Housing Wealth, Financial Wealth, Money Demand and Policy Rule: Evidence from the euro area

Ricardo M. Sousa*

University of Minho, NIPE, London School of Economics and FMG

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Abstract

This paper investigates empirically the relation between monetary policy and asset markets using quarterly data for the euro area. I find that a monetary policy contraction leads to a substantial fall in wealth. Nevertheless, while financial wealth effects are of short duration, housing wealth effects are very persistent.

After a positive interest rate shock there is a flight towards assets that are less liquid and earn higher rates of return. Moreover, expected inflation seems to be the major source of fluctuations in nominal rates over long periods.

Finally, the findings suggest that the money demand function is characterized by small output elasticity and large interest elasticity. By its turn, the estimated policy rule reveals that the monetary authority pays a special attention to developments in monetary aggregates and adopts a vigilant posture regarding financial markets.

Keywords: *housing wealth, financial wealth, monetary policy.*

JEL Classification: *E37, E52.*

1 Introduction

Understanding the role of monetary policy requires a deep knowledge of the models that describe monetary transmission. The money demand and the monetary policy rule are key ingredients of this mechanism. In one hand, money demand brings together the real and the nominal sides of the economy, and allows one to extract information about medium to long-term price stability. On the other hand, the monetary policy rule describes the systematic relationship among economic developments and the central bank's response to them, and provides the basis for forecasting future changes in its instruments.

Despite the relevance of these two major elements, the economic literature has only recently modelled them in an unified framework, namely, by using parsimoniously restricted multivariate time-series models. Moreover, it has typically neglected the impact that monetary policy decisions may have on different categories of wealth, and, consequently, on other macroeconomic aggregates through the so called "wealth effects".

It is well known that asset markets react to economic news and policy changes, and consumers react to changes in asset markets. The consumption-wealth channel of monetary policy reflects this mechanism: changes in monetary policy affect asset values, and these, in turn, affect consumer spending.

The recent developments in asset markets have renewed the interest of academics, central bankers and governments on the role that fiscal and/or monetary policy decisions can play in order to prevent and minimize the (negative) consequences of financial turmoils. Financial markets undoubtedly contain relevant information about agents' expectations for the course of policy, economic activity, and inflation. Similarly, housing markets represent a large share of GDP and a major asset in households' portfolios from which they derive direct utility and collateral services. As a result, understanding how the two sides of monetary policy (namely, money demand and policy rule) and the two components of wealth (that is, financial and housing wealth) interact is of crucial importance, and is simultaneously the major goal of this paper.

The present work looks at the relationship between monetary policy and asset markets. Using data for the euro area at quarterly frequency and for the period 1980:1-2007:4, I ask how financial wealth and housing wealth are affected by monetary policy shocks. To the extent that I find a link between monetary shocks and wealth, I look at the magnitude and the persistence of the effects.

I pay close attention to the identification of the monetary policy shock and focus on the empirical evidence linking monetary policy and wealth variables. Specifically, I identify the monetary policy shock using a recursive partial identification based on the work of Christiano et al. (1996, 2005), and estimate a Bayesian Structural Vector Autoregression (B-SVAR), therefore, accounting for the posterior uncertainty of the impulse-response functions. I also use a fully simultaneous system approach in a Bayesian framework based on the works of Leeper and Zha (2003), and Sims and Zha (1999, 2006a, 2006b), therefore, allowing for simultaneity of the response of money to shocks in the interest rate.

The results show that after a monetary policy contraction, both financial and housing wealth substantially fall. However, while the adjustment in financial wealth is relatively fast, housing wealth changes very slowly.

Other dimensions of monetary policy are also analyzed. To be more concrete, I consider the effects of monetary policy on a set of macroeconomic aggregates (GDP and unemployment rate), aggregate prices (GDP deflator and price of raw materials), and monetary aggregate

(broad money, M_3 minus M_1). Additionally, I show that after a positive interest rate shock: (i) the GDP falls and the unemployment rate rises; (ii) the price of raw materials substantially falls, but the aggregate price level exhibits strong persistence; and (iii) there is a flight towards assets that are less liquid but also earn higher rates of return.

In general, the initial liquidity effect lasts for 6 to 8 quarters, after which the interest rate falls to a persistently lower (than initial) level. This, therefore, gives rise to the idea that the monetary authority should increase the interest rate only briefly in order to achieve a lower inflation. Moreover, in the long-run, the fall in the interest rate is quantitatively similar to the fall in the inflation rate, suggesting that expected inflation is the major source of fluctuations in nominal rates over long periods.

The empirical findings also support the existence of a money demand function for the euro area characterized by a small output elasticity and a relatively large interest elasticity. By its turn, the policy rule reveals that the monetary authority pays a lot of attention to developments in the monetary aggregates while adopting a vigilant posture regarding the dynamics of financial markets.

Finally, I estimate the effects of monetary policy shocks on regional asset prices, that is, on housing and stock prices at the country level. This provides an informative summary of the spillover effects generated by monetary policy decisions and assesses the similarities/differences in the patterns of regional asset markets' reaction. The results are in line with the findings for the euro area and suggest that the effects of monetary policy contractions on stock prices are particularly important for France, Germany, Italy, Netherlands, and Spain - that is, the most important countries in terms of stock market capitalization - where the trough is normally associated with a fall of 3% to 4% in the stock price. In addition, an increase of the interest rate leads to a negative and very persistent impact on the housing prices. This pattern is particularly visible for France, Ireland, Italy, and Netherlands, where the trough is characterized by a fall of 1% to 2%.

The rest of the paper is organized as follows. Section 2 provides a brief review of the related literature. Section 3 explains the modeling strategy used in the identification of the monetary policy shocks. Section 4 describes the data and discusses the results. Section 5 looks at the impact of monetary policy on stock prices and housing prices at the country level. Section 6 conducts a VAR counter-factual exercise aimed at describing the effects of shutting down the shocks in the interest rate. Section 7 concludes with the main findings and policy implications.

2 A Brief Review of the Literature

According to popular wisdom, the dramatic run ups in housing prices have been caused by market-wide low interest rates, the increased availability of credit, or even money illusion.[1] Additional factors such as the fundamental restructuring of the housing finance system from a regulated system dominated by savings, loans and mutual savings banks to a relatively unregulated system dominated by mortgage bankers and brokers, the process of mortgage securitization, and a greater competitiveness in the primary mortgage market have also led to a reduction in volatility of residential investment. In fact, the housing finance system is now integrated with the broader capital markets in the sense that "mortgage rates move in

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[1]Brunnermeier and Julliard (2008) show that a reduction in inflation can fuel housing prices if people suffer from money illusion.

response to changes in other capital market rates, and mortgage funds are readily available at going market rates" (Hendershott and Shiling, 1989).

As a result of these transformations, the transmission of monetary policy to residential investment has changed and a tightening of monetary policy is now less likely to result in nonprice rationing of mortgage credit. McCarthy and Peach (2002) show that the eventual magnitude of the response of residential investment to a given change in monetary policy is similar to what it has been in the past. Fratantoni and Schuh (2003) also study the effects of monetary policy on regions in the U.S. and find that the response of housing investment to monetary policy varies by region. Iacoviello and Minetti (2003) document the role that the housing market plays in creating a credit channel for monetary policy. Aoki et al. (2004) argue that there is a collateral transmission mechanism to consumption but do not condition on monetary policy. Iacoviello (2005) emphasizes the monetary policy-house price to consumption channel and finds that monetary policy shocks have a significant effect on house prices. Iacoviello and Neri (2007) analyze the contribution of the housing market to business fluctuations and show that: (i) a large fraction of the upward trend in real housing prices over the last 40 years can be accounted for by slow technological progress in the housing sector; (ii) residential investment and housing prices are very sensitive to monetary policy and housing demand shocks; and (iii) the wealth effects from housing on consumption are positive and significant. Del Negro and Otrok (2007) try to disentangle the relative importance of the common component in OFHEO house price movements from local (state- or region-specific) shocks and find that while historically movements in house prices were mainly driven by the local component, the increase in house prices in the period 2001-2005 is mainly a national phenomenon. Chirinko et al. (2008) study the interrelationship between stock prices, house prices, and real activity, focusing on the role that asset prices play in the formulation of monetary policy, and show that housing shocks have a much greater impact that equity shocks.

While the literature mentioned above discusses the role of monetary policy on housing markets, some authors have also looked at its impact on financial markets or, more specifically, on stock prices. Goto and Valkanov (2000) use a VAR-based method to analyze the covariance between inflation and stock returns. Rigobon and Sack (2002, 2003) report a significant response of the stock market to interest rate surprises using an heteroskedasticity-based estimator to correct for possible simultaneity bias, an approach subsequently extended by Craine and Martin (2003). Bernanke and Kuttner (2005) find that, on average, a hypothetical unanticipated 25-basis-point cut in the Federal funds rate target is associated with about a 1% increase in broad stock indexes. Adapting a methodology due to Campbell and Ammer (1993) and identifying the monetary policy shock from data on futures, the authors show that the effects of unanticipated actions on expected excess returns account for the largest part of the response of stock prices. Boyd et al. (2005) also consider the linkage between policy and stock prices, but their analysis focuses on market's response to employment news, rather than to monetary policy directly.

Whichever is the asset market under consideration, the empirical evidence tells us that the linkages between financial markets and housing markets have substantially increased in recent years.[2] Moreover, understanding the linkages between monetary policy and asset markets also

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[2]Not surprisingly, developments in housing markets are now widely considered in models of stock re-turns'predictability. See, for instance, Lustig and Van Nieuwerburgh(2005), Yogo (2006), Gomes et al. (2007), Piazzesi et al. (2007) and Sousa (2008).

requires modelling monetary transmission. In this context, money demand is commonly seen as an important link in that transmission mechanism, as it relates real and nominal aspects of the economy and plays a central role in resource allocation, and it is a crucial element of the framework used to extract signals about the risks to medium and long term price stability. In addition, the other important ingredient for the analysis of the systematic relationship among economic developments and the central bank's response to them is the monetary authority's reaction function, which has received a large interest both from academics and central banks for several reasons: (i) it captures the major considerations underlying a central bank's interest rate setting; (ii) it provides a basis for forecasting changes in the central bank's policy instruments, as it illustrates how interest rates were set in the past; (iii) it allows one to evaluate the monetary authority's policy and the effects of other economic shocks in the context of macroeconomic modelling; and (iv) it is an crucial element in the estimation of models with rational expectations.

Since the beginning of the nineties, many studies have, therefore, been devoted to the econometric analysis of the money demand for the euro area. These have focused on aggregate M_3 and attempted to estimate the parameters of the long-run money demand using either single equation approaches (Fagan and Henry, 1998; Fase and Winder, 1999; Coenen and Vega, 2001) or a cointegrated VAR approach (Brand and Cassola, 2000; Calza et al., 2001; Coenen and Vega, 2001; Funke, 2001; Cassola and Morana, 2002; Golinelli and Pastorello, 2002; Kontolemis, 2002; Bruggemann et al., 2003; Avouyi-Dovi et al., 2003; Carstensen, 2006; Dreger and Wolters, 2006; Landesberger, 2007). In contrast to these classical maximum likelihood techniques, Warne (2006) estimates a cointegrated VAR using Bayesian methods, and shows that the interest rate semi-elasticities are often imprecisely estimated as the error bands tend to be wide.[3]

As for the monetary policy rule, several authors have also tried to estimate it for the euro area and the major European countries with the use of different methodologies.[4] Gerlach and Schnabel (2000) find that the original Taylor rule is able to explain the fall in the average interest rate over the last decade. Peersman and Smets (1999) confirm the robustness of the forward-looking policy rule in Clarida et al. (1998), while Faust et al. (2001) conclude that the European Central Bank (ECB) puts a higher weight on the output gap that the Bundesbank. Dornbusch et al. (1998) and Clausen and Hayo (2002) estimate the reaction function by means of Full Information Maximum Likelihood (FIML), while Angeloni and Dedola (1999) estimate a set of bivariate systems of equations, each including Germany and another country (France, Italy, Spain or Netherlands). Muscatelli et al. (2002, 2003) use a Recursive Least Squares method and include the long-term yield spread vis-à-vis Germany and the German interest rate in the policy rule. Ruth (2004) applies panel techniques and estimates interest rate reaction functions within an error-correction model. Dolado et al. (2000), Wesche (2003),

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[3] A large body of the empirical literature is also available in estimating money demand functions for the US (Goldfeld, 1973; Jain and Moon, 1994; Butkiewicz and McConnell, 1995; Ireland, 2008) and the UK (Thomas, 1997a, 1997b; Brigden and Mizen, 1999; Chrystal and Mizen, 2000, 2001).

[4] The seminal work in this area is Taylor (1993), who postulates that, in the US, central bank bases the setting of short-term interest rate on the current situation regarding inflation and the business cycle. Subsequent studies have developed different versions of the reaction function. Some include a lagged interest rate term and justify the decision on optimal monetary policy inertia or interest rate smoothing behavior (Woodford, 1999), data uncertainty (Orphanides, 1998), or simply a misspecification that fails to take into account the existence of correlation among different shocks (Rudebusch, 2002). Others incorporate features of forward-looking behavior in the policy rule and emphasize the importance of inflation targeting (Clarida et al., 1998) or real-time data in the information set of the monetary authority (Orphanides, 2001).

and Arghyrou (2005) focus on non-linear reaction functions by using dummy variables to capture the asymmetric response to inflation and to output gap or by estimating Markov-switching models. Gerdesmeier and Roffia (2003) emphasize the importance of accounting for monetary developments. Eleftheriou et al. (2006) use a GMM approach and show that the rule followed by each EMU country is distinct, but the parameter estimates reflect the principles proclaimed by the monetary policy authority.

Despite the relevance of the money demand function and the monetary policy rule as key pillars in the understanding of market developments and the conduction of monetary policy, they have only recently been modelled in parsimoniously restricted multivariate time-series models. Sims and Zha (1999, 2006a, 2006b) introduce an information variable[5] - the commodity prices - in an identified VAR model that allows for simultaneity, and solve two puzzling characteristics: (*i*) the liquidity puzzle", that is, a monetary contraction apparently failing to produce any rise in interest rates; and (*ii*) the "price puzzle", that is, a monetary contraction apparently unable to generate a decline in prices. In the same spirit, Leeper and Zha (2003) consider a setting in which the economy is divided into three sectors: (*i*) the financial sector summarized by commodity prices that react contemporaneously to all new information; (*ii*) the monetary sector that comprises the "money demand" (linking money reserves, short term interest rate, GDP, and GDP deflator) and the "money supply" (where monetary policy is assumed to react only to commodity prices - which are observed in real time -, money reserves and the interest rate; and (*iii*) the production sector.

Most importantly, little attention has been given to the wealth effects from monetary policy and the role that monetary authority plays by influencing real spending through household wealth. These are important gaps in the literature that I try to close with the current work. This paper, therefore, builds on the literature on restricted multivariate time-series models and its usefulness for the identification of monetary policy shocks as in Christiano et al. (2005), Leeper and Zha (2003), and Sims and Zha (1999, 2006a, 2006b). I quantify the magnitude of the wealth effects from monetary policy shocks, while improving and extending the existing literature in several directions. First, I do not look at the effects of monetary policy on the net funds raised by a specific sector of the economy - as in Christiano et al. (1996) - or on aggregate asset wealth - as in Ludvigson et al. (2002) - but focus on the response of different components of wealth instead.[6] Second, I aim at disentangling between the quantity effects (that emerge from the impact of monetary policy on the net stock of financial wealth and the net stock of housing wealth) and the price effects (that is, the effects of monetary policy on stock prices and housing prices) and, as a result, the analysis is broader than Julliard et al. (2007).[7] Third, while the previous studies have focused on evidence for the US and/or

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[5] This practice has been followed in other studies (Christiano et al., 1999; Hanson, 2004) and the information-variable idea has been extended to variables such as the exchange rate in open-economy studies (Kim and Rubini, 2000) and the interest rate of long-term bonds in term-structure works (Evans and Marshall, 1998, 2004).

[6] Christiano et al. (1996) show that after a contractionary monetary policy shock, net funds raised by the business sector increases for roughly a year, after which it falls, and find that households do not adjust their financial assets and liabilities for several quarters after the shock. On the other hand, Ludvigson et al. (2002) suggest that the wealth channel plays a minor role in the transmission of monetary policy to consumption, a finding that the authors attribute to the transitory nature of interest rate innovations on asset values.

[7] Julliard et al. (2007) develop a setup that simultaneously integrates the effects of monetary policy on housing prices and stock prices and show that: (*i*) monetary policy contractions have a large and significantly negative impact on real housing prices, but the reaction is extremely slow; and (*ii*) monetary policy shocks do not seem to cause a significant impact on stock markets, and the effect quickly erodes.

the UK, I use data for the euro area. Finally, as a robustness check of the previous point, I look at both the effects for the euro area and country level evidence, therefore, assessing the importance of the spillover effects.

3 Modelling Strategy

The modelling strategy adopted consists in the estimation of the following Structural VAR (SVAR)

$$\underbrace{\Gamma\left(L\right)}_{n \times n} \underbrace{X_t}_{n \times 1} = \Gamma_0 X_t + \Gamma_1 X_{t-1} + ... = c + \varepsilon_t \text{ where } \varepsilon_t | X_s, s < t \sim N\left(\underline{0}, \Lambda\right) \tag{1}$$

where $\Gamma\left(L\right)$ is a matrix valued polynomial in positive powers of the lag operator L, n is the number of variables in the system, and ε_t (the fundamental economic shocks) that span the space of innovations to X_t. That is, in the "reduced form"

$$\Gamma_0^{-1} \Gamma\left(L\right) X_t = B\left(L\right) X_t = a + v_t \sim N\left(\underline{0}, \Sigma\right) \tag{2}$$

where $\Sigma := \Gamma_0^{-1} \Lambda \left(\Gamma_0^{-1}\right)'$, the vector $v_t = \Gamma_0^{-1} \varepsilon_t$ contains the innovations of X_t, and Γ_0 pins down the contemporaneous relations among the variables in the system. In what follows I use the normalization $\Lambda = I$.

3.1 Recursive Partial Identification

In this setting, the key issue in identifying monetary policy shocks is the choice of identification restrictions in the Γ_0 matrix. I report results based on Christiano et al. (2005), that is, a recursive partial identification procedure. I assume that the variables in X_t can be separated into 3 groups: (i) a subset of n_1 variables, X_{1t}, whose contemporaneous values appear in the policy function and do not respond contemporaneously to the policy shocks; (ii) a subset of n_2 variables, X_{2t}, that respond contemporaneously to the monetary policy shocks and whose values appear in the policy function only with a lag; and (iii) the policy variable itself in the form of a short term interest rate, i_t. I include in the system the same variables as in Christiano et al. (2005) but also add a housing wealth measure among the X_{1t} variables, that is, I allow the monetary policy authority to react contemporaneously to changes in the housing wealth. I also add a financial wealth measure in X_{2t}. The recursive assumptions can be summarized by $X_t = [X_{1t}',\ i_t,\ X_{2t}']'$ and

$$\Gamma_0 = \begin{bmatrix} \underbrace{\gamma_{11}}_{n_1 \times n_1} & \underbrace{0}_{n_1 \times 1} & \underbrace{0}_{n_1 \times n_2} \\ \underbrace{\gamma_{21}}_{1 \times n_1} & \underbrace{\gamma_{22}}_{1 \times 1} & \underbrace{0}_{1 \times n_2} \\ \underbrace{\gamma_{31}}_{n_2 \times n_1} & \underbrace{\gamma_{32}}_{n_2 \times 1} & \underbrace{\gamma_{33}}_{n_2 \times n_2} \end{bmatrix}. \tag{3}$$

The two upper blocks of zeros correspond, respectively, to the assumptions that the variables in X_1 do not respond to the monetary policy shock either directly or indirectly. This approach delivers a correct identification of the monetary policy shock but not of the other shocks in the system.

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To make Γ_0 invertible, I add arbitrary zero restrictions in the non-policy blocks to obtain a total of $(n-1)\,n/2$ linearly independent restrictions - therefore delivering an exactly identified system. The identification of the monetary policy shocks, as well as the shape of the impulse-response function following a monetary policy shock are, by construction, independent from the choice of these additional restrictions.

Finally, I assess the posterior uncertainty about the impulse-response functions by using a Monte Carlo Markov-Chain (MCMC) algorithm. Appendix A provides a detailed description of the computation of the error bands.

3.2 Fully Simultaneous System

Leeper and Zha (2003) abandon two potentially unsatisfactory assumptions of the Christiano et al. (2005) type of identification scheme seen before: (i) they do not assume that the central bank reacts only to variables that are predetermined relative to policy shocks; and most importantly (ii) they assume that there are no predetermined variables with respect to the policy shock (this implies that one cannot do OLS – nor IV – to identify the policy shocks). This is particularly appealing, especially with quarterly frequency data (their approach is also motivated by a structural model of the economy).

In this setting, the economy is divided into three sectors: a financial, a monetary and a production sector. The financial sector – summarized by commodity prices index, Pcm – reacts contemporaneously to all new information. The monetary sector, that allows for simultaneous effects, comprises: (i) "money demand" that links money reserves, M, with the short term interest rate, i, GDP, Y, and the GDP deflator, P; and (ii) "money supply", where monetary policy is assumed to react only to commodity prices (since they are observed in real time), money reserves and the interest rate (since the other data are not observed in real time by the central bank). In order to reach identification, I follow Leeper and Zha (2003) and postulate the following money demand function

$$M_t = b_1 Y_t + b_2 i_t + b_3 P_t + \text{lagged}\,(X_t) + \sigma_M \varepsilon_t^M$$

where M_t is the log monetary aggregate, P_t is the log aggregate price index, Y_t is the log GDP, ε_t^M is the money demand shock, X_t is a vector of variables in the information set of the central bank, and σ_M is its standard deviation (the coefficients on these variables are restricted to unity). I also assume that the monetary policy function can be expressed as

$$i_t = \phi_M M_t + \phi_{FW} FW_t + \text{lagged}\,(X_t) + \sigma \varepsilon_t^{mp}$$

where FW_t is the log of net financial wealth. In this case, I depart from Leeper and Zha (2003) in that I assume that: (i) net financial wealth, FW, reacts contemporaneously to all new information; and (ii) the monetary policy reacts only to net financial wealth, money reserves and interest rate. In practice, I replace the commodity prices index (included in the Leeper and Zha (2003) specification) by net financial wealth, as financial prices can be observed in real time.

Two important remarks about the "money demand" and the "policy rule" functions need to be mentioned at this stage. First, Leeper and Zha (2003) consider a Markov switching structure but do not assume short-run price homogeneity in the money demand function, an approach that is also followed by Sims and Zha (2006a) and in this work. In contrast, Sims

and Zha (1999, 2006b) develop models in which short-run price homogeneity is imposed.[8] Second, while much literature specifies a policy rule that depends on the output gap and the inflation, the current paper presents a policy rule that depends on both money and financial wealth. In this way, it is consistent with the works of Leeper and Zha (2003) and Sims and Zha (2006a, 2006b), who rely on the estimation of fully simultaneous systems of equations. Moreover, the use of detrended real GDP in multivariate time-series models is inexistent (see Iacoviello (2005) for an exception). In particular, while its inclusion in restricted multivariate frameworks could potentially improve the estimation of the "policy rule" function, it would severely difficult the interpretation of the "money demand" equation which would depend on the output gap instead of the income as is typically done in the literature.

Finally, the production sector consists of log real GDP, Y, unemployment rate, U, the GDP deflator, P. I also add the housing wealth, HW. This sector does react contemporaneously to the financial sector but not directly to the monetary sector. The orthogonalization within this sector is irrelevant to identify monetary policy shocks correctly. The identification can be summarized in the following table where "+" indicates non-zero elements and I added a triangular orthogonalization for the production sector that is irrelevant for the identification of monetary policy shocks.

	Sector:						
Variable:	Financial	M Demand	M Policy	Prod Y	Prod P	Prod U	Housing
Financial wealth	+	+	+				
Money	+	+	+				
Interest rate	+	+	+				
GDP	+	+	+	+	+	+	+
Deflator	+	+			+	+	+
Unemployment	+					+	+
Housing wealth	+						+

The fully simultaneous identification scheme delivers overidentification. This implies that the estimates of Γ_0 are obtained via numerical maximization of the integrated likelihood and that confidence bands for the impulse-response functions should be constructed by drawing jointly from the posterior distribution of $B(L)$ and Γ_0 (Sims and Zha, 1999). This task is complicated by the fact that the integrated likelihood is not in the form of any standard probability density function, implying that one cannot draw Γ_0 from it directly to make inference. This problem is solved by: (i) taking draws for Γ_0 using an importance sampling approach that combines the posterior distribution with the asymptotic distribution of Γ_0; and (ii) drawing $B(L)$ from its posterior distribution conditional on Γ_0. Confidence bands are then constructed from the weighted percentiles of the impulse-response functions drawn in this fashion. This Monte Carlo approach is explained in detail in the Appendix B.

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[8]The assumption of short-run homogeneity in prices is not consensual. Goldfeld and Sichel (1990) suggest that the rejection of the unity of the price level coefficient can be interpreted as an indicator for misspecification. On the contrary, Evans and Wang (2008) show that the price elasticity of money demand should be less than unity under commodity standards, whenever monetary gold and nonmonetary gold are included in a standard money-in-utility model.

4 Results and Discussion

4.1 Data

This section provides a summary description of the data employed in the empirical analysis. A detailed description can be found in Section C of the Appendix. All variables are in natural logarithms and measured at constant prices unless stated otherwise.

This use of data for the euro area has some drawbacks such as the fact that the historical data originates from the time prior to EMU when the member economies experienced different monetary policy regimes and the possibility of aggregation bias (Beyer et al. 2001). There are, in fact, two alternative approaches: (i) to construct separate models of the member economies and link them to form a multi-country model of the euro area; and (ii) to start by aggregating the relevant macroeconomic time series across member economies and then estimate a model for the euro area as a whole. I follow the last approach, because the objectives and instruments of Eurosystem monetary policy are defined in terms of aggregates for the euro area.[9]

The economic variables for the euro area are, therefore, computed by aggregating national data using the irrevocable fixed exchange rates and for the period 1980:1-2007:4.

For the recursive partial identification of the monetary policy shock (based upon the work of Christiano et al., 2005), the variables in X_{1t} – the ones predetermined with respect to monetary policy innovations – are the net stock of housing wealth, NHW_t, the producer price index of raw materials, PPI_t^{RM}, the real GDP, Y_t, and the GDP deflator, P_t. The variables in X_{2t} – the ones allowed to react contemporaneously to monetary policy shocks – are the growth rate of broad money, $M_{3t} - M_{1t}$, and the net stock of financial wealth, NFW_t. That is, the recursive assumptions defined in (3) can be explicitly represented by $X_t = [X_{1t}', \ i_t, \ X_{2t}']'$, where $X_{1t} = [NHW_t, PPI_t^{RM}, GDP_t, P_t]$ and $X_{2t} = [M_{3t} - M_{1t}, NFW_t]$. I use the interest rate denoted by i_t as the monetary policy instrument. Following Peersman and Smets (2003), I include a set of foreign exogenous variables - namely, the US real GDP and the US Fed funds rate - aimed at controlling for changes in world inflation and demand and helping to solve the price puzzle. I also include in the set of exogenous variables a constant and a time trend. The selected optimal lag length is 2, in accordance with the Akaike (1974), Schwarz (1978), Hannan and Quinn (1979) and Hsiao (1981) criteria. However, the results are not sensible to different lag lengths.

For the other identification procedure, I follow the data choice of Leeper and Zha (2003) with two major differences: (i) I add housing wealth; and (ii) I replace the commodity price index by a measure of financial wealth. That is, in practice, I include the net stock of financial wealth, nominal M_3, the interest rate - the monetary policy instrument -, the real GDP, the GDP deflator, the unemployment rate, and net stock of housing wealth.

4.2 Recursive Partial Identification

I start by analyzing the impact of changes in the interest rate. I identify the monetary policy shock by imposing the recursive assumptions defined in (3) and estimate the Bayesian Structural VAR (B-SVAR) represented by (1).

Figure 1 plots the impulse-response functions to a positive shock in the interest rate. The solid line corresponds to the point estimate, the red line represents the median response,

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[9]This approach is also pursued by Brand and Cassola (2000), Fagan et al. (2001), Gerdesmeier and Roffia (2003), and Coenen and Wieland (2005).

and the dashed lines are the 68% probability intervals estimated by using a Monte-Carlo Markov-Chain algorithm based on 10000 draws.

The results are, broadly speaking, in line with the findings of Christiano et al. (2005) and suggest that after a contractionary monetary policy, the GDP falls with a lag of 2 quarters and the trough (of -1.8%) is reached at after around 6 quarters. The price of raw materials also decreases substantially and the reaction is quick. In addition, the price level exhibits a high persistence and starts falling significantly only after around 4 to 8 quarters, in accordance with the findings of Peersman and Smets (2003), for the euro area, and Leeper and Zha (2003) and Sims and Zha (2006a), for the US. The response of the growth rate of M_3 minus M_1 (that is, the broad measure of money that includes short-term time and saving deposits and marketable instruments) is interesting: as a result of a positive interest rate shock, the growth rate of the monetary aggregate increases, reflecting the flight towards assets that are less liquid but also earn higher rates of return; then, as the shock to the interest rate erodes, the growth rate starts falling and even becomes negative at around after 8 quarters.

Looking at the behavior of wealth, the empirical findings show that both net financial wealth and net housing wealth fall after the shock. However, while the adjustment in financial wealth is relatively fast, housing wealth changes very slowly. In fact, net financial wealth falls, reaches a trough (of around -0.4%) at after 4 quarters, and then starts recovering. In contrast, net housing wealth slowly falls over time and the effects are much more persistent: the trough (of about -0.3%) is reached 12 quarters ahead, but this component of wealth remains at a lower (than initial) level even after 20 quarters.

The evidence suggests, therefore, that shocks to the interest rate have important wealth effects. Additionally, while housing wealth effects are very persistent, financial wealth effects tend to be of relatively short duration. The reasons for such distinct reaction pattern may include: (i) differences in liquidity (Pissarides, 1978; Muellbauer and Lattimore, 1999); (ii) the utility (in the form of housing services and bequest motives) derived from the property right of housing assets (Poterba, 2000); (iii) the concentrated nature of financial wealth across income groups vis-a-vis housing wealth (Banks et al., 2002); (iv) the expected permanency of changes of different categories of wealth; (v) mismeasurement of wealth, in particular, in the case of houses which are less homogenous and less frequently traded than shares; and (vi) 'psychological factors' and or 'mental accounting' (Shefrin and Thaler, 1988).
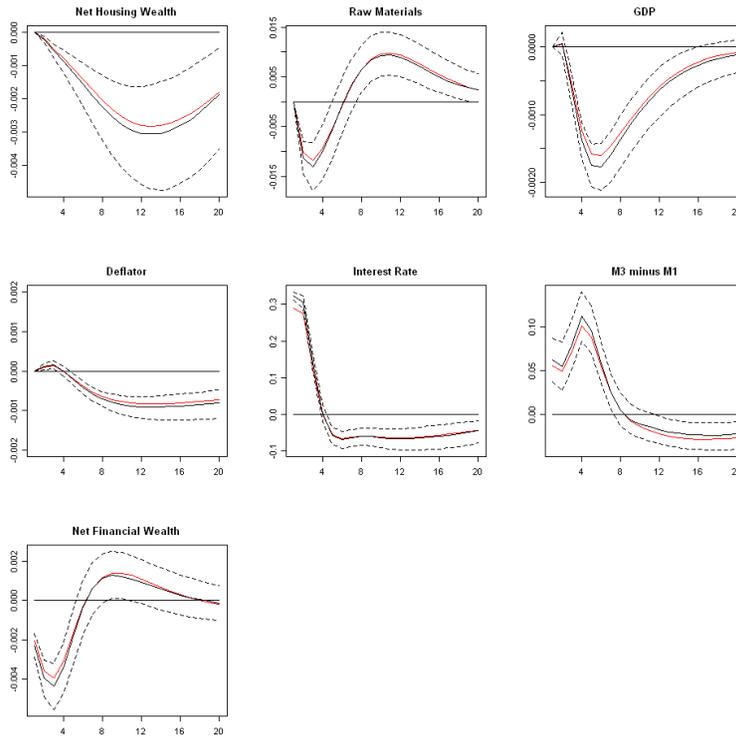
Figure 1: Impulse-response functions to a monetary policy contraction using Christiano et al. (2005) identification.

The strategy for estimating the parameters of the model focuses on the portion of fluctuations in the data that is caused by a monetary policy shock. It is, therefore, natural to ask how large that component is. With this question in mind, Table 1 reports variance decompositions, and displays the percentage of variance of the k-step-ahead forecast error in the elements of X_t due to an interest rate shock, for $k = 1$, 4, 8 and 20. Notice that while policy shocks account for only a small fraction of inflation they are important determinants of the price of raw materials. On the other hand, monetary policy shocks are responsible for a substantial fraction of the variation in GDP (about 9% of the variation 20 quarters ahead). A similar conclusion can be drawn with respect to wealth variables: monetary policy shocks explain about 3.2% of the variation in net housing wealth and 4.9% of the variation in net financial wealth 20 quarters ahead.

4.3 Fully Simultaneous System

I now consider a fully simultaneous system based on the identification procedure of Leeper and Zha (2003). I look at the effects of a monetary policy contraction when broad money, M_3, is included in the model. Figure 2 plots the impulse-response functions to a positive shock in the interest rate. The solid line corresponds to the point estimate, the red line represents the median response, and the dashed lines are the 68% probability intervals estimated by using a Monte-Carlo importance sampling algorithm based on 10000 draws.

Table 1: Percentage variance due to a monetary policy contraction.

	1 Quarter Ahead	4 Quarters Ahead	8 Quarters Ahead	20 Quarters Ahead
Net housing wealth	0.0 [0.0; 0.0]	0.9 [0.4; 1.7]	1.8 [0.8; 3.5]	3.2 [1.5; 5.9]
PPI for raw materials	0.0 [0.0; 0.0]	2.0 [1.0; 3.5]	3.3 [2.1; 4.9]	5.1 [3.5; 7.2]
GDP	0.0 [0.0; 0.0]	4.6 [3.1; 6.6]	11.0 [7.8; 14.7]	9.1 [6.2; 12.7]
Deflator	0.0 [0.0; 0.0]	0.9 [0.5; 1.5]	3.7 [5.7; 5.6]	5.8 [4.1; 9.1]
Interest rate	94.5 [92.5; 96.1]	63.4 [58.7; 67.9]	41.4 [37.8; 45.1]	17.0 [14.2; 20.3]
M_3 minus M_1 growth	1.3 [0.5; 2.4]	5.1 [3.2; 7.5]	6.9 [4.6; 9.8]	6.8 [4.8; 9.4]
Net financial wealth	3.0 [1.7; 4.7]	5.0 [2.9; 7.6]	4.8 [3.2; 7.0]	4.9 [3.3; 7.0]

Note: Median estimates and 68% probability intervals computed using a Monte Carlo Markov-chain (MCMC) algorithm.

The empirical findings roughly replicate the ones from the Christiano et al. (2005) identification. After a positive interest rate shock: (*i*) broad money falls; (*ii*) the price level exhibits strong persistence and starts to fall significantly after 4 to 8 quarters; (*ii*) GDP falls with a lag of 2 quarters and the trough (of -2%) is reached at after 8 to 12 quarters; (*iii*) the unemployment rate significantly rises by about 0.9 percentage points, peaking at after 12 quarters. Regarding wealth components, the results suggest that while financial wealth quickly falls after the shock - the trough of -1.6% is achieved after 6 quarters -, housing wealth adjusts at a slower pace and remains at a persistently lower level even 20 quarters ahead.

The response of the interest rate to an exogenous policy contraction also shows that the initial liquidity effect lasts for about 8 quarters. However, after this period, the interest rate reverts and remains persistently at a lower level even 20 quarters ahead. Friedman (1968) and Cagan (1972) describe this shape of the path of the short-term nominal interest rate following a monetary expansion as a short-lived liquidity effect that is followed by expected inflation and income effects. The fall in inflation and the interest rate are about the same size after 20 quarters, consistent with the argument that expected inflation is the driving source of fluctuations in nominal rates in the long-run. As a result, Figure 2 shows, therefore, that the monetary authority should raise the interest rate only briefly in order to achieve a persistent fall in inflation. Because lower inflation is ultimately associated with lower interest rate, the monetary authority must reduce the rate within 8 quarters and keep it lower afterwards.
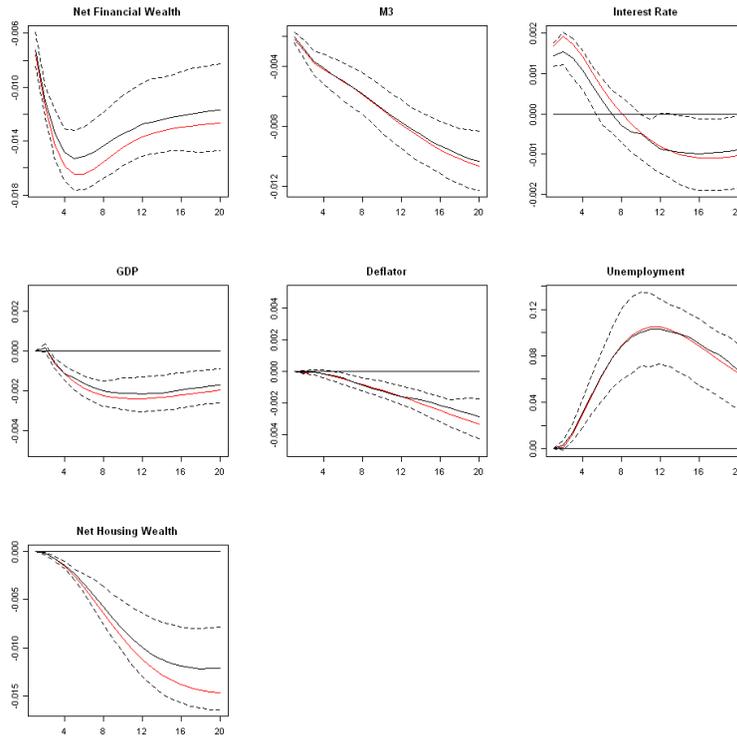
Figure 2: Impulse-response functions to a monetary policy
contraction using Leeper and Zha (2003) identification.

Table 2 reports the median estimates of the contemporaneous coefficient matrix. Money demand allows one to the following economic interpretations: the interest elasticity of demand is negative and relatively large in magnitude; and the output elasticity is positive but small. By its turn, the policy rule shows a larger contemporaneous coefficient on M_3 than the interest rate, suggesting that the monetary authority strongly responds to the developments in the money stock: disturbances that raise the monetary aggregate induce an increase of the interest rate. Moreover, it shows that the monetary authority is vigilant about the dynamics of the financial markets: a shock that raises the net stock of financial wealth induces the monetary authority to increase the interest rate.

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Table 2: Contemporaneous coefficient matrix.

				Sector:			
Variable:	Financial	M Demand	M Policy	Prod Y	Prod P	Prod U	Housing
Financial wealth	-76.8	0.0	-48.7	0.0	0.0	0.0	0.0
M3	141.9	203.7	-167.8	0.0	0.0	0.0	0.0
Interest rate	-105.9	248.0	128.7	0.0	0.0	0.0	0.0
GDP	-9.9	-55.0	0.0	-258.3	-10.4	-151.2	19.6
Deflator	-139.2	75.0	0.0	0.0	-460.2	139.0	-487.8
Unemployment	-1.9	0.0	0.0	0.0	0.0	-14.3	0.2
Housing wealth	-132.9	0.0	0.0	0.0	0.0	0.0	-614.7

Note: Median estimates computed using a Monte Carlo Importance Sampling algorithm.

Table 3 displays the percentage of variance of the k-step-ahead forecast error due to an interest rate shock, for $k = 1$, 4, 8 and 20. Interest rate shocks account for a relatively small fraction of both GDP, inflation, and unemployment (respectively, 9.3%, 4.6% and 6.6% at 20 quarters ahead). The percentage of variance of the forecast error in M_3 that is due to an interest rate shock is large (26.8%). This reflects the fact that financial wealth is allowed to enter the monetary policy rule and, not surprisingly, the forecast error in financial wealth is now large (27.4% at 20 quarters ahead). For housing wealth, the shocks explain about 9.9% of the variation after 20 quarters.

Table 3: Percentage variance due to a monetary policy contraction.

Variable:	1 Quarter Ahead	4 Quarters Ahead	8 Quarters Ahead	20 Quarters Ahead
Financial wealth	42.3 [27.6; 56.0]	45.6 [32.2; 57.8]	38.5 [28.0; 48.7]	27.4 [19.0; 36.7]
M3	39.2 [22.0; 58.3]	28.6 [13.4; 47.4]	24.6 [11.2; 41.6]	26.8 [16.2; 39.0]
Interest rate	16.1 [8.8; 25.3]	7.9 [3.7; 14.0]	5.1 [3.3; 8.0]	5.4 [3.5; 8.2]
GDP	0.0 [0.0; 0.0]	1.9 [1.0; 3.3]	5.9 [2.9; 9.7]	9.3 [4.6; 8.2]
Deflator	0.0 [0.0; 0.0]	0.4 [0.2; 0.9]	1.3 [0.5; 2.6]	4.6 [2.1; 8.2]
Unemployment	0.0 [0.0; 0.0]	0.8 [0.4; 1.5]	3.7 [1.9; 6.1]	6.6 [3.4; 11.2]
Housing wealth	0.0 [0.0; 0.0]	1.0 [0.4; 1.7]	3.8 [1.9; 6.1]	9.9 [5.4; 15.4]

Note: Median estimates and 68% probability intervals computed using a Monte Carlo Importance Sampling algorithm.

5 Country Level Evidence

As a robustness check of the previous findings, I look at the country level effects of a monetary policy contraction. Specifically, I analyze the impact of a rise in the interest rate on stock prices and housing prices at the country level. In practice, I estimate the B-SVAR defined in (1), that is, using data for the euro area. However, the net stock of financial wealth for the

euro area (included in X_{2t}) is replaced by the stock price of a specific country, and net stock of housing wealth for the euro area (included in X_{1t}) is replaced by a country-level housing price. I repeat this procedure for each country and look at the impulse-response functions of stock and housing prices at the country level. This allows one to understand the magnitude of the spillover effects generated by a common shock in the monetary policy and disseminated among the different countries.

5.1 Stock Prices

Figure 3 plots the impulse-response functions of stock prices to a positive shock in the interest rate. The solid line corresponds to the point estimate, the red line represents the median response, and the dashed lines are the 68% probability intervals estimated by using a Monte-Carlo Markov-Chain algorithm based on 10000 draws.

The results are in line with the findings for the euro area: a monetary policy contraction has a negative impact on the stock price which reaches a trough at around after 4 to 8 quarters; then, stock markets quickly return to their original levels, that is, the impact tends to be of short duration. The effect of monetary policy is particularly important for France, Germany, Italy, Netherlands, and Spain - that is, the most important countries in terms of stock market capitalization - where the trough is normally associated with a fall of 3% to 4% in the stock price.
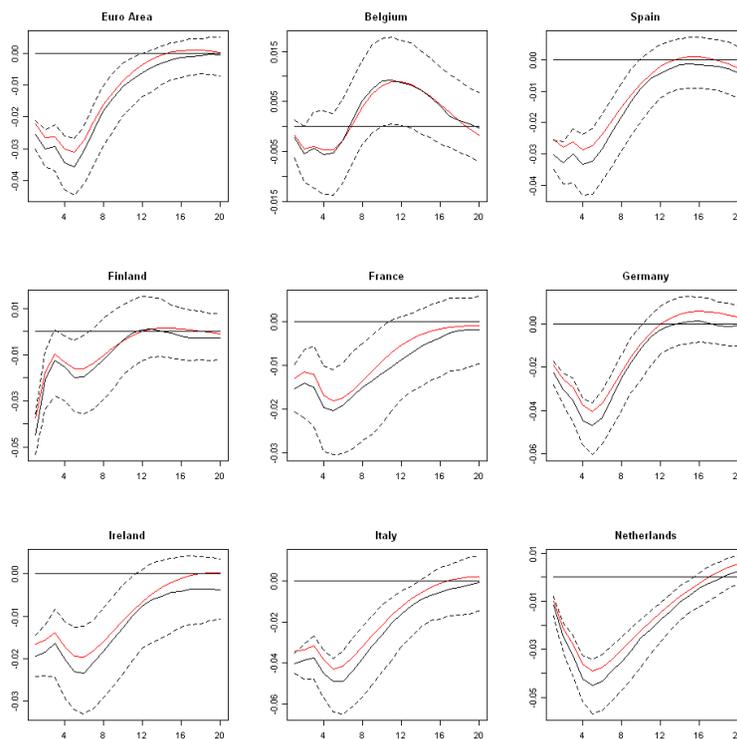

Figure 3: Impulse-response functions to a monetary policy contraction: comparison of the reaction of stock prices at the country level.

5.2 Housing Prices

Figure 4 displays the impulse-response functions of stock prices to a positive shock in the interest rate. The solid line represents the point estimate, the red line corresponds to the median response, and the dashed lines are the 68% probability intervals estimated by using a Monte-Carlo Markov-Chain algorithm based on 10000 draws.

As before, the results corroborate the findings for the euro area: an increase of the interest rate leads to a negative and very persistent impact on the housing price. Housing prices remain at a lower level even 20 quarters after the shock, and this pattern is particularly important for France, Ireland, Italy and Netherlands, where the trough is characterized by a fall of between 1% and 2%.
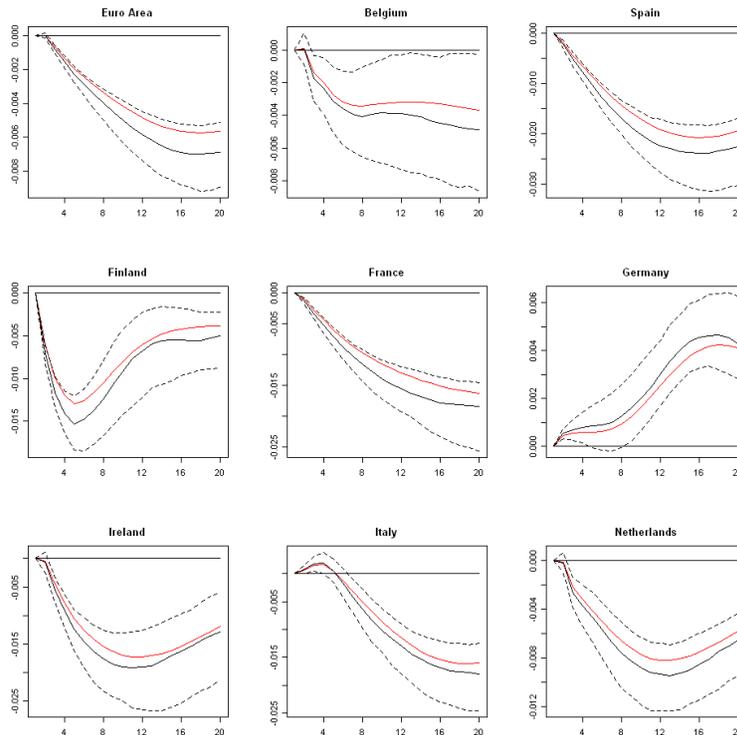

Figure 4: Impulse-response functions to a monetary policy contraction: comparison of the reaction of housing prices at the country level.

6 A VAR Counter-Factual Exercise

I now build a VAR counter-factual exercise aimed at describing the effects of shutting down the shocks in interest rate. In practice, after estimating the B-SVAR summarized by (1), I construct the counter-factual (CFT) series as follows:

$$\underbrace{\Gamma\left(L\right)}_{n \times n}\underbrace{X_t^{CFT}}_{n \times 1} = \Gamma_0 X_t^{CFT} + \Gamma_1 X_{t-1}^{CFT} + ... = c + \varepsilon_t^{CFT} \qquad (4)$$

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$$v_t = \Gamma_0^{-1} \varepsilon_t^{CFT} \tag{5}$$

This is equivalent to consider two vectors of structural shocks:

$$\varepsilon_t^{CFT} = [\varepsilon_t^{NHW}, \varepsilon_t^{PPI^{RM}}, \varepsilon_t^{GDP}, \varepsilon_t^{P}, \varepsilon_t^{i}, \varepsilon_t^{M_3-M_1}, \varepsilon_t^{NFW}]'$$

$$\varepsilon_t^{CFT} = [\varepsilon_t^{HP}, \varepsilon_t^{PPI^{RM}}, \varepsilon_t^{GDP}, \varepsilon_t^{P}, \varepsilon_t^{i}, \varepsilon_t^{M_3-M_1}, \varepsilon_t^{SP}]'$$

$$\varepsilon_t^{i} = 0 \qquad \forall t.$$

The empirical exercise allows one to analyze the role played by monetary policy shocks. Moreover, it helps understanding what the dynamics of financial wealth and housing wealth would be in the case of absence of unexpected variation in the interest rate.

Figure 5 plots the actual and the counter-factual series for the interest rate, net financial wealth and net housing wealth, stock prices and housing prices. The results suggest a considerable difference between the actual and the counter-factual series for the interest rate and, therefore, the importance of interest rate shocks. Moreover, it can be seen that while there are significant effects on both stock prices and housing prices, the importance of monetary policy actions tends to be stronger for financial and housing wealth: in the case of financial wealth, the actual and counter-factual series substantially depart from each other in the period 1985-2000; as for housing wealth, the deviations are larger in the period 1990-2005. This evidence shows that monetary policy has not only important asset price effects but also very relevant wealth effects.
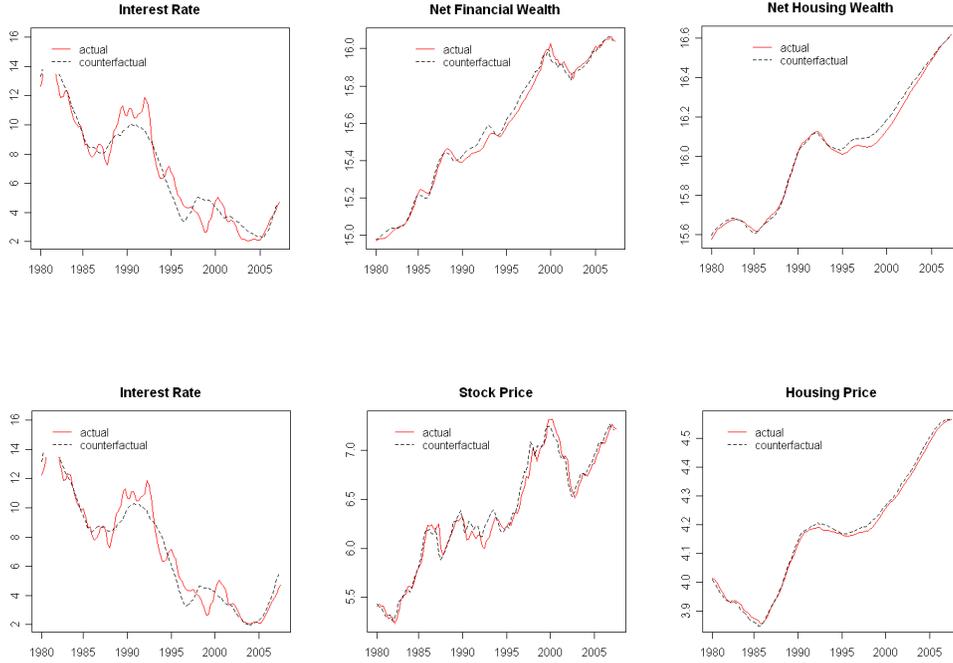

Figure 5: Actual and counter-factual series for the interest rate, net financial wealth, net housing wealth, stock prices and housing prices.

7 Conclusion

In this paper, I investigate the relationship between wealth and monetary policy in the euro area. I show that, after a monetary policy contraction, both financial and housing wealth substantially fall. Nevertheless, while the adjustment in financial wealth is relatively fast, housing wealth changes are very slowly. Moreover, the effects tend to be substantial both for stock prices and housing prices, but the first ones are of shorter duration.

Additionally, I show that after a positive interest rate shock: (i) the GDP falls, while the unemployment rate rises; (ii) the price of raw materials substantially falls, but there is strong persistence of prices at the aggregate level; and (iii) there is a flight towards assets that are less liquid but also earn higher rates of return.

The response of the interest rate to an exogenous policy contraction reveals that the initial liquidity effect, in general, lasts for between 6 and 8 quarters. However, after this period, the interest rate persistently reaches a lower level where it remains even 20 quarters ahead. This suggests that to persistently lower inflation the monetary authority should raise the interest rate only briefly. Moreover, it shows that expected inflation is the dominant source of fluctuations in nominal rates over long periods.

The results from the estimation of the money demand function and the monetary policy rule for the euro area also lead to interesting conclusions. First, the interest elasticity of money demands is negative and relatively large in magnitude, while the output elasticity tends to be small and positive. Second, the monetary authority seems to pay a lot of attention to developments in broad money, that is, the interest rate seems to play a secondary role in the monetary policy rule. This is in accordance with the findings of Julliard et al. (2007), who argue that the same focus on monetary aggregates can be found for the Bank of England while, on the contrary, the Federal Reserve emphasizes the role of the interest rate. Third, the monetary authority exhibits a vigilant behavior regarding the dynamics of financial markets, although it does not allocate a large weight to it in the policy rule.

Finally, I estimate the effects of monetary policy shocks on asset prices at the country level. The results are in line with the findings for the euro area and suggest that the effects of monetary policy contractions on stock prices are particularly important for countries with the largest stock market capitalization. On the other hand, an increase of the interest rate leads to a negative and very persistent impact on regional housing prices.

These findings can be useful when constructing models to better understand the aggregate implications of the dynamics of financial and housing market. Generating a highly persistent response of house prices and a quick answer of stock prices to monetary policy may prove to be a challenge in quantitative models of housing and stock market fluctuations.

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Appendix

A   The Posterior Distribution of the Impulse-Response Function

The impulse-response function to a one standard-deviation shock is:

$$B\left(L\right)^{-1}\Gamma_0^{-1}. \tag{A.1}$$

To assess uncertainty regarding the impulse-response functions, I follow Sims and Zha (1999) and construct confidence bands by drawing from the Normal-Inverse-Wishart posterior distribution of $B\left(L\right)$ and Σ

$$\beta|_\Sigma \ \sim \ N\left(\hat{\beta}, \Sigma \otimes \left(X'X\right)^{-1}\right) \tag{A.2}$$

$$\Sigma^{-1} \ \sim \ \text{Wishart}\left(\left(T\hat{\Sigma}\right)^{-1}, T - m\right)$$

where β is the vector of regression coefficients in the VAR system, Σ is the covariance matrix of the residuals, the variables with a hat denote the corresponding maximum-likelihood estimates, X is the matrix of regressors, T is the sample size and m is the number of estimated parameters per equation (see Zellner, 1971; Schervish, 1995; and Bauwens et al., 1999).[10] Note that the use of this Bayesian approach allows one to draw inference that is robust to the presence of non-stationary behavior in the variables, since the posterior will have an asymptotically Gaussian shape even in the presence of unit roots (Kim, 1994).

B   A Mixed Monte Carlo Importance Sampling Algorithm for Drawing from the Posterior Distribution of the Impulse-Response Function

To be able to identify the structural monetary shocks, one needs at least $(n-1)\,n/2$ linearly independent restrictions. With enough restrictions in the Γ_0 matrix and no restrictions in the matrix of coefficients on the lagged variables, the estimation of the model is numerically simple since the log-likelihood will be

$$l\left(B, a, \Gamma_0\right) \ = \ -\frac{T}{2} + \log|\Gamma_0| - \frac{1}{2}trace\left[S\left(B, a\right)\Gamma_0'\Gamma_0\right] \tag{B.1}$$

$$\text{where } S\left(B, a\right) \ = \ \sum_{t=1}^{T}\left(B\left(L\right)X_t - a\right)\left(B\left(L\right)X_t - a\right)'$$

and the maximum-likelihood estimator of B and a can be found simply doing OLS equation-by-equation regardless of the value of Γ_0. Integrating $l\left(B, a, \Gamma_0\right)$ (or the posterior with conjugate priors) with respect to (B, a) the marginal log probability density function of Γ_0 is

---

[10]This result is exact under normality and the Jeffreys' prior $f\left(\beta, \Sigma\right) \propto |\Sigma|^{-(p+1)/2}$ (where p is the number of right hand side variables), but can also be obtained, under mild regularity conditions, as an asymptotic approximation around the posterior MLE. The Jeffreys' prior formulates the idea of "lack of prejudice" on the space of distribution for the data, and is also flat over the space of the βs and remains flat under reparameterization.

proportional to

$$-\frac{T-k}{2}\log\left(2\pi\right)+(T-k)\log\left|\Gamma_0\right|-\frac{1}{2}trace\left[S\left(\hat{B}_{OLS},\hat{a}_{OLS}\right)\Gamma_0'\Gamma_0\right].\qquad(B.2)$$

In the S-VAR setting considered, the impulse-response functions are given by

$$B\left(L\right)^{-1}\Gamma_0^{-1}.\qquad(B.3)$$

This implies that to assess posterior uncertainty regarding the impulse-response function one needs joint draws for both $B\left(L\right)$ and Γ_0.[11]

Since equation (B.2) is not in the form of any standard probability density function one cannot draw directly from Γ_0 to make inference. Nevertheless, if one takes a second order expansion of equation (B.2) around its peak one gets the usual Gaussian approximation to the asymptotic distribution of the elements in Γ_0. Since this is not the true form of the posterior probability density function, one cannot use it directly to produce a Monte Carlo sample. A possible approach is importance sampling, in which one draws from the Gaussian approximation, but weigh the draws by the ratio of (B.2) to the probability density function from which one draws. The weighted sample cumulative density function then approximates the cumulative density function corresponding to (B.2).

Note also that the distribution of $B\left(L\right),$ given $\Gamma_0,$ is the usual normal distribution

$$vec\left(B\left(L\right)\right)|\Gamma_0\sim N\left(vec\left(\hat{B}_{OLS}\right),\Gamma_0^{-1}\left(\Gamma_0^{-1}\right)'\otimes\left(X'X\right)^{-1}\right).\qquad(B.4)$$

So one can take joint draws using the following simple algorithm: (i) draw Γ_0 using (B.2); and (ii) draw $vec\left(B\left(L\right)\right)$ using equation (B.4). Confidence bands for the impulse-response function are then constructed from the weighted percentiles of the Monte Carlo sample where the weights are computed by importance sampling.

Denote with $\hat{H}$ the numerical Hessian from the *minimization* routine at the point estimate and $\hat{\Gamma}_0$ the maximum-likelihood estimator. The algorithm used to draw the confidence bands from the posterior distribution is the following:

1. Check that all the coefficients on the main diagonal of $\hat{\Gamma}_0$ are positive. If they are not, flip the sign of the rows that have a negative coefficient on the main diagonal [that is, our point estimates are normalized to have positive elements on the main diagonal).

2. Set $i=0$.

3. Drawn $vech\left(\tilde{\Gamma}_0\right)$ from a normal $N\left(vech\left(\hat{\Gamma}_0\right),\hat{V}\right)$, where $\hat{V}=\hat{H}^{-1}$ and $vech\left(.\right)$ vectorizes the unconstrained elements of a matrix. That is, this step draws from the asymptotic distribution of Γ_0. There are 3 possible options to handle draws in which some of the diagonal elements of $\tilde{\Gamma}_0$ are not positive:

---

[11]If we take the classical approach instead and maximize $l\left(B,a,\Gamma_0\right)$ for $\left(B\left(L\right),a\right)$ holding Γ_0 fixed, we have the same expression with T rather than $T-k$ multiplying the first terms. I follow the common approach of using $\left|\Gamma_0\right|^k$ as an improper prior, so that the concentrated likelihood and the marginal posterior coincide. The last expression can be maximized with respect to Γ_0 to obtain the maximum-likelihood estimator, and a consistent estimate of the asymptotic variance of these parameters can be constructed from the Hessian evaluated at the estimated parameter values.

(a) if some of the diagonal entries of $\tilde{\Gamma}_0$ are not positive, reject the draw and go back to 2. to take another draw (this is what is also done in the Sims and Zha (2006a) and I follow this approach).

(b) reject the draw if and only if one of the negative entries on the main diagonal is more than "alpha" standard deviations away from the maximum-likelihood estimator.

(c) accept the draw and continue.

4. Compute and store the importance sampling weight

$$
m_i = \exp \left[
\begin{array}{c}
T \log \left| \det \left(\tilde{\Gamma}_0 \right) \right| - \frac{1}{2} trace \left(S \left(\hat{B}_{OLS}, \hat{a}_{OLS} \right) \tilde{\Gamma}_0' \tilde{\Gamma}_0 \right) \\
- \log \left| \hat{V} \right|^{-\frac{1}{2}} + .5 \left(vech \left(\tilde{\Gamma}_0 \right) - vech \left(\hat{\Gamma}_0 \right) \right)' \hat{V}^{-1} \left(vech \left(\tilde{\Gamma}_0 \right) - vech \left(\hat{\Gamma}_0 \right) \right) \\
- SCFT
\end{array}
\right]
$$
(B.5)

where $SCFT$ is a scale factor that prevents overflow/underflow [a good choice for it is normally the value of the likelihood at its peak).[12]

5. Draw $vec \left(\tilde{B} \left(L \right) \right)$ from a normal $N \left(vec \left(\hat{B}_{OLS} \right), \tilde{\Gamma}_0^{-1} \left(\tilde{\Gamma}_0^{-1} \right)' \otimes \left(X'X \right)^{-1} \right)$ to get a draw for $\tilde{B} \left(L \right)$.

6. Compute the impulse-response function and store it in a multidimensional array.

7. If $i < \#draws$, set $i = i + 1$ and go back to 3.

The stored draws of the impulse-response function, jointly with the importance sampling weights, are used to construct confidence bands from their percentiles. Moreover, the draws of $\tilde{\Gamma}_0$ are stored to construct posterior confidence interval for these parameters from the posterior (weighted) quantiles.

Normalized weights that sum up to 1 are simply constructed as:

$$
w_i = \frac{m_i}{\sum_i^{\#draws} m_i}.
$$
(B.6)

When the number of draws is sufficiently large for the procedure outlined above to deliver accurate inference, the plot of the normalized weights should ideally show that none of them is too far from zero – that is, one single draw should not receive 90% of the weight.[13]

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[12] Confidence bands constructed using unweighted quantiles are asymptotically justified (due to the asymptotic Gaussianity), and are good to give a quick look at the shape of the impulse-response function using a small number of draws. The unweighted approach should be used with caution since: (i) it is likely to produce unrealistically tight bands in the presence of multiple local maxima; and (ii) will not capture asymmetries of the confidence bands (that are important in detecting whether an impulse-response function is significantly different from zero).

[13] When the importance sampling performs too poorly (due to the variability in the weights), we can replace that part of the algorithm with the random walk Metropolis Markov-Chain Monte Carlo of Waggoner and Zha (1997), using also their approach to handle switch in the sign of the rows of Γ_0 (that is, use a normalization for each draw that minimizes the distance of Γ_0 from the maximum likelihood estimate).

C Detailed Data Description

Euro Area aggregates are calculated as weighted average of euro-11 before 1999 and, thereafter, as break-corrected series covering the real-time composition of the euro area. The weights are computed using GDP at irrevocable fixed conversion rates.

GDP

Seasonally adjusted nominal GDP ('stocks') at market prices. From 1999:1 onwards, this series covers nominal GDP of the real-time composition of the euro area, correcting for the breaks caused by the several enlargements, i.e. currently the observations from 2007:4 backwards are extrapolations based on growth rates calculated from the levels series compiled for the euro area 15 in 2008. For period before 1999, the nominal GDP series for the euro area is constructed by aggregating national GDP data for euro 11 using the irrevocable fixed exchange rates of 31 December 1998 for the period 1980:1-1998:4. Again, growth rates from this series are used to backward extend the euro area GDP series.

The euro area seasonally adjusted real GDP series (at 2000 constant prices) has been constructed before 1999 by aggregating national real GDP data using the irrevocable fixed exchange rates. As for the euro area nominal GDP, an artificial euro area real GDP series has also been constructed using the procedure illustrated above. Data are quarterly, seasonally adjusted, expressed in million of Euro, and comprise the period 1980:1-2007:4.

Deflator

All variables are expressed in real terms by using the GDP deflator. The GDP deflator is calculated as a simple ratio between nominal and real GDP. The year base is 2000 (2000 = 100). Data are quarterly, seasonally adjusted, and comprise the period 1980:1-2007:4.

Short-Term Interest Rate

For short-term interest rates from January 1999 onwards, the euro area three-month Euribor is used. Before 1999, the artificial euro area nominal interest rates used are estimated as weighted averages of national interest rates calculated with fixed weights based on 1999 GDP at PPP exchange rates. National short-term rates are three-month market rates. Data are quarterly averages, and comprise the period 1980:1-2007:4.

M_3

All the data used are denominated in euro. The seasonally adjusted M_3 series for the euro area has been constructed using the index of adjusted stocks for the corresponding real time composition of the currency area. This index corrects for breaks due to enlargement, but as well for reclassifications, exchange rate revaluations and other revaluations. In order to translate the index into outstanding amounts, the M_3 seasonally adjusted index of adjusted stocks for the euro area has been re-based to be equal to the value of the seasonally adjusted stock for the euro area M_3 in January 2008. Before 1999, stocks and flows of the estimated "euro area M3" are derived by by aggregating national stocks and flows at irrevocable fixed exchange rates. Data are seasonally adjusted quarterly averages covering the period 1980:2 to 2007:4.

M_1

"Adjusted stock" (millions of euro). The seasonally adjusted index of adjusted stocks for M_1 is derived as described above for M_3. Data are quarterly averages, seasonally adjusted, and comprise the period 1980:2-2007:4.

PPI of Raw Materials

World market prices of raw materials. Total index. USD basis, converted into euro. Weighted according to commodity imports of OECD countries, 1989-1991, excluding EU-internal trade. Share in total index: 100%. Data are quarterly, seasonally adjusted, and comprise the period 1980:1-2007:4.

Financial Wealth

Net financial wealth is the difference between financial assets (currency and deposits, debt securities, shares and mutual fund shares, insurance reserves, net others) and financial liabilities (excluding mortgage loans) held by households and non-profit institutions serving households. Original series are provided at quarterly frequency from the euro area quarterly sectoral accounts for the period 1999:1-2007:4 and at annual frequency from the monetary union financial accounts for the period 1995-1998 and from national sources for the period 1980-1994. Quarterly data before 1999 are back-casted and interpolated using quadratic smoothing and corrected for breaks. Data are quarterly, seasonally adjusted, expressed in million of Euro, and comprise the period 1980:1-2007:4.

Housing Wealth

Net housing wealth is the difference between gross housing wealth and mortgage loans held by households and non-profit institutions serving households. Original series are provided at annual frequency and quarterly data are back-casted and interpolated using quadratic smoothing. Housing wealth data are at current replacement costs net of capital depreciation based on ECB estimates. Data are quarterly, seasonally adjusted, expressed in million of Euro, and comprise the period 1980:1-2007:4.

Stock Price

The source is the International Financial Statistics (IFS) of the International Monetary Fund (IMF).

- For Belgium: series "12462...ZF Share price index (Share prices: INDUSTRIAL)";

- For Denmark: series "12862A..ZF Share prices: Industrial";

- For Finland: series "17262...ZF Share price index (Share prices: Industrial)";

- For France: series "13262...ZF Share price index (Share prices)";

- For Germany: series "13462...ZF Share price index (Share prices)";

- For Ireland: series "17862...ZF Share price index (Share prices)";

- For Italy: series "13662...ZF Share price index (Share prices)";

- For Netherlands: series "13862...ZF Share price index (Share prices:General)";

- For Norway: series "14262...ZF Share price index (Share prices: Industrial (2000=100))";

- For Spain: series "18462...ZF Share price index (Share prices)"; and

- For Sweden: series "14462...ZF Share price index (Share prices)".

Housing Price
The data on country-level housing prices comes from different sources.

- For Belgium: Price index of existing and new dwellings; Quarterly data 1980:1-2006:4 (Source BIS); Annual data 1970-1979 (Source: BIS) interpolated based on the Chow-Lin procedure using a construction cost index (Source: BIS) as reference series.

- For Denmark: Price index of new and existing houses, Good & poor condition; Quarterly data 1971:1-2006:4 (Source: ECB).

- For Finland: Price index of new and existing dwellings; Quarterly data 1978:1-2006:4 (Source: BIS); Annual data 1970-1977 (Source: BIS) interpolated based on the Chow-Lin procedure using the rent CPI (Source: OECD MEI) as reference series.

- For France: Price index for existing dwellings; Quarterly data 1996:1-2006:4 (Source: ECB); Price index for existing homes; Annual data 1970-1995 (Source: BIS) interpolated based on the Chow-Lin procedure using for 1980:2-1995:4 a price index for existing flats in Paris (Source: ECB) and for 1970:1- 1980:1 a cost index for new residential construction (source: BIS) and the rent CPI (Source: OECD MEI) as reference series.

- For Germany: Prices of good quality existing dwellings in 125 cities (in 4 capital cities prior to 1975); Annual data 1970-2006 (Source: BIS) interpolated based on the Chow-Lin procedure using a building cost index (Source: BIS) and the rent CPI (Source: OECD MEI) as reference series..

- For Ireland: Second hand house prices (from 1978) and new house prices (prior to 1978); Quarterly data 1975:1-2006:4 (Source: Irish Department of the Environment); New house prices; Annual data 1970-1974 (Source: ECB) interpolated based on the Chow-Lin procedure using the rent CPI (Source: OECD MEI) as reference series.

- For Italy: Price index new and existing dwellings; Semi-annual data (Source: ECB) interpolated based on the Chow-Lin procedure using a construction cost index (Source: BIS) and the rent CPI (Source: OECD MEI) as reference series.

- For Netherlands: Price index for one-family houses and existing flats; Quarterly data 1970:1-2006:4 (Source: BIS).

- For Norway: Registered purchase price of all dwellings; Quarterly data 1970:1-2006:4 (Source: BIS)

- For Spain: Price index of new and existing dwellings; Quarterly data 1987:1-2006:4 (Source: BIS); Madrid house prices; Annual data 1971-1986 (Source: BIS) interpolated based on the Chow-Lin procedure using a construction cost index (Source: OECD MEI) and the rent CPI (Source: OECD MEI) as reference series.

- For Sweden: Price Index of owner occupied new and existing dwellings; Quarterly data 1970:1-2006:4 (Source: BIS).