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Does Money Matter for the Identification of Monetary Policy Shocks: A DSGE Perspective

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Abstract

This paper investigates how the identification assumptions of monetary policy shocks modify the inference in a standard DSGE model. Considering SVAR models in which either the interest rate is predetermined for money or money and the interest rate are simultaneously determined, two DSGE models are estimated by Minimum Distance Estimation. The estimation results reveal that real balance effects are necessary to replicate the high persistence implied by the simultaneity assumption. In addition, the estimated monetary policy rule is sensitive to the identification scheme. This suggests that the way money is introduced in the identification scheme is not neutral for the estimation of DSGE models.

Keywords: SVAR model; DSGE model; Non recursive identification; Money

JEL Codes: E41, E52, C52.

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1 Introduction

Recent years have seen the withdrawal of monetary aggregates from discussions of the implementation of monetary policy. A part of the literature admits that money perfectly accommodates to variations in the interest rate – used as a policy instrument by central banks – and assumes that it does not affect the dynamics of output and inflation. From this perspective, Dynamic Stochastic General Equilibrium (DSGE) textbook models nowadays omit money from behavioral equations. The view that money is irrelevant to understanding business cycles has been supported by Woodford (2003) who argues that real balances do not govern consumption dynamics. Ireland (2004) and Andrès et al. (2006) confirm this prediction by estimating a New Keynesian DSGE model including money; they conclude that the real balances enter into neither the IS nor the Phillips curve.¹ However, this idea is still debated; for instance Favara and Giordani (2009) show that Ireland’s conclusions might be the result of failures in his theoretical model’s restrictions. Drawing on a monetary Structural Vector AutoRegressive (SVAR) model, these authors show that money demand shocks affect the dynamic behavior of output, prices and the interest rate.² Money’s role in the pursuit of monetary policy is also discussed in the literature. For instance, Woodford (2007) argues that there is no valid argument in favor of the exploitation of the information delivered by monetary aggregates. Dotsey and Hornstein (2003) reach the same conclusion by focusing on the usefulness of money in a context of optimal monetary policy. However, Christiano et al. (2007) contest this view by arguing that central banks should include

¹However, it should be noticed that Andrès et al. (2003) find that money enters significantly into the Taylor-type monetary policy rule, by estimating a DSGE model for the euro area.

²Other contributors to this debate include Rudebush and Svensson (2002) and Nelson (2002).

money and credit indicators into their information set so as to anchoring inflation expectations. Another contribution is in Leeper and Roush (2003). Based on the estimation of a SVAR model, they show that the dynamic impacts of monetary policy shocks on inflation and output depend on how money interacts with the interest rate in the identification strategy of this shock.

This paper contributes to this literature by questioning the role of money in the transmission of monetary policy shocks. Following the contributions by Rotemberg and Woodford (1997, 1999) and Christiano et al. (2005), a DSGE model featuring nominal and real rigidities is estimated by relying on the Minimum Distance Estimation (MDE) strategy that matches theoretical model-based impulse responses with those obtained from the SVAR model.³ The identification strategy of the monetary policy shock is of particular interest in this analysis.

In the MDE-DSGE literature, most papers resort to the *recursive identification strategy* – namely the Cholesky decomposition – to identify monetary policy shocks. This implies that certain private sector variables are predetermined with respect to the monetary policy shock whereas some informative variables are assumed to respond immediately after the shock. In a purely empirical analysis, Leeper and Roush (2003) estimate a monetary SVAR model but they depart from this *recursive identification strategy* by identifying the monetary policy shock so that the interest rate and money are simultaneously determined. In other words, they freely estimate both the interest elasticities of supply and demand for money.

³A non exhaustive list of contributions using the MDE strategy includes Amato and Laubach (2003), Trigari (2004), Altig et al. (2005), Boivin and Giannoni (2006), Hülsewig et al. (2006), Meier and Müller (2006), DiCecio and Nelson (2007), Carrillo et al. (2007).

Under this assumption, their key findings are a rise in both the degree of inertia exhibited by inflation and the magnitude of the responses of output and consumption to the monetary policy shock. In addition, standard overidentifying restriction tests suggest that the data favor the simultaneity specification between the interest rate and money rather than the Cholesky-type decomposition. Thus, the omission of this simultaneity in the identification strategy might result in a misspecification of the SVAR model.

In the light of these findings, one may legitimately wonder how the inferences about a DSGE model, estimated by MDE, are changed once one resorts the *non recursive identification strategy* proposed by Leeper and Roush (2003), instead of the standard Cholesky decomposition, implemented in the CEE-based model.⁴ This is the question under study in this paper. Precisely, I address two specific issues: (i) Can the CEE-based model replicate the increased amount of persistence in inflation, without relying on unreasonable degrees of nominal rigidity? (ii) Is money's role in the transmission channels of monetary policy shocks is modified by the assumptions made regarding simultaneity between the interest rate and money.

To answer these questions, I proceed in two steps. First, two SVAR models are considered which differ in the restrictions imposed to identify the monetary policy shock. In a first specification, I assume that all the macroeconomic variables are predetermined for the interest rate, except money growth, which roughly corresponds to the Cholesky decomposition. In a second specification, I follow Leeper and Roush (2003) by assuming that

⁴By CEE-based model, I mean the fully fledged model proposed by Christiano et al. (2005). This framework has become a benchmark in the literature when it comes to understanding the effects of monetary policy shocks. It features a set of frictions, namely habit formation, nominal rigidities on prices and wages, investment adjustment costs and variable capital utilization in order to reproduce the persistence properties of key macroeconomic variables.

money growth and the interest rate are simultaneously determined, which is to say that the interest elasticities of supply and demand for money are unconstrained. These quarterly SVAR models are estimated on a set of U.S. variables over the sample 1959Q2-2006Q4. Second, by using these two SVAR models, the structural parameters of a standard CEE-based model are estimated by MDE. In other words, the model's parameters are estimated so as to minimize the distance between the model-based and the SVAR-based impulse response functions.

The results emphasize that a standard DSGE model, which embodies reasonable degrees of rigidities, does a very good job to replicate the stronger persistence implied by the simultaneity assumption between the interest rate and money growth. In addition, the estimated monetary policy rule in the DSGE model is deeply changed by the identification scheme. Indeed, when the Cholesky decomposition is used, it corresponds to the standard Taylor rule in which the central bank does not pay explicit attention to money to implement its policy. However, as soon as the simultaneity assumption is made, the interest elasticity to money supply in the monetary policy rule is high and significant. This paper also shows that the real balance effect is an important monetary transmission channel under the simultaneity assumption. Indeed, allowing for unconstrained elasticities of money supply and money demand makes money highly sensitive to monetary policy shocks. This affects thereby output and inflation dynamics through the standard Euler equation and New Phillips Curve. Finally, the taste parameters and the degrees of nominal rigidities are not strongly changed by the identification scheme. Consequently, I show that the way money is inserted in the identification scheme is not neutral on the inference about DSGE models when we are interested in the transmission of monetary policy shocks.

The remainder is organized as follow. Section 2 expounds the SVAR models. Section 3 presents the theoretical model. Section 4 introduces theoretical mechanisms through which money influences the transmission of monetary policy shocks on business cycle. Section 5 presents the estimation strategy. Section 6 discusses the estimation results. The last section briefly concludes.

2 Money in a SVAR model

Two empirical SVAR models are estimated by identifying monetary policy shocks with a non recursive identification strategy. I compare two identification schemes, based on the simultaneity (or otherwise) between the interest rate and the money growth, in order to see whether the monetary aggregate provides information useful to identify monetary policy shocks. Firstly, I introduce the estimation method and secondly, I describe the identification strategy and the results.

2.1 Estimation Method

Before identifying the monetary policy shock in the SVAR model, the following canonical VAR(p) model is estimated⁵

$$x_t = \phi_1 x_{t-1} + \dots + \phi_p x_{t-p} + \varepsilon_t, \quad (1)$$

where x_t is an $(n \times 1)$ vector of data, p is the maximum lag and $\varepsilon_t \sim \text{iid}(0, \Sigma)$, where Σ is a symmetric positive definite matrix. For the estimation, U.S. quarterly data over the sample

⁵A detailed technical appendix is available upon request.

1959Q2-2006Q4 are used.⁶ Let us define x_t , the data vector

$$x_t = [\log(y_t), \log(i_t/y_t), \log(c_t/y_t), \pi_t^w, \pi_t, R_t, \Delta \log(m_t), \log(crb_t)]', \quad (2)$$

where y_t is the real output, i_t the real investment, c_t the real consumption expenditures, π_t^w the wage inflation, π_t the inflation, R_t the Fed funds rate, $\Delta \log(m_t)$ the growth rate of M2 and crb_t is commodity prices.⁷ The variables in the SVAR model have been selected so as to be consistent with the theoretical model introduced below. In addition, minimization of the Hannan-Quinn information criterion yields $p = 4$.

In order to identify monetary policy shocks, some identification restrictions are required. The relation between the reduced form residuals, ε_t , and the structural innovations, η_t can be expressed by the linear combination

$$A\varepsilon_t = \eta_t, \quad (3)$$

where A is a non singular matrix. The structural innovations are assumed to be normally distributed, such that $\eta_t \sim N(0, I_n)$.⁸

The monetary policy shock is identify by restricting the parameters on matrix A , the remaining free parameters having to be estimated. Following Lütkepohl (2005), the free parameters of A are stacked in vector denoted by γ_A and estimated by Full Information Maximum Likelihood (FIML) subject to the identification restrictions. In addition, the

⁶In the technical appendix, we proceed to a subsample analysis. Results are not modified by this analysis.

⁷A detailed description of the data sources and construction is provided in the appendix.

⁸As explained by Lutkepöhl (2005), the Gaussian distribution is assumed for computational convenience. The FIML estimators are consistent and asymptotically Normal without the Gaussian assumption, once the structural innovations are independent and identically distributed.

order condition is fulfilled by imposing no more than $n(n - 1)/2$ free parameters. Under local identification, Lütkepohl (2005) shows that the FIML estimators $\hat{\gamma}_A$ are consistent and asymptotically normally distributed.

2.2 Identification Strategy of Monetary Policy Shocks

The choice of the ordering of the variables is essential for the identification strategy of monetary policy shocks. Let the partition data vector x_t given by Equation (2) be

$$x_t = [x_{1,t}, R_t, x_{2,t}]',$$

where $x_{1,t}$ is composed of predetermined variables. I assume that private variables, namely output, investment, consumption, wage inflation and inflation respond only to their own contemporaneous disturbances and then are determined before the realization of monetary policy shocks. Vector $x_{2,t}$ collects informative variables, namely money growth and the commodity price index, responding to disturbances of all the variables within the period. Assuming that money growth is an informative variable implies that the interest elasticity of money supply is finite and has to be estimated. In addition, the commodity price index are introduced into the SVAR model in an attempt to mitigate the so-called price puzzle (Sims, 1992, Leeper and Roush, 2003).

I now turn to the identification of the monetary policy shock. Drawing on an estimated SVAR model including money, Leeper and Roush (2003) argue that the Cholesky decomposition requires extreme assumptions about the interest elasticities of money supply and money demand which in turn may imply a misspecification of the SVAR model. Following

these authors, I appraise two identification strategies differing only in the specification of the contemporaneous interactions between money growth and the interest rate. Each identification scheme results in an overidentified SVAR model. More precisely, monetary policy shocks can be formally identified with the disturbance term by

$$R_t = f(\Omega_t) + \sigma_R \eta_t^R,$$

where $\sigma_R \eta_t^R$ is a monetary policy shock, $f(\cdot)$ a linear function that represents the monetary authority's feedback rule and Ω_t the monetary authority's information set.⁹ In this paper, the two identification schemes differ in terms of Ω_t . In Scheme \mathcal{B} , it is set $\Omega_t \equiv (\eta_t^y, \eta_t^\pi)$. Then, the monetary authority's information set contains only contemporaneous disturbances of output and inflation. Therefore, the interest elasticity of money supply is assumed to be infinite which, as argued by Leeper and Roush (2003), might be viewed as an extreme assumption. This identification assumption conforms to the Cholesky decomposition (Kim, 2000; Amato and Laubach, 2003; Christiano et al., 2005). In Scheme \mathcal{C} , a non-zero restriction is relaxed by setting $\Omega_t \equiv (\eta_t^y, \eta_t^\pi, \eta_t^{\Delta m})$. Then, the contemporaneous disturbances of money growth are added into the monetary authority's information set. Consequently, the interest rate and money growth are simultaneously determined. This means that the interest elasticity of money supply has to be freely estimated. This simultaneity assumption has been used by Christiano et al. (1997), Leeper and Roush (2003) and Sims and Zha (2006). Its advantage is that it offers the possibility of distinguishing money demand disturbances

⁹Some authors also propose to measure the monetary policy instrument with the non borrowed reserves (Eichenbaum, 1992) or the money base (Poole, 1970). However, following most of the literature, the monetary policy rule features in this paper a short term interest rate as the monetary authorities' instrument (Clarida et al., 2000; Giannoni and Woodford, 2004).

from monetary policy shocks through the interest elasticities of money demand and money supply.

2.2.1 Comparison of the Impulse Response Functions

Figure 1 compares Schemes \mathcal{B} and \mathcal{C} -based Impulse Response Functions (IRFs), over 20 quarters, of the key variables in x_t , to an exogenous increase in the interest rate which corresponds to a monetary contraction.¹⁰ The overall pattern of the IRFs is not greatly altered by a change in the identification restrictions. It is worth notice that the confidence interval for all variables are nested in the two schemes, except for the response of money. The difference between the two schemes is mainly reflected in the extra persistence and the greater size of the responses. Indeed, when the interest rate and money growth are simultaneously determined, the recession is deeper. In addition, consistent with Leeper and Roush (2003), the price puzzle is reduced in Scheme \mathcal{C} . The response of wage inflation is stronger and much more persistent when simultaneity is assumed. Finally, in Scheme \mathcal{C} , the impact response of the interest rate is smaller, it displays much more persistence and the impact response of money growth is stronger.¹¹ These shifts in the responses of the interest rate and money growth highlight the key role of the assumptions made to identify monetary policy shocks.¹²

These results confirm the findings of Leeper and Roush (2003). Indeed, the size of the

¹⁰In Scheme \mathcal{C} , the size of the shock equals one standard deviation of the shock. In scheme \mathcal{B} , it corresponds to 0.68 times its standard deviation, in order to ensure that the response of the interest rate on impact is the same as in Scheme \mathcal{C}

¹¹This result was also found by Smets (2003) on euro area data.

¹²These SVAR models are not just identified. Overidentifying restriction tests (LR tests and Schwarz criterion minimization) are reported in the technical appendix. Similar results to Leeper and Roush (2003) are obtained: Scheme \mathcal{C} fits the data better than Scheme \mathcal{B} .

response of inflation, output, consumption and investment increases once we depart from the restrictions made in the Cholesky decomposition.¹³ Below, it will be investigated whether a CEE-based model is able to replicate this stronger degree of persistence without relying on unreasonable degrees of nominal rigidity. In addition, the implications on the model's inference of taking into account simultaneity between the interest rate and money growth will be examined. From this perspective, I seek to highlight the money's role in transmission channels of a monetary policy shock, especially through the real balance effects and the monetary policy representation.

3 The Theoretical Model

In this section, I describe the theoretical model based on Christiano et al. (2005).¹⁴ The framework is built so that in which the timing of events is consistent with the previous identification schemes. This means that all the optimization decisions of households and firms are made before the realization of the monetary policy shock, except households' decisions concerning asset and money holdings which are made at the same period. This specification implies that production, investment, consumption, prices and wages decisions are predetermined for monetary variables.

¹³In the technical appendix, an interesting result is provided: omitting money in a SVAR model identified with the Cholesky decomposition is not harmful. Indeed, the empirical IRFs obtained in Scheme \mathcal{B} are very close to those obtained if money is excluded from the SVAR model. This means that the inclusion of money in the empirical model has a very small effect on the variables' dynamics if the recursive decomposition assumption is made. I will show below that a theoretical monetary model is able to capture this limited role of money.

¹⁴The details of calculations are given in a technical appendix available upon request.

3.1 Production Side and Price Setting

Final good sector In the first sector, the final good d_t is produced in a competitive market by combining a continuum of intermediate goods indexed by $\varsigma \in [0, 1]$ using a CES technology

$$d_t = \left(\int_0^1 d_t(\varsigma)^{\frac{\theta_p-1}{\theta_p}} dj \right)^{\frac{\theta_p}{\theta_p-1}}, \quad (4)$$

where $d_t(\varsigma)$ denotes the overall demand addressed to the producer of intermediate good ς and θ_p is the elasticity of demand for a producer of intermediate good. The aggregate demand for final good can be decomposed into a consumption good (y_t) and a material good (x_t), which are both produced by combining the same intermediate goods, and which have the same nominal price P_t .

Intermediate good sector In the second sector, monopolistic firms produce the intermediate goods $\varsigma \in [0, 1]$. Each firm ς is the sole producer of intermediate good ς . Monopolist ς uses labor ($n_t(\varsigma)$), capital ($k_t(\varsigma)$) and material goods ($x_t(\varsigma)$) as inputs in order to produce $d_t(\varsigma)$.¹⁵ Following Rotemberg and Woodford (1995), the production process takes the functional form

$$\min \left\{ \frac{k_t(\varsigma)^\phi n_t(\varsigma)^{1-\phi} - \varkappa}{1 - s_x}, \frac{x_t(\varsigma)}{s_x} \right\} \geq d_t(\varsigma), \quad (5)$$

where s_x is the share of material goods in gross output, $0 < \phi < 1$ is the elasticity of value added with respect to capital, and \varkappa is a fixed production cost ensuring that aggregate profits are zero in its steady state. Assuming that material goods are used as input factors

¹⁵Rotemberg and Woodford (1995) emphasize the importance of distinguishing between add value in production and primary factor inputs (i.e. material goods) in imperfect competition models.

to produce intermediate goods helps to increase the degree of strategic complementarities between price-setting firms (Woodford, 2003).

Given the production function (5), firm ς chooses the level of inputs that minimize the real cost, denoted by $\mathbb{S}(d_t(\varsigma))$, of producing $d_t(\varsigma)$ units of good ς ¹⁶

$$\mathbb{S}(d_t(\varsigma)) = w_t n_t(\varsigma) R_t + r_t^k k_t(\varsigma) + x_t(\varsigma), \quad (6)$$

where w_t is the real wage and r_t^k is the real rental rate of physical capital. Following Christiano et al. (2005), the model embodies the so-called working capital channel. Precisely, firm ς must borrow wage bill ($w_t n_t(\varsigma)$) from a financial intermediary so as to pay workers one period in advance. At the end of period t , the loans are repaid by the firm at gross nominal interest rate R_t . As seen in Equation (6), *ceteris paribus*, an increase in the nominal interest rate affects positively the real marginal cost inducing in turn a transient raise in inflation.¹⁷ The aggregation of inputs is defined by $\int_0^1 n_t(\varsigma) d\varsigma = \ell_t$, and $\int_0^1 k_t(\varsigma) d\varsigma = u_t k_t$, where u_t is the utilization rate of capital. Then, the loglinearized version of the real factor demands can be expressed as¹⁸

$$\hat{w}_t = (1 - \mu_p s_x)^{-1} \hat{s}_t + \phi(\hat{k}_t + \hat{u}_t - \hat{\ell}_t) - \hat{R}_t, \quad (7)$$

$$\hat{r}_t^k = (1 - \mu_p s_x)^{-1} \hat{s}_t + (\phi - 1)(\hat{k}_t + \hat{u}_t - \hat{\ell}_t), \quad (8)$$

¹⁶Notice that since capital and aggregate labor are supplied in economy-wide markets, w_t and r_t^k do not depend on ς (Yun, 1996; Erceg et al., 2000, for instance).

¹⁷Barth III and Ramey (2002) argue that the so-called price puzzle observed in the data can be explained by the substantial investment in working capital in the US.

¹⁸Following Christiano et al. (2005), I assume for convenience, that capital accumulation and utilization decisions are made by households.

where \hat{s}_t is the logdeviation of the real marginal cost, s_t , and μ_p is the steady state price markup.¹⁹

Lastly, following Calvo (1983), I assume that in each period of time, a monopolistic firm can reoptimize its price with probability $1 - \alpha_p$, irrespective of the elapsed time since it last revised its price. If the firm cannot reoptimize its price, the latter is fully indexed to past inflation. When firm ς is allowed to reoptimize her price, she selects it so as to maximize the present discounted sum of profit streams subject to the demand she faces. Standard manipulation yield the loglinearized New Phillips Curve²⁰

$$\hat{\pi}_t - \hat{\pi}_{t-1} = \frac{(1 - \alpha_p)(1 - \beta\alpha_p)}{\alpha_p} \mathbb{E}_{t-1}\{\hat{s}_t\} + \beta \mathbb{E}_{t-1}\{\hat{\pi}_{t+1} - \hat{\pi}_t\}, \quad (9)$$

where $\hat{\pi}_t$ is the logdeviation of gross inflation $(1 + \pi_t)$ around its steady state. In addition, $\mathbb{E}_{t-1}\{\cdot\}$ is the expectation operator conditional on the information set available as of time $t - 1$ and $\beta \in (0, 1)$ is the subjective discount factor. The New Phillips Curve (9) links expected and past inflation terms to the real marginal cost, which is an increasing function of wages, rental rate of capital and the nominal interest rate.

3.2 Households' Decisions

The economy is inhabited by differentiated households indexed by $v \in [0, 1]$, each of which is endowed with a specific labor type. Typical household v seeks to maximize its lifetime

¹⁹Below, \hat{x}_t denotes the logdeviation of x_t , around its steady state, where x_t is a generic variable of the model.

²⁰The computation of the standard New Phillips Curve is detailed in a technical appendix available upon request.

utility

$$\mathbb{E}_{\Theta_t} \sum_{T=t}^{\infty} \beta^{T-t} [\mathbb{U}(c_T - bc_{T-1}, m_T) - \mathbb{V}(\ell_T(v))], \quad (10)$$

where c_T denotes real consumption at time T , $\ell_T(v)$ is the labor supplied by type- v household and m_T denotes real cash balances. In addition, \mathbb{E}_{Θ_t} is an expectation operator conditioned on the particular information set available to agents at the time they make their decisions. The aim of the paper is to stress money's role in the transmission of monetary policy shocks. To do so, I adopt the money in the utility function specification. Precisely, it is assumed that broad monetary aggregate facilitates transactions and it is held by households because it provides utility.

Household v maximizes Utility (10) subject to the sequence of constraints

$$P_T[c_T + i_T + a(u_T)k_T] + M_T + \frac{B_T}{R_T} + P_T \text{tax}_T \leq W_T(v) \ell_T(v) + P_T r_T^k u_T k_T + B_{T-1} + M_{T-1} + P_T \text{div}_T, \quad (11)$$

$$k_{T+1} = (1 - \delta)k_T + i_T \left(1 - F\left(\frac{i_T}{i_{T-1}}\right) \right), \quad (12)$$

where $w_T(v) \equiv W_T(v)/P_T$ is the real wage rate earned by type- v labor, and $b_T \equiv B_T/P_T$, where B_T denotes the nominal bonds acquired in period T and maturing in period $T + 1$. In addition, div_T denotes the profits redistributed by monopolistic firms and tax_T is a real lump-sum tax designed to finance the subsidies granted to monopolistic firms²¹. Finally, $a(u_T)$ denotes the real cost (in units of consumption good) of setting the utilization rate of u_T , and $F(\cdot)$ measures the adjustment costs related to investment. Let us assume that

²¹ Like Christiano et al. (2005), it is assumed that the government manages lump-sum taxes and it pursues a Ricardian fiscal policy. This implies that fiscal policy has no impact on the variables. Therefore, the fiscal policy is not specified.

$a(u) = 0$, where u is the deterministic steady state value of u_t . Similarly, $F(1) = F'(1) = 0$, so that the adjustment costs vanish along a deterministic balanced growth path. Let us denote $\lambda_t \equiv \Lambda_t P_t$ and $p_{k,t} \equiv \Upsilon_t / \lambda_t$, where Λ_t and Υ_t are Lagrange multipliers associated with the budget constraint (11) and the law of motion of capital (12), respectively.

Solving the household's optimization program yields the following behavioral equations expressed in their loglinearized version. First, the risk free bond equation is given by

$$\hat{\lambda}_t - \hat{R}_t = E_t\{\hat{\lambda}_{t+1} - \hat{\pi}_{t+1}\}, \quad (13)$$

where $\hat{\lambda}_t$ is marginal utility of wealth.

Second, the loglinearized version of the Euler equation on consumption is given by

$$E_{t-1}\{(1 - \beta b) \sigma \hat{\lambda}_t\} = E_{t-1}\{\beta b \hat{c}_{t+1} - (1 + \beta b^2) \hat{c}_t + b \hat{c}_{t-1} + \tau(\hat{m}_t - \beta b \hat{m}_{t+1})\}, \quad (14)$$

where $b \in (0, 1)$ is the consumption habit parameter. Let $\sigma \equiv -\mathbb{U}_c / \mathbb{U}_{cc} c$ denote the curvature of the utility function with respect to c_t . In addition, τ measures the real balance effects upon aggregate demand, such that

$$\tau = \sigma \chi, \quad \text{where } \chi = \frac{\mathbb{U}_{cm} m}{\mathbb{U}_c}.$$

Here, \mathbb{U}_m and \mathbb{U}_c denote the steady state value of the derivative of the utility function with respect to m_t and c_t , respectively.

Hereafter, τ measures to what extent a change in real money balances affects household's

consumption. The assumption of additive separability in preferences between consumption and money is well established in the literature ($\mathbb{U}_{cm} = 0$). This implies that real balance effects do not affect the marginal utility of wealth. Since $\hat{\lambda}_t$ drives the dynamics of output and inflation, a nil value of χ induces that fluctuations in real money balances have no impact on the economy. In this paper, I assume that real money balances facilitate transactions and it is complement with consumption expenditures ($\mathbb{U}_{cm} > 0$). This leads to a positive value of χ , making the marginal utility of consumption and then output and inflation responsive to real balances fluctuations. Thereafter, this parameter will be essential to investigate money's role in the monetary policy transmission channels.

Third, the money demand condition is described by

$$\hat{m}_t = \eta_c(\hat{c}_t - b\hat{c}_{t-1}) - \eta_R\hat{R}_t, \quad (15)$$

where $\eta_c \equiv -\mathbb{U}_{mc}/(\mathbb{U}_{mm}m)$ measures the consumption elasticity of money demand and $\eta_R \equiv -(1 - \beta b)\mathbb{U}_c/(\mathbb{U}_{mm}m)$ measures the interest semi-elasticity of money demand. Consequently, parameter η_R drives the magnitude of the response of money to a monetary policy shock: a high value involves that money is strongly sensitive to the interest rate variations. When the marginal utility in wealth is partially driven by real balances, the high value of η_R magnifies the response of output and inflation to monetary shocks. It will be showed below that the value of this parameter is crucial when it comes to understand money's role in the transmission of monetary policy shocks. Finally, I assume that the representative household stands next to the satiation level of money, which implies that \mathbb{U}_m tends to zero.²² Given

²²A satiation level in money is assumed here for a sake of simplicity. The idea is that the representative

their definition, parameters η_c , η_R and χ are linked by the following relationship²³

$$\eta_c = \frac{\eta_R \chi^\nu}{1 - \beta b}, \quad \text{where } \nu \equiv \frac{c}{m}. \quad (16)$$

Fourth, the Euler equation on capital is given by

$$\mathbb{E}_{t-1}\{\hat{\lambda}_{t+1} + [1 - \beta(1 - \delta)]\hat{r}_{t+1}^k + (1 - \delta)\beta\hat{p}_{k,t+1} - \hat{\lambda}_t - \hat{p}_{k,t}\} = 0, \quad (17)$$

where $\hat{p}_{k,t}$ can be interpreted as the shadow price of installed capital and δ is the depreciation rate of capital. Fifth, the household's capital utilization decision is given by

$$\sigma_a^{-1}\mathbb{E}_{t-1}\{\hat{r}_t^k\} = \mathbb{E}_{t-1}\{\hat{u}_t\}, \quad (18)$$

where $\sigma_a^{-1} \equiv a'(u)/ua''(u)$ is the elasticity of capital utilization with respect to the rental rate of capital. Fifth, the evolution of investment is given by

$$\mathbb{E}_{t-1}\{(\hat{i}_t - \hat{i}_{t-1}) - \beta(\hat{i}_{t+1} - \hat{i}_t) - \kappa^{-1}\hat{p}_{k,t}\} = 0, \quad (19)$$

household holds enough money to purchase all the consumption goods she needs, involving that holding additional cash does not facilitate transactions any further. Then, the marginal utility in money is zero at this satiation point of real balances. This assumption is relevant in an economy characterized by a monetary authority that can make large quantity of money (e.g. Woodford, 2003). Considering a non-satiation level of money would modify the money demand equation as following

$$\sigma_m^{-1}\hat{m}_t = s_m\chi(\hat{c}_t - b\hat{c}_{t-1}) - \hat{\lambda}_t - \left[\frac{s_m}{\nu}(1 - \beta b) - 1\right]\hat{R}_t,$$

where $s_m \equiv c\mathbb{U}_c/m\mathbb{U}_m$ and $\sigma_m^{-1} \equiv -m\mathbb{U}_{mm}/\mathbb{U}_m$. Parameters are linked by $s_m = \varrho/\chi$, where $\varrho \equiv c\mathbb{U}_{cm}/\mathbb{U}_m$ is the elasticity of \mathbb{U}_m with respect to changes in the level of real consumption. The estimation of the money demand equation in the non-satiation point of money would require to calibrate σ_m and s_m .

²³Practically, the value of η_c is deduced from the estimation/calibration of the parameters included in the right side of the identity. Assuming separability between consumption and money in preferences would imply that $\chi = 0$. Then, the money demand equation would be $m_t = -\eta_R\hat{R}_t$.

where \hat{i}_t denotes investment and $\kappa^{-1} = F''(1)^{-1}$ is the elasticity of investment with respect to the current price of installed capital. The loglinearized version of the law of motion for capital is defined by

$$\hat{k}_{t+1} = (1 - \delta)\hat{k}_t + \delta\hat{i}_t. \quad (20)$$

3.3 Households' Wage Setting

In this section, I focus on type- v household's labor supply decisions. Following Erceg et al. (2000), I assume for convenience that a set of differentiated labor inputs, indexed by v , are aggregated into a single labor index ℓ_t by competitive firms, which will be referred to a labor intermediaries in the sequel. They produce the aggregate labor input according to the CES technology

$$\ell_t = \left(\int_0^1 \ell_t(v)^{(\theta_w-1)/\theta_w} dv \right)^{\theta_w/(\theta_w-1)},$$

where $\theta_w > 1$ is the elasticity of substitution between any two labor types

It is assumed that, at each point in time, only a fraction $1 - \alpha_w$ of the households can set a new wage, which will remain fixed until the next time period the household is drawn to reset its wage. The remaining households fully index their wages to past inflation.

In period t , household v that can reoptimize her wage rate chooses it so as to maximize its lifetime utility subject to the budget constraint and the demand function that the labor intermediaries faces. Standard manipulations yield the loglinearized version of the wage

setting equation²⁴

$$\hat{\pi}_t^w - \hat{\pi}_{t-1} = \frac{(1 - \alpha_w)(1 - \beta\alpha_w)}{\alpha_w(1 + \omega_w\theta_w)} \mathbf{E}_{t-1}\{\omega_w \hat{\ell}_t - \hat{\lambda}_t - \hat{w}_t\} + \beta \mathbf{E}_{t-1}\{\hat{\pi}_{t+1}^w - \hat{\pi}_t\} \quad (21)$$

where $\hat{\pi}_t^w$ denotes wage inflation and $\omega_w \equiv \ell \nabla_{\ell\ell} / \nabla_{\ell}$ is the elasticity of labor disutility.

3.4 Monetary Authorities

To close the model, I consider the augmented Taylor-type rule

$$\hat{R}_t = \rho_R \hat{R}_{t-1} + (1 - \rho_R) a_\pi \hat{\pi}_t + (1 - \rho_R) a_y \hat{y}_t + (1 - \rho_R) a_m \Delta \hat{m}_t + \epsilon_{R,t}, \quad (22)$$

where $\epsilon_{R,t}$ is a serially uncorrelated monetary policy shock with $\epsilon_{R,t} \sim \text{iid}(0, \sigma_\epsilon^R)$. In addition, ρ_R measures the speed of adjustment of the interest rate to its steady state level and a_π , a_y and a_m measure the sensitivity of the interest rate to current inflation, output and money growth, respectively. The specification of this reaction function aims at being consistent with the identification Schemes \mathcal{B} and \mathcal{C} for which the elasticity of the interest rate to money growth, a_m , constitutes a key component of the analysis.

So as to be fully consistent with Scheme \mathcal{B} specification made in the SVAR model, a_m should be constrained to zero, so as to catch the standard Taylor rule. Therefore, money could be supplied perfectly elastically at the interest rate chosen by the monetary authority. Therefore, when $a_m = 0$, money could only have a role through the real balance effects since it does not appear in the interest rate rule. If these effects are negligible ($\chi = 0$)

²⁴The computation of the standard wage setting equation is detailed in a technical appendix available upon request.

– as some authors have suggested (Woodford, 2003; McCallum, 2001, Ireland, 2004) – introducing money into the model only determines the quantity of money that the monetary authorities have to supply in order to clear the monetary market. In Scheme \mathcal{C} -based theoretical specification, a_m has to be different from zero, such that money and the interest rate are determined simultaneously. Then, households acquire their money and bonds in the same period as the monetary shock and the interest rate responds to contemporaneous variations in money growth. In doing so, I seek to deal with a potential misspecification resulting from the usual assumption that the elasticity of the interest rate to money is nil. In this paper, a uniform theoretical model is considered including the augmented Taylor-type rule (a_m is not constrained to zero during the estimation procedure).

3.5 Model's Summary

The theoretical model can be summarized by Equations (9), (7), (8), (13), (14), (15), (17), (18), (19), (20), (21), the monetary policy rule (22), together with the resources and aggregate production constraints

$$[1 - \beta(1 - \delta) - \delta\beta\phi] \hat{c}_t + \delta\beta\phi\hat{l}_t + [1 - \beta(1 - \delta)] \phi\hat{u}_t = [1 - \beta(1 - \delta)] \hat{y}_t, \quad (23)$$

$$(1 - \mu_p s_x) \hat{y}_t = \mu_p(1 - s_x)[\phi(\hat{u}_t + \hat{k}_t) + (1 - \phi)\hat{l}_t], \quad (24)$$

and $\hat{\pi}_t^w = \hat{w}_t - \hat{w}_{t-1} + \hat{\pi}_t$.

4 Money's Role in the Transmission of Monetary Policy Shocks

Allowing for the non-separability of preferences between consumption and real balances extends the transmission channels of monetary policy shocks since marginal utility in wealth depends upon real balances. This section aims to stress the role assigned to money in the transmission of monetary policy shocks, particularly on output and inflation dynamics. To do this, I focus on the simplest form of the model to assess how money alters model-based dynamics. To illustrate the mechanisms, I assume that the intermediate goods are produced only with labor inputs, wages are perfectly flexible and habit persistence and price indexation can be omitted. Then, the previous New Keynesian model can be formulated in a four-equation system

$$\hat{y}_t - \hat{y}_{t+1} = \sigma\chi[\hat{m}_t - \mathbf{E}_t\{\hat{m}_{t+1}\}] - \sigma\hat{R}_t + \sigma\mathbf{E}_t\{\hat{\pi}_{t+1}\}, \quad (25)$$

$$\hat{\pi}_t = \kappa_p \left[\left[\frac{\omega_w + \phi}{1 - \phi} + \sigma \right] \hat{y}_t - \chi\hat{m}_t \right] + \beta\mathbf{E}_t\{\hat{\pi}_{t+1}\}, \quad (26)$$

$$\hat{m}_t = \chi\eta_R\nu\hat{y}_t - \eta_R\hat{R}_t, \quad (27)$$

$$\hat{R}_t = a_m\Delta\hat{m}_t + a_\pi\hat{\pi}_{t-1} + \epsilon_t. \quad (28)$$

Equation (25) corresponds to the Euler equation in output. As described above, the real balance effect is measured by the elasticity of output to changes in money. When parameter χ is strictly positive (due to the non-separability assumption between output and money), real balances fluctuations affect output dynamics. Equation (26) corresponds to the New Phillips Curve describing the dynamics of inflation. It is worth noticing that money alters

inflation dynamics for $\chi > 0$. The reason is obvious: inflation is determined by the real marginal cost. The latter is driven by wages which are, in turn, partially led by money through its impact on the marginal utility in wealth. However, a high degree of price rigidity results in a small value of κ_p , damping the effect of real balances on inflation dynamics. As emphasized by Christiano et al. (2005), allowing for wage stickiness raises inertia in inflation and lowers also the impact of real balances on inflation. Equation (27) corresponds to the money demand equation. The value of the interest semi-elasticity of money demand indicates how money is responsive to the monetary policy shock on impact. Therefore, a high value of η_R encourages fluctuations of real balances in response to monetary policy shocks, magnifying the responses of output and inflation through the real balance effect. Equation (28) corresponds to the Taylor rule enriched by money growth. A positive value of parameter a_m allows for simultaneity between money and the interest rate, indicating that these variables both influence the dynamics of the economy.

Consequently, it is worth pointing out that three parameters, namely χ , η_R and a_m , are of particular interest in exploring whether money plays a role in the transmission mechanisms of monetary policy shocks. The evaluation of these parameters allows us to explore whether the way money is introduced in the empirical and theoretical models impacts on the overall dynamics of the economy. The baseline model, described in Section 3, is estimated so as to match the SVAR-based IRFs on Schemes \mathcal{B} and \mathcal{C} . This procedure allows the performance of this model for each identification strategy to be explored.

5 Model Estimation

5.1 Calibration

The model parameters are partitioned into two groups. The first collects the parameters which are calibrated prior to estimation. These include parameters given by first order moments in the data, as well as parameters that cannot be separately identified. Let $\psi^c = (\beta, \phi, \theta_p, s_x, \theta_w, \omega_w, \delta, \nu)'$ denote the vector of calibrated parameters, whose values are reported in Table 1. The subjective discount factor is set to $\beta = 0.99$ as is conventional in the literature for models confronted with quarterly data. As usual in the literature, the elasticity of output to capital is set to $\phi = 0.36$. In addition, μ_p and s_x are calibrated since these parameters cannot be identified, once the degree of price rigidities α_p is estimated (Equation (9)). The steady state markup charged by intermediate goods producers μ_p is set to a value of 10%, as proposed by Christiano et al. (2005). In addition, I set $s_x = 0.55$ implying that $\mu_p s_x = 0.6$, as suggested by Woodford (2003). The elasticity of substitution between any two labor types θ_w is set to 21, as in Christiano et al. (2005). Choosing $\omega_w = 1$ implies a quadratic disutility of labor. In addition, the conventional value $\delta = 0.025$ implies an annual rate of depreciation on capital of 10% and actual data was used to calibrate the steady state value of money's velocity, ν , such that $\nu = 1.18$.

5.2 Estimation Strategy

The second set of model parameters is estimated by MDE. Let ψ denote the vector of estimated parameters

$$\psi = (\sigma, \chi, \eta_c, \eta_R, \alpha_p, \alpha_w, b, \kappa, \sigma_a, \rho_R, a_\pi, a_y, a_m, \sigma_\epsilon^R)'$$

In the first section, SVAR models were estimated on output, investment, consumption, wage inflation, inflation, the Fed funds rate, money growth and commodity prices from 1959Q2 to 2006Q4. The empirical $(n \times 1)$ vector of dynamic responses of the variables to a monetary policy shock j periods ago, denoted by Φ_j , are²⁵

$$\Phi_j = \frac{\partial x_{t+j}}{\partial \eta_t^R},$$

and Φ is defined by

$$\Phi = \text{vec}(\Phi_0, \dots, \Phi_h),$$

where the $\text{vec}(\cdot)$ operator transforms an $(n \times m)$ matrix into an $(nm \times 1)$ vector by stacking the columns of the original matrix and h is the final horizon. Recall that $h = 20$ quarters.²⁶

Let $\hat{\Phi}_T$ denote the empirical estimate of Φ , resulting from the estimated SVAR model where T is the sample size. As showed Lütkepohl (2005)

$$\sqrt{T}(\hat{\Phi}_T - \Phi) \xrightarrow{d} N(0, \Sigma_\Phi),$$

²⁵Since the commodity prices variable, crb_t , does not have any counterpart in the DSGE model, this variable is removed from x_t for the MDE procedure.

²⁶Since some variables are predetermined for monetary policy shocks, the corresponding lines are zero in vector Φ_0 . Thus, these lines are removed from vector Φ before estimation.

where Σ_{Φ} depends on the VAR parameters and matrices \hat{A} . In a second step, the theoretical counterparts of vector Φ , denoted by $\Phi^m(\psi^c, \psi)$, are obtained from the theoretical system which has been solved with the AIM algorithm (Anderson and Moore, 1985). Finally, estimated values of ψ , denoted by $\hat{\psi}_T$, fulfil

$$\hat{\psi}_T = \arg \min_{\psi \in \Psi} [\Phi^m(\psi^c, \psi) - \hat{\Phi}_T]' W_T [\Phi^m(\psi^c, \psi) - \hat{\Phi}_T], \quad (29)$$

where W_T is a diagonal matrix with the inverse of the asymptotic variances of each element of $\hat{\Phi}_T$ along the diagonal. Following Christiano et al. (2005), the standard errors of the estimated parameters are computed by using the asymptotic delta function method applied to the first order condition associated with Equation (29).

6 Simultaneity between Money and the Interest Rate: Some Results

In the spirit of Leeper and Roush's (2003) results, the foregoing empirical analysis indicates that simultaneity between the interest rate and money growth changes the magnitude and the persistence of the empirical responses of key variables. The purpose of this section is to investigate whether the standard CEE-based model is able to replicate these features and whether money can play a key role in the transmission channels of monetary policy shocks when the simultaneity assumption is set.

6.1 Comparison of Empirical and Theoretical IRFs

Figures 2 and 3 display model-based and SVAR-based impulse response functions, as well as the 90% asymptotic confidence intervals of the latter, when the SVAR model is identified with Schemes \mathcal{B} and \mathcal{C} , respectively. The comparison of the empirical and theoretical IRFs helps us to assess the model's ability to replicate the main features of the aggregates' dynamics after a monetary contraction.

In Figure 2, the monetary policy shock has been identified so that the interest rate is predetermined for money growth (Scheme \mathcal{B}). The empirical responses of most of the variables are well replicated by the theoretical model. Indeed, the degree of persistence and the magnitude of the model-based IRFs fit their empirical counterparts. The model is able to reproduce the hump-shaped responses of output, investment and consumption. In addition, as in Christiano et al. (2005), the introduction of the working capital channel helps the model to generate a price puzzle. Finally, the responses of the interest rate and money growth are also well reproduced. In Figure 3, the interest rate and money growth are simultaneously determined (Scheme \mathcal{C}). The goodness-of-fit of the theoretical model does not seem to be impaired while it has to generate a stronger magnitude and persistence in the IRFs. The impact response of the interest rate is over-estimated and the model has difficulty reproducing the strong magnitude of the response of consumption. Nevertheless, the model works well when it comes to reproducing the responses of output, investment and inflation. In addition, it is worth notice that the strong impact response of money growth is well replicated. Finally, the theoretical response of money growth fits its empirical counterpart reasonably well.

The goodness-of-fit of the model is quantified by resorting to bootstrap techniques so as to reveal the distribution of the minimum distance²⁷. In Schemes \mathcal{B} and \mathcal{C} , 200 bootstrap replications of the SVAR model are generated. For each replication, the parameters of the DSGE models are re-estimated and the value of the minimum distance is computed. Then, the bootstrapped distribution of this distance allows us to deduce a p-value for the overidentification test. This methodology enables us to check whether these DSGE model pass the overidentification test implied by the choice of moments. The p-value of the overidentification test statistic equals 28.06% in Scheme \mathcal{B} and 34.04% in Scheme \mathcal{C} . This means that estimated models are neither rejected by the data.

A standard fully-fledged DSGE model is able to match the extra magnitude and persistence resulting from the simultaneity assumption between the interest rate and money growth. But is this goodness-of-fit of the model is obtained in return for unreasonable estimation values? The implications for monetary parameters of taking the simultaneity in the identification procedure of the SVAR model into account are also investigated below.

6.2 Estimation Results

The first two columns in Table 2 report the estimated parameters for identification Schemes \mathcal{B} and \mathcal{C} . In a first step, I tried to estimate all the parameters in vector ψ . In each identification scheme, some parameters were characterized by binding constraints. In a second step, I enforced these equalities and estimated the remaining parameters.

²⁷Recall that since the weighting matrix W_T is not optimal, this statistic is not distributed as a χ^2 with $\dim(\hat{\Phi}_T) - \dim(\hat{\psi}_T)$ degrees of freedom. Bootstrapping the minimum distance allows us to circumvent this difficulty.

6.2.1 Monetary Policy Shock and Deep Parameters

The magnitude of the monetary policy shock, σ_e^R , is significantly estimated at between a value of 0.11 in Scheme \mathcal{B} and a value of 0.18 in Scheme \mathcal{C} . This suggests that the impulsion in the economy is not strongly altered by the identification scheme although the Fed Funds rate response is slightly over-estimated in Scheme \mathcal{C} .

Turning to the questions of whether the estimates of taste and nominal rigidity parameters vary with respect to the identification scheme, different results are found. The probability of no price adjustment, α_p , is estimated at a value of 0.71 in Scheme \mathcal{B} , which is consistent with the findings reported by Bils and Klenow (2004) based on a micro-econometrics analysis. This parameter α_p is estimated at a smaller value in Scheme \mathcal{C} ($\alpha_p = 0.43$) and is still significant. This might result from the stronger response of inflation in the first horizons, which requires more price flexibility. The probability of no wage adjustment, α_w , is estimated between 0.72 (in Scheme \mathcal{C}) and 0.75 (in Scheme \mathcal{B}) which is higher than Christiano et al. (2005) but consistent with Del Negro et al. (2007).

The preference parameters are represented by the degree of habit consumption (b) and the curvature of the utility function with respect to consumption (σ) which are closely linked in the estimation. The estimated value of parameter b is higher in Scheme \mathcal{C} ($b = 0.87$) than in Scheme \mathcal{B} ($b = 0.78$). This illustrates the difficulties encountered by the theoretical model in Scheme \mathcal{C} in reproducing the strong magnitude in the response of consumption. Parameter σ is precisely estimated and it does not vary with respect to the specification since its value is between 0.08 and 0.09.

Focusing now on the parameters related to the investment behavior, given by the invest-

ment adjustment costs parameter (κ) and the elasticity of capital utilization with respect to the rental rate of capital (σ_a^{-1}), I find that: the investment adjustment costs parameter, κ , is estimated at 12.70 in Scheme \mathcal{B} and 8.00 in Scheme \mathcal{C} , which is slightly higher than Smets and Wouters' value (2005, 2007). These values indicate that the investment is slightly elastic to a variation in the current price of capital. In addition, in Scheme \mathcal{B} , the algorithm estimation drives σ_a to a very small value. Following Christiano et al. (2005), I set $\sigma_a = 0.01$. In Scheme \mathcal{C} , the estimated value of this parameter is 0.21, but it is not significant. These small values of σ_a mean that capital utilization is highly sensitive to a variation of the rental rate of capital, as in Christiano et al. (2005).

Consequently, it appears that the estimation of the deep parameters is quite robust to the identification schemes. This fact suggests that the overall structure of the economy is not dependent on the assumptions made to identify monetary policy shocks.

6.2.2 Monetary Frictions

I can now turn to a discussion of the estimation of the degree of transaction frictions and the money demand function. Firstly, I focus on the estimated real balance effects, τ , in order to investigate whether real money balances can have an impact on consumption behavior.²⁸

The estimates of τ imply that the real balance effects are small ($\tau = 0.05$ in Scheme \mathcal{B} and 0.02 in Scheme \mathcal{C}) but significant, whatever the identification restrictions. This suggests

²⁸Ireland (2004) points out that shifts in money demand have to be considered as measures of the effect of variations in money on output and inflation. However, in this paper, we focus on the impact of money on consumption after monetary policy shocks. In this case, we do not need to take explicitly exogenous shifts in money demand into account since variations of money balances result from the monetary policy shock. Therefore, contrary to Ireland (2004), τ can be viewed only as a monetary transmission channel.

that money's role in the transmission of monetary policy shocks is not neutral.²⁹

I seek now to emphasize how identification schemes alter the estimation of the money demand equation. It appears that the consumption elasticity of money demand (η_c) and the interest semi-elasticity of money demand (η_R) are significantly estimated and they are highly sensitive to a change in the identification scheme. Indeed, η_R is close to one in Scheme \mathcal{B} ($\eta_R = 1.12$), but it strongly increases when simultaneity between the interest rate and money growth is assumed ($\eta_R = 3.39$). This result suggests that money demand is more sensitive to a variation in the interest rate in Scheme \mathcal{C} . This is not surprising if we look at the impact response of money growth to monetary policy shocks (Figure 1). Indeed, this impact response is stronger in Scheme \mathcal{C} , implying a higher interest semi-elasticity of money demand. This higher elasticity results in a larger value of η_c in Scheme \mathcal{C} ($\eta_c = 6.41$) than in Scheme \mathcal{B} ($\eta_c = 3.52$). This effect is due to Equality (16) which links these elasticities.³⁰ The estimated values of η_c are higher than usually assumed in the literature – i.e. an income elasticity of money demand of one – and emphasizes the wealth effect on money demand. Therefore, once it is assumed that the interest rate is determined simultaneously with money growth, the sensitivity of broad monetary aggregates to consumption and the interest rate is high.

6.2.3 Monetary Policy Rule

I will now explore the policy implications of enforcing the simultaneity between the interest rate and money growth in the empirical framework. The estimation of the monetary policy

²⁹Let us recall that $\tau = \chi\sigma$. I estimate χ and σ and the standard error of τ is calculated using the numerical Delta method.

³⁰Let us recall that $(1 - \beta b)\eta_c = \eta_R\chi\nu$. Since b , χ and ν are not strongly modified between Schemes \mathcal{B} and \mathcal{C} , most of the increase in η_R is offset by an increase in η_c .

rule is essential in this discussion. It appears that the degree of smoothing of the interest rate is high in Schemes \mathcal{B} and \mathcal{C} ($\rho_R = 0.85$ and 0.87 , respectively). This suggests that the behavior of the Federal Reserve is rather gradualist over the time period. In addition, in both schemes, the algorithm drives parameter a_y to zero.

In Scheme \mathcal{B} , the elasticity of the interest rate to inflation ($a_\pi = 0.89$) is higher than the elasticity of the interest rate to money growth ($a_m = 0.11$) which is not significant. On the contrary, in Scheme \mathcal{C} , parameter a_π is estimated to a smaller value ($a_\pi = 0.64$) than parameter a_m ($a_m = 0.90$). In addition, parameter a_m is just significantly estimated at a 10% level. The reversal in the weights between inflation and money growth in the monetary policy rule suggests that the propagation channels of the monetary policy shock change with respect to the identification assumption. By considering the simultaneity between the interest rate and money growth in the empirical model, I obtain that the monetary authority might react more strongly in favor of money aggregate than inflation. This suggests that money growth could constitute a variable of interest for the central bank. This is confirmed by the result that parameter a_m is not significant in Scheme \mathcal{B} whereas it is quite well estimated in Scheme \mathcal{C} . This result underlines the fact that money plays an important role in the monetary transmission channel once the simultaneity between the interest rate and money is taken into account, as suggested by Leeper and Roush (2003).

6.3 Discussion

So far, I have shown that the estimation of the monetary policy rule in the DSGE model can be modified once the simultaneity between the interest rate and money growth is taken into consideration in the empirical framework. The simultaneity assumption results in a higher

interest elasticity to money growth supply than to inflation. In addition, I have shown that a variation in the real balances has a small but significant effect on the consumption path, whatever the identification scheme. In view of these findings, it can be inferred that the question of money's role in the transmission of monetary policy shocks in a DSGE model is not straightforward. In this section, a set of exercises are carried out to investigate to what extent the consideration of monetary aggregates in the model is necessary to understand the effects of a monetary policy shock.

Investigating the Omission of Money in the Taylor Rule I start by investigating how the interest rate elasticity to money supply matters for the dynamics of a standard DSGE model. In order to emphasize money's role in the central bank's reaction function, the theoretical model is re-estimated subject to the constraint $a_m = 0$. Figures 4 and 5 depict model-based and SVAR-based IRFs (Schemes \mathcal{B} and \mathcal{C} respectively), as well as their 90% asymptotic confidence intervals, when parameter a_m is set to be zero. It clearly appears that the theoretical model is not able to replicate the response of the interest rate in Scheme \mathcal{C} . In particular, it does not generate enough persistence, implying that the model-based IRF is outside the confidence interval. In addition, this model generates less output and inflation persistence on the long-run than the baseline model. On the other hand, the model's goodness-of-fit is basically not affected in Scheme \mathcal{B} when $a_m = 0$. Surprisingly, if we compare the baseline IRFs with the constrained IRFs in Scheme \mathcal{B} , they coincide closely. This result confirms that money is not essential in the model once the Cholesky decomposition is considered. Using this bootstrap procedure, the p-value of the overidentification test statistic equals 39.03% in Scheme \mathcal{B} and 14.70% in Scheme \mathcal{C} .

The re-estimated parameters are reported in the last two columns of Table 2 where the “Constrained Model” refers to the estimation under the restriction $a_m = 0$. The estimates of the deep parameters are quite robust when money growth is removed from the monetary policy rule. However, in Scheme \mathcal{C} , due to the model’s failure to generate enough persistence in the interest rate dynamics, the smoothing parameter tends to be high ($\rho_R = 0.94$) and the elasticity of the interest rate to inflation does not even approach significance. Interestingly, the interest semi-elasticity of money demand is higher than in the benchmark estimation ($\eta_R = 4.8$), unlike the consumption elasticity of money demand ($\eta_c = 3.5$). This indicates that, deprived of money in the monetary policy rule, the model links the interest rate and money through the money demand equation. Under the simultaneity assumption, the dynamics of these monetary variables have to be closely related to replicate the strong persistence in the interest rate.

This result confirms that money is essential in the monetary policy rule if the relationship between the interest rate and money growth is left free during the identification of monetary policy shocks. The primordial role of money in central bank decisions is interpreted by Smets (2003) as an indication that money contains information about future output and price so that money can be viewed as a forward looking indicator. Although the DSGE model of this paper cannot be used to confirm this interpretation, it may be that money can be viewed as a useful indicator for monetary policy decisions.

What Determines Real Balance Effects? In a second exercise, I will further investigate the role of real balance effects in monetary transmission channels and its determinants. Although the real balance effects seem to be small for both identification strategies, I will

seek to demonstrate their contribution to the model's dynamics.

Figure 6 compares Schemes \mathcal{B} and \mathcal{C} 's theoretical IRFs based on the benchmark estimation when parameter τ is set to zero³¹. In Scheme \mathcal{B} , it appears that the IRFs do not vary much when real balances are omitted, except for consumption. The previous result – which emphasizes that the non-augmented Taylor-type rule is sufficient in Scheme \mathcal{B} to represent the reaction function of the Federal Reserve – leads us to conclude that money plays a negligible role in monetary transmission channels when the Cholesky decomposition is retained. This result supports the assertion of Woodford (2003) and Ireland (2004), among others, that real balances have basically no role in the behavioral equations of the theoretical model. On the contrary, in Scheme \mathcal{C} , all the theoretical IRFs are modified once the real balance effects assumption is dropped. It appears that the real balance effects help the model to generate persistent impulse response functions. In addition, the magnitude of the response of the interest rate is greater once real balances are introduced into the Euler equation on consumption.

This exercise shows that the omission of real balances in the Scheme \mathcal{C} -based model has a dramatic impact on the model's dynamics, especially for output and inflation. This observation brings us to the question: why do real balances matter in monetary transmission channels when we allow for simultaneity between money and the interest rate? As emphasized in Section 4, the value of the interest semi-elasticity of money demand, η_R , plays a crucial role in the determination of money's response to monetary policy shocks. In particular, a high sensitivity of real balances to monetary policy shocks magnifies the responses of output and inflation, through the Euler Equation (25) and the Phillips Curve

³¹In practice, all the model's parameters are set to their estimated value except for χ which is set to zero.

(26). Figure 7 compares Scheme \mathcal{C} 's theoretical IRFs of output and inflation when real balance effects are included and omitted, for different values of η_R . The first panel shows the effect of omitting real balance effects in the benchmark calibration, characterized by a high value of η_R ($\eta_R = 3.39$). As discussed above, when money is highly responsive to the monetary policy shock, the responses of output and inflation are magnified by real balance effects. The second panel shows the effect of omitting real balance effects for a small η_R ($\eta_R = 1.18$, as estimated in Scheme \mathcal{B}). As expected, the responses of output and inflation are less affected by the omission of real balance effects since money is slightly sensitive to the monetary policy shock.

This result leads us to investigate whether the high estimated value of η_R in Scheme \mathcal{C} matches the reduced form money demand equation obtained from the SVAR model. Reporting the estimated coefficients on money demand equation from the SVAR model yields³²

$$\Delta m_t = \underset{(0.20)}{0.41} y_t - \underset{(1.71)}{4.13} R_t + \underset{(0.06)}{0.14} i_t + \underset{(0.17)}{0.23} c_t + \underset{(0.11)}{0.11} \pi_t^w + \underset{(0.25)}{0.24} \pi_t. \quad (30)$$

It appears that the interest semi-elasticity of money demand is significantly estimated at a value of 4.13. As shown above, the theoretical model is able to match this value ($\eta_R = 3.39$). This indicates that the theoretical model does a good job of reflecting the strong link between money and the interest rate observed in the data when simultaneity between these variables is allowed.³³ It is worth noticing that the MDE procedure is a relevant approach for allowing

³²The reduced form of the money demand equation is deduced from the estimation by FIML of the coefficients in matrices A and B . The numbers in parentheses are the standard errors of the parameters.

³³When it comes to the reduced form of the monetary policy rule, the elasticity of the interest rate to money growth is 0.62 with a standard error of 0.48. Therefore, the theoretical model is also able to reproduce this high elasticity.

the model to capture the high interest semi-elasticity of money demand. Indeed, the latter is only determined by the impact response of money growth to the monetary policy shock, all other variables being predetermined. In other words, the MDE procedure allows us to focus on the role of money in the transmission of monetary policy shocks and to replicate the strong relationship between money and the interest rate observed in the SVAR model.³⁴

The interest semi-elasticity of money demand is crucial to understanding the role of money in monetary transmission channels. However, other factors potentially affect the role of real balances in the model's dynamics. For instance, Section 4 suggests that the degree of price stickiness also plays a role in the determination of real balance effects on inflation dynamics. Indeed, a high degree of price rigidity, α_p , makes inflation less sensitive to the real marginal cost and thereby to monetary fluctuations (e.g. Equation (26)). Figure 8 compares Scheme \mathcal{B} 's theoretical IRFs of output and inflation when real balance effects are included and omitted, for different values of α_p .³⁵ In the benchmark calibration, α_p is estimated at a value of 0.71, and inflation is slightly altered by the omission of real balance effects. Setting a smaller degree of price rigidity ($\alpha_p = 0.43$, as estimated in Scheme \mathcal{C}) does not affect this result since real balance effects seem to play a minor role in the monetary transmission channel. This suggests that price rigidity does not alter the role of money in monetary transmission channels.

³⁴This could explain why the results differ from those obtained by Ireland (2004) and Andrés et al. (2006). These authors evaluate the role of money in the business cycle and therefore do not focus on the transmission of monetary policy shocks. By adopting the MDE procedure, I focused on the response of money to a monetary policy shock and showed that the impact response of real balances growth is strong under the simultaneity assumption. In turn, this results in fluctuations in real balances that spread into output and inflation dynamics.

³⁵Since the interest semi-elasticity of money demand is estimated to a small value in Scheme \mathcal{B} , real balances fluctuations have a negligible role on output and inflation dynamics. Therefore, investigating the determinants of real balance effects requires us to emphasize those factors which are able to expand this role.

The elasticity of the interest rate to real balances, a_m , indicates whether money and the interest rate are related into the monetary policy rule. A high value of a_m makes the interest rate and money dynamics more dependant, implying that real balances are more sensitive to monetary policy shocks, spreading in turn to output and inflation dynamics (Equations (25) and (26)). As shown above, omitting simultaneity between money and the interest rate in the Scheme \mathcal{C} -based model modifies money's role in the transmission of monetary policy shocks. In particular, it alters the estimation of the money demand equation. To investigate further the role of a_m , Figure 8 compares Scheme \mathcal{B} 's theoretical IRFs of output and inflation when real balance effects are included and omitted, for different values of a_m . As shown in Figure 6, the real balance does not play a significant role in the model's dynamics in the benchmark calibration characterized by a small value of a_m ($a_m = 0.11$). As expected, assuming a stronger elasticity of the interest rate to real balances ($a_p = 0.614$ and $a_m = 0.90$, as estimated in Scheme \mathcal{C}) clearly affects money's role in output and inflation dynamics. Omitting the real balance effects makes the responses of output and inflation to the monetary policy shock less persistent.

Overall, these results confirm that high interest semi-elasticity of money demand and elasticity of the interest rate to real balances are key elements in understanding money's role in monetary transmission channels. Allowing simultaneity between money and the interest rate makes the real balances more sensitive to the monetary policy shocks which affect output and inflation dynamics through the Euler equation and the Phillips curve.

Conclusion

In this paper, I proceeded in two steps. First, two monetary SVAR models were estimated. They differ in terms of the restrictions, set to identify monetary policy shocks. A misspecification of an empirical SVAR model might result from the extreme assumptions on the interest elasticities of money supply and money demand, which are imposed when the Cholesky decomposition is used (Leeper and Roush, 2003). The impulse responses of key variables according to the degree of simultaneity between the interest rate and money growth were compared. Second, a theoretical monetary model was estimated by MDE. Then, it was investigated whether this standard DSGE model was able to replicate the higher persistence and magnitude of inflation and output resulting from the assumption that the interest rate and money growth are simultaneously determined. In addition, I assessed how the estimates of the DSGE model are changed with respect to the identification scheme in several SVAR model. Finally, I explored whether the money's role in the transmission channel of monetary policy shocks varies according to the identification strategy.

Many results were obtained. The CEE-based model, which embodies reasonable degrees of rigidities, is able to replicate the stronger persistence implied by the simultaneity assumption between the interest rate and money growth. In addition, I highlight the significant role of money in the transmission channels of monetary policy shocks when the interest rate and money growth are simultaneously determined in the identification of the shock. The high interest semi-elasticity of money demand and the high interest elasticity to money supply implies that money fluctuations spread into the output and inflation dynamics through the real balance effect operating into the Euler equation and the New Phillips Curve. This

suggests that money is not neutral on the model's dynamics once the relationship between the interest rate and money growth is left free during the identification of monetary policy shocks.

Accepted manuscript

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Data Appendix

The SVAR model is estimated with quarterly data over the sample 1959Q2-2006Q4. All the series are seasonally adjusted except for the interest rate and commodity prices. The series are constructed as follows. y_t is the real output from non-farm business sector (Source: Bureau of Labor Statistics). i_t is the fixed private investment (Source: Bureau of Economic Analysis) which is divided by the implicit price deflator of output. c_t is personal consumption of non-durable goods and services (Source: Bureau of Economic Analysis) which is divided by the implicit price output deflator. π_t^w is the growth rate of hourly compensation in the non-farm business sector (Source: Bureau of Labor Statistics). π_t is the growth rate of the implicit price output deflator in the non-farm business sector (Source: Bureau of Labor Statistics). R_t is the Federal funds rate (Source: Federal Reserve Board). Δm_t is the growth money of M2 (Source: Federal Reserve Board). crb_t is the Commodity Research Bureau (CRB) spot commodity price index for raw industrials (Source: CRB). The variables y_t , i_t , c_t and Δm_t are expressed in per-capita terms by dividing by the civilian non-institutional population, age 16 and over. In addition, $\log(y_t)$, $\log(i_t)$, $\log(c_t)$, $\log(crb_t)$ are linearly detrended.

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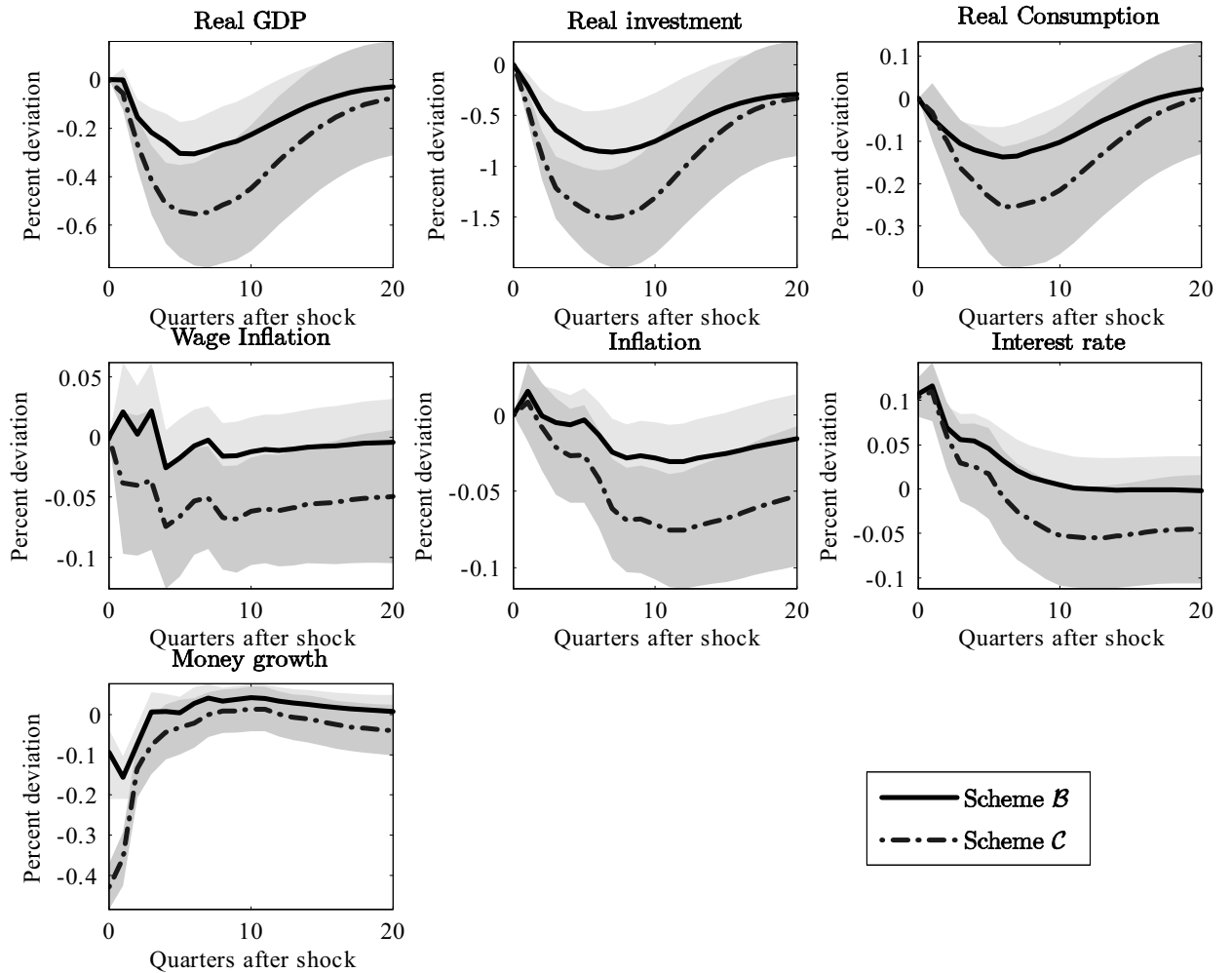


Figure 1: Comparison of the empirical impulse response functions (multiplied by 100) over the period 1959Q2-2006Q4. Light grey areas correspond to the 90% confidence intervals in Scheme \mathcal{B} . Dark grey areas correspond to the 90% confidence intervals in Scheme \mathcal{C} .

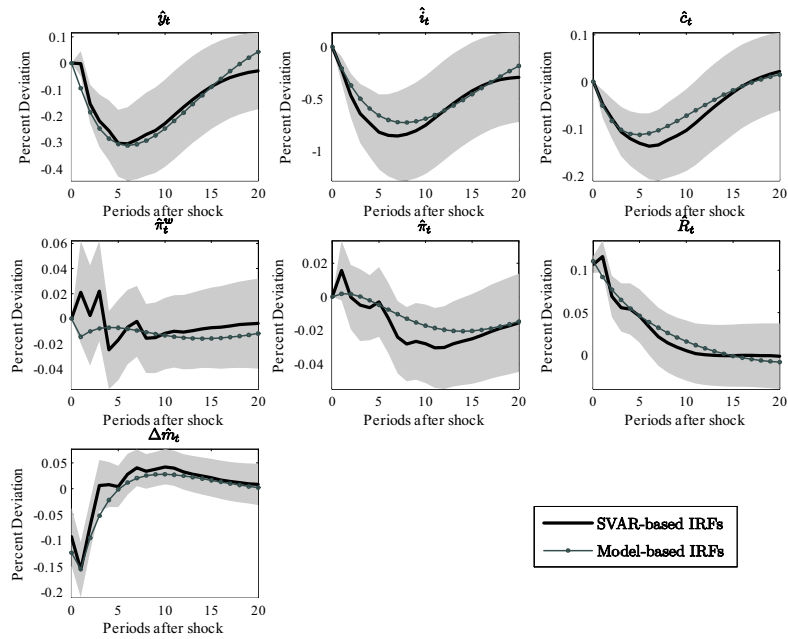


Figure 2: SVAR-based IRFs (solid lines) and model-based IRFs (lines with circle) (multiplied by 100) for a monetary policy shock, in Scheme \mathcal{B} . Grey areas correspond to the 90% confidence intervals.

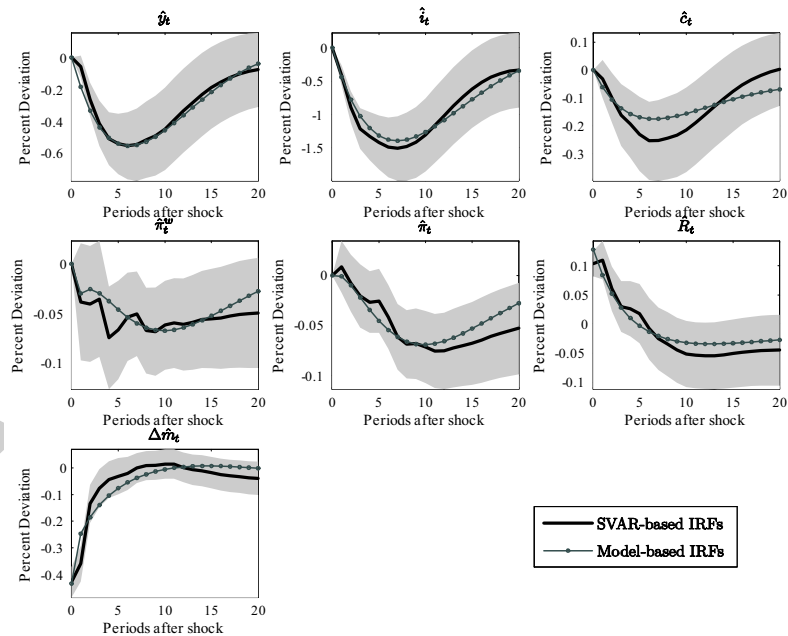


Figure 3: SVAR-based IRFs (solid lines) and model-based IRFs (lines with circle) (multiplied by 100) for a monetary policy shock, in Scheme \mathcal{C} . Grey areas correspond to the 90% confidence intervals.

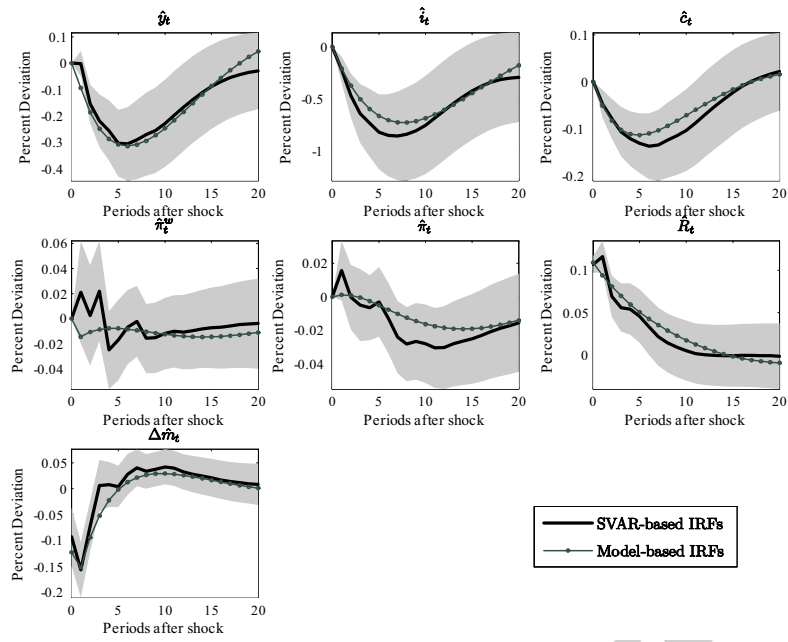


Figure 4: SVAR-based IRFs (solid lines) and model-based IRFs (lines with circle) (multiplied by 100) for a monetary policy shock, in Scheme \mathcal{B} , when $a_m = 0$. Grey areas correspond to the 90% confidence intervals.

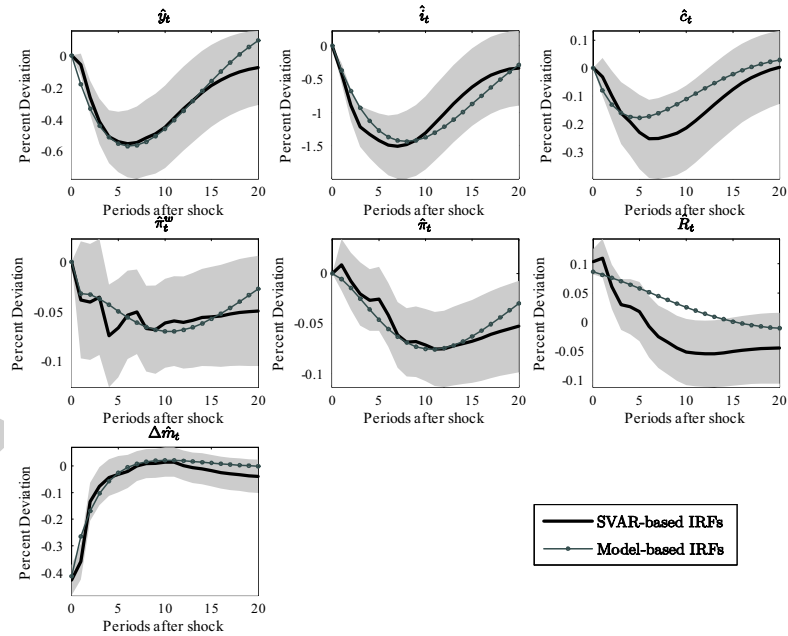


Figure 5: SVAR-based IRFs (solid lines) and model-based IRFs (lines with circle) (multiplied by 100) for a monetary policy shock, in Scheme \mathcal{C} , when $a_m = 0$. Grey areas correspond to the 90% confidence intervals.

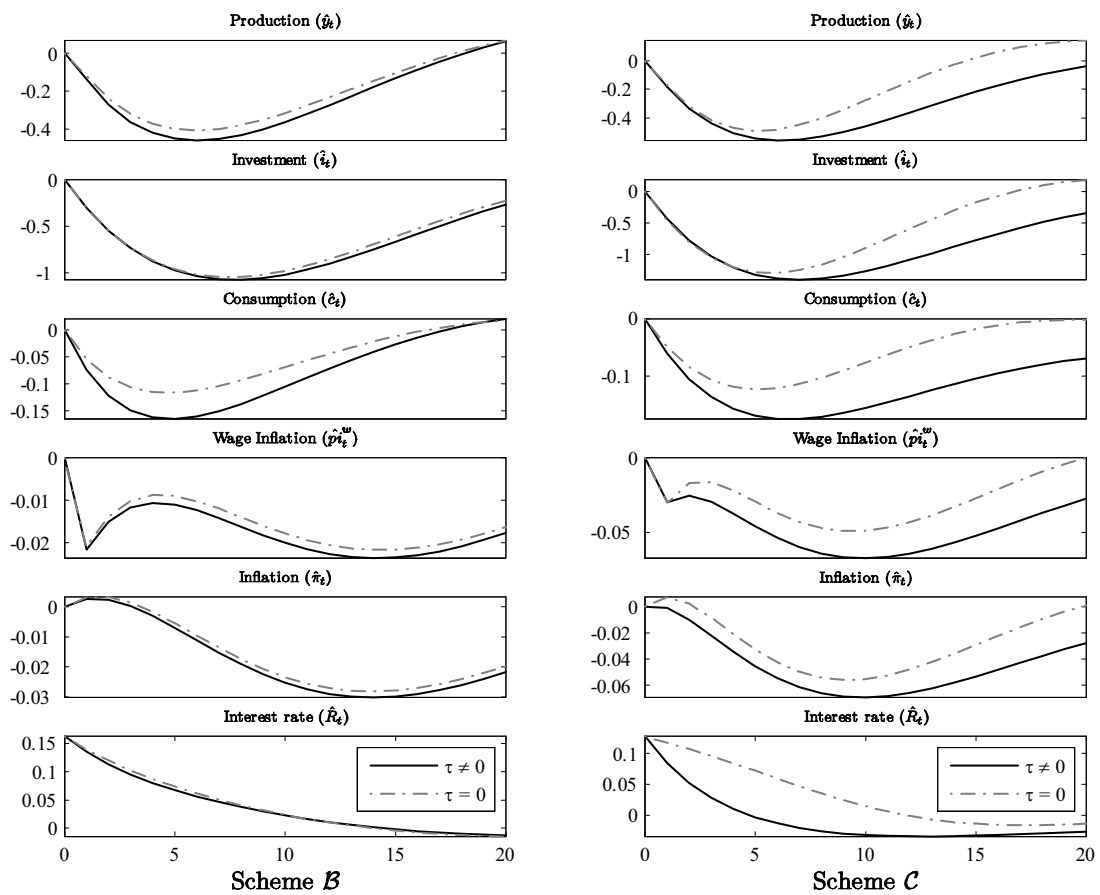


Figure 6: Model-based IRFs (multiplied by 100) in the benchmark estimation (solid lines) and when real balance effects are omitted (dotted lines). The left panel corresponds to Scheme \mathcal{B} and the right panel corresponds to Scheme \mathcal{C} .

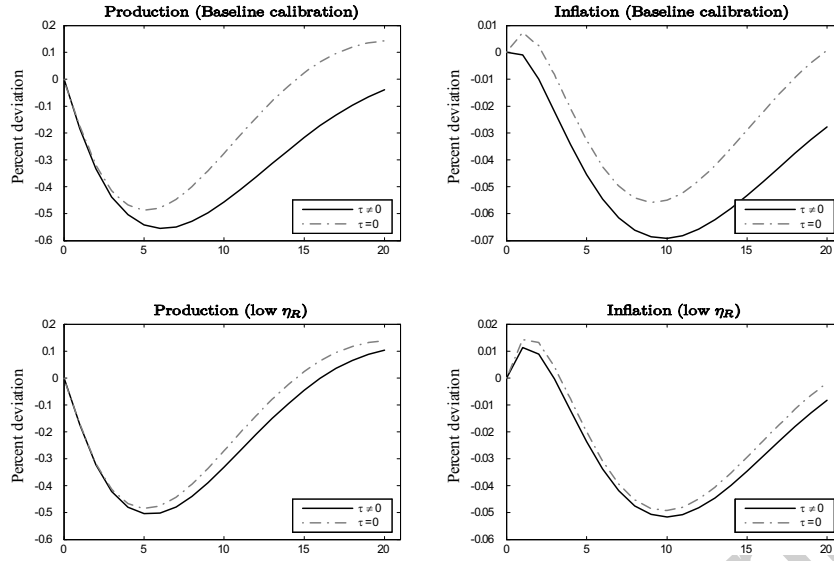


Figure 7: Scheme \mathcal{C} -based IRFs (multiplied by 100) in the benchmark estimation (upper panel) and for $\eta_R = 1.11$ (lower panel). Solid lines correspond to the benchmark estimation of τ ($\tau = 0.02$), while dotted lines corresponds to the case that omits real balance effects.

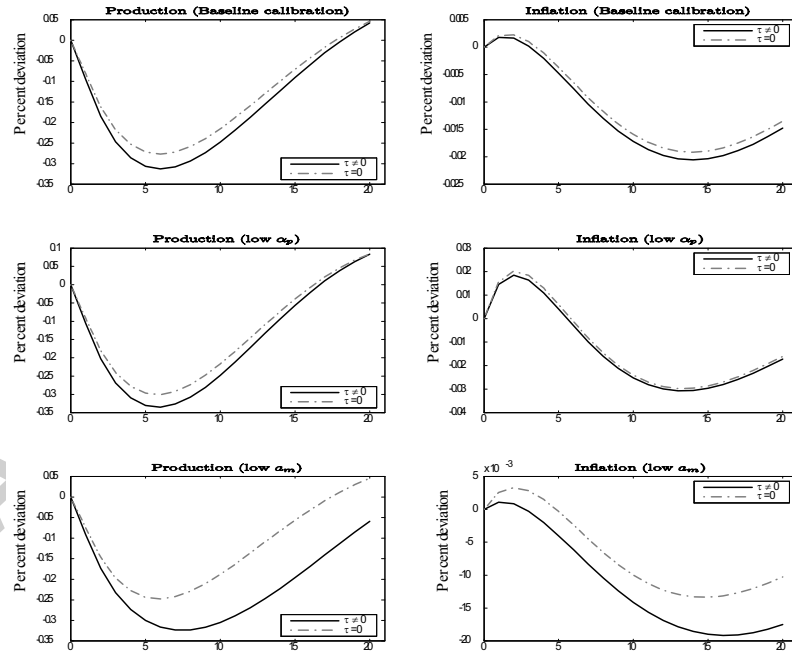


Figure 8: Scheme \mathcal{B} -based IRFs (multiplied by 100) in the benchmark estimation (upper panel), for $\alpha_p = 0.43$ (medium position panel) and for $a_m = 0.90$ (lower panel). Solid lines correspond to the benchmark estimation of τ ($\tau = 0.05$), while dotted lines corresponds to the case that omits real balance effects ($\tau = 0$).

Table 1. Calibrated Parameters

Parameters	Value
β	0.99
ϕ	0.36
θ_p	6.00
s_x	0.55
θ_w	21.00
ω_w	1.00
δ	0.025
ν	1.18

Table 2. Results of MDE estimation (1959Q2-2006Q4)

Scheme	Baseline Model		Constrained Model ($a_m = 0$)	
	\mathcal{B}	\mathcal{C}	\mathcal{B}	\mathcal{C}
Monetary Policy Shocks				
σ_ϵ^R	0.113 (0.007)	0.176 (0.021)	0.109 (0.005)	0.086 (0.010)
Taste and Rigidity Parameters				
α_p	0.715 (0.100)	0.429 (0.194)	0.749 (0.097)	0.593 (0.164)
α_w	0.754 (0.022)	0.720 (0.058)	0.758 (0.032)	0.768 (0.037)
b	0.787 (0.052)	0.869 (0.049)	0.796 (0.050)	0.725 (0.054)
σ	0.085 (0.020)	0.093 (0.036)	0.087 (0.022)	0.063 (0.011)
κ	12.697 (2.848)	8.002 (2.657)	13.094 (2.884)	18.095 (2.242)
σ_a	0.010 (*)	0.206 (0.208)	0.010 (*)	0.070 (0.151)
Monetary Frictions				
τ	0.050 (0.001)	0.021 (0.000)	0.046 (0.001)	0.011 (0.000)
η_R	1.118 (0.298)	3.395 (0.420)	1.125 (0.303)	4.797 (0.700)
η_c	3.524 (0.022)	6.410 (0.039)	3.389 (0.020)	3.551 (0.024)
Monetary Policy Rule				
ρ_R	0.853 (0.017)	0.875 (0.053)	0.860 (0.017)	0.943 (0.038)
a_π	0.894 (0.256)	0.641 (0.271)	1.013 (0.380)	1.038 (1.160)
a_y	0.000 (*)	0.000 (*)	0.000 (*)	0.000 (*)
a_m	0.114 (0.144)	0.901 (0.549)	—	—
$\mathcal{J} - stat$	49.562 (0.281)	64.049 (0.340)	50.238 (0.390)	110.178 (0.147)

Notes: *Unconstrained model:* Scheme \mathcal{B} : the interest rate predetermined for money growth. Scheme \mathcal{C} , the interest rate and money growth simultaneously determined. *Constrained model:* the model is re-estimated by enforcing $a_m = 0$. The numbers in parentheses are the standard errors of the parameters. A star refers to a constraint imposed during the estimation stage to avoid convergence issues.