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Abstract

In a VAR model of the US, the response of the relative price of durables to a monetary contraction is either flat or mildly positive. It significantly falls only if narrowly defined as the ratio between new house and nondurables prices. These findings survive three identification strategies and across subsamples. Then, they are rationalized via the estimation of a two-sector New-Keynesian model. Here, the degree of overall durables price stickiness is not dramatically lower than that of nondurables. Such macroeconometric results are close to recent microeconometric evidence. Moreover, they suggest that monetary policy is not very distortive of sectoral allocations.

JEL-Code: E520, E320.

Keywords: monetary policy, durables, nondurables, comovement, relative price, DSGE, Bayesian estimation, SVAR, sign restrictions, narrative approach.

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1 Introduction

Whether monetary policy innovations create distortions in allocations across durable and nondurable goods boils down to the extent to which such shocks change their relative price. The importance of the response of the relative price of durables to monetary policy has been explored in a small number of theoretical contributions, but surprisingly largely neglected in the empirical literature.

In the context of optimal policy, Erceg and Levin (2006) show that the relative price of durables affects both the user cost and the demand of durable goods. A stable relative price of durables keeps output close to potential in both sectors and its role for the conduct of monetary policy is therefore non-negligible.[1] Petrella and Santoro (2011), in an economy with input-output structure, show that the relative price of services affects sectoral marginal costs and creates a channel through which the comovement between consumption of the two goods is attained. They claim that their results can be generalized to any sticky price model with two sectors. In fact, in a similar model featuring durable and nondurable goods, Sudo (2012) demonstrates that if the change in the relative price is small, the substitution effect between durables and nondurables is likewise small and the two goods comove in response to a monetary policy shock.

The comovement between durables and nondurables in response to monetary policy has been a popular topic in the literature and has been documented in a number of papers employing recursive Structural Vector-Autoregressive (SVAR) models (see Bernanke and Gertler, 1995; Erceg and Levin, 2006; Monacelli, 2009; Di Pace and Hertweck, 2012; Sterk and Tenreyro, 2014, among others). Barsky et al. (2003) confirm this empirical result using Romer dates. However, Barsky et al. (2003, 2007, BHK henceforth) were the first to notice that a two-sector New-Keynesian (NK) model fails to replicate such a comovement, hence the so-called comovement puzzle. Consequently, several extensions of the baseline model have been explored in order to solve it.[2]

The crucial assumption that prevents the baseline model from generating the comovement concerns sectoral price stickiness. In fact, BHK assume that prices of durable goods are flexible whereas prices of nondurables are sticky. This assumption is made

[1] In a similar model Aoki (2001) reaches the same conclusion.

[2] Carlstrom and Fuerst (2010), DiCecio (2009) and Iacoviello and Neri (2010) introduce nominal wage stickiness; Monacelli (2009), Sterk (2010), Tsai (2010) and Chen and Liao (2014) evaluate the role of credit frictions; Bouakez et al. (2011) and Sudo (2012) study an economy with input-output interactions; finally, Kim and Katayama (2013) assume non-separable preferences.

for two reasons. First, durables prices such as houses are largely negotiated and most homes are priced for the first time when they are sold. Second, they appeal to microeconometric studies, such as Bils and Klenow (2004), documenting that durables are substantially more flexible than nondurables. On these grounds, although durables price stickiness turn out to play a key role in the comovement issue (see Sterk, 2010), BHK and most of the subsequent papers assume that durables prices are completely flexible. On the contrary, more recently, Nakamura and Steinsson (2008) and Klenow and Malin (2010) report microeconometric evidence of stickiness in many categories of durables other than houses (investment in housing represents 23% of aggregate durables in US NIPA tables in the period 1958Q3-2007Q4).

The assumption about sectoral price stickiness is closely related to the response of the relative price of durables to a monetary policy shock. In fact, when durables prices are assumed to be flexible, while nondurables prices are sticky, the relative price of durables necessarily falls following a monetary policy tightening, implying that monetary policy creates a distortion in sectoral allocations.

Quite surprisingly, no empirical analysis has focused specifically on this issue. Table 1 reports unconditional correlations between lags of changes in the Federal funds rate (FFR) and changes in key macroeconomics variables in a post-WWII sample.[3] As expected, changes in the FFR are negatively associated with changes in real GDP, durables and nondurables with some lags. As regards inflation, it takes up to three years to detect a negative (though insignificant) correlation. However, what is most interesting is that changes in the relative price of durables seem to be uncorrelated with changes in the FFR, this being in accordance with overall price stickiness not being dramatically different across the two sectors.

Given the important policy and modeling implications, this topic deserves more careful investigation. In the paper we exploit both SVAR and Dynamic Stochastic General Equilibrium (DSGE) models, in order to assess the effects of a monetary policy shock on the relative price of durables. The monetary policy shock in SVAR models is identified through recursive, sign restrictions and narrative approaches. Across subsamples and methodologies, the response of the relative price of durables is either flat or mildly positive, but it never falls, contrary to what most DSGE models predict. A significant fall is found only if the relative price is narrowly defined as the ratio between new house prices and nondurables prices. We then build a DSGE model able

[3]The durables sector is defined as the sum of durable goods and residential investment.

	GDP	Durables	Nondurables	Inflation	Relative Price
FFR (-1)	0.0804	-0.2804^*	-0.2134^*	0.1443^*	0.1133
FFR (-4)	-0.1876^*	-0.2860^*	-0.2074^*	0.1945^*	0.0694
FFR (-8)	-0.1478^*	-0.0657	-0.0530	0.1248	0.0327
FFR (-12)	0.0401	0.0778	0.0565	-0.0025	0.0370

Note: GDP, durables and nondurables are first differences in log real per-capita variables. Inflation is the first difference in the log of the GDP deflator. The relative price is the first difference of the ratio of the two price indices. More data details are available in the Appendix. Frequency: quarterly. Sample: 1954Q3-2007Q4. * denotes significance at a 5 percent level.

Table 1: Correlations between lags of changes in the Federal funds rate (FFR) and changes in selected macroeconomic variables

to solve the comovement puzzle and we bring it to the data via Bayesian estimation. The estimated DSGE model corroborates and helps rationalizing the SVAR results. In line with the latest microeconometric evidence, also using macroeconomic observables, the degree of price stickiness in a sector comprising all durable goods is estimated to be lower, but not dramatically lower than in the nondurables sector. Thus the credible set of impulse responses of the relative price to a monetary policy shock includes zero.

Our SVAR and DSGE results have two important implications. The first is that when building a two-sector New-Keynesian model it is desirable to assume that prices of durable goods are somewhat sticky, unless the model's aim is to specifically address issues related to the housing sector. The second is that monetary policy innovations do not foster big distortions in tradables/nontradables sectoral allocations and this represents a desirable feature of the monetary policy conduct.

The remainder of the paper is organized as follows. Section 2 reviews the literature of two-sector NK models. In section 3 we perform the SVAR analysis. Section 4 presents the DSGE model and discusses the results of the Bayesian estimation. Section 5 concludes. An appendix complements the paper by providing details about the dataset, the theoretical model, and by reporting robustness checks.

2 Literature review

Since their seminal papers, Barsky et al. (2003, 2007) started a research agenda, and various authors subsequently contributed to a deeper understanding of two-sector NK models. BHK were the first to show that when prices of durables are flexible while prices of nondurables are sticky, such models fail to generate the comovement between consumption in the two sectors, and money is neutral. The comovement puzzle arises due to various modeling features, namely the near constancy of the shadow value of durable goods, firms in the durables sector setting prices as a constant markup over marginal costs and perfect mobility of labour across sectors. However, the crucial assumption lies in the flexibility of durable goods prices. Furthermore, BHK show that with symmetric price rigidity across sectors, the comovement is attained, but although the shock is expansionary the nominal interest rate increases.[4] The counterintuitive response of the nominal interest rate follows from the near constancy of the shadow value of durables which makes their real rate of return constant thus forcing the nominal interest rate to track expected inflation in the durable goods sector.

Building on BHK, different extensions of the model have been explored in order to solve the comovement puzzle, where the key mechanism consists of inducing some nominal stickiness in the durables sector. Carlstrom and Fuerst (2006, 2010) and Iacoviello and Neri (2010) build a model with a housing sector and show that nominal wage rigidities are crucial in order to generate the comovement. DiCecio (2009) reaches the same conclusion in a real business cycle model where the comovement is obtained between the consumption and investment sectors. Di Pace and Hertweck (2012) introduce search and matching frictions together with right-to-manage bargaining and wage stickiness. They argue that in order to obtain the comovement, the relative price of durables needs to fall less than the increase in the marginal utility of consumption. This is true when real marginal costs in the durables sector are inelastic, as in the case of wage or price stickiness. Despite the introduction of labour market frictions, wage stickiness is crucial in order to generate the comovement.

Another strand of the literature introduced credit frictions. Monacelli (2009) builds a model with heterogenous agents in which borrowers face a collateral constraint. As a result, the near constancy of the shadow value of durables is violated and a monetary policy tightening increases the user cost and decreases the consumption of durables, hence the comovement is attained. However, Sterk (2010) uses Monacelli's model to analytically and numerically demonstrate that credit frictions make the puzzle harder to solve. He also shows that only when prices of durable goods are sticky for 2.5 quarters the comovement puzzle is solved and the nominal interest rate features the expected response. Chen and Liao (2014) add two features to Monacelli's model. First,

[4]See subsection 4.3 for a brief discussion of different monetary policy rules used in the literature.

they introduce capital in the production function. Then, they assume that durables can be used both for consumption and for investment. In general, the fall in the relative price makes durable goods cheaper, hence consumers substitute nondurables with durables. In Chen and Liao's model the fall in the relative price reduces the return on investment hence less profits are remitted to savers who decrease the consumption of durables. Furthermore, they analytically show why credit frictions together with capital solve the comovement. The shadow value of durables for savers is affected by the next period's marginal product of capital in the durables sector and hence by the demand for capital in this sector. With respect to the model without capital, the savers' marginal utility of durables is larger, hence the consumption of durables is smaller. In Monacelli (2009) and Chen and Liao (2014) borrowers are consumers hence credit frictions arise on the demand side of the economy. Conversely, in Tsai (2010) financial frictions arise on the supply side: firms must pay in advance for their inputs, i.e. working capital and the wage bill. As a result, a monetary contraction increases production costs and output decreases in both sectors.

Bouakez et al. (2011) extend the BHK model by introducing input-output (I-O) interactions and limited mobility of labour to solve to comovement puzzle. They argue that these two features alone do not solve the puzzle but it is their interaction that solves it. The I-O structure implies that both goods are used as production inputs in the two sectors and they calibrate their model according to the empirical evidence that nondurables constitute a large fraction of durable goods production. Consequently, although the price of durable goods is flexible they inherit the stickiness of nondurable goods through the marginal costs. Furthermore, imperfect labour mobility prevents the real wages from increasing in the durables sector hence marginal costs and prices are barely affected by the (expansionary) monetary policy shock and this prevents a fall in consumption. These two features actually show that production and consumption do not fall, but in order to show that they increase a further argument is needed. Indeed, they analytically show that when aggregate and durable sector employment increase, then the marginal product of labour (MPL) also increases. Usually a higher MPL implies lower labour. However, in this model a higher MPL can be achieved with higher material inputs so that employment in durable sector needs not fall. As a result, durables production and consumption increase. Their model is able to generate the desired comovement but the response of durables is smaller than that of nondurables contrary to the predictions of empirical models. Sudo (2012) builds the same model with I-O structure but with perfect labour mobility and adjustment costs of changing the capital stock. Contrary to Bouakez et al. (2011), despite the fact that labour is perfectly mobile the model is able to generate the comovement.

Finally, Kim and Katayama (2013) aim at solving the puzzle by introducing non-separable preferences in the spirit of Guerron-Quintana (2008). The key mechanism is that consumption of nondurable goods negatively affects the marginal disutility of labour. With a monetary policy tightening the former decreases and the latter increases. As a consequence, labour supply decreases. This prevents a decrease in the real wage hence firms in the durable sector reduce hirings and production decreases, thus attaining the comovement. Conversely, with separable preferences, the decrease in demand for nondurables is matched by decreasing labour, since prices are sticky, hence there is a decrease in wage common across sectors. For the firms in the durables sector this is just a cost shock, hence they increase labour and production and the puzzle occurs. As a result, they need to introduce imperfect capital mobility and variable capital utilization for their model to generate the comovement with a reasonable value of the intertemporal elasticity of substitution between consumption and labour. Building on this model, Katayama and Kim (2013) check whether habit formation in nondurable consumption and investment adjustment costs generate hump-shaped responses. However, the Bayesian estimation shows that it is the combination of habit, investment adjustment costs and sticky wages that delivers hump-shaped impulse responses.

All the papers mentioned above aim at exploring the role of several features in solving the comovement puzzle whereas other papers explore different aspects of a New-Keynesian model with durable and nondurable goods. Auray et al. (2013) build a two-sector NK model with news and contemporaneous shocks in order to account for the Pigou cycle. They find that news shocks in nondurables lead to Pigou cycles whereas news shocks in durables do not.

Aoki (2001) argues that, in a two-sector model, targeting inflation in the sticky-price sector is optimal. Erceg and Levin (2006) determine the optimal monetary policy rule in a model with durable and nondurable goods, sticky wages and imperfect labour mobility. The optimal rule can be approximated by a hybrid rule that targets a weighted average of price and wage inflation. Petrella and Santoro (2011) perform a similar analysis in a model with the I-O structure of Bouakez et al. (2011) and conclude that the optimal rule is approximated by a rule that targets aggregate inflation and consumption gaps in the two sectors.

By surveying the literature of two-sector NK models, the usual modeling assumption that prices of durable goods are completely flexible is noticeable. To what extent this assumption is consistent with empirical evidence is an issue that our paper investigates.

3 Structural vector-autoregressive models

3.1 Methodology

As regards the estimation of the empirical model, we use quarterly, seasonally adjusted US data for the Federal funds rate, real GDP, real consumption of durable goods, real consumption of nondurable goods and services, the GDP deflator and the relative price of durables.[5] In order to thoroughly investigate the effects of a monetary policy shock on the relative price of durables, we employ two alternative definitions of durables sector. We first follow Erceg and Levin (2006), Monacelli (2009), Di Pace and Hertweck (2012) and Sterk and Tenreyro (2014) in defining durables as the sum of durable goods consumption and residential investments.[6] Then, we assume that durables comprise only houses. We label the former model *baseline* VAR and the latter *housing* VAR.

The main analysis is performed over the sample 1969Q2-2007Q4. This choice is dictated by the availability of the narrative measure of monetary policy shocks constructed by Romer and Romer (2004, RR henceforth) and extended by Coibion et al. (2012) and Tenreyro and Thwaites (2015).[7] The vector of variables employed in the VAR is the following:

$$x_t \equiv [GDP_t,\ D_t,\ C_t,\ P_t,\ Q_t,\ FFR_t]' \tag{1}$$

where GDP_t denotes gross domestic product, D_t and C_t represent consumption of durable and nondurable goods, respectively, P_t is the GDP deflator, Q_t is the the relative price of durable goods and FFR_t denotes the Federal funds rate. We take the natural logarithm of all variables except for the FFR, which is in levels.

For the sake of robustness, we take three different approaches to the identification

[5]Sources, description and details about the transformation of the data can be found in Section A of the Appendix.

[6]Erceg and Levin (2006) slightly depart from the other studies by disaggregating GDP into an index of consumer durables and residential investment and an index of all other components of output.

[7]Section B of the Appendix presents results obtained over seven subsamples and further robustness checks.

of monetary policy shocks. First, we apply a standard recursive (Cholesky) approach, then we use sign restrictions, and finally we employ the monetary shocks identified by Romer and Romer (2004) through a narrative approach.

3.1.1 Recursive approach

Let Σ_ε be the variance-covariance matrix of the reduced-form shocks of the VAR model. Under the recursive approach, the structural shocks are identified through a Cholesky decomposition of Σ_ε. Consequently, the order of the variables in vector x_t matters for the identification of the monetary disturbance. Indeed, at time t one variable is affected by the previous but not from those which follow. In our estimation, we make the standard assumption that the monetary policy variable is ordered last hence it has no contemporaneous effect on the other variables (see Bernanke and Mihov, 1998, among others). Furthermore, our VAR model includes a vector of constant terms and four lags, as commonly assumed in the literature for a monetary VAR with quarterly frequency.

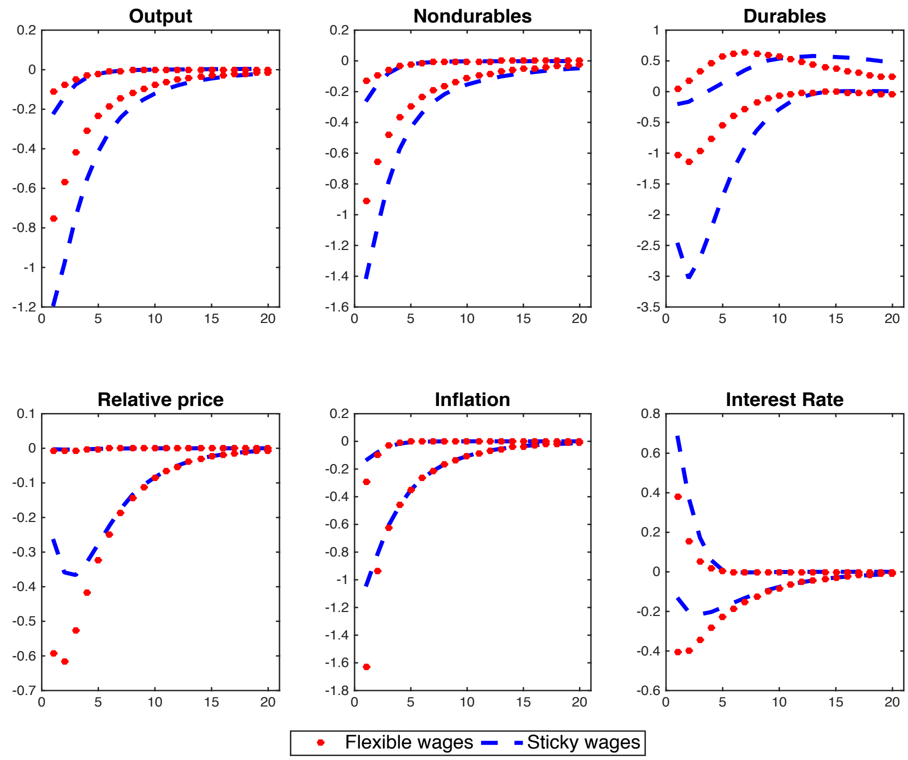
3.1.2 Sign restrictions approach

The second approach we employ is the pure sign restrictions proposed by Uhlig (2005). This method implies that shocks are identified when they follow specific and unique patterns by imposing restrictions on the impulse response functions (IRFs) of the SVAR model. Several orthogonal matrices linking the reduced-form and the structural shocks are drawn, where we retain those generating impulse responses that satisfy the set of restrictions while discarding the others.[8] We employ the model-based methodology outlined by Canova (2002) and applied in Dedola and Neri (2007), Pappa (2009) and Bermperoglu et al. (2013), among others, according to which the restrictions are extracted from a theoretical model. We can summarize the procedure in three main steps:

1. Build a nested DSGE model in which nominal and real frictions can be removed via appropriate parameterizations. We do this in Section 4, where our two-sector model encompasses a continuum of models featuring different subsets of frictions.

2. Define ranges for the structural parameters, generate thousands of random draws of the parameter values from their support and obtain IRFs for each draw.

[8] We repeat this process a large number of times until 500 draws are accepted.



Note: Blue dashed lines refer to the model in which wages are sticky. Red dotted lines refer to a model with flexible wages. Each pair of lines depicts the 84th and 16th percentiles of the distribution of impulse responses. The shock is a 1% increase in the nominal interest rate.

Figure 1: Robust impulse responses to a contractionary monetary policy shock

3. Use the robust IRFs to impose sign restrictions on the IRFs of the SVAR model.

More formally, let θ be a $N \times 1$ vector of the structural parameters of the model. We assume that each parameter is uniformly distributed over a particular range Θ_i, that is each parameter i in θ is defined over $\Theta = \prod_i \Theta_i$. Then we randomly draw the parameter values θ_i^m, $i = 1, ..., N;\ m = 1, ..., 10273$ from each Θ_i, where m is the number of random draws. For each draw, we construct a $K \times 1$ vector of impulse response functions of the data $h\left(y_t\left(\theta^m|u_t\right)\right)$ to the structural shocks u_t and order them increasingly. A function $h^K\left(y_t\left(\theta|u_t\right)\right)$ is considered robust if in the impact period the signs of the 84th and 16th percentiles of the simulated distribution of $h\left(y_t\left(\theta|u_t\right)\right)$ are the same, that is $sign\left[h_U^K\left(y_t\left(\theta|u_t\right)\right)\right] = sign\left[h_L^K\left(y_t\left(\theta|u_t\right)\right)\right]$ where h_U and h_L are the 84th and 16th percentiles respectively.

Shock	GDP	D	C	P	FFR
Business Cycle	< 0	< 0	< 0	> 0	> 0
Monetary Policy	< 0		< 0	< 0	> 0

Table 2: Sign restrictions

Figure 1 plots the 68% probability bands of impulse responses to a 1% increase in the nominal interest rate for two sets of simulations. The first leaves the wage stickiness parameter unrestricted (blue dashed lines) whereas, in the second, wages are fully flexible (red dotted lines).[9] Regarding the first set of simulations, on impact, output, nondurable and durable consumption, and inflation exhibit robust negative responses. In fact, our model features frictions such as wage and price rigidities that solve the comovement puzzle for different combinations of parameter values. In order to be consistent with the literature, we impose that price stickiness of durables can either be lower or equal to price rigidity in the nondurables sector but never higher. Consequently, the response of the relative price of durables is by construction bounded below zero. The response of the nominal interest rate deserves more attention as it is not robust and in some cases at odds with the monetary policy shock being restrictive. However, this is a common issue of two-sector NK models as reported by BHK and Sterk (2010).[10]

Turning to the identification of the monetary policy shock, Fry and Pagan (2011) critically review the sign restrictions approach arguing that if there is not enough information to discriminate among the various shocks, it may be problematic to correctly identify them. In principle, only if the researcher describes the sign pattern for each shock in the model it is possible to avoid this problem. In order to partially address this identification issue we proceed as follows. We first determine the sign pattern of another important source of business cycles, namely a *business cycle shock*, and then we identify the monetary policy shock.[11]

Table 2 summarizes the set of sign restrictions imposed. A contractionary business cycle shock curbs output, nondurable and durable consumption, while increasing infla-

[9]The latter is included to show that wage stickiness is crucial for the comovement issue. See section D of the Appendix for a discussion of the choice of ranges, the dynamics of the impulse response functions and further details of the methodology employed.

[10]According to BHK, the counter-intuitive response of the nominal interest rate follows from the near constancy of the shadow value of durables which makes their real rate of return constant thus forcing the nominal interest rate to track expected inflation in the durable goods sector.

[11]Robust IRFs for the business cycle shock are completely standard and are available upon request.

tion and the nominal interest rate. Conversely, the monetary policy shock is characterized by a decrease in output, nondurable consumption and inflation. Notwithstanding the lack of a robust response, in order to correctly identify the monetary policy shock, we assume that the nominal interest rate is positive in the first quarter. We remain agnostic on the response of the relative price as it is the main objective of our investigation. The different restriction imposed on the response of the GDP deflator is what ensures the orthogonality between the two disturbances and the correct identification of the monetary policy shock.

3.1.3 Narrative approach

The third approach we employ is based on the contribution of Romer and Romer (2004). RR develop a new measure of U.S. monetary policy shock that is somewhat immune to two problems embedded in monetary policy variables such as the actual FFR. Indeed, RR argue that such measures suffer from *endogeneity* and *anticipatory movements*. In particular, the former implies that the FFR moves with changes in economic conditions hence not with changes in the conduct of monetary policy. The latter implies that movements in the FFR represent responses to information about future events in the economy. As a result, RR argue that such measures of monetary policy do not really represent exogenous shocks and they derive a new measure that enables the researcher to overcome these shortcomings.

The derivation of the alternative monetary policy variable consists of two main steps. RR first derive a series of *intended FFR changes* around meetings of the Federal Open Market Committee (FOMC) of the Federal Reserve (Fed). They rely on a combination of narrative and quantitative evidence in order to retrieve the direction and the magnitude of such intended changes. This step eliminates the endogeneity between the interest rate and economic conditions thus solving the first of the two shortcomings outlined above. The second step consists of controlling for the Fed's internal forecasts in order to disentangle the effects of information about future economic developments. RR then regress the change in the intended FFR on its level, on the level and the changes of forecasts about GDP growth and the GDP deflator, and forecasts about the unemployment rate. Then they take the residuals of this regression as the new measure of monetary policy shocks. Consequently, the resulting series gains a higher degree of exogeneity with respect to the FFR since it represents movements in the monetary policy measure not stemming from forecasts about inflation, GDP growth and unemployment.

In order to determine whether the results of the first two approaches are robust under this alternative measure of monetary shocks, we re-estimate the recursive VAR model by replacing the FFR with the variable constructed by RR and extended by Coibion et al. (2012) and Tenreyro and Thwaites (2015).

3.2 Results

The estimated impulse responses are presented in Figure 2. Rows refer to the variables of the model whereas columns refer to the three different identification approaches. The shock is a one standard deviation increase in the monetary policy measure. Solid lines depict the responses for the baseline VAR model, and the shaded areas are the corresponding one-standard-deviation confidence bands. Dashed lines show the responses for the housing VAR model, with dotted lines representing the corresponding one-standard-deviation confidence bands.[12] The impulse responses show that results are broadly robust across models and identification approaches, with the exception of the relative price. There is evidence for the comovement between durables and nondurables, and the responses of durables are always larger than those of nondurables, a finding that is consistent with Erceg and Levin (2006), Monacelli (2009), Di Pace and Hertweck (2012) and Sterk and Tenreyro (2014), who estimate similar VAR models.

Turning to the dynamic behaviour of the relative price, the estimated responses to a monetary policy tightening are highly dependent on the definition of the durables sector adopted. If durables account for both consumption goods and residential investments, the response of the relative price is either flat or mildly positive, this being at odds with the assumption of flexible durable prices adopted in most of the theoretical literature. Conversely, a model in which the durables sector coincides exclusively with the housing sector, the relative price falls consistently with the notion of flexible new house prices.

Full sample results are confirmed by the responses of the relative price across seven subsamples.[13] In Figure 3 rows plot the relative price responses for each subsample, whereas columns represent the three identification approaches. The relative price of durables never falls in the baseline VAR model whereas it significantly decreases in the

[12]One-standard-deviation confidence bands in the recursive approaches are computed by Monte Carlo methods based on 2000 draws. In the sign restrictions approach we construct a distribution of impulse responses and we report the median together with the 16th and the 84th percentiles in order to report a comparable confidence band.

[13]The size of each subsample is 24 years. See Appendix B for details.

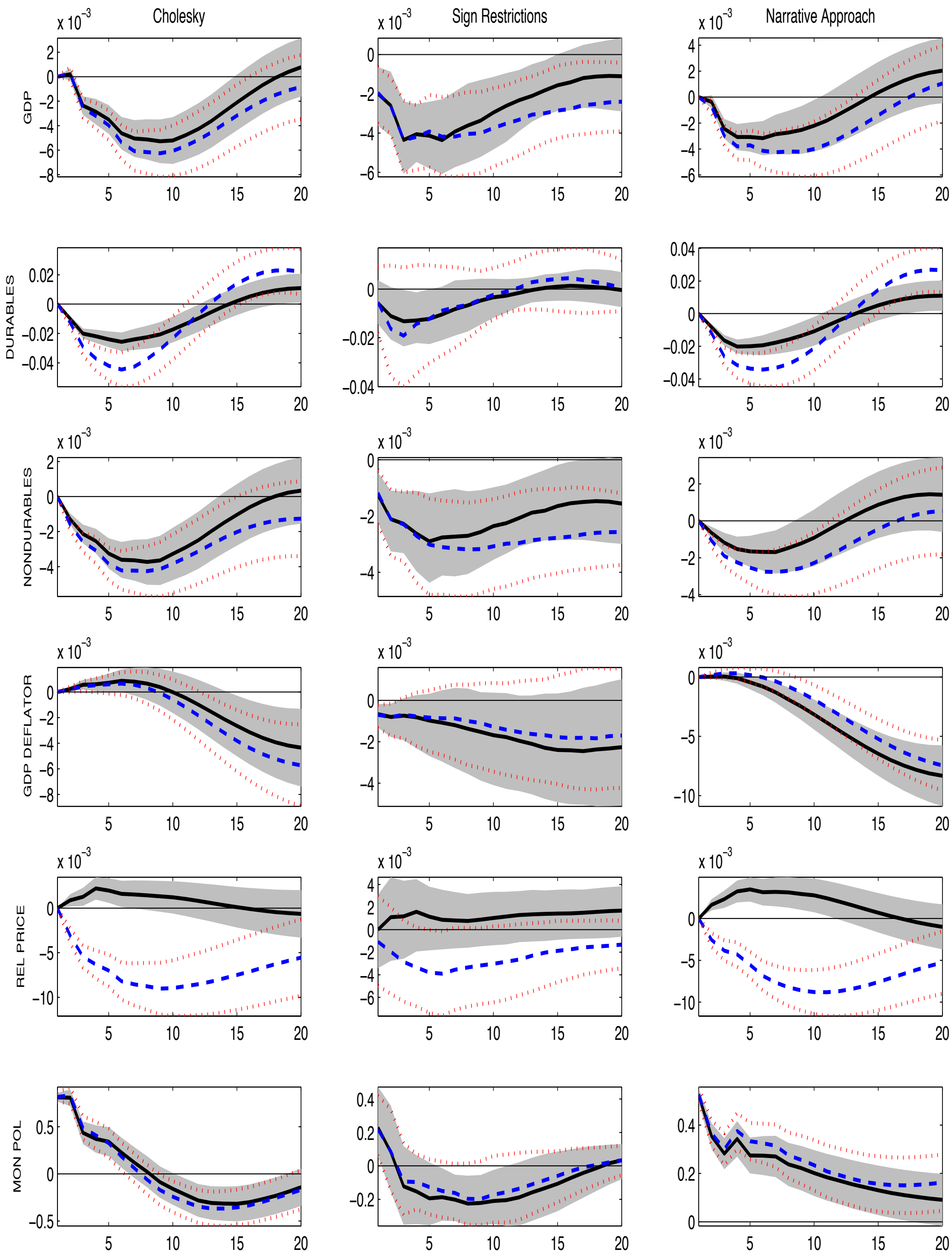


Figure 2: Impulse responses to a one standard deviation increase in the monetary policy measure. Sample: 1969Q2-2007Q4 (bold lines refer to the model with all durable goods; dashed lines refer to the model with only houses; shaded areas and dotted lines represent one-standard-deviation confidence bands)

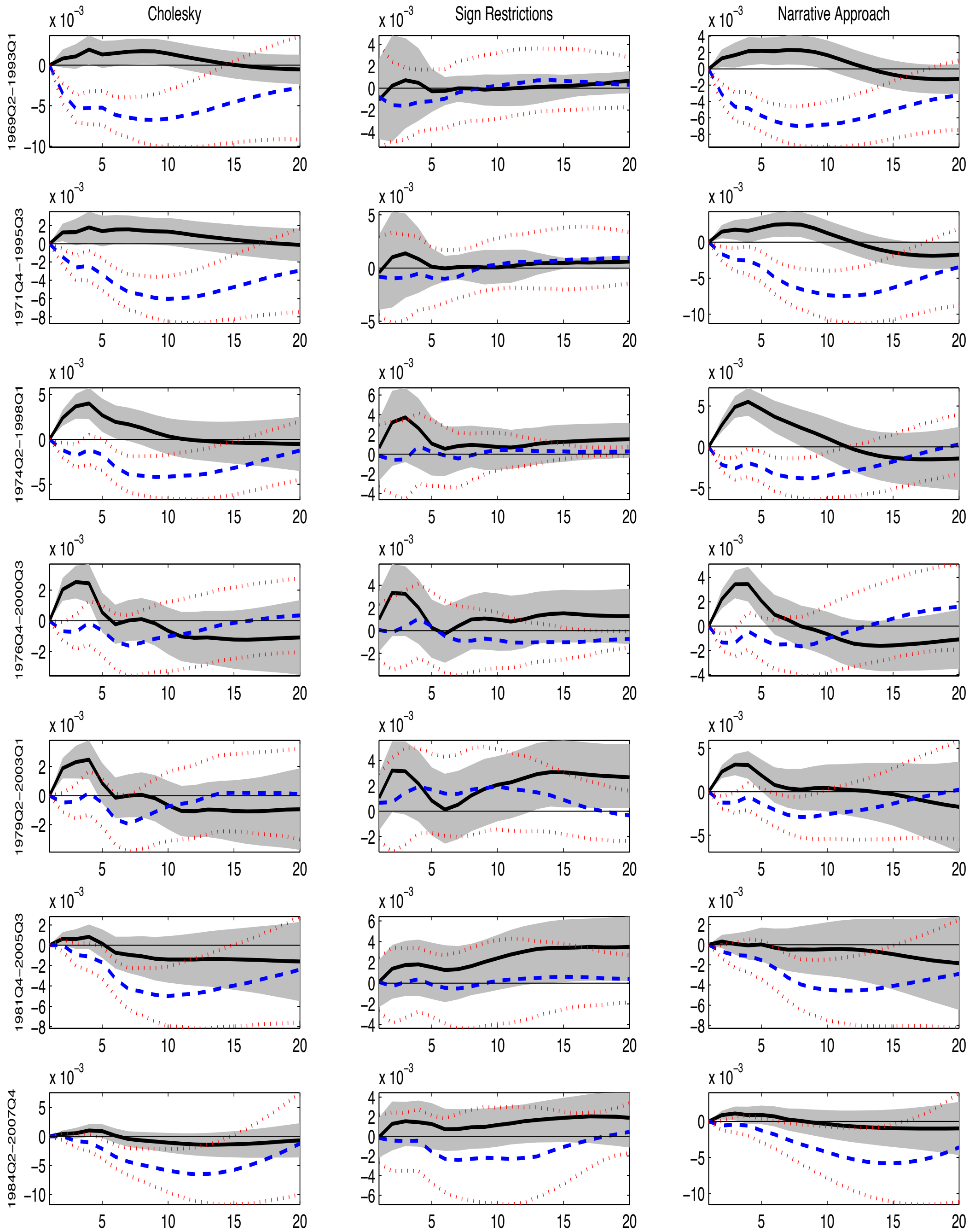


Figure 3: Responses of the relative price to a one standard deviation increase in the monetary policy measure. Rows denote samples, columns denote identification methods (bold lines refer to the model with all durable goods; dashed lines refer to the model with only houses; shaded areas and dotted lines represent one-standard-deviation confidence bands)

housing VAR model.

To sum up, this empirical evidence suggests that the definition of the durables sector is crucial. If durable goods are defined to include both consumption goods and residential investments, these display dynamics consistent with a non-negligible degree of price stickiness. Conversely, durable goods defined to include only the housing sector exhibit a behavior compatible with flexible prices. In the next section, we directltly investigate whether the durables degree of price stickiness is substantially different from the price stickiness of nondurable goods in an estimated DSGE model.

4 Theoretical model

We analyze a two-sector New-Keynesian model in which households consume both durable and nondurable goods. The economy is characterized by several frictions, the importance of which is empirically assessed. These are price and wage stickiness, investment adjustment costs in durable goods (IAC, henceforth) and habit formation in consumption of nondurable goods. Finally, the monetary authority sets the nominal interest rate according to a Taylor-type interest rate rule.

4.1 Households

The economy is populated by a continuum of identical and infinitely-lived households indexed by $i \in [0,1]$ in which consumers derive utility from consumption of durable and nondurable goods and get disutility from supplying labor,

$$E_0 \sum_{t=0}^{\infty} e_t^B \beta^t U\left(X_{i,t}, N_{i,t}\right), \tag{2}$$

where $\beta \in [0,1]$ is the subjective discount factor, e_t^B is a preference shock, $X_{i,t} = Z_{i,t}^{1-\alpha} D_{i,t}^{\alpha}$ is a Cobb-Douglas consumption aggregator between nondurable ($Z_{i,t}$) and durable goods ($D_{i,t}$) with $\alpha \in [0,1]$ representing the share of durable consumption on total expenditure, and $N_{i,t}$ being the household's labor supply.

We assume that nondurable consumption is subject to external habit formation so that

$$Z_{i,t} = C_{i,t} - \zeta S_{t-1}, \tag{3}$$
$$S_t = \rho_c S_{t-1} + (1-\rho_c) C_t, \tag{4}$$

where $C_{i,t}$ is the level of the household's nondurable consumption; S_t, $\zeta \in (0,1)$ and $\rho_c \in (0,1)$ are the stock, the degree and the persistence of external habit formation, respectively, while C_t represents average consumption across households. Each household monopolistically supplies labor to satisfy the following demand function:

$$N_{i,t} = \left(\frac{w_{i,t}}{w_t}\right)^{-e_t^W \eta} N_t, \tag{5}$$

where $w_{i,t}$ is the real wage of each household whereas w_t is the average real wage in the economy. Parameter η is the intratemporal elasticity of substitution between labour services and e_t^W is a wage markup shock. Finally, firms on average demand a quantity N_t of labour services. Nominal wages are subject to quadratic costs of adjustment à la Rotemberg (1982): $\frac{\vartheta^W}{2}\left(\frac{w_{i,t}}{w_{i,t-1}}\widetilde{\Pi}_t - \widetilde{\Pi}_{ss}\right)^2 w_t N_t$, where ϑ^W is the parameter governing the degree of wage stickiness, $\widetilde{\Pi}_t \equiv \left(\Pi_t^C\right)^{1-\tau}\left(\Pi_t^D\right)^{\tau}$ is an aggregator of the gross rates of inflation in the two sectors with $\tau \in [0,1]$ representing the weight of durables, and $\widetilde{\Pi}_{ss}$ is the steady-state value of the inflation aggregator.

The stock of durables evolves according to law of motion

$$D_{i,t+1} = (1-\delta) D_{i,t} + e_t^I I_{i,t}^D \left[1 - S\left(\frac{I_{i,t}^D}{I_{i,t-1}^D}\right)\right], \tag{6}$$

where δ is the depreciation rate of durables, $I_{i,t}^D$ is investment in durable goods that is subject to adjustment costs and e_t^I represents an investment-specific shock. The adjustment costs function $S(\cdot)$ satisfies $S(1) = S'(1) = 0$ and $S''(1) > 0$. In addition, each household purchases nominal bonds $B_{i,t}$, receives profits $\Omega_{i,t}$ from firms and pays a lump-sum tax T_t so that the period-by-period real budget constraint reads as follows:

$$C_{i,t} + Q_t I_{i,t}^D + \frac{\vartheta^W}{2}\left(\frac{w_{i,t}}{w_{i,t-1}}\widetilde{\Pi}_t - \widetilde{\Pi}_{ss}\right)^2 w_t N_t + \frac{R_t B_{i,t-1}}{\Pi_t^C} = \frac{B_{i,t}}{P_t^C} + \frac{W_{i,t}}{P_t^C} N_{i,t} + \Omega_{i,t} - T_t, \tag{7}$$

where $Q_t \equiv \frac{P_{D,t}}{P_{C,t}}$ is the relative price of durables, R_t is the gross nominal interest rate,

Π_t^C is the gross rate of inflation of nondurable goods and $W_{i,t}$ is the nominal wage. Households choose $Z_{i,t}, B_{i,t}, D_{i,t+1}, I_{i,t}^D, w_{i,t}$ to maximize (2) subject to (3), (4), (5), (6) and (7). At the symmetric equilibrium, the household's optimality conditions are:

$$1 = E_t\left[\Lambda_{t,t+1}\frac{R_{t+1}}{\Pi_{t+1}^C}\right], \tag{8}$$

$$Q_t\psi_t = \frac{U_{D,t}}{U_{Z,t}} + (1-\delta)\,E_t\left[\Lambda_{t,t+1}Q_{t+1}\psi_{t+1}\right], \tag{9}$$

$$1 = \psi_t e_t^I\left[1 - S\left(\frac{I_t^D}{I_{t-1}^D}\right) - S'\left(\frac{I_t^D}{I_{t-1}^D}\right)\frac{I_t^D}{I_{t-1}^D}\right] + \tag{10}$$

$$+E_t\left\{\Lambda_{t,t+1}\psi_{t+1}\frac{Q_{t+1}}{Q_t}e_{t+1}^I\left[S'\left(\frac{I_{t+1}^D}{I_t^D}\right)\left(\frac{I_{t+1}^D}{I_t^D}\right)^2\right]\right\}, \tag{11}$$

$$0 = \left[1 - e_t^W\eta\right] + \frac{e_t^W\eta}{\tilde{\mu}_t} - \vartheta^W\left(\Pi_t^W - \widetilde{\Pi}_{ss}\right)\Pi_t^W +$$

$$+E_t\left[\Lambda_{t,t+1}\vartheta^W\left(\Pi_{t+1}^W - \widetilde{\Pi}_{ss}\right)\Pi_{t+1}^W\frac{w_{t+1}N_{t+1}}{w_tN_t}\right]. \tag{12}$$

Equation (8) is a standard Euler equation with $\Lambda_{t,t+1} \equiv \beta\frac{U_{Z,t+1}}{U_{Z,t}}\frac{e_{t+1}^B}{e_t^B}$ representing the stochastic discount factor and $U_{Z,t}$ denoting the marginal utility of habit-adjusted consumption of nondurable goods. Equation (9) represents the asset price of durables, where $U_{D,t}$ is the marginal utility of durables consumption and ψ_t is the Lagrange multiplier attached to constraint (6). Equation (11) is the optimality condition w.r.t. investment in durable goods. Finally, equation (12) is the wage setting equation in which $\tilde{\mu}_t \equiv \frac{w_t}{MRS_t}$ is the wage markup, $MRS_t \equiv -\frac{U_{N,t}}{U_{Z,t}}$ is the marginal rate of substitution between consumption and leisure, $U_{N,t}$ is the marginal disutility of work and Π_t^W is the gross wage inflation rate.

4.2 Firms

Firms face quadratic costs of changing prices as in Rotemberg (1982): $\frac{\vartheta_j}{2}\left(\frac{P_{\omega,t}^j}{P_{\omega,t-1}^j} - 1\right)^2 Y_t^j$, where ϑ_j is the parameter of sectoral price stickiness. Each firm produces differentiated goods according to a linear production function,

$$Y_{\omega,t}^j = e_t^A N_{\omega,t}^j, \tag{13}$$

where $\omega \in [0,1]$ and $j = C, D$ are indices for firms and sectors respectively, and e_t^A is a labour augmenting shock. Firms maximize the present discounted value of profits,

$$E_t \left\{ \sum_{t=0}^{\infty} \Lambda_{t,t+1} \left[\frac{P_{\omega,t}^j}{P_t^j} Y_{\omega,t}^j - \frac{W_{\omega t}}{P_t^j} N_{\omega,t}^j - \frac{\vartheta_j}{2} \left(\frac{P_{\omega,t}^j}{P_{\omega,t-1}^j} - 1 \right)^2 Y_t^j \right] \right\}, \tag{14}$$

subject to production function (13) and a standard Dixit-Stiglitz demand equation $Y_{\omega,t}^j = \left(\frac{P_{\omega,t}^j}{P_t^j} \right)^{-e_t^j \epsilon_j} Y_t^j$, where ϵ_j and e_t^j are the sectoral intratemporal elasticies of substitution across goods and the sectoral price markup shocks, respectively. At the symmetric equilibrium, the price setting equations for the two sectors read as

$$\begin{aligned} \left(1 - e_t^C \epsilon_c\right) + e_t^C \epsilon_c MC_t^C &= \vartheta_c \left(\Pi_t^C - 1\right) \Pi_t^C - \\ &\quad -\vartheta_c E_t \left[\Lambda_{t,t+1} \frac{Y_{t+1}^C}{Y_t^C} \left(\Pi_{t+1}^C - 1\right) \Pi_{t+1}^C \right], \end{aligned} \tag{15}$$

$$\begin{aligned} \left(1 - e_t^D \epsilon_d\right) + e_t^D \epsilon_d MC_t^D &= \vartheta_d \left(\Pi_t^D - 1\right) \Pi_t^D - \\ &\quad -\vartheta_d E_t \left[\Lambda_{t,t+1} \frac{Q_{t+1}}{Q_t} \frac{Y_{t+1}^D}{Y_t^D} \left(\Pi_{t+1}^D - 1\right) \Pi_{t+1}^D \right], \end{aligned} \tag{16}$$

where $MC_t^C = \frac{w_t}{e_t^A}$ and $MC_t^D = \frac{w_t}{e_t^A Q_t}$. When $\vartheta_j = 0$ prices are fully flexible and are set as constant markups over the marginal costs.

4.3 Fiscal and monetary policy

Every period, a lump-sum tax equates government spending so that the government budget is balanced. Government spending e_t^G follows an exogenous process and, as in Erceg and Levin (2006), we assume that the government purchases only nondurable goods and services. Monetary policy is set according to the following Taylor rule:

$$\log\left(\frac{R_t}{\bar{R}}\right) = \rho_r \log\left(\frac{R_{t-1}}{\bar{R}}\right) + (1-\rho_r)\left[\rho_\pi \log\left(\frac{\tilde{\Pi}_t}{\tilde{\Pi}}\right) + \rho_y \log\left(\frac{Y_t}{\bar{Y}}\right)\right] + e_t^R, \tag{17}$$

where ρ_r is the interest rate smoothing parameter, ρ_π and ρ_y are the monetary policy responses to the deviations of the inflation aggregator and output from their respective steady states, and e_t^R represents the exogenous innovation to the monetary policy rule. Three different monetary policy rules have been employed in two-sector NK models. Some authors (Barsky et al., 2003, 2007; Katayama and Kim, 2010; Bouakez et al., 2011; Sudo, 2012, 2007) assume a money supply rule. Other authors (Carlstrom and Fuerst, 2006, 2010; Monacelli, 2009; Sterk, 2010; Chen and Liao, 2014) introduce an interest rate rule that responds only to the inflation aggregator. Similarly to recent contributions (Junhee, 2009; Tsai, 2010; Di Pace and Hertweck, 2012; Auray et al., 2013; Kim and Katayama, 2013; Katayama and Kim, 2013), we set a Taylor-type rule featuring interest rate smoothing and responses to inflation and output as widely common in estimated DSGE models.

4.4 Market clearing conditions and exogenous processes

In equilibrium all markets clear and the model is closed by the following identities:

$$Y_t^C = C_t + e_t^G + \frac{\vartheta_c}{2}\left(\Pi_t^C - 1\right)^2 Y_t^C, \tag{18}$$

$$Y_t^D = \left[D_t - (1-\delta) D_{t-1}\right] + \frac{\vartheta_d}{2}\left(\Pi_t^D - 1\right)^2 Y_t^D, \tag{19}$$

$$N_t = N_t^C + N_t^D, \tag{20}$$

$$Y_t = Y_t^C + Q_t Y_t^D. \tag{21}$$

As in Smets and Wouters (2007), the wage markup and the price markup shocks follow ARMA (1,1) processes:

$$\log\left(\frac{\varkappa_t}{\bar{\varkappa}}\right) = \rho_\varkappa \log\left(\frac{\varkappa_{t-1}}{\bar{\varkappa}}\right) + \epsilon_t^\varkappa - \theta_i \epsilon_{t-1}^\varkappa \tag{22}$$

with $\varkappa = \left[e^W, e^C, e^D\right]$, $i = [W, C, D]$, whereas all other shocks follow an AR (1) process:

$$\log\left(\frac{\kappa_t}{\bar{\kappa}}\right) = \rho_\kappa \log\left(\frac{\kappa_{t-1}}{\bar{\kappa}}\right) + \epsilon_t^\kappa \tag{23}$$

where $\kappa = \left[e^B, e^I, e^R, e^A, e^G\right]$ is a vector of exogenous variables, $\rho_\varkappa$ and ρ_κ are the autoregressive parameters, θ_i are the moving average parameters, $\epsilon_t^\varkappa$ and ϵ_t^κ are i.i.d shocks with zero mean and standard deviations $\sigma_\varkappa$ and σ_κ. The systems of equations describing the full symmetric equilibrium and the steady state are presented in Sections C.1 and C.2 of the Appendix.

4.5 Functional forms

The utility function is additively separable and logarithmic in the consumption aggregator: $U(X_t, N_t) = \log(X_t) - \nu \frac{N_t^{1+\varphi}}{1+\varphi}$, where ν is a scaling parameter for hours worked and φ is the inverse of the Frisch elasticity of labour supply.[14] Following Christiano et al. (2005), adjustment costs in durables investment are quadratic: $S\left(\frac{I_t^D}{I_{t-1}^D}\right) = \frac{\phi}{2}\left(\frac{I_t^D}{I_{t-1}^D} - 1\right)^2$ with $\phi > 0$ representing the degree of adjustment costs.

4.6 Bayesian estimation

The model is estimated with Bayesian methods. The Kalman filter is used to evaluate the likelihood function, which combined with the prior distribution of the parameters yields the posterior distribution. Then, the Monte-Carlo-Markov-Chain Metropolis-Hastings (MCMC-MH) algorithm with two parallel chains of 150,000 draws each is used to generate a sample from the posterior distribution in order to perform inference.[15] We estimate the model over the sample 1969Q2-2007Q4, the same as in the VAR analysis.[16] We use eight observables: GDP, consumption of durable goods, consumption of nondurable goods, real wage, hours worked, inflation in the nondurables sector, inflation in the durables sector and the nominal interest rate, using US data. We define the durables sector as the sum of durable goods and residential investments. The following measurement equations link the data to the endogenous variables of the model:

$$\Delta Y_t^o = \gamma + \hat{Y}_t - \hat{Y}_{t-1}, \tag{24}$$

$$\Delta I_{D,t}^o = \gamma + \hat{I}_{D,t} - \hat{I}_{D,t-1}, \tag{25}$$

$$\Delta C_t^o = \gamma + \hat{C}_t - \hat{C}_{t-1}, \tag{26}$$

$$\Delta W_t^o = \gamma + \hat{W}_t - \hat{W}_{t-1}, \tag{27}$$

$$N_t^o = \hat{N}_t, \tag{28}$$

$$\Pi_{C,t}^o = \bar{\pi}_C + \hat{\Pi}_t^C, \tag{29}$$

$$\Pi_{D,t}^o = \bar{\pi}_D + \hat{\Pi}_t^D, \tag{30}$$

$$R_t^o = \bar{r} + \hat{R}_t, \tag{31}$$

[14] Kim and Katayama (2013) assume non-separable preferences as in Guerron-Quintana (2008).

[15] More details about the estimation strategy are in Section E of the Appendix.

[16] Results are robust to estimating the model over the sample 1984Q1-2007Q4 (Great Moderation), see Section G of the Appendix.

where γ is the common quarterly trend growth rate of GDP, consumption of durables, consumption of nondurables and the real wage; $\bar{\pi}_C$ and $\bar{\pi}_D$ are the average quarterly inflation rates in nondurable and durable sectors respectively; $\bar{r}$ is the average quarterly Federal funds rate. Hours worked are demeaned so no constant is required in the corresponding measurement equation (28). Variables with a $\hat{}$ are in log-deviations from their own steady state.

4.6.1 Calibration and priors

The structural parameters and steady state values represented in Table 3 are calibrated at a quarterly frequency. The discount factor β is equal to the conventional value of 0.99, implying an annual steady-state gross interest rate of 4%. Following Monacelli (2009), the depreciation rate of durable goods δ is calibrated at 0.010 amounting to an annual depreciation of 4%, and the durables share of total expenditure α is set at 0.20. The sectoral elasticities of substitution across different varieties ϵ_c and ϵ_d equal 6 in order to target a steady-state gross mark-up of 1.20. The elasticity of substitution in the labor market η is set equal to 21 as in Zubairy (2014), implying a 5% steady-state gross wage mark-up. The preference parameter ν is set to target steady-state hours of work of 0.33. The government-output ratio g_y is calibrated at 0.20, in line with the data.

Table 4 summarizes the prior and posterior distributions of the parameters and the shocks. The choice of priors correspond to a large extent to those in previous studies of the US economy. We set the prior mean of the inverse Frisch elasticity φ to 0.5, in line with Smets and Wouters (2007, SW henceforth) who estimate a Frisch elasticity of 1.92. We also follow SW in setting the prior means of the habit parameter, ζ, to 0.7, the interest rate smoothing parameter, ρ_r, to 0.80 and in assuming a stronger response of the central bank to inflation than output. As far as the the constants in the measurement equations are concerned, we set the prior means equal to the average values in the dataset. In general, we use the Beta distribution for all parameters bounded between 0 and 1. We use the Inverse Gamma (IG) distribution for the standard deviation of the shocks for which we set a loose prior with 2 degrees of freedom. Kim and Katayama (2013) are the only authors who jointly estimate the price and wage stickiness parameters whereas all the other studies calibrate them such that prices of nondurable goods are sticky whereas prices of durable goods are flexible. However, they define Calvo parameters for prices and a Rotemberg parameter

Parameter		Value
Discount factor	β	0.99
Durables depreciation rate	δ	0.010
Durables share of total expenditure	α	0.20
Elasticity of substitution nondurable goods	ϵ_c	6
Elasticity of substitution durable goods	ϵ_d	6
Elasticity of substitution in labor	η	21
Preference parameter	ν	set to target $\bar{N} = 0.33$
Government share of output	g_y	0.20

Table 3: Calibrated parameters

for wages.[17] Our model features Rotemberg parameters for both prices and wages and we choose a Gamma distribution, given that these are nonnegative. One of our main interests is to assess whether the durables price stickiness parameter is close to zero, or whether it tends towards values closer to those estimated for the nondurables sector. This is crucial in order to assess whether the response of the relative price of durables is significantly different from zero or not. To this aim, we assign a prior whereby durables prices are as sticky as nondurables prices and both degrees of price stickiness are low (corresponding to firms resetting prices around 1.5 quarters on average in a Calvo world). Then, we let the data decide whether and to what extent these should depart from one another.

4.6.2 Estimation results

Table 4 also reports the posterior mean with 90% probability intervals in square brackets and the log-marginal likelihood of the model. The posterior means suggest that various frictions are supported by the data. There is a sizable degree of habit in nondurables consumption ($\zeta = 0.79$) with a persistence of $\rho_c = 0.40$. Quadratic costs of adjustment in wages and investment of durable goods are also sizable, with parameters estimated at $\vartheta^W = 98.10$ and $\phi = 3.68$, respectively. Estimates of the Taylor rule parameters show a high degree of policy inertia, with ρ_r estimated to be 0.71, and a stronger response to inflation ($\rho_\pi = 1.52$) than to output ($\rho_y = 0.02$), a likely consequence of estimating the model over a sample including the Great Moderation.

As regards price stickiness in the two sectors, the posterior means do not seem to dramatically diverge from each other – with confidence intervals largely overlapping –

[17] Iacoviello and Neri (2010) build and estimate a two-sector NK model where durables include only houses. However, they do not estimate the price stickiness parameter in the housing sector.

Parameter		Distrib.	Prior Mean	Std/df	Posterior Mean
Structural					
Inverse Frisch elasticity	φ	Normal	0.50	0.10	0.6528 [0.5048;0.8000]
Habit in nondurables consumption	ζ	Beta	0.70	0.10	0.7918 [0.7585;0.8271]
Habit persist. nondurables consumption	ρ_c	Beta	0.70	0.10	0.3983 [0.3040;0.4963]
Price stickiness nondurables	ϑ_c	Gamma	15.0	5.00	34.2668 [23.7045;44.0698]
Price stickiness durables	ϑ_d	Gamma	15.0	5.00	25.0930 [16.4743;33.2991]
Wage stickiness	ϑ^W	Gamma	100.0	10.00	98.0976 [82.8225;113.4535]
Invest. adjust. costs durable goods	ϕ	Normal	1.5	0.50	3.6839 [3.0590;4.2986]
Share of durables inflation in aggregator	τ	Beta	0.20	0.10	0.1478 [0.0677;0.2345]
Inflation -Taylor rule	ρ_π	Normal	1.50	0.20	1.5160 [1.3246;1.7096]
Output -Taylor rule	ρ_y	Gamma	0.10	0.05	0.0208 [0.0052;0.0354]
Interest rate smoothing	ρ_r	Beta	0.80	0.10	0.7146 [0.6672;0.7602]
Averages					
Trend growth rate	γ	Normal	0.49	0.10	0.3927 [0.3685;0.4170]
Inflation rate nondurables	$\bar{\pi}_C$	Gamma	1.05	0.10	1.0575 [0.9622;1.1494]
Inflation rate durables	$\bar{\pi}_D$	Gamma	0.55	0.10	0.4995 [0.3981;0.5971]
Interest rate	$\bar{r}$	Gamma	1.65	0.10	1.6386 [1.5153;1.7699]
Exogenous processes					
Technology	ρ_{e^A}	Beta	0.50	0.20	0.95011 [0.9189;0.9847]
	σ_{e^A}	IG	0.10	2.0	0.0070 [0.0063;0.0076]
Monetary Policy	ρ_{e^R}	Beta	0.50	0.20	0.1275 [0.0366;0.2088]
	σ_{e^R}	IG	0.10	2.0	0.0029 [0.0026;0.0032]
Investment Durables	ρ_{e^I}	Beta	0.50	0.20	0.4098 [0.2416;0.5774]
	σ_{e^I}	IG	0.10	2.0	0.0747 [0.0515;0.0968]
Preference	ρ_{e^B}	Beta	0.50	0.20	0.6448 [0.5595;0.7294]
	σ_{e^B}	IG	0.10	2.0	0.0192 [0.0159;0.0224]
Price mark-up nondurables	ρ_{e^C}	Beta	0.50	0.20	0.9362 [0.8940;0.9792]
	θ_C	Beta	0.50	0.20	0.3943 [0.2178;0.5675]
	σ_{e^C}	IG	0.10	2.0	0.0195 [0.0147;0.0242]
Price mark-up durables	ρ_{e^D}	Beta	0.50	0.20	0.9860 [0.9759;0.9965]
	θ_D	Beta	0.50	0.20	0.6266 [0.5097;0.7479]
	σ_{e^D}	IG	0.10	2.0	0.0383 [0.0275;0.0484]
Wage mark-up	ρ_{e^W}	Beta	0.50	0.20	0.9565 [0.9271;0.9883]
	θ_W	Beta	0.50	0.20	0.5600 [0.4546;0.6688]
	σ_{e^W}	IG	0.10	2.0	0.0424 [0.0357;0.0495]
Government spending	ρ_{e^G}	Beta	0.50	0.20	0.9283 [0.8968;0.9613]
	σ_{e^G}	IG	0.10	2.0	0.0356 [0.0323;0.0390]
Log-marginal likelihood					-1393.745

Table 4: Prior and posterior distributions of estimated parameters

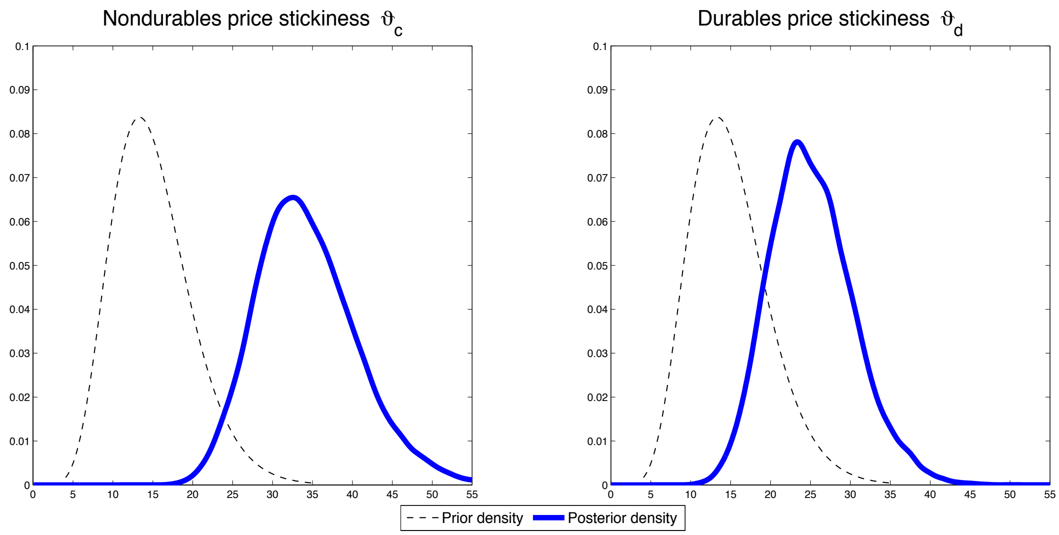


Figure 4: Prior and posterior densities of price stickiness parameters

although the point estimate of durables price stickiness ($\vartheta_d = 25.09$) is lower than that of nondurables ($\vartheta_c = 34.27$). It is noteworthy that these two key parameters seem well identified in the data, as shown in Figure 4, where the prior and posterior distributions are rather apart from each other.

This result contrasts with Kim and Katayama (2013) who find that prices of durables are substantially more flexible than prices of nondurables, in a model with fewer shocks and different observables.[18] We try and be as close as possible to mainstream estimated models as far as shocks and observables are concerned, with the natural addition of observables related to durables consumption and durables inflation. Moreover, such results are closer to the latest microeconometric evidence of Nakamura and Steinsson (2008) and Klenow and Malin (2010).

4.6.3 Impulse response functions

In order to investigate the dynamic properties of the model, Figure 5 displays the estimated impulse responses of the variables of interest to a one standard-deviation increase in the nominal interest rate.[19]

The posterior estimated IRFs imply that an increase in the monetary policy rate leads to an output contraction and a decrease in overall and sectoral inflations. Furthermore, the presence of wage and price stickiness generates the desired comovement

[18] Also Bouakez et al. (2009) provide qualitatively similar results in a larger model.

[19] Impulse responses represent percentage deviations from the steady state.

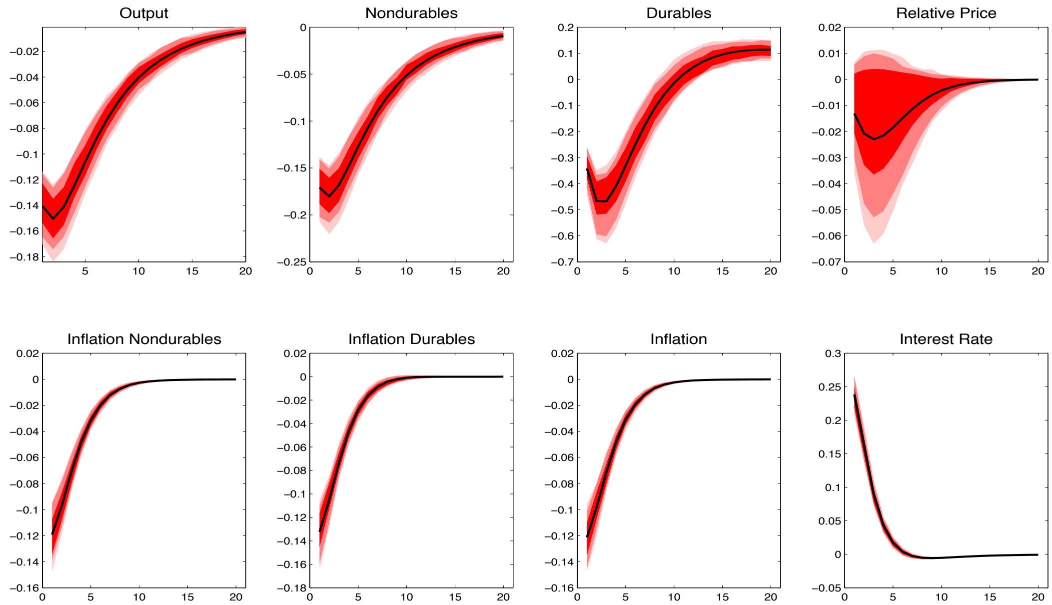


Figure 5: Bayesian impulse responses to a contractionary monetary policy shock (bold lines are mean responses, dark-shaded areas are 68% confidence bands, medium and lighter shaded areas represent 90% and 95% confidence bands respectively)

between durables and nondurables. IAC and habit formation are essential in generating hump-shaped responses as discussed in Subsection 4.7.

Qualitatively, the responses of the estimated DSGE model are consistent with those of the VAR model. Also from a quantitative perspective, durables turn out to be more volatile than nondurables and output, as in the SVAR results.

Turning to the relative price of durables, the credible set of estimated impulse responses to a monetary policy tightening does not exclude zero at any of the confidence levels considered. Also this finding is consistent with the SVAR results and arises from the fact that there is no big difference in the degree of price stickiness between the two sectors. This last result is a novel contribution of our paper and it is at odds with the assumption made in most two-sectors New-Keynesian models that prices of durables, defined as the sum of durable goods and residential investments, are fully flexible.

4.7 Models comparison

We take two approaches to assess how well our (unrestricted) model's features help fitting the data. First, we perform a likelihood race between the baseline and five restricted models, in which the DSGE model is estimated with one friction removed

Model	Restrictions	Log-marg. likelihood	Kass-Raftery
Baseline		-1393.745	
Flexible Wages	$\vartheta^W = 0$	-1424.502	61.514
Flexible Durables Prices	$\vartheta_d = 0$	-1449.463	111.436
No IAC	$\phi = 0$	-1957.035	1126.58
No Habit	$\zeta = 0$	-1505.8881	224.286
No Durables Inflation	$\tau = 0$	-1395.221	2.952

Table 5: Likelihood comparison

at a time.[20] Then, we plot the impulse responses of the baseline and a few restricted models to a contractionary monetary policy shock.

Table 5 reports the log-marginal likelihoods of the models, in conjunction with the statistic by Kass and Raftery (1995, KR henceforth).[21] The KR statistic decisively favors the baseline model. Indeed, there is positive evidence in favor of this with respect to the model in which the central bank responds only to inflation in nondurables ($\tau = 0$). Furthermore, very strong evidence is found against a model with flexible prices in the durables sector ($\vartheta_d = 0$), a model with flexible wages ($\vartheta^W = 0$), a model without IAC in durable goods ($\phi = 0$), and a model without habit formation in consumption of nondurable goods ($\zeta = 0$). These results suggest that the frictions considered are important when the theoretical model is brought to the data.

In Figure 6 the black-solid line represents the same impulse responses of the baseline model as in Figure 5, while the blue-dashed line depicts the dynamic behavior of a model with flexible wages.[22] Thanks to price stickiness in durable goods, the responses are close to the baseline model and the comovement between durables and nondurables is attained. When prices of durables are assumed to be flexible and wages are sticky

[20] See Section F of the Appendix for the posterior estimates of the restricted models.

[21] The KR statistic is computed as twice the log of the Bayes Factor (BF), with the BF between the baseline models m_i and the restricted model m_j being

$$BF_{i/j} = \frac{L(Y|m_i)}{L(Y|m_j)} = \frac{exp(LL(Y|m_i))}{exp(LL(Y|m_j))}$$

where $L(Y|m_i)$ is the marginal data density of model i for the common dataset Y and LL stands for log-marginal likelihood. Values of the KR statistics above 10 can be considered "very strong" evidence in favor of model i relative to model j; between 6 and 10 represent "strong" evidence; between 2 and 6 "positive" evidence; while values below 2 are "not worth more than a bare mention".

[22] We calibrate the parameters with the point estimates of the baseline model and remove a friction at a time. In order to ease the graphical analysis, we do not plot the responses of the model in which the central bank responds only to inflation in nondurables since they overlap with the others. These are available upon request.

(red-dotted line), the comovement still survives. The only tangible difference lies in the response of the relative price, which is almost flat in the baseline case, whereas it decreases in the restricted scenario. Excluding habit formation in consumption of nondurable goods (red-dashed and dotted line) leads to a considerable larger fall in nondurables and output. In particular, we confirm the results of Katayama and Kim (2013) that including this friction is crucial to obtain hump-shaped responses of nondurables consumption and output that are reasonable in size. Similarly, IACs in durable goods are crucial to account for plausible magnitudes of the responses of durables and output. Indeed, the black-rounded lines show that in the absence of IACs, at the trough, durables fall by almost 15% whereas output falls by about 1%. Thus the maximum fall in durables is about 15 times larger than the maximum fall of output, an implausible result according to our VAR estimates. Finally, we also plot the responses of a model with flexible durables prices and flexible wages (blue-dashed line with a star). In line with the literature, a contractionary monetary policy shock triggers a decrease in output and inflation but the comovement puzzle arises since the response of durables is positive. In DSGE models calibrated such that prices of durables are flexible and prices of nondurables are sticky (red-dotted line), the relative price of durables experiences a substantial contraction. On the contrary, both the estimated VAR and DSGE models show that the response of the relative price is rather flat. When both durables prices and wages are flexible (starred-dashed line), not only the relative price falls to a larger extent, but this also comes at the cost of not generating the comovement between durables and nondurables.

5 Concluding remarks

Several papers engaged in building a two-sector New-Keynesian model able to generate the comovement between durable and nondurable goods following a monetary policy shock, as documented by the VAR literature. This paper contributes to this literature by focusing on the effects of a monetary policy innovation on the relative price of durables.

We first estimate a SVAR model in which the monetary policy shock is identified with three alternative identification methods. Results from the empirical model show that, robustly across identifications and subsamples, the response of the relative price of durables crucially depends on the definition of the durables sector. A broad measure

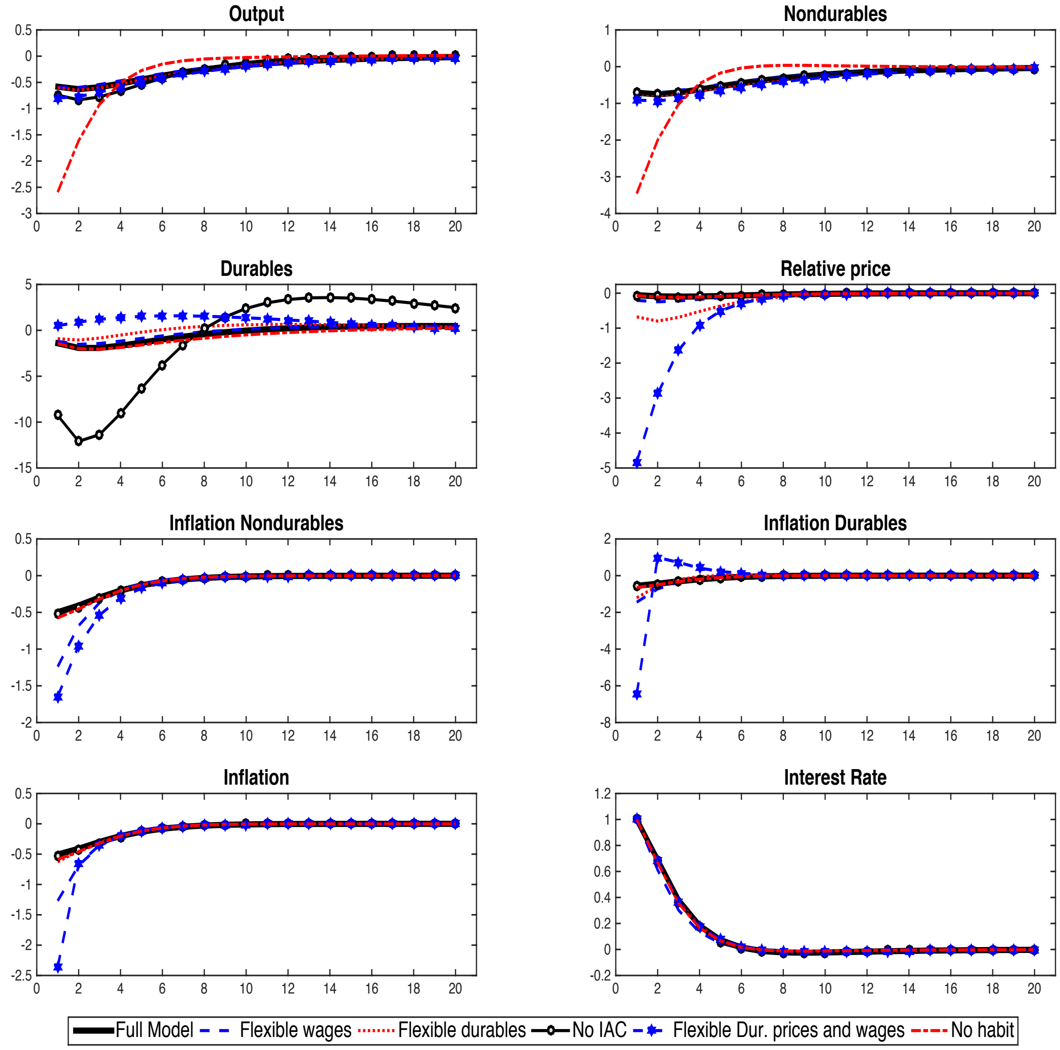


Figure 6: Impulse responses to a 1% increase in the nominal interest rate across restricted models

of durables – including durable goods and residential investments (the most commonly used in the literature) – implies that the relative price is either flat or mildly positive in response to a monetary policy contraction. This is at odds with the degree of price stickiness in the two sectors being substantially different, an assumption usually made within two-sector New-Keynesian models, where durables prices are fully flexible whereas nondurables prices are sticky. Conversely, employing a narrow measure of durable goods including only new houses generates a fall of the relative price, this being in accordance with flexible new house prices.

To rationalize the SVAR results we bring a two-sector DSGE model to the data.

The Bayesian estimation of the model confirms the results of the empirical model. In particular, the credible set of responses of the relative price of durables to a monetary policy shock includes zero. This is due to not dramatically dissimilar estimated degrees of price stickiness in the two sectors. In fact, our estimates, based on macroeconomic observables, are close to the latest microeconometric evidence that prices in the durables sector are indeed less sticky than prices in the nondurables sector, but not to a vast extent. In fact, imposing completely flexible durables prices significantly worsens the model's marginal likelihood.

The importance of these findings is twofold. First, the estimation of structural models, either VAR or DSGE, robustly suggests that when building a two-sector New-Keynesian model it is desirable to assume that prices of durable goods are somewhat sticky, unless the model's aim is to specifically address issues related to the housing sector. As a consequence, the comovement puzzle becomes less of an issue: calibrating the sectoral price stickiness according to the data ensures that durables and nondurables move in the same direction following a monetary policy shock. As we show, several other ingredients – especially nominal wage stickiness and durables investment adjustment costs – are empirically important and help the model behave in line with the data. Second, an important policy implication arise from these results, i.e. that the central bank does not create big allocative distortions between the two sectors since the relative price is barely affected by monetary policy. This represents a desirable feature of the monetary policy conduct.

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Appendix

A Data: sources and transformations

Series	Definition	Source	Mnemonic
DUR^N	Nominal Durable Goods	BEA	Table 2.3.5 Line 3
RI^N	Nominal Residential Investment	BEA	Table 1.1.5 Line 13
ND^N	Nominal Nondurable Goods	BEA	Table 2.3.5 Line 8
S^N	Nominal Services	BEA	Table 2.3.5 Line 13
P_{DUR}	Price Deflator, Durable Goods	BEA	Table 1.1.9 Line 4
P_{RI}	Price Deflator, Residential Investment	BEA	Table 1.1.9 Line 13
P_{ND}	Price Deflator, Nondurable Goods	BEA	Table 1.1.9 Line 5
P_S	Price Deflator, Services	BEA	Table 1.1.9 Line 6
Y^N	Nominal GDP	BEA	Table 1.1.5 Line 1
P_Y	Price Deflator, GDP	BEA	Table 1.1.9 Line 1
FFR	Effective Federal Funds Rate	FRED	FEDFUNDS
N	Nonfarm Business Sector: Average Weekly Hours	FRED	PRS85006023
W	Nonfarm Business Sector: Compensation Per Hour	FRED	COMPNFB
POP	Civilian Non-institutional Population, over 16	FRED	CNP16OV
CE	Civilian Employment, 16 over	FRED	CE16OV
NH^N	Nominal New-single family houses	BEA	Table 5.3.5 Line 23
P_{NH}	Price Deflator, New-single family houses	BEA	Table 5.3.4 Line 23
MH^N	Nominal Multifamily houses	BEA	Table 5.3.5 Line 24
P_{MH}	Price Deflator, Multifamily houses	BEA	Table 5.3.4 Line 23

Table 6: Data Sources

A.1 Durables and Residential Investments

1. Sum nominal series: $DUR^N + RI^N = DR^N$

2. Calculate sectoral weights of deflators: $\omega^D = \frac{DUR^N}{DR^N}$; $\omega^{RI} = \frac{RI^N}{DR^N}$

3. Calculate Deflator: $P_D = \omega^D P_{DUR} + \omega^{RI} P_{RI}$
4. Calculate Real Durable Consumption: $D = \frac{DUR^N + RI^N}{P_D}$

A.2 Nondurables and Services

1. Sum nominal series: $ND^N + S^N = NS^N$
2. Calculate sectoral weights of deflators: $\omega^{ND} = \frac{ND^N}{NS^N}$; $\omega^S = \frac{S^N}{NS^N}$
3. Calculate Deflator: $P_C = \omega^{ND} P_{ND} + \omega^S P_S$
4. Calculate Real Nondurable Consumption: $C = \frac{ND^N + S^N}{P_C}$

A.3 Only broad measure of houses

1. Sum nominal series: $NH^N + MH^N = DR^N$
2. Sectoral weights of deflators: $\omega^{NH} = \frac{NH^N}{DR^N}$; $\omega^{MH} = \frac{MH^N}{DR^N}$
3. Calculate Deflator: $P_D = \omega^{NH} P_{NH} + \omega^{MH} P_{MH}$
4. Calculate Real Durable Consumption: $D = \frac{NH^N + MH^N}{P_D}$

A.4 Durable goods and New-single family houses

1. Sum nominal series: $DUR^N + NH^N = DR^N$
2. Calculate sectoral weights of deflators: $\omega^D = \frac{DUR^N}{DR^N}$; $\omega^{NH} = \frac{NH^N}{DR^N}$
3. Calculate Deflator: $P_D = \omega^D P_{DUR} + \omega^{NH} P_{NH}$
4. Calculate Real Durable Consumption: $D = \frac{DUR^N + NH^N}{P_D}$

A.5 Durable goods and broad measure of houses

1. Sum nominal series: $DUR^N + NH^N + MH^N = DR^N$
2. Sectoral weights of deflators: $\omega^D = \frac{DUR^N}{DR^N}$; $\omega^{NH} = \frac{NH^N}{DR^N}$; $\omega^{MH} = \frac{MH^N}{DR^N}$
3. Calculate Deflator: $P_D = \omega^D P_{DUR} + \omega^{NH} P_{NH} + \omega^{MH} P_{MH}$
4. Calculate Real Durable Consumption: $D = \frac{DUR^N + NH^N + MH^N}{P_D}$

A.6 Data transformation for Bayesian estimation

Variable	Description	Construction
POP_{index}	Population index	$\frac{POP}{POP_{2009:1}}$
CE_{index}	Employment index	$\frac{CE}{CE_{2009:1}}$
Y^o	Real per capita GDP	$\ln\left(\frac{\frac{Y^N}{P_Y}}{POP_{index}}\right)100$
D^o	Real per capita consumption: durables	$\ln\left(\frac{D}{POP_{index}}\right)100$
C^o	Real per capita consumption: nondurables	$\ln\left(\frac{C}{POP_{index}}\right)100$
W^o	Real wage	$\ln\left(\frac{W}{P_Y}\right)100$
N^o	Hours worked per capita	$\ln\left(\frac{H \times CE_{index}}{POP_{index}}\right)100$
Π^o_C	Inflation: nondurables sector	$\Delta\left(\ln P_C\right)100$
Π^o_D	Inflation: durables sector	$\Delta\left(\ln P_D\right)100$
R^o	Quarterly Federal Funds Rate	$\frac{FFR}{4}$

Table 7: Data transformation - Observables

B Robustness checks for the VAR model

This section shows some robustness checks performed in order to validate further our results in the VAR analysis. In Section B.1 we estimate the SVAR model with alternative definitions of durables sector over the sample 1969Q2-2007Q4. Figure 7 shows the estimated responses when the durables sector is defined as the sum of durable goods and new single family houses, as calculated in Section A.4. Figure 8 shows the estimated responses when the durables sector is defined as the sum of durable goods and a broad measure of houses, as calculated in Section A.5. Figure 9 shows the estimated responses when the durables sector is defined as only new single family houses. Each figure plots the estimated impulse responses of the alternative models against the baseline VAR. We confirm the results of the main analysis. When the durables sector includes both durable goods and a measure of houses, the relative price never falls in response to a monetary policy tightening. On the contrary, when durables are defined as including only new houses, regardless of the measure used, the relative price falls.

In Section B.2 we perform a subsample analysis of both the baseline and the housing VARs. Figures 10 to 16 plot the impulse responses of the two models for seven subsamples. The subsample are constructed as rolling windows of 24 years, each subsample starting after 2.5 years after the previous one. Again, the results of the full sample analysis are widely robust across all the subsample.

Finally, in Section B.3 we assess whether imposing the sign restrictions for more than one period has a significant effect on our results. Figures 17 and 18 plot the responses of the baseline VAR and the housing VAR respectively, when we impose the restrictions for 2 and 4 periods. In both cases the responses are virtually unaffected by these alternative identification assumptions.

B.1 Alternative definitions of durables

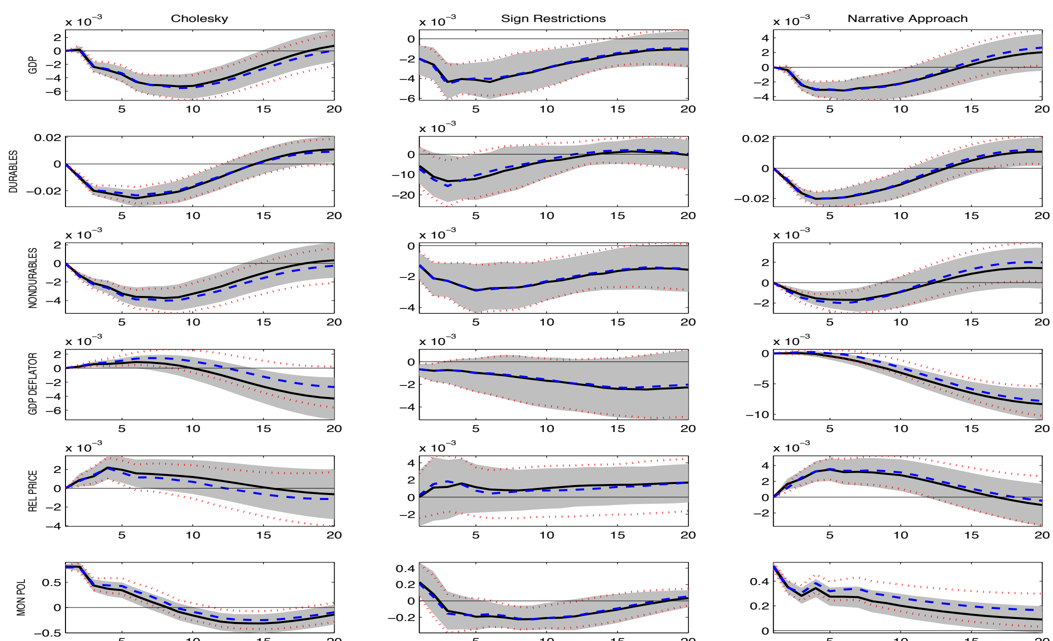

Figure 7: VAR impulse responses. Sample: 1969Q2-2007Q4 (bold lines = baseline model; dashed lines = durables goods and new single family houses; shaded areas and dotted lines = one-standard-deviation confidence bands)

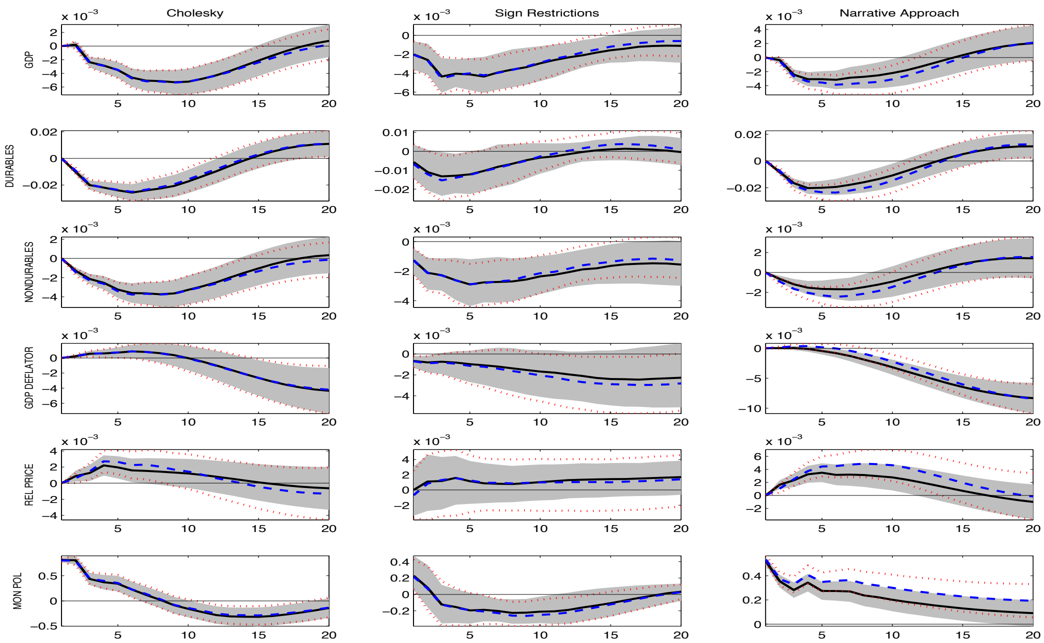

Figure 8: VAR impulse responses. Sample: 1969Q2-2007Q4 (bold lines = baseline model; dashed lines = durables goods and broad measure of houses; shaded areas and dotted lines = one-standard-deviation confidence bands)

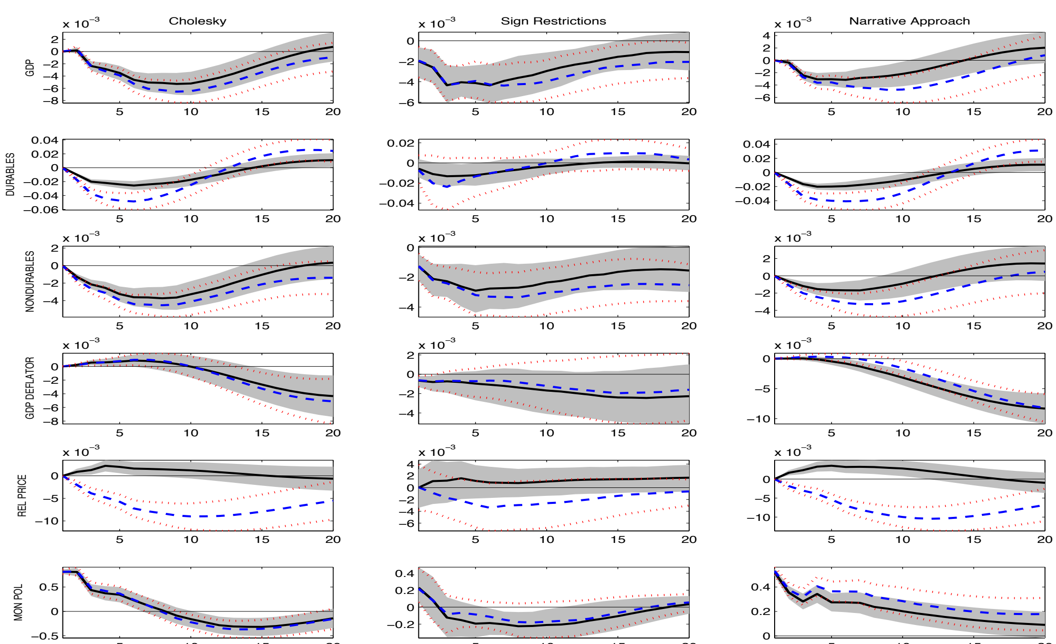

Figure 9: VAR impulse responses. Sample: 1969Q2-2007Q4 (bold lines = baseline model; dashed lines refer to = new single family houses; shaded areas and dotted lines represent one-standard-deviation confidence bands)

B.2 Subsample analysis

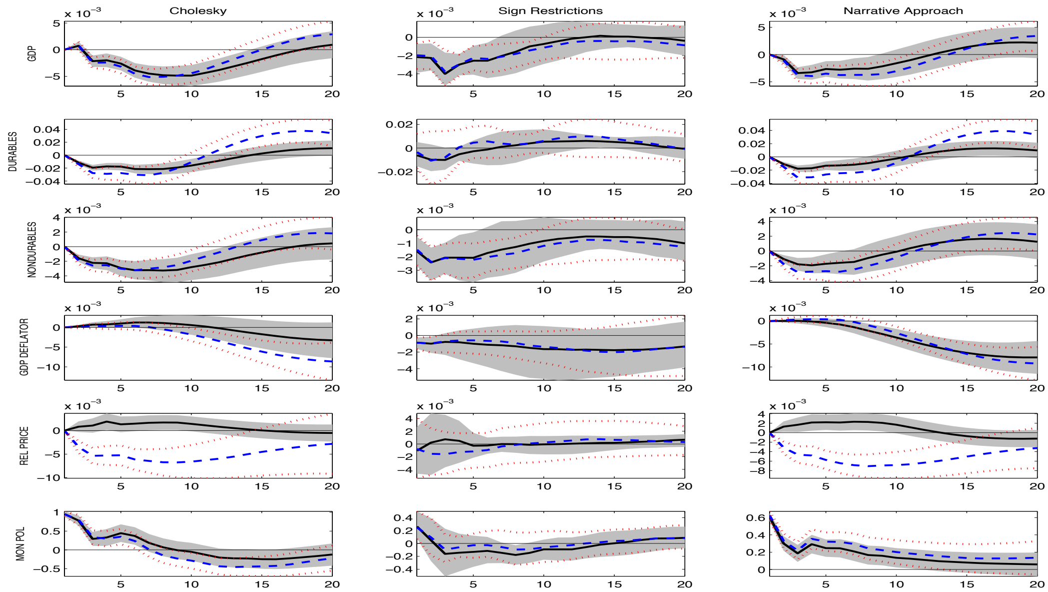

Figure 10: VAR impulse responses. Sample: 1969Q2-1993Q1 (bold lines = all durable goods; dashed lines = only houses; shaded areas and dotted lines = one-standard-deviation confidence bands)

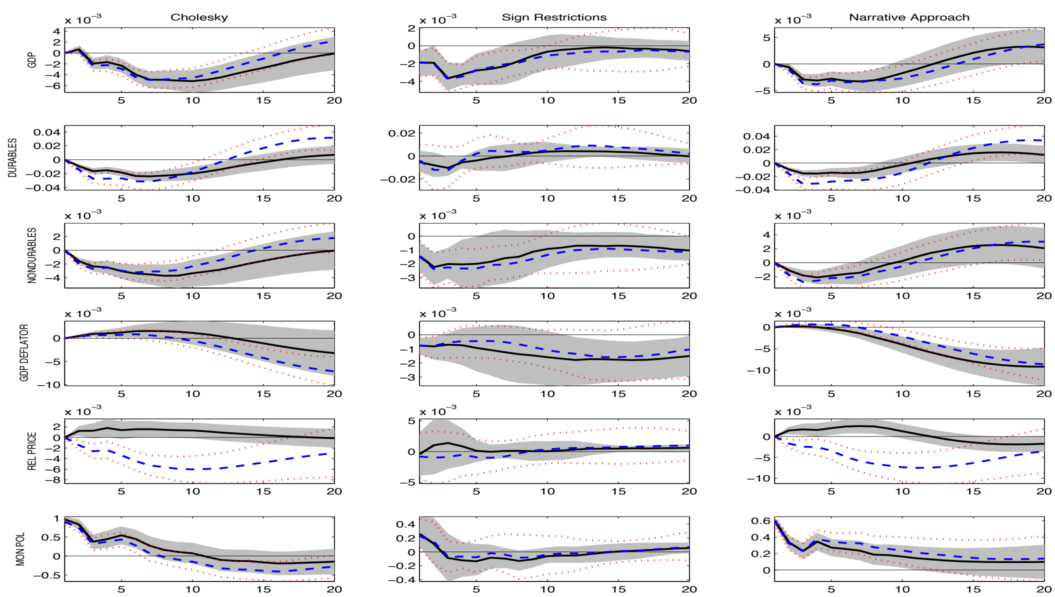

Figure 11: VAR impulse responses. Sample: 1971Q4-1995Q3 (bold lines = all durable goods; dashed lines = only houses; shaded areas and dotted lines = one-standard-deviation confidence bands)

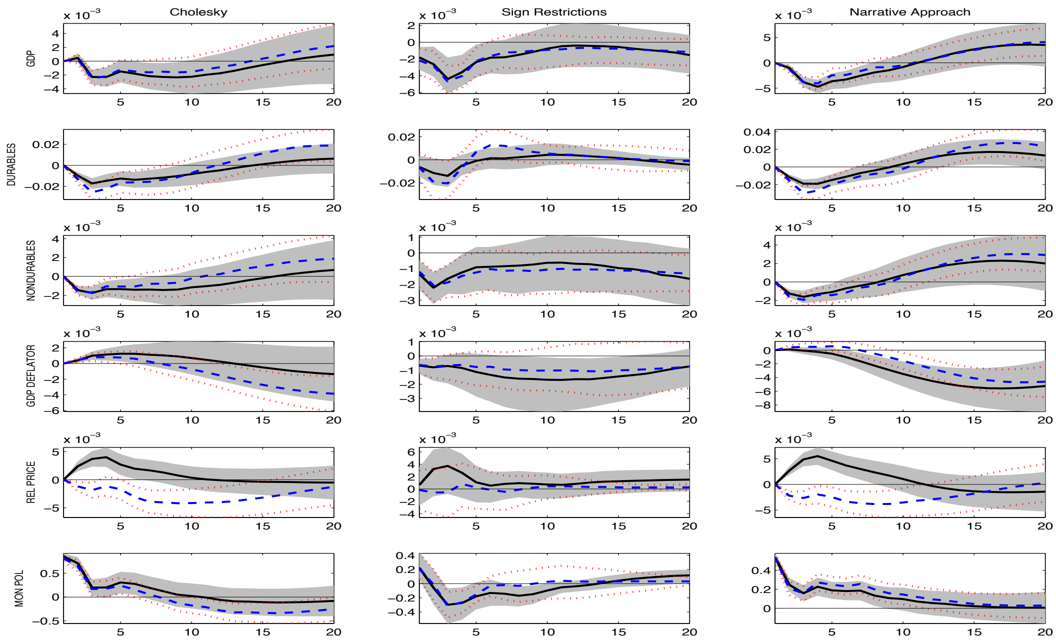

Figure 12: VAR impulse responses. Sample: 1974Q2-1998Q1 (bold lines = all durable goods; dashed lines = only houses; shaded areas and dotted lines = one-standard-deviation confidence bands)

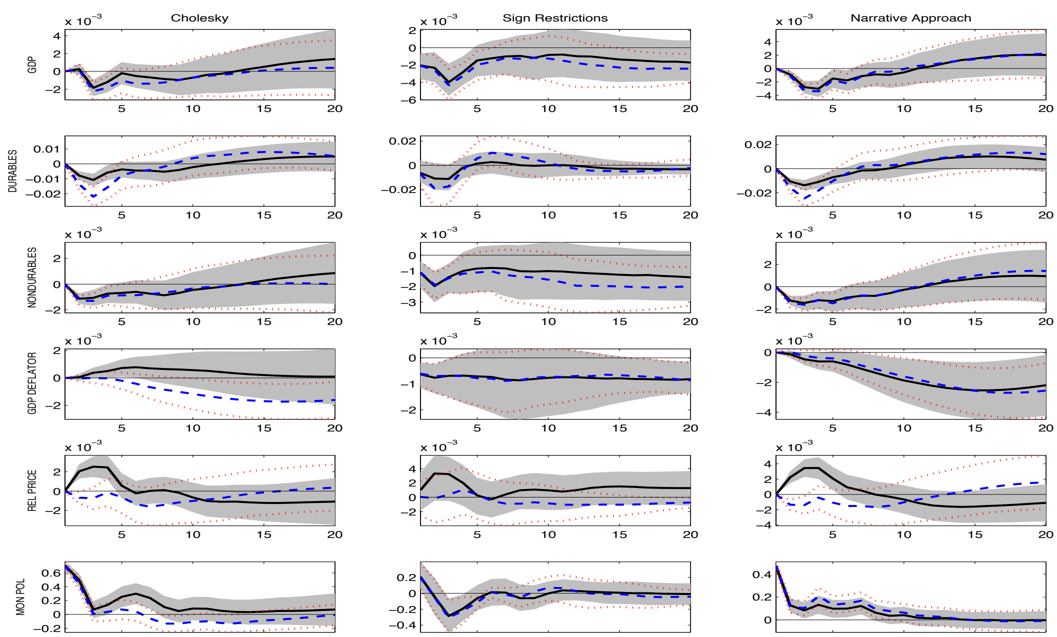

Figure 13: VAR impulse responses. Sample: 1976Q4-2000Q3 (bold lines = all durable goods; dashed lines = only houses; shaded areas and dotted lines = one-standard-deviation confidence bands)

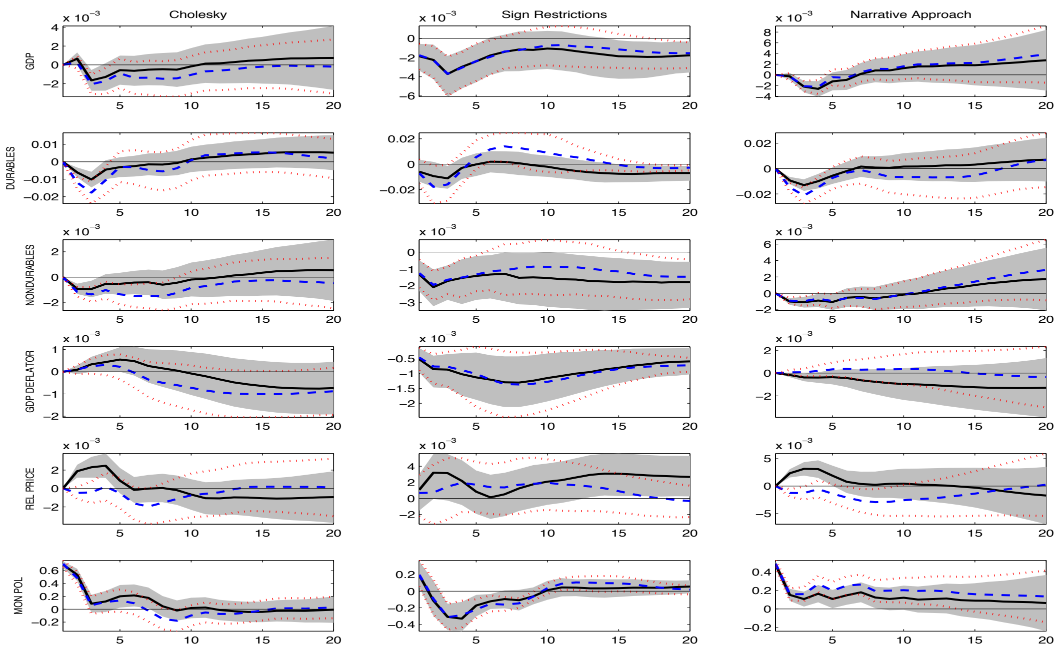

Figure 14: VAR impulse responses. Sample: 1979Q2-2003Q1 (bold lines = all durable goods; dashed lines = only houses; shaded areas and dotted lines = one-standard-deviation confidence bands)

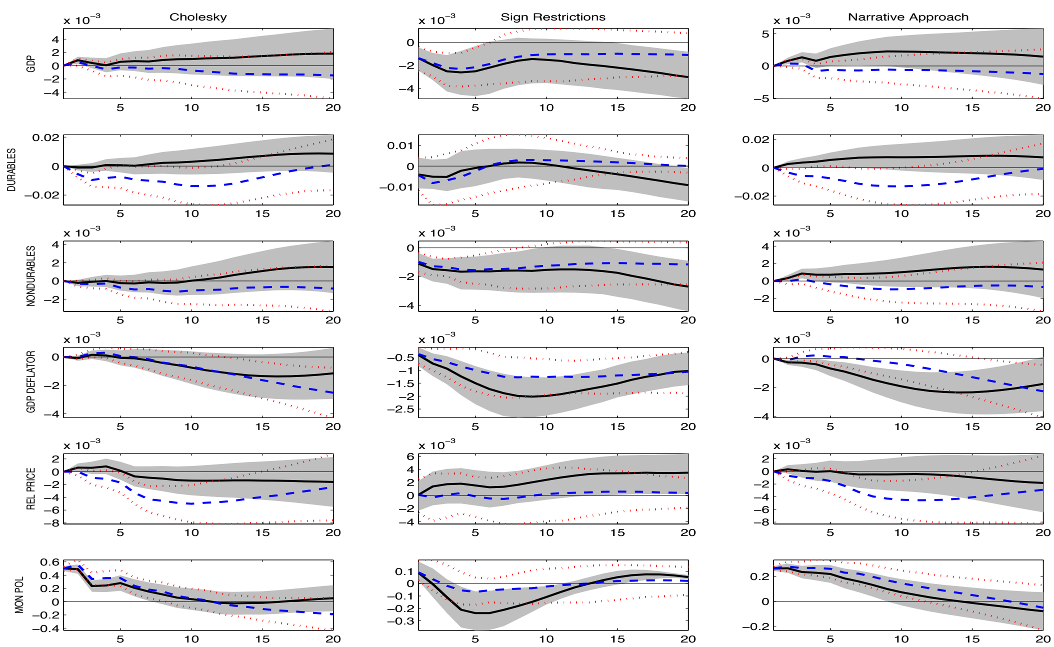

Figure 15: VAR impulse responses. Sample: 1981Q4-2005Q3 (bold lines = all durable goods; dashed lines = only houses; shaded areas and dotted lines = one-standard-deviation confidence bands)

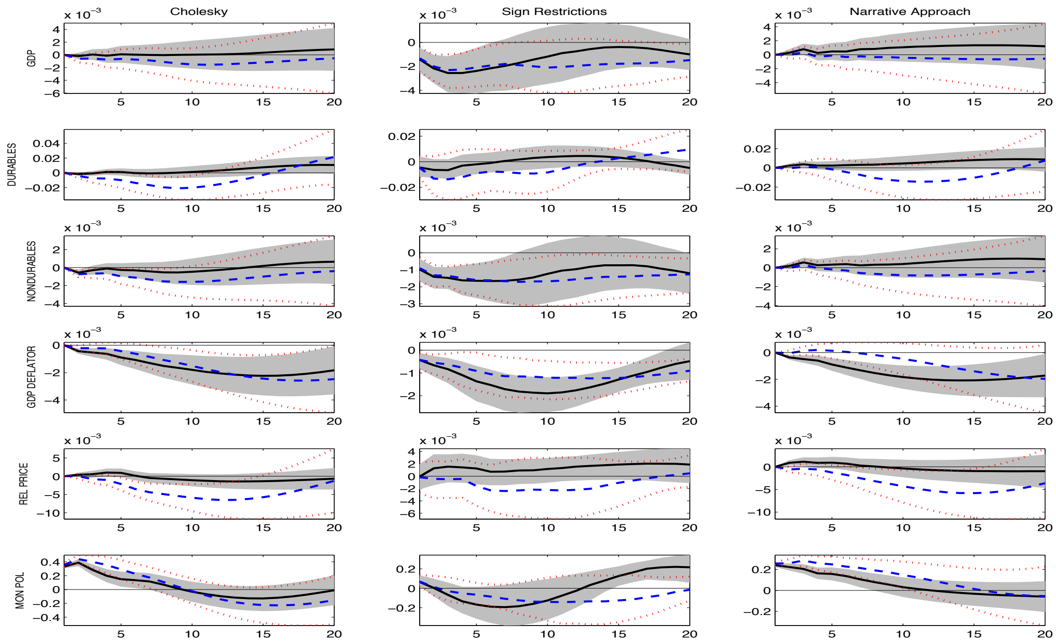

Figure 16: VAR impulse responses. Sample: 1984Q2-2007Q4 (bold lines = all durable goods; dashed lines = only houses; shaded areas and dotted lines = one-standard-deviation confidence bands)

B.3 Sign restrictions

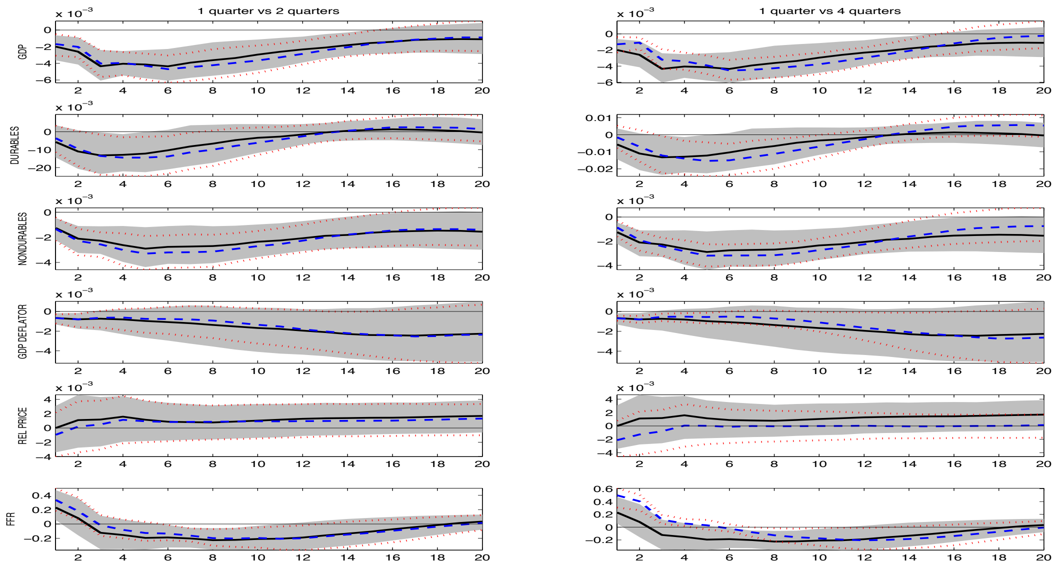

Figure 17: Sign restrictions imposed for 2 and 4 quartes against 1 quarter, baseline model. Sample: 1969Q2-2007Q4 (bold lines = one quarter; dashed lines = more quarters; shaded areas and dotted lines = one-standard-deviation confidence bands)

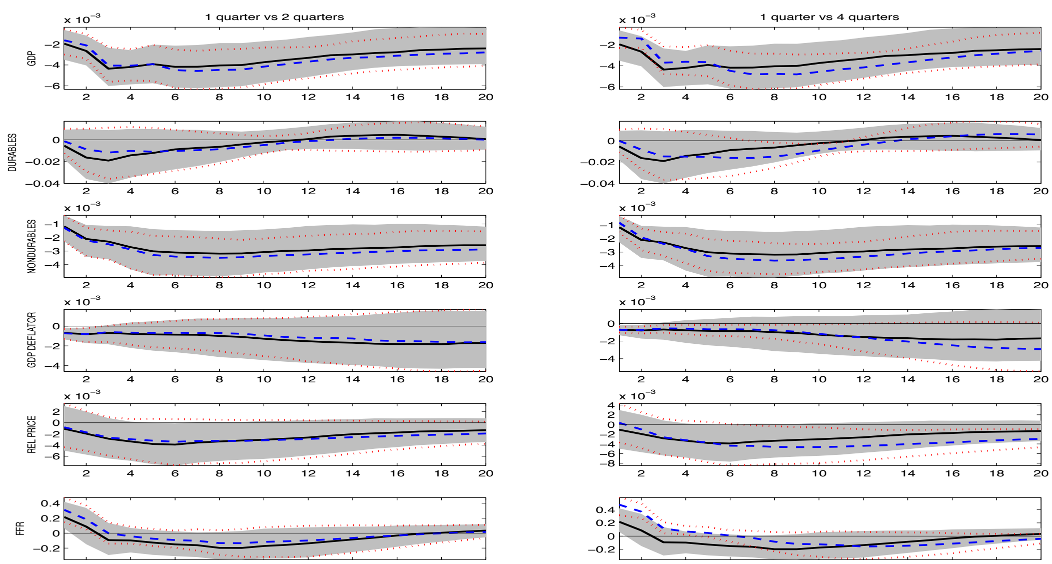

Figure 18: Sign restrictions imposed for 2 and 4 quartes against 1 quarter, model with broad measure of houses as durables. Sample: 1969Q2-2007Q4 (bold lines = one quarter; dashed lines = more quarters; shaded areas and dotted lines = one-standard-deviation confidence bands)

C DSGE model

C.1 Symmetric equilibrium

$$X_t = Z_t^{1-\alpha} D_t^{\alpha} \tag{32}$$

$$Z_t = C_t - \zeta S_{t-1} \tag{33}$$

$$S_t = \rho_c S_{t-1} + (1-\rho_c) C_t \tag{34}$$

$$U(X_t, N_t) = log(X_t) - \nu \frac{N_t^{1+\varphi}}{1+\varphi} \tag{35}$$

$$U_{Z,t} = \frac{(1-\alpha)}{Z_t} \tag{36}$$

$$U_{D,t} = \frac{\alpha}{D_t} \tag{37}$$

$$U_{N,t} = -\nu N_t^{\varphi} \tag{38}$$

$$\Lambda_{t,t+1} \equiv \beta \frac{U_{Z,t+1}}{U_{Z,t}} \frac{e_{t+1}^B}{e_t^B} \tag{39}$$

$$\begin{aligned} \left[1 - e_t^W \eta\right] + \frac{e_t^W \eta}{\tilde{\mu}_t} &= \vartheta^W \left(\Pi_t^W - \widetilde{\Pi}_{ss}\right) \Pi_t^W + \\ &+ E_t \left[\Lambda_{t,t+1} \vartheta^W \left(\Pi_{t+1}^W - \widetilde{\Pi}_{ss}\right) \Pi_{t+1}^W \frac{w_{t+1} N_{t+1}}{w_t N_t}\right] \end{aligned} \tag{40}$$

$$\tilde{\mu}_t = -\frac{U_{Z,t}}{U_{N,t}} w_t \tag{41}$$

$$Q_t \psi_t = \frac{U_{D,t}}{U_{Z,t}} + (1-\delta) E_t \left[\Lambda_{t,t+1} Q_{t+1} \psi_{t+1}\right] \tag{42}$$

$$\begin{aligned} 1 &= \psi_t e_t^I \left[1 - S\left(\frac{I_t^D}{I_{t-1}^D}\right) - S'\left(\frac{I_t^D}{I_{t-1}^D}\right) \frac{I_t^D}{I_{t-1}^D}\right] + \\ &+ E_t \left\{\Lambda_{t,t+1} \psi_{t+1} \frac{Q_{t+1}}{Q_t} e_{t+1}^I \left[S'\left(\frac{I_{t+1}^D}{I_t^D}\right) \left(\frac{I_{t+1}^D}{I_t^D}\right)^2\right]\right\} \end{aligned} \tag{43}$$

$$S\left(\frac{I_t^D}{I_{t-1}^D}\right) = \frac{\phi}{2} \left(\frac{I_t^D}{I_{t-1}^D} - 1\right)^2 \tag{44}$$

$$S'\left(\frac{I_t^D}{I_{t-1}^D}\right) = \phi \left(\frac{I_t^D}{I_{t-1}^D} - 1\right) \tag{45}$$

$$1 = E_t \left[\Lambda_{t,t+1} \frac{R_{t+1}}{\Pi_{t+1}^C}\right] \tag{46}$$

$$
\begin{aligned}
\Pi_t^D &= \Pi_t^C \frac{Q_t}{Q_{t-1}} &(47)\\
\Pi_t^W &= \frac{w_t}{w_{t-1}} \widetilde{\Pi}_t &(48)\\
Y_t^C &= e_t^A N_t^C &(49)\\
Y_t^D &= e_t^A N_t^D &(50)\\
\left(1 - e_t^C \epsilon_c\right) + e_t^C \epsilon_c M C_t^C &= \vartheta_c \left(\Pi_t^C - 1\right) \Pi_t^C - \\
&\quad -\vartheta_c E_t \left[\Lambda_{t,t+1} \frac{Y_{t+1}^C}{Y_t^C} \left(\Pi_{t+1}^C - 1\right) \Pi_{t+1}^C\right] &(51)\\
MC_t^C &= \frac{w_t}{e_t^A} &(52)\\
\left(1 - e_t^D \epsilon_d\right) + e_t^D \epsilon_d M C_t^D &= \vartheta_d \left(\Pi_t^D - 1\right) \Pi_t^D - \\
&\quad -\vartheta_d E_t \left[\Lambda_{t,t+1} \frac{Q_{t+1}}{Q_t} \frac{Y_{t+1}^D}{Y_t^D} \left(\Pi_{t+1}^D - 1\right) \Pi_{t+1}^D\right] &(53)\\
MC_t^D &= \frac{w_t}{e_t^A Q_t} &(54)\\
\widetilde{\Pi}_t &= \left(\Pi_t^C\right)^{1-\tau} \left(\Pi_t^D\right)^{\tau} &(55)\\
\log\left(\frac{R_t}{\bar{R}}\right) &= \left[\rho_\pi \log\left(\frac{\Pi_t}{\bar{\Pi}}\right) + \rho_y \log\left(\frac{Y_t}{\bar{Y}}\right)\right] + e_t^M &(56)\\
Y_t^C &= C_t + e_t^G + \frac{\vartheta_c}{2}\left(\Pi_t^C - 1\right)^2 Y_t^C &(57)\\
Y_t^D &= \left[D_t - (1-\delta) D_{t-1}\right] + \frac{\vartheta_d}{2}\left(\Pi_t^D - 1\right)^2 Y_t^D &(58)\\
N_t &= N_t^C + N_t^D &(59)\\
Y_t &= Y_t^C + Q_t Y_t^D + \frac{\vartheta^W}{2}\left(\Pi_t^W - \widetilde{\Pi}_{ss}\right)^2 w_t N_t &(60)
\end{aligned}
$$

C.2 Steady state

In the deterministic steady state all expectation operators are removed and for each variable it holds that $x_t = x_{t+1} = x$. Moreover, the stochastic shocks are absent. U_Z and Y solve equations (36) and (60) respectively whereas all other variables can be found recursively from the following relationships:

$$\Lambda = \beta \tag{61}$$
$$R = \frac{1}{\beta} \tag{62}$$
$$MC_t^C = \frac{\epsilon_c - 1}{\epsilon_c} \tag{63}$$
$$w = MC^C e^A \tag{64}$$
$$MC_t^D = \frac{\epsilon_d - 1}{\epsilon_d} \tag{65}$$
$$Q = \frac{w}{MC^D e^A} \tag{66}$$
$$S = 0 \tag{67}$$
$$S^{'} = 0 \tag{68}$$
$$\psi = 1 \tag{69}$$
$$\tilde{\mu} = \frac{\eta}{\eta - 1} \tag{70}$$
$$U_D = U_z Q \psi \left[1 - (1 - \delta)\beta\right] \tag{71}$$
$$D = \frac{\alpha}{U_D} \tag{72}$$
$$U_{N,t} = -\frac{U_{Z,t}}{\tilde{\mu}_t} w_t \tag{73}$$
$$N = -\left(\frac{U_N}{\nu}\right)^{\frac{1}{\varphi}} \tag{74}$$
$$Y^D = \delta D \tag{75}$$
$$N^D = Y^D \tag{76}$$
$$N^C = N - N^D \tag{77}$$
$$e^G = g_y Y \tag{78}$$
$$Y^C = N^C \tag{79}$$
$$C = Y^C - e^G \tag{80}$$
$$S = C \tag{81}$$
$$Z = (1 - \zeta) S \tag{82}$$
$$X = Z^{1-\alpha} D^{\alpha} \tag{83}$$

D Robust impulse responses

In our model, for each simulation, all the structural parameters are assumed to have a uniform distribution over a specific range. Each interval is set around a value consistent with a quarterly calibration of the U.S. economy and its length is determined both to include reasonable values and to avoid indeterminacy. As a result, some ranges result to be narrower whereas others result to be broader, but overall our choices should be uncontroversial. Table 8 summarizes the supports of the structural parameters. Consistently with the calibration of the two-sector NK models so far used in the literature, we define the same range for the parameters of price stickiness but we impose the restriction $\vartheta_c \geq \vartheta_d$ so that prices of nondurables are stickier or at least as sticky as prices of durables. Note that this condition does not prevent us from obtaining a fully-flexible price model whenever a random draw implies that $\vartheta_c = \vartheta_d = 0$.

The parameter ν is set in order to have hours worked in steady state between 0.2 and 0.5. Finally, we perform our main simulations by randomly drawing the values of the Rotemberg parameter of wage stickiness from the support $[0, 120]$ hence including cases in which wages are completely flexible. However, in order to highlight the crucial role played by wage stickiness in solving the comovement puzzle, we perform another set of simulations by calibrating $\vartheta^W = 0$ while keeping the same ranges for the remaining parameters.

Furthermore, it is important to briefly discuss the number of random draws used to construct the robust impulse responses. Indeed, two issues are likely to arise when parameter values are randomly drawn from their support. The first is indeterminacy whenever the Blanchard-Kahn conditions are not satisfied. The second consists of violating the condition that we impose on the degree of price stickiness in the two sectors. In order to make our analysis robust, our aim is to generate about 10000 sets of impulse response functions. That is why we performed 22000 draws, of which 10273 were accepted. 97% of the discarded draws did not satisfy the restriction on price stickiness and only 3% of them did not satisfy the Blanchard-Kahn conditions.

We next proceed to discuss the results of the simulations of the model with fully-flexible wages (red dotted lines of Figure 1). As expected, nominal wage rigidities play a crucial role in solving the comovement puzzle (see Carlstrom and Fuerst 2006, 2010). Indeed, when wages are kept flexible, there exist combinations of parameter values such that consumption of durables increases in response to a monetary policy tightening. Furthermore, also in this second set of simulations there are cases in which

Parameter		Range
Households' discount factor	β	$[0.985, 0.995]$
Durables depreciation rate	δ	$[0.0025, 0.025]$
Durables share of total expenditure	α	$[0.05, 0.35]$
Elasticity of substitution in nondurables	ϵ_c	$[4, 11]$
Elasticity of substitution in durables	ϵ_d	$[4, 11]$
Elasticity of substitution in labor	η	$[4, 25]$
Inverse Frisch elasticity	φ	$[0.3, 3]$
Disutility of labour	ν	$\bar{N} \in [0.2, 0.5]$
Habits degree	ζ	$[0, 0.9]$
Habits persistence	ρ_c	$[0, 0.9]$
Price stickiness in nondurables	ϑ_c	$[0, 58]^*$
Price stickiness in durables	ϑ_d	$[0, 58]^*$
Nominal wage rigidities	ϑ^W	$[0, 120]^{**}$
Investment adjustment cost	ϕ	$[0, 5]$
Share of durables inflation in inflation aggregator	τ	$[0, 1]$
Steady state government share of output	g_y	$[0.1, 0.3]$
Monetary policy to inflation	ρ_π	$[1.05, 5]$
Monetary policy to output gap	ρ_y	$[0, 0.5]$
Interest rate smoothing	ρ_R	$[0, 0.9]$
Persistence of monetary policy shock	ρ_{e^R}	$[0, 0.95]$
Persistence of business cycle shock	ρ_{e^A}	$[0, 0.95]$
Persistence of preference shock	ρ_{e^B}	$[0, 0.95]$
Persistence of durables investment shock	ρ_{e^I}	$[0, 0.95]$
Persistence of wage markup shock	ρ_{e^W}	$[0, 0.95]$
Persistence of nondurables price markup shock	ρ_{e^C}	$[0, 0.95]$
Persistence of durables price markup shock	ρ_{e^D}	$[0, 0.95]$
Persistence of government consumption shock	ρ_{e^G}	$[0, 0.95]$

Note: * denotes that parameters are subject to the restriction $\vartheta_c \geq \vartheta_d$. ** denotes that in a second set of simulations we impose $\vartheta^W = 0$.

Table 8: Parameter ranges

the comovement between durables and nondurables is attained due to specific values of the parameters of price stickiness (see Sterk, 2010). However, the aim of this second set of simulations is to show that when wages are assumed to be flexible there exist fewer combinations of parameter values that generate a comovement between consumption in the two sectors.

E Technical details on Bayesian estimation

In order to estimate the DSGE model, we take a first-order log-linear approximation around the non-stochastic steady state. We thus obtain a linear rational expectations system, the solution of which takes the following state-space representation:

$$x_t = A(\theta)\, x_{t-1} + B(\theta)\, v_t, \tag{84}$$

$$X_t = C(\theta)\, x_t + u_t, \tag{85}$$

where x_t is the vector of the variables of the model, v_t is a vector of innovations and θ is a vector of parameters. It follows that, given a set of parameters θ, equation (84) describes the state of model at any point in time. Equation (85) is a measurement equation linking the observables X_t to the variables of the model, where u_t is a vector of measurement errors. Finally, the matrices A, B and C are functions of the parameters of the model. The aim of the bayesian approach is to perform inference from the posterior distribution of the parameters:

$$\pi(\theta|y) = \frac{L(y|\theta)\, \pi(\theta)}{\int L(y|\theta)\, \pi(\theta)\, d\theta} \propto L(y|\theta)\, \pi(\theta), \tag{86}$$

which is obtained by combining the likelihood $L(y|\theta)$ and the prior information $\pi(\theta)$ by applying the Bayes' theorem. Ideally, we would generate many draws of θ, calculate the likelihood and use posterior to make inference. However, the likelihood of a DSGE model is a highly complicated object. By assuming that the state-space representation is linear and that the shocks are normally distributed, we employ the Kalman filter in order to characterize it.[23] Then, the approximated posterior density is explored using Monte-Carlo-Markov-Chain (McMc) methods. The idea is to specify a transition kernel, choose some initial value for the parameters of the model, draw new values a number of times and produce $\pi(\theta|y)$, which is the target distribution we want to sample from. The Markov chain that generates the posterior distribution is obtained by applying the Metropolis-Hastings (MH) algorithm, which evaluates whether the new proposed parameter values increase the posterior or not and we accept it according to a specified rule. In such a way, we sample from the higher region of the posterior, but we explore as much as possible the parameter space in order to avoid getting

[23] See Fernández-Villaverde, 2009 for a detailed description of the methodology.

trapped in local maxima. The results reported in the paper are based on two parallel chains of the MH algorithm with 150,000 draws each where the first 25% of them are discarded as burn-in period. At the ith draw of the MH algorithm, a candidate parameter vector θ^* is drawn from a normal distribution $N \sim (\theta_{i-1}, \sigma_\kappa^2)$ with $\sigma_\kappa^2 = c\Omega_\theta$ where $\Omega_\theta = [-L''(\theta|y)]^{-1}$ is the inverse of the Hessian at the posterior mode and c is a scaling factor. The acceptance ratio is defined as

$$r = \frac{\pi(\theta^*|y)}{\pi(\theta_{i-1}|y)}, \qquad (87)$$

where we accept the candidate draw θ^* with probability $min(r, 1)$. The scaling factor c is set such that the acceptance ratio is 0.35 hence the fraction of accepted draws is 35%. This ensures that the algorithm visits the tails of the parameter space but it is more likely that a draw from the region of high probability is accepted.

F Posterior estimates of the restricted models

Parameters	Flexible wages	Flexible durable prices	No IAC	No Habit	No durables inflation
Structural					
φ	0.57216 [0.4310;0.7022]	0.6487 [0.4970;0.8028]	0.7149 [0.5189;0.9071]	0.6847 [0.5414;0.8273]	0.6515 [0.4982;0.8024]
ζ	0.6767 [0.6269;0.7279]	0.8003 [0.7663;0.8344]	0.2959 [0.2168;0.3778]	n.a.	0.7964 [0.7638;0.8300]
ρ_c	0.5131 [0.4144;0.6099]	0.4034 [0.3067;0.5014]	0.5644 [0.4093;0.7123]	n.a.	0.3963 [0.2989;0.4902]
ϑ_c	14.885 [9.646;20.187]	33.566 [23.463;42.922]	48.069 [30.966;71.039]	32.529 [22.495,41.796]	32.368 [22.992;41.356]
ϑ_d	21.257 [13.487;28.724]	n.a.	47.2965 [30.733;63.492]	23.608 [15.334;31.831]	26.175 [16.860;35.033]
ϑ^W	n.a.	97.736 [81.193;113.11]	111.83 [89.613;136.04]	90.863 [75.058;105.65]	98.484 [82.336;113.87]
ϕ	3.0878 [2.4483;3.7183]	3.5961 [2.9488;4.2121]	n.a.	2.5853 [1.9402;3.2169]	3.6860 [3.0644;4.3131]
τ	0.1352 [0.0597;0.2105]	0.1487 [0.0596;0.2294]	0.1096 [0.0518;0.1624]	0.2184 [0.1283;0.3145]	n.a.
ρ_π	1.6379 [1.4241;1.8467]	1.5479 [1.3586;1.7487]	2.1692 [1.8180;2.5647]	1.2017 [1.0899;1.3120]	1.5535 [1.3542;1.7562]
ρ_y	0.0193[0.0056;0.0328]	0.0230 [0.0066;0.0384]	0.7347 [0.6504;0.7925]	0.0094 [0.0019;0.0166]	0.0199 [0.0054;0.0340]
ρ_r	0.5985 [0.5315;0.6665]	0.7251 [0.6805;0.7709]	0.2522 [0.1587;0.3438]	0.6076 [0.5552;0.6618]	0.7278 [0.6852;0.7721]
Averages					
γ	0.3602 [0.3273;0.3945]	0.3912 [0.3659;0.4167]	0.4107[0.3947;0.4275]	0.3798 [0.3471;0.4126]	0.3960 [0.3750;0.4181]
$\bar{\pi}_C$	1.0649 [0.9748;1.1511]	1.0454 [0.9527;1.1403]	1.0505 [0.9401;1.1613]	1.0722 [0.9717;1.1668]	1.0534 [0.9600;1.1411]
$\bar{\pi}_D$	0.4904 [0.3904;0.5848]	0.5177 [0.4199;0.6170]	0.5256 [0.4132;0.6440]	0.4976 [0.3945;0.5960]	0.4974 [0.3983;0.5972]
$\bar{r}$	1.6553 [1.5311;1.7786]	1.6328 [1.5077;1.7596]	1.6468 [1.5320;1.7636]	1.6534 [1.5356;1.7701]	1.6419 [1.5130;1.7662]
Exog. processes					
ρ_{e^A}	0.9663 [0.9458 ;0.9890]	0.9528 [0.9205;0.9858]	0.8913 [0.8342;0.9562]	0.9759 [0.9583;0.9931]	0.9423 [0.9088;0.9782]
σ_{e^A}	0.0071 [0.0064;0.0077]	0.0070 [0.0063;0.0077]	0.0073 [0.0066;0.0080]	0.0071 [0.0064;0.0077]	0.0070 [0.0063;0.0077]
ρ_{e^R}	0.1379 [0.0452;0.2231]	0.1191 [0.0346;0.1991]	0.8642 [0.8053;0.9340]	0.0808 [0.0196;0.1388]	0.1187 [0.0344;0.1971]
σ_{e^R}	0.0036 [0.0031;0.0042]	0.0029 [0.0026;0.0032]	0.0087 [0.0073;0.0101]	0.0032 [0.0028;0.0036]	0.0029 [0.0026;0.0032]
ρ_{e^I}	0.5096 [0.3516;0.6681]	0.4327 [0.2643;0.5920]	0.4763 [0.3828;0.6572]	0.4265 [0.2678;0.5776]	0.4320 [0.2571;0.6020]
σ_{e^I}	0.0535 [0.0352;0.0711]	0.0725 [0.0505;0.0950]	0.0082 [0.0071;0.0093]	0.0523 [0.0342;0.0701]	0.0735 [0.0492;0.0956]
ρ_{e^B}	0.7820 [0.7339;0.8337]	0.6311 [0.5445;0.7198]	0.8915 [0.8200;0.9679]	0.8552 [0.8076;0.9052]	0.6449 [0.5629;0.7304]
σ_{e^B}	0.0110 [0.0921;0.0127]	0.0199 [0.0165;0.0230]	0.0147 [0.0103;0.0192]	0.0100 [0.0081;0.0117]	0.0198 [0.0166;0.0230]
ρ_{e^C}	0.9584 [0.9309;0.9887]	0.9410 [0.8998;0.9826]	0.9103 [0.8268;0.9896]	0.9357 [0.8955;0.9791]	0.9379 [0.8994;0.9772]
θ_C	0.2817 [0.1294;0.4285]	0.3986 [0.2312;0.5754]	0.3670 [0.1451;0.5825]	0.4085 [0.2228;0.6028]	0.4077 [0.2388;0.5764]
σ_{e^C}	0.0126 [0.0102;0.0151]	0.0194 [0.0148;0.0241]	0.0179 [0.0118;0.0243]	0.0183 [0.0136;0.0230]	0.0191 [0.0147;0.0237]
ρ_{e^D}	0.9919 [0.9851;0.9987]	0.9858 [0.9757;0.9964]	0.9956 [0.9919;0.9995]	0.9935 [0.9881;0.9991]	0.9859 [0.9761;0.9964]
θ_D	0.6251 [0.5025;0.7509]	0.1027 [0.0277;0.1709]	0.8201 [0.7560;0.8831]	0.6142 [0.4755;0.7443]	0.6461 [0.5285;0.7696]
σ_{e^D}	0.0337 [0.0240;0.0430]	0.0114 [0.0103;0.0126]	0.0678 [0.0455;0.0898]	0.0356 [0.0252;0.0453]	0.0400 [0.0281;0.0512]
ρ_{e^W}	0.9906 [0.9826;0.9985]	0.9606 [0.9330;0.9900]	0.9541 [0.9120;0.9958]	0.9710 [0.9533;0.9886]	0.9532 [0.9237;0.9857]
θ_W	0.0448 [0.0100;0.0753]	0.5486 [0.4450;0.6464]	0.7899 [0.6912;0.8855]	0.7006 [0.6244;0.7788]	0.5571 [0.4524;0.6666]
σ_{e^W}	0.0140 [0.0119;0.0161]	0.0422 [0.0353;0.0490]	0.0514 [0.0394;0.0648]	0.0390 [0.0319;0.0457]	0.0430 [0.0356;0.0500]
ρ_{e^G}	0.9290 [0.8977;0.9625]	0.9283 [0.8955;0.9618]	0.9262 [0.9003;0.9523]	0.9576 [0.9386;0.9763]	0.9304 [0.8990;0.9622]
σ_{e^G}	0.0351 [0.0318;0.0383]	0.0357 [0.0324;0.0391]	0.0349 [0.0314;0.0384]	0.0338 [0.0306;0.0370]	0.0357 [0.0324;0.0390]
Log-marg. lik.	-1424.502	-1449.463	-1957.035	-1505.888	-1395.221

Table 9: Posterior distributions of estimated parameters of the restricted models of Section 4.7

G DSGE Estimation: Great Moderation

Parameter		Prior			Posterior Mean
		Distrib.	Mean	Std/df	
Structural					
Inverse Frisch elasticity	φ	Normal	0.50	0.10	0.4843 [0.3187 0.6494]
Habit in nondurables consumption	ζ	Beta	0.70	0.10	0.8094 [0.7710 0.8478]
Habit persist. nondurables consumption	ρ_c	Beta	0.70	0.10	0.4952 [0.3842 0.6046]
Price stickiness nondurables	ϑ_c	Gamma	15.0	5.00	27.9960 [19.1055 36.5420]
Price stickiness durables	ϑ_d	Gamma	15.0	5.00	26.0723 [16.5135 35.6160]
Wage stickiness	ϑ^W	Gamma	100.0	10.00	91.8664 [76.5556 107.8759]
Invest. adjust. costs durable goods	ϕ	Normal	1.5	0.50	3.3233 [2.6629 3.9921]
Share of durables inflation in aggregator	τ	Beta	0.20	0.10	0.1856 [0.0834 0.2849]
Inflation -Taylor rule	ρ_π	Normal	1.50	0.20	1.8045 [1.5539 2.0391]
Output -Taylor rule	ρ_y	Gamma	0.10	0.05	0.0293 [0.0081 0.0494]
Interest rate smoothing	ρ_r	Beta	0.80	0.10	0.8130 [0.7768 0.8489]
Averages					
Trend growth rate	γ	Normal	0.49	0.10	0.4429 [0.4116 0.4763]
Inflation rate nondurables	$\bar{\pi}_C$	Gamma	1.05	0.10	0.7100 [0.6094 0.8108]
Inflation rate durables	$\bar{\pi}_D$	Gamma	0.55	0.10	0.1689 [0.0500 0.2797]
Interest rate	$\bar{r}$	Gamma	1.65	0.10	1.3119 [1.1831 1.4361]
Exogenous processes					
Technology	ρ_{e^A}	Beta	0.50	0.20	0.9523 [0.9220 0.9826]
	σ_{e^A}	IG	0.10	2.0	0.0049 [0.0043 0.0055]
Monetary Policy	ρ_{e^R}	Beta	0.50	0.20	0.3872 [0.2780 0.4997]
	σ_{e^R}	IG	0.10	2.0	0.0014 [0.0012 0.0016]
Investment Durables	ρ_{e^I}	Beta	0.50	0.20	0.4576 [0.2326 0.6700]
	σ_{e^I}	IG	0.10	2.0	0.0485 [0.0288 0.0664]
Preference	ρ_{e^B}	Beta	0.50	0.20	0.7478 [0.6836 0.8109]
	σ_{e^B}	IG	0.10	2.0	0.0205 [0.0163 0.0244]
Price mark-up nondurables	ρ_{e^C}	Beta	0.50	0.20	0.9350 [0.8932 0.9767]
	θ_C	Beta	0.50	0.20	0.3152 [0.1321 0.5045]
	σ_{e^C}	IG	0.10	2.0	0.0140 [0.0105 0.0177]
Price mark-up durables	ρ_{e^D}	Beta	0.50	0.20	0.9866 [0.9747 0.9992]
	θ_D	Beta	0.50	0.20	0.4670 [0.2748 0.6672]
	σ_{e^D}	IG	0.10	2.0	0.0238 [0.0162 0.0311]
Wage mark-up	ρ_{e^W}	Beta	0.50	0.20	0.9697 [0.9475 0.9925]
	θ_W	Beta	0.50	0.20	0.7193 [0.6483 0.7965]
	σ_{e^W}	IG	0.10	2.0	0.0438 [0.0353 0.0525]
Government spending	ρ_{e^G}	Beta	0.50	0.20	0.8568 [0.7925 0.9247]
	σ_{e^G}	IG	0.10	2.0	0.0210 [0.0185 0.0235]
Log-marginal likelihood					-645.999

Table 10: Prior and posterior distributions of estimated parameters. Sample: 1984Q1-2007Q4

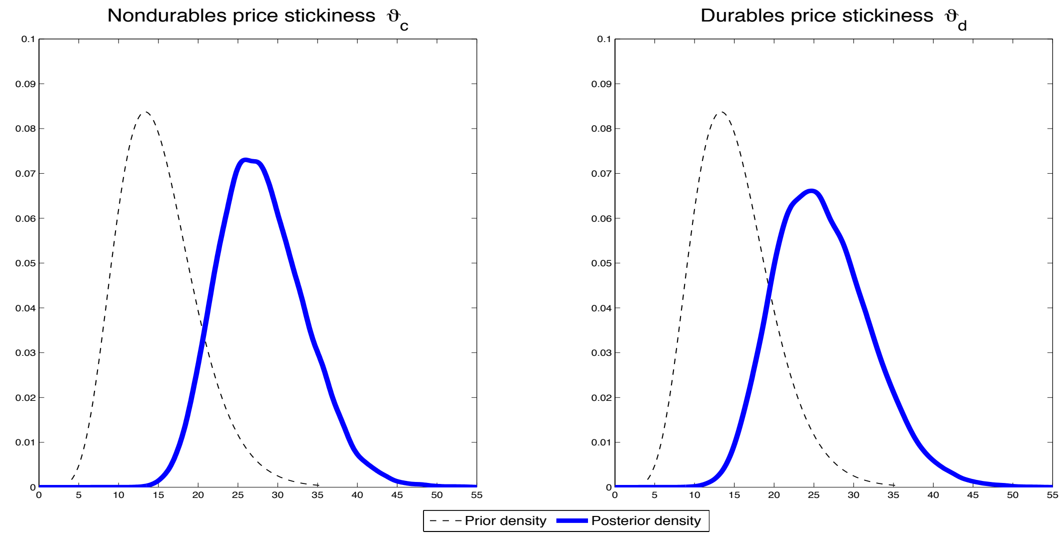

Figure 19: Prior and posterior densities of price stickiness parameters

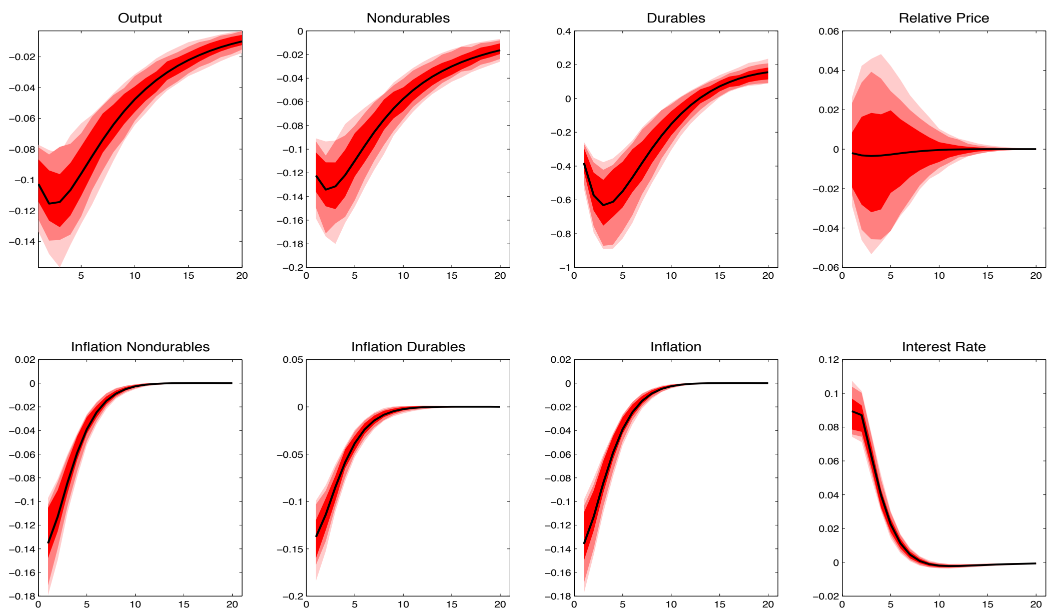

Figure 20: Bayesian impulse responses to a contractionary monetary policy shock, Great Moderation (bold lines are mean responses, dark-shaded areas are 68% confidence bands, medium and lighter shaded areas represent 90% and 95% confidence bands respectively)