Less House for a Home; Less House, and More Money, for a Home," *New York Times.*]

And for the recent boom:

- In 1998, the beginning of the housing boom: "Another show of wealth is a trend for buyers to raze expensive houses to build newer, even more expensive houses more to their taste" [Rather, John (1998, January 11). "Luxury Houses: Strong Market, Low Inventory; A strong economy and Wall St. are just part of a boom," *New York Times.*]
- In 2001, signs of strong demand again, not based on clear fundamentals: "Housing strength also reflects surprisingly resilient consumer confidence. Memories have faded away of the early 1990s... Faith in real estate as an investment remains strong" [Norris, Floyd (2001, June 22). "Will This Slowdown Spare Housing, or Just Hit It Late?" *New York Times*]

For Housing supply shocks

The 1970's are also a period where supply-side conditions were often cited (at least, they were cited far more than in the recent housing cycle) by the press and commentators are one of the reasons for rising high prices in a period where the quantity could not keep up pace with demand. Examples include:

- In 1973: "Building executives complained of severe shortages of various types of lumber products" [Tomasson, Robert E. (1973, January 14). "Lumber Costs Smashing Control Barriers: So the Prices Of Homes Go Up and Up," *New York Times.*]
- In 1974: "As the cost of building materials have increased drastically, and the wages of construction workers have soared, the cost of new housing has brought up the selling price on existing homes" [Jensen, Micheal C. (1974, August 25). "Home Buyers All Over U.S. Feel the Economy's Crunch," *New York Times*]
- In 1978: "Unless some significant improvements occur on the supply side, [construction] prices will remain high... lumber mills have been shut or curtailed for lack of timber [...] The major question now is whether there will be a change in national forest policies" [Mullaney, Thomas E. (1978, April 28). "Trimming Cost of Home Building By Cutting Into National Forests," *New York Times.*]

Table D.1a. Volatilities of selected observables (percentages): the role of frictions

	data	baseline	no k. adj.	full lab. mob.	fixed cap.	flex. w and p.	flex. w.	flex. p.	no collat. constr.
	(a)	(b)	(c)	(d)	(e)	(f)	(g)	(h)	(i)
	.	.	.	.	.	.	.	.	.
C	1.22	1.40	1.28	1.51	1.37	0.88	1.16	1.76	1.37
π	0.40	0.47	0.48	0.47	0.50	-	0.46	0.69	0.45
IH	9.97	8.01	9.05	8.37	12.59	5.96	6.16	9.87	7.81
q	1.87	2.08	1.80	2.12	4.83	1.90	2.04	2.73	2.06
R	0.32	0.32	0.47	0.31	0.36	-	0.33	0.39	0.31
IK	4.87	3.80	7.25	3.71	4.08	2.83	3.52	5.98	3.78
GDP	2.17	2.11	2.07	2.02	1.90	1.26	1.66	1.90	2.04

Notes: The volatilities are computed using 500 draws of the time series obtained by setting the parameters of the model at the mode of the posterior distribution. The business cycle component of each variable is obtained using the HP filter with smoothing parameter set at 1,600. C: real consumption; IH: real residential investment; q: real house prices; R: nominal interest rate; IK: real business investment; GDP: output.

Table D.1b. Selected correlations: the role of frictions

	data	baseline	no k. adj.	full lab. mob.	fixed cap.	flex. w and p.	flex. w.	flex. p.	no collat. constr.
	(a)	(b)	(c)	(d)	(e)	(f)	(g)	(h)	(i)
$\rho\,(C, GDP)$	0.88	0.82	0.41	0.86	0.65	0.67	0.83	0.03	0.88
$\rho\,(IH, GDP)$	0.78	0.65	0.09	0.56	0.53	0.42	0.30	0.57	0.66
$\rho\,(IK, GDP)$	0.75	0.89	0.86	0.88	0.82	0.87	0.89	0.79	0.90
$\rho\,(q, GDP)$	0.58	0.65	0.12	0.60	0.20	0.36	0.51	0.45	0.62
$\rho\,(q, C)$	0.48	0.46	0.32	0.59	0.19	0.12	0.45	-0.25	0.58
$\rho\,(q, IH)$	0.41	0.45	0.29	0.25	-0.17	0.12	0.06	0.57	0.43

Notes: The correlations are computed using 500 draws of the time series obtained by setting the parameters of the model at the mode of the posterior distribution. The business cycle component of each variable is obtained using the HP filter with smoothing parameter set at 1,600. C: real consumption; IH: real residential investment; Q: real house prices; R: nominal interest rate; IK: real business investment; NC: hours worked in the goods sector; NH; hours worked in the residential sector; Y: output.

Table D.2. Posterior modes of alternative models: the role of frictions

par.	baseline (a)	no capital adj. cost (b)	full labor mobility (c)	fixed capital util. (d)	flex. wage and price (e)	flex. wage (f)	flex. price (g)	no collateral constraint (h)
	.	.	.	.	.	.	.	.
ε	0.3117	0.3774	0.3053	0.3883	0.2642	0.1656	0.4110	0.2802
ε'	0.5749	0.5471	0.5495	0.6608	0.3547	0.4914	0.5708	-
η	0.4789	0.4415	0.4520	0.5662	0.4553	0.4604	0.6640	0.5057
η'	0.4738	0.4731	0.4858	0.5577	0.4680	0.5175	0.4818	-
ξ	0.7523	0.7367	-	1.0703	1.2294	0.6810	0.7740	0.6862
ξ'	0.9790	0.9802	-	1.0319	1.1485	0.9938	0.9590	-
$\phi_{k,c}$	16.0126	-	16.4534	16.5198	15.6971	16.0854	15.2134	16.0838
$\phi_{k,h}$	10.0026	-	10.0170	9.9059	13.3400	8.5111	9.3556	10.0392
α	0.7970	0.7785	0.8170	0.8841	0.6086	0.8725	0.7632	-
r_R	0.6071	0.2607	0.6091	0.6539	-	0.5771	0.6699	0.6008
r_π	1.3743	1.5156	1.3902	1.3883	-	1.3895	1.7849	1.3404
r_Y	0.4938	0.7128	0.5104	0.4010	-	0.4284	0.3220	0.4785
θ_π	0.8393	0.7987	0.8453	0.7987	-	0.8157	-	0.8548
ι_π	0.6961	0.0452	0.6791	0.8223	-	0.7294	-	0.6373
$\theta_{w,c}$	0.7901	0.9118	0.7674	0.7460	-	-	0.7497	0.7598
$\iota_{w,c}$	0.0656	0.0783	0.0988	0.0354	-	-	0.1996	0.0656
$\theta_{w,h}$	0.9218	0.9169	0.7995	0.7202	-	-	0.9352	0.9170
$\iota_{w,h}$	0.4134	0.6371	0.4298	0.2787	-	-	0.4482	0.4101
ζ	0.7469	0.6171	0.7683	-	0.1747	0.6784	0.9866	0.7520
γ_{AC}	0.0032	0.0033	0.0032	0.0032	0.0031	0.0032	0.0055	0.0032
γ_{AH}	0.0008	0.0014	0.0010	0.0008	0.0007	0.0005	0.0103	0.0007
γ_{AK}	0.0027	0.0026	0.0027	0.0027	0.0029	0.0028	-0.0009	0.0027

Table D.3. Volatilities: the model with only technology shocks

	C	π	IH	q	R	IK	n_c	n_h	GDP
Data	1.22	0.40	10.00	1.87	0.32	4.85	1.43	4.07	2.17
Benchmark	1.40	0.47	8.01	2.08	0.32	3.80	2.40	8.74	2.11
Only tech. shocks	0.92	0.11	5.72	0.90	0.09	3.07	0.80	5.73	1.53

Notes: The volatilities are computed using 500 draws of the time series obtained by setting the parameters of the model at the mode of the posterior distribution. The business cycle component of each variable is obtained using the HP filter with smoothing parameter set at 1,600. C: real consumption; IH: real residential investment; Q: real house prices; R: nominal interest rate; IK: real business investment; NC: hours worked in the goods sector; NH; hours worked in the residential sector; Y: output.

Table D.4. Selected correlations: the model with only technology shocks

	$\rho\,(C, GDP)$	$\rho\,(IH, GDP)$	$\rho\,(IK, GDP)$	$\rho\,(q, GDP)$	$\rho\,(q, C)$	$\rho\,(q, IH)$
Data	0.88	0.78	0.75	0.58	0.48	0.41
Benchmark	0.82	0.65	0.89	0.65	0.46	0.45
Only tech. shocks	0.83	0.54	0.84	0.73	0.95	0.17

Notes: The correlations are computed using 500 draws of the time series obtained by setting the parameters of the model at the mode of the posterior distribution. The business cycle component of each variable is obtained using the HP filter with smoothing parameter set at 1,600. C: real consumption; IH: real residential investment; Q: real house prices; R: nominal interest rate; IK: real business investment; NC: hours worked in the goods sector; NH; hours worked in the residential sector; Y: output.

Table D.5. Posterior modes of the model using alternative data for house prices

parameter	Census (a)	OFHEO (b)	Both (c)
ε	0.3117	0.2953	0.2925
ε'	0.5749	0.5671	0.5263
η	0.4789	0.5013	0.5091
η'	0.4738	0.4903	0.4902
ξ	0.7523	0.7908	0.7761
ξ'	0.9790	0.9931	0.9743
$\phi_{k,c}$	16.0126	15.0621	16.7160
$\phi_{k,h}$	10.0026	10.0242	10.6020
α	0.7970	0.7891	0.7741
r_R	0.6071	0.6066	0.5975
r_π	1.3743	1.3686	1.3847
r_Y	0.4938	0.4906	0.4959
θ_π	0.8393	0.8448	0.8523
ι_π	0.6961	0.6899	0.6515
$\theta_{w,c}$	0.7901	0.7774	0.7770
$\iota_{w,c}$	0.0656	0.0593	0.0627
$\theta_{w,h}$	0.9218	0.9276	0.9237
$\iota_{w,h}$	0.4134	0.3346	0.3776
ζ	0.7469	0.6919	0.6244
γ_{AC}	0.0032	0.0034	0.0032
γ_{AH}	0.0008	-0.0013	0.0005
γ_{AK}	0.0027	0.0025	0.0027

Table D.6. Posterior modes of alternative models: the role of household preferences

parameter	Benchmark (a)	Same preferences (b)
ε	0.3117	0.3929
ε'	0.5749	0.3929
η	0.4789	0.5115
η'	0.4738	0.5115
ξ	0.7523	0.8691
ξ'	0.9790	0.8691
$\phi_{k,c}$	16.0126	16.1596
$\phi_{k,h}$	10.0026	10.0581
α	0.7970	0.8062
r_R	0.6071	0.6358
r_π	1.3743	1.3913
r_Y	0.4938	0.5012
θ_π	0.8393	0.8526
ι_π	0.6961	0.6771
$\theta_{w,c}$	0.7901	0.7964
$\iota_{w,c}$	0.0656	0.0642
$\theta_{w,h}$	0.9218	0.9311
$\iota_{w,h}$	0.4134	0.4144
ζ	0.7469	0.5981
γ_{AC}	0.0032	0.0032
γ_{AH}	0.0008	0.0008
γ_{AK}	0.0027	0.0027

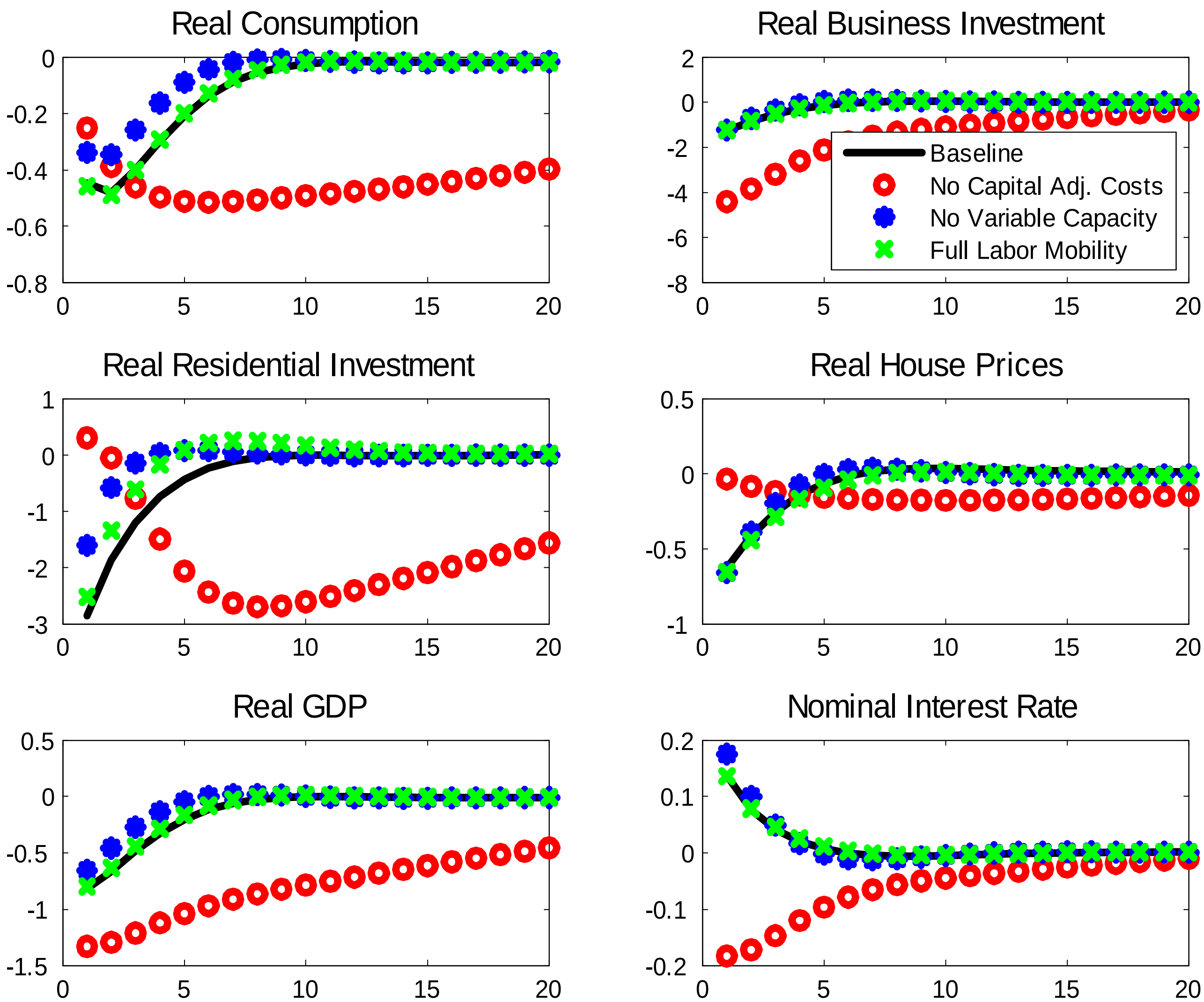

Figure D.1. Impulse responses to a monetary policy shock: the role of real rigidities

Note: horizontal axis: quarters from the shock; vertical axis: percentage deviation from the steady state.

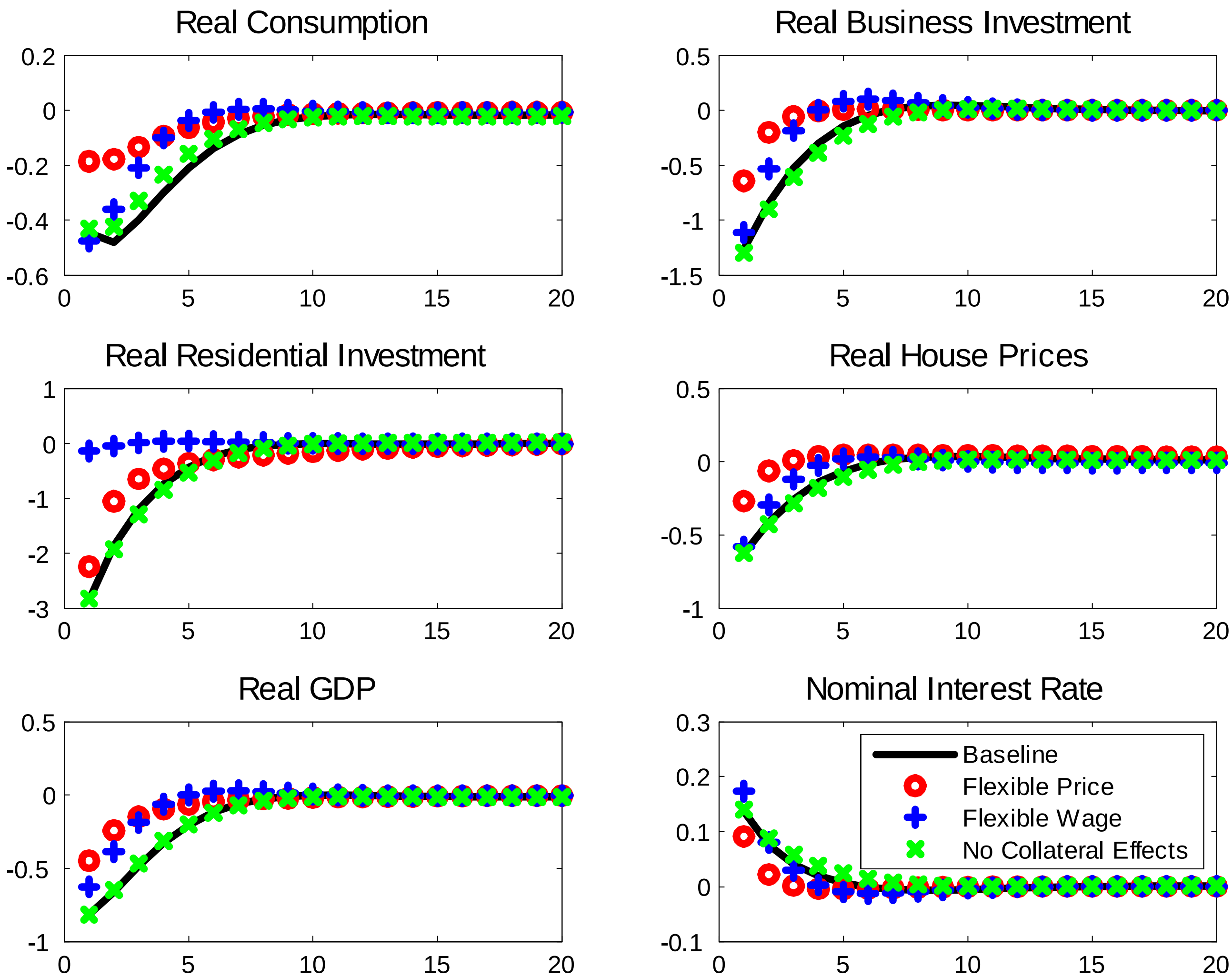

Figure D.2. Impulse responses to a monetary policy shock: the role of nominal rigidities and collateral constraints

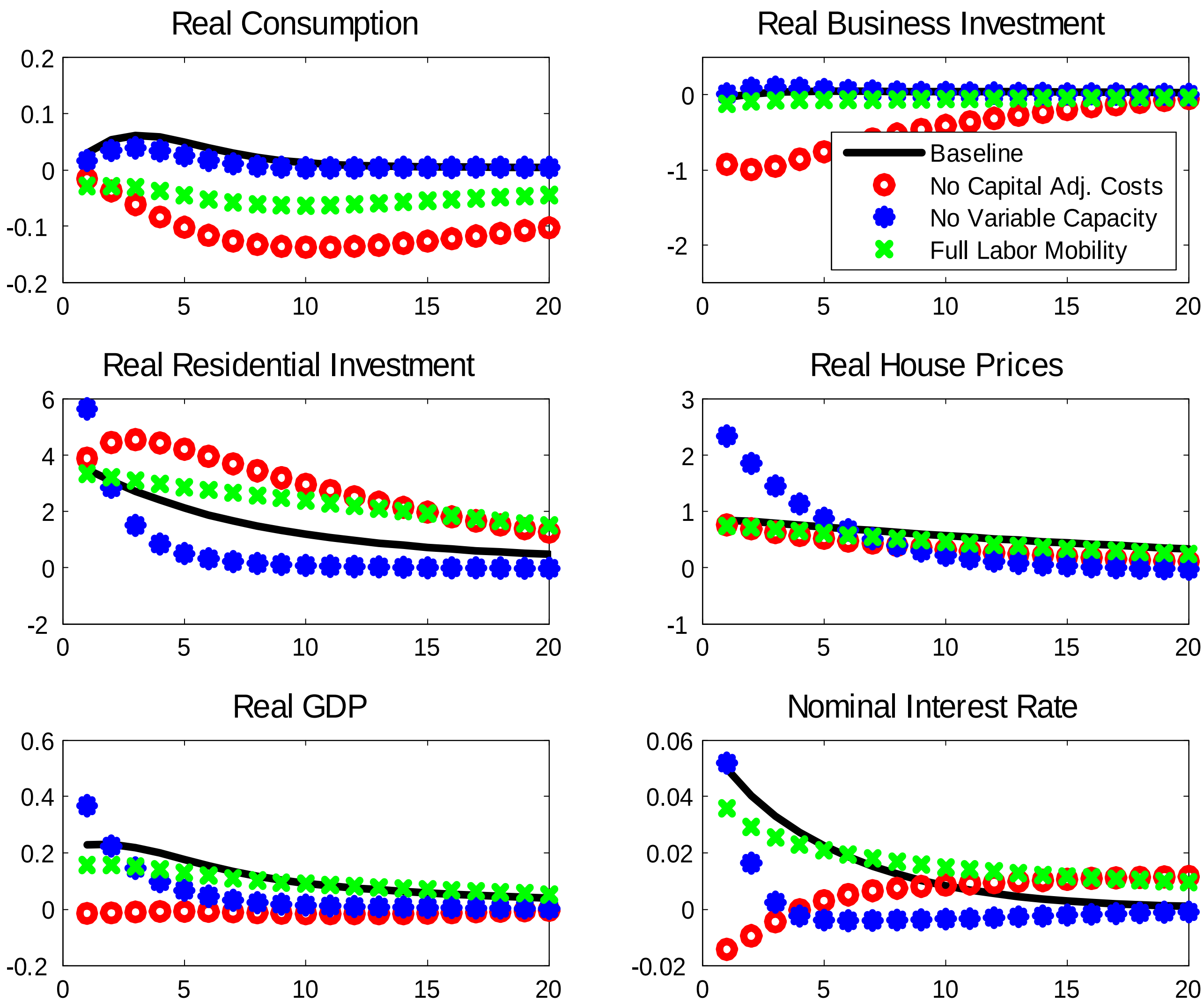

Figure D.3. Impulse responses to a housing preference shock: the role of real rigidities

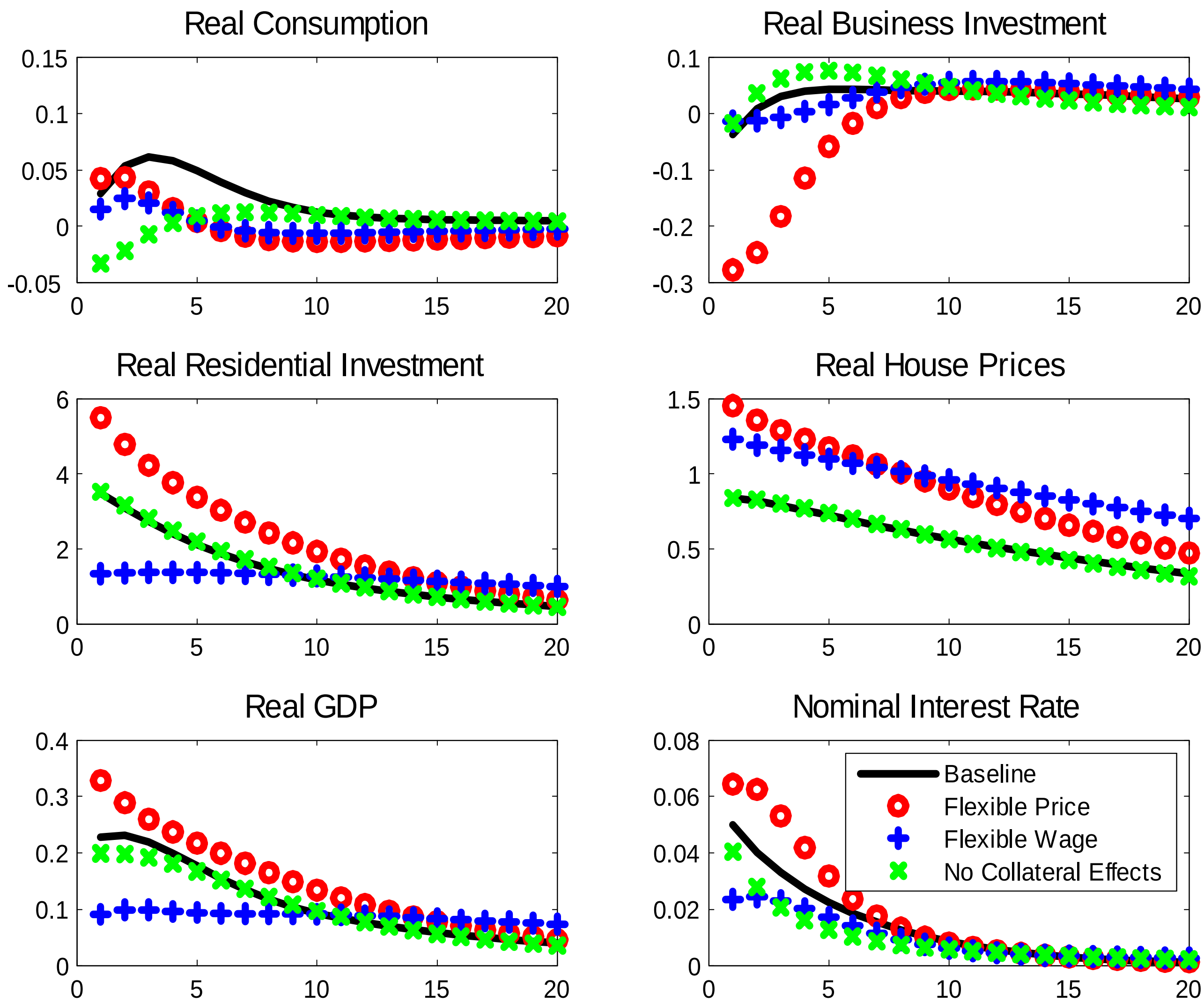

Figure D.4. Impulse responses to a housing preference shock: the role of nominal rigidities and collateral constraints

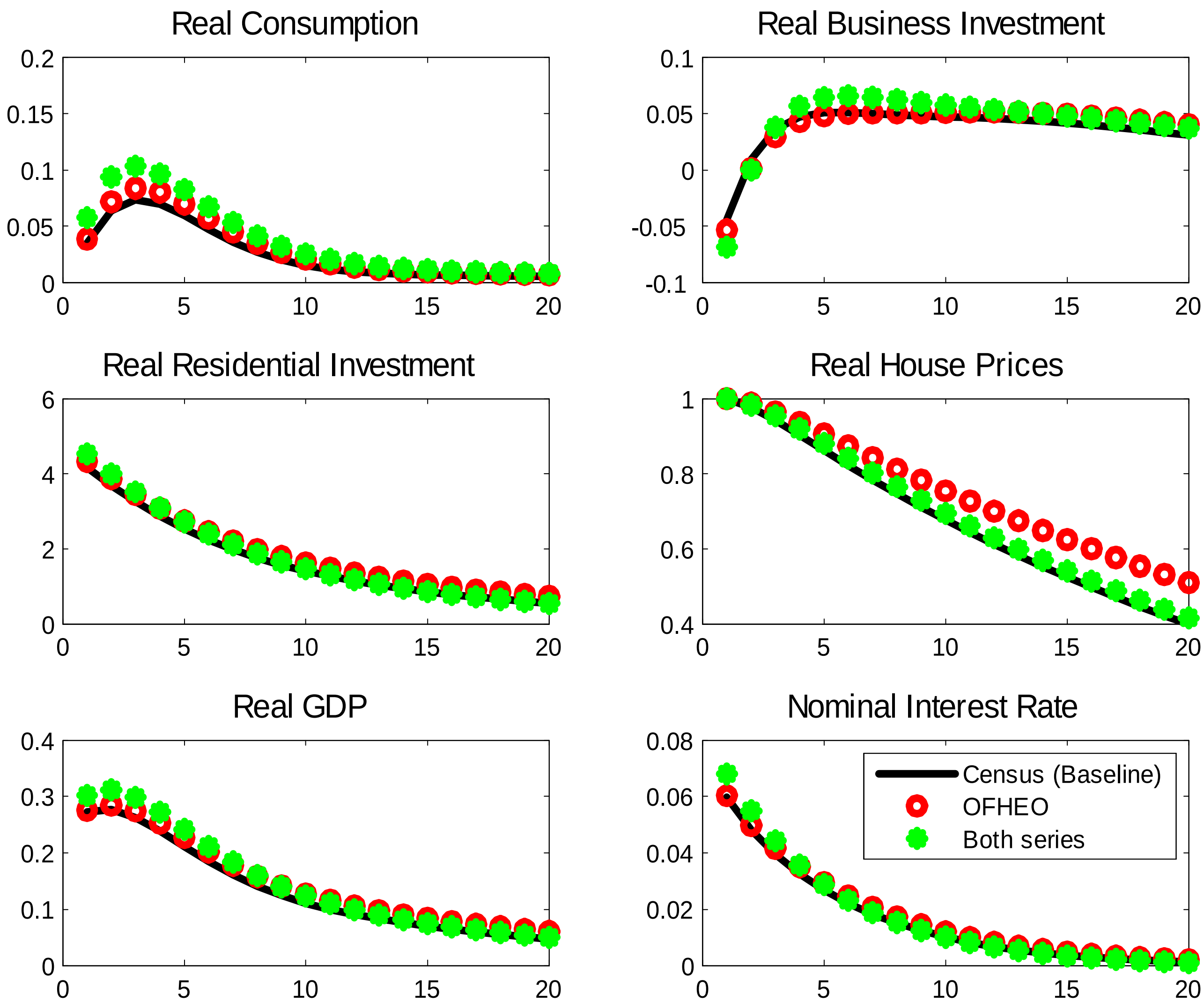

Figure D.5. Impulse responses to a housing preference shock: parameters estimated using the Census, the OFHEO and both indices at the same time

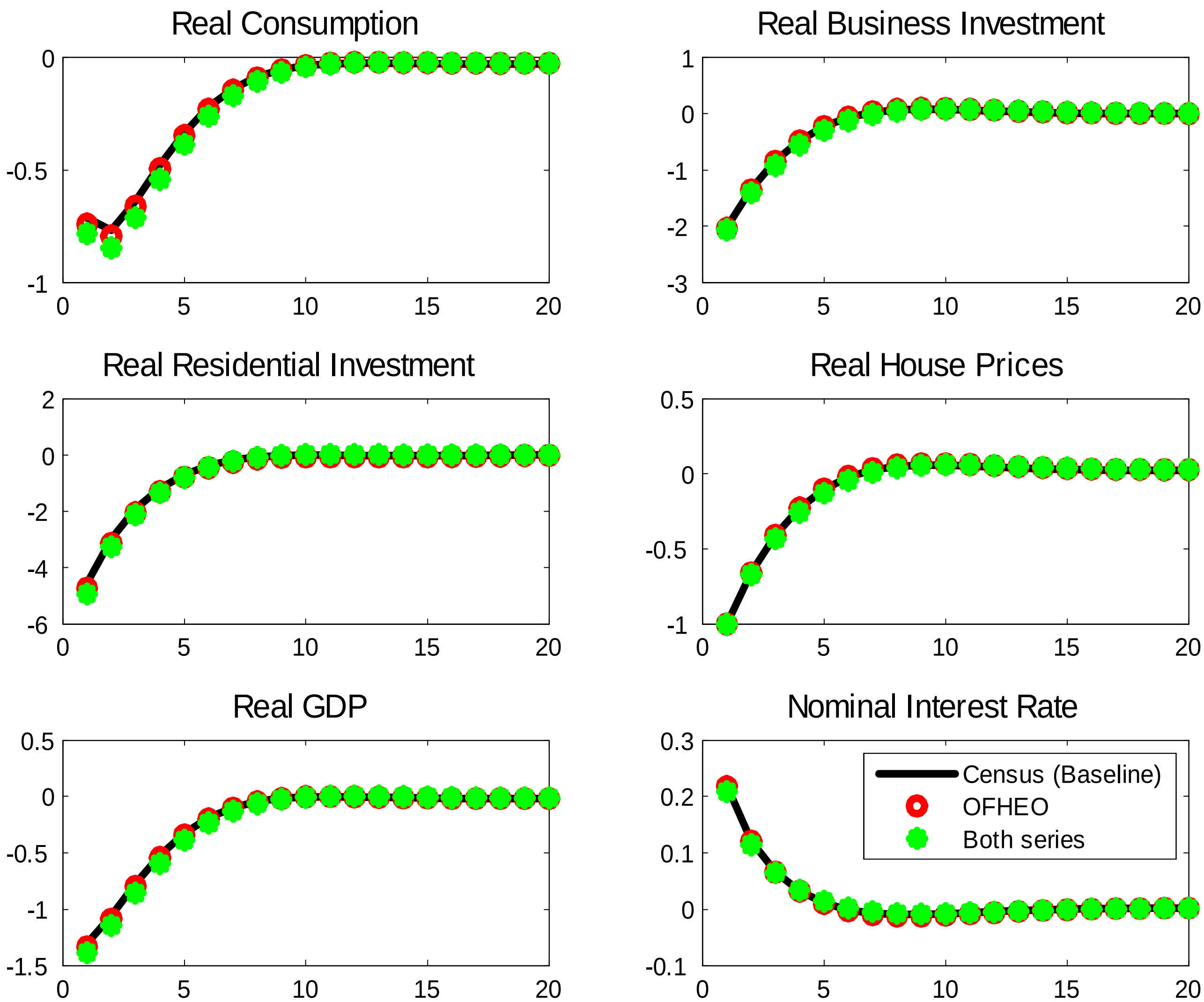

Figure D.6. Impulse responses to a monetary policy shock: parameters estimated using the Census, the OFHEO and both indices at the same time

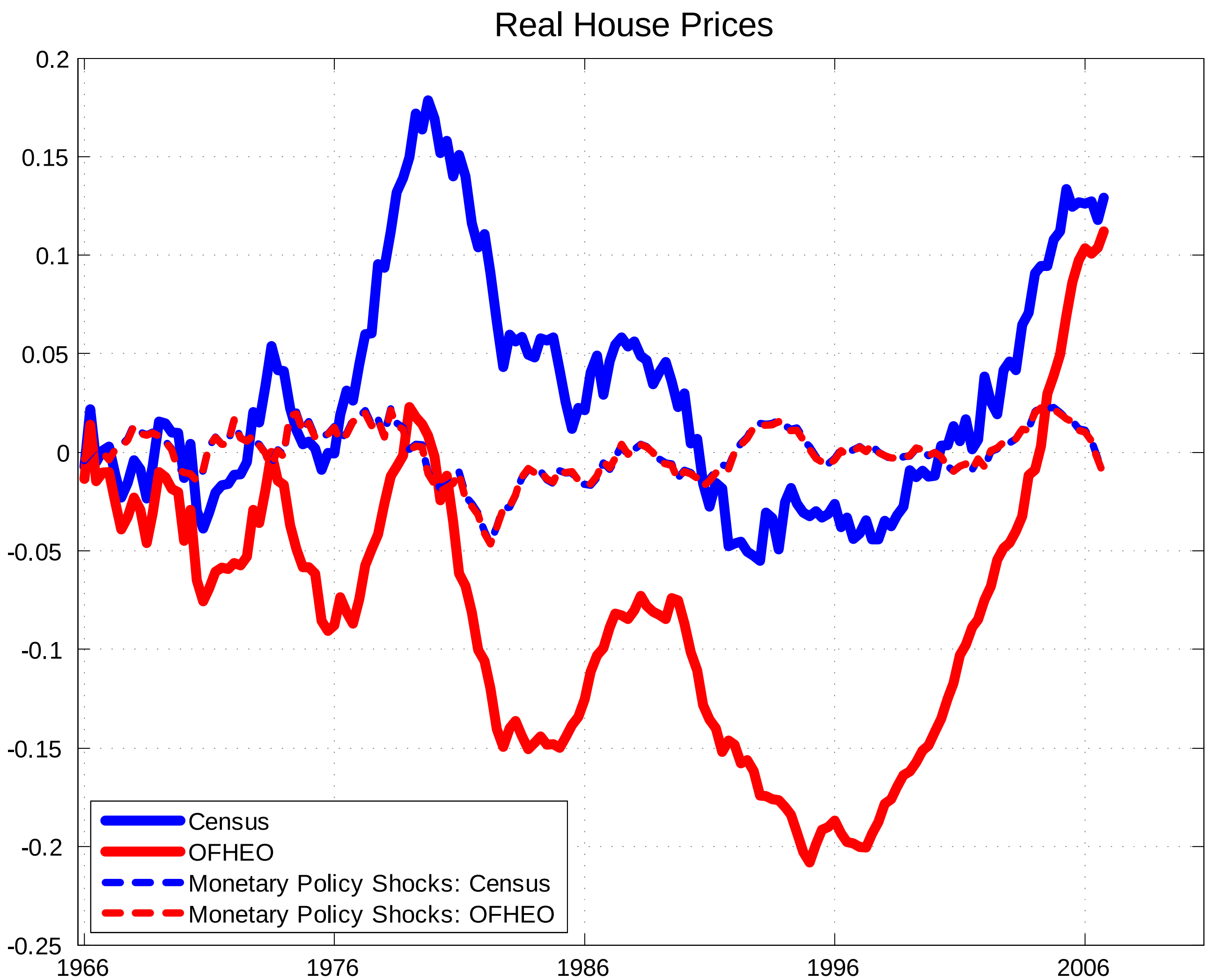

Figure D.7. Historical decomposition of real house prices: contribution of monetary policy (Census vs. OFHEO)

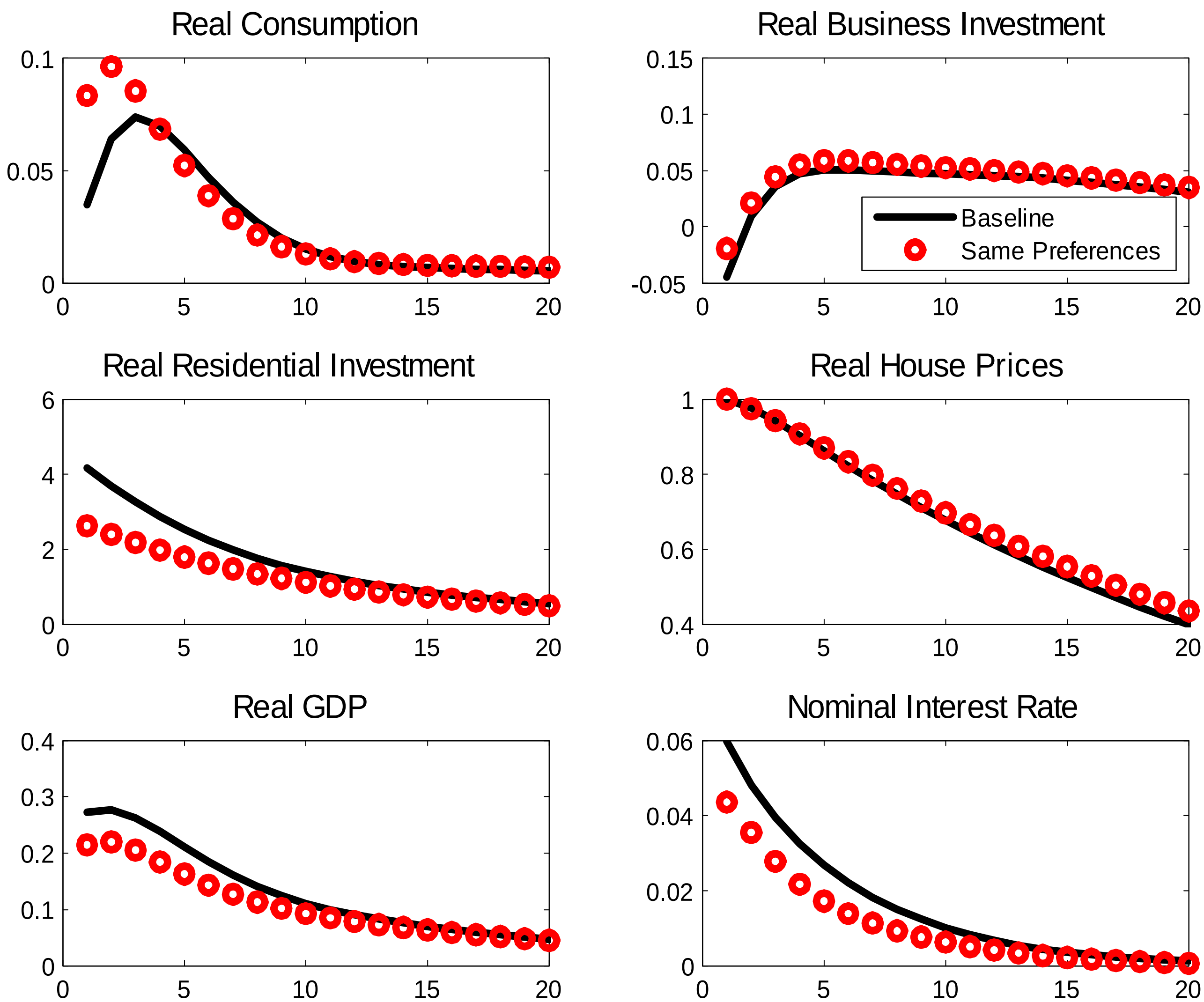

Figure D.8. Impulse responses to a housing preference shock: the role of heterogeneous preferences

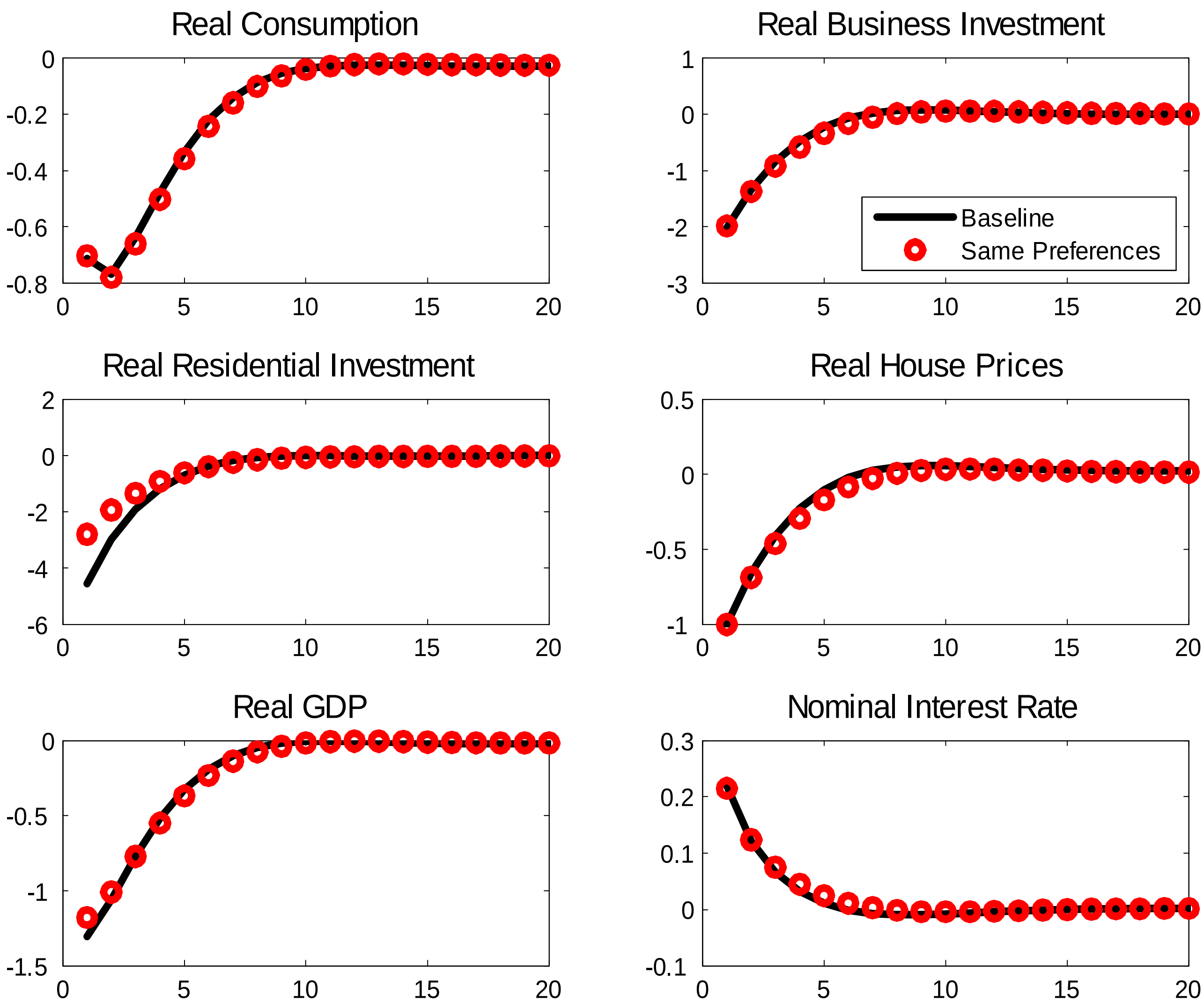

Figure D.9. Impulse responses to a monetary policy shock: the role of heterogeneous preferences

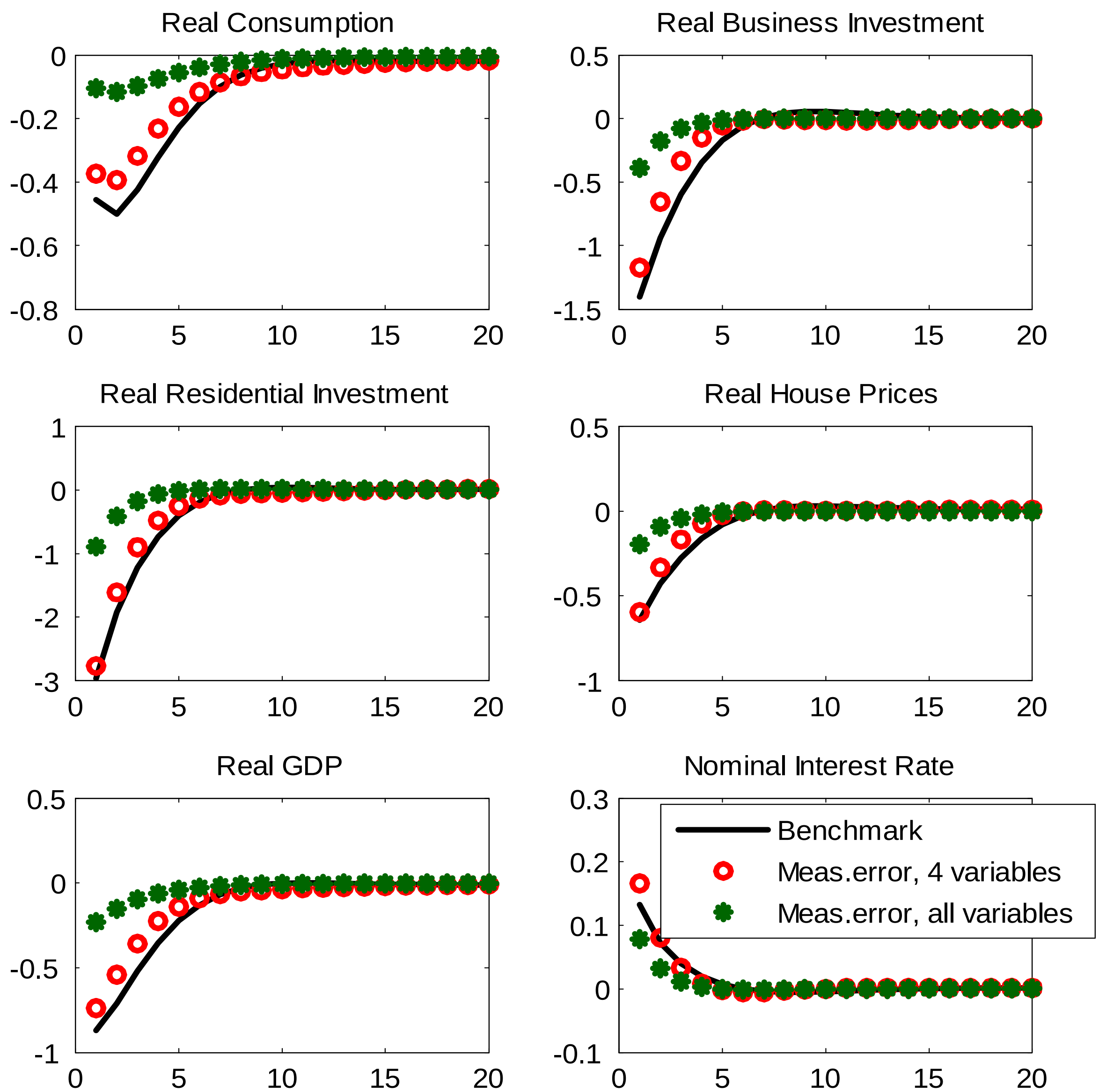

Figure D.10: Impulse Responses to a Monetary Shock. The Role of Measurement Error.

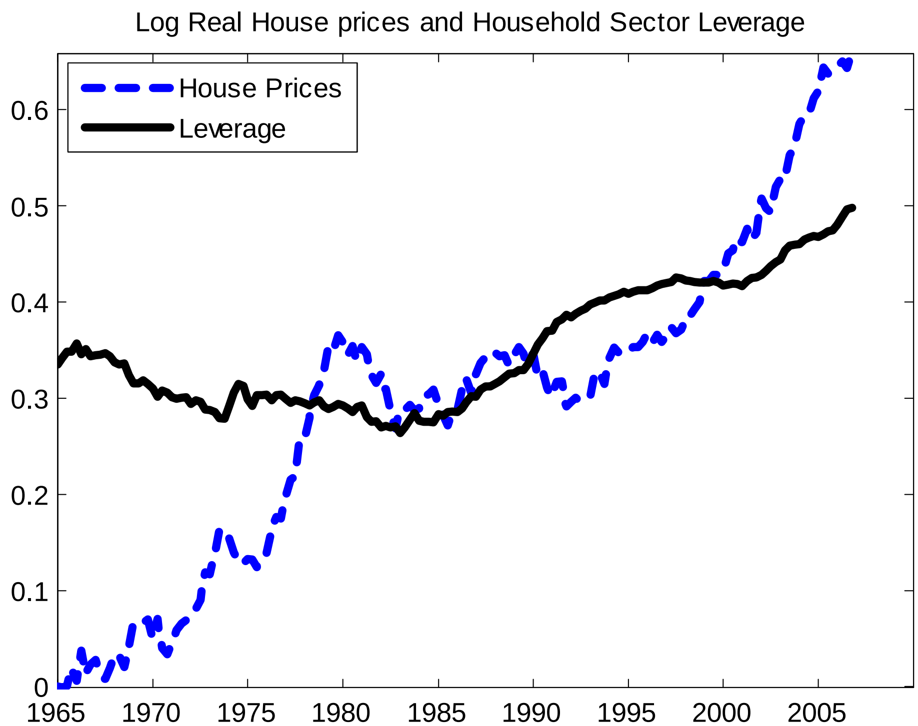

Figure D.11: House Prices and Households' Mortgage Debt to Housing Wealth Ratio

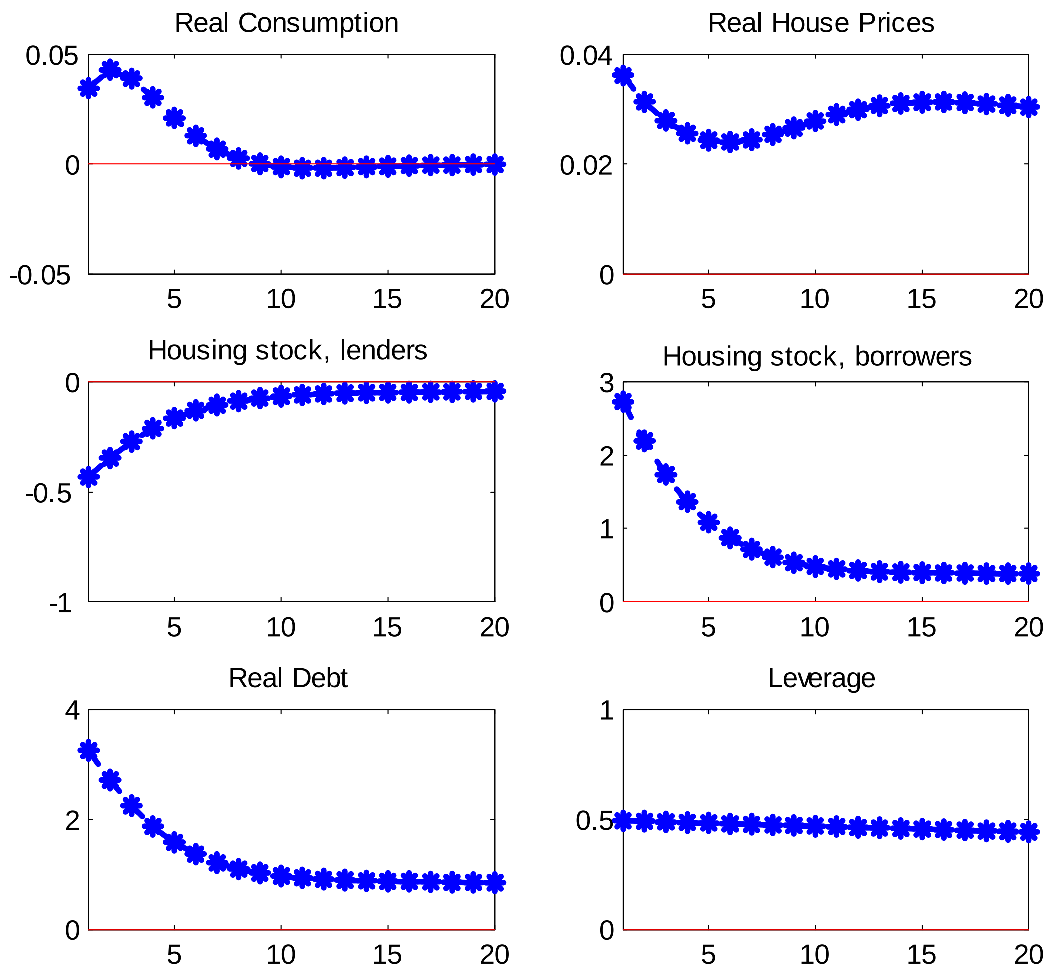

Figure D.12: Impulse responses to an estimated innovation in the loan-to-value ratio