The role of money and monetary policy in crisis periods: the case of the Eurozone

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Abstract

We study the role of money and monetary policy in crisis periods, with reference to the Eurozone. In this analysis, we compare the performance of two New Keynesian dynamic stochastic general equilibrium (DSGE) models, that is, (i) a baseline model without money and (ii) a model with money factored in. We test both models by using successive Bayesian estimations over three crisis periods, namely, the ERM crisis, the dot-com crisis, and the subprime crisis along with the beginning of the debt crisis. The results indicate that money shocks have a larger impact on output variations during crises, especially in the case of the subprime crisis. Furthermore, the response of output to a money shock is more persistent during the subprime crisis than the other crises. The impact of monetary policy also changes during crises. Insofar as the financial crisis is concerned, this impact increases at the beginning of the crisis, but decreases sharply thereafter. Finally, the analysis demonstrates that during crises, the model with money generally provides better output forecasts than the baseline model.

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1 Introduction

Since the seminal paper of Smets and Wouters (2003), and even as far back as the development of the New Keynesian paradigm in the mid-1990s, traditional New Keynesian dynamic stochastic general equilibrium (DSGE) models have not given an explicit role to money, neither in the Eurozone, nor in the US. When money is taken into consideration, its impact is generally found to be negligible (Ireland, 2003; Andrés et al., 2006, 2009; Barthélemy et al., 2011). Yet, Benchimol and Fourçans (2012) find that when risk aversion is sufficiently high, money has an impact on output dynamics. Furthermore, Canova and Menz (2011) use a small-scale structural monetary business cycle model to find that output and inflation fluctuations are influenced by money.

Whatever the structures of these models, monetary policy is a central tenet and its impact on output and inflation—through interest rate adjustments—is well-documented, for example, in Smets and Wouters (2007).

The roles of money and monetary policy may also change during crises. The Great Financial Crisis hints at these possible changes. The policy arena surrounding these questions is ripe with endless debates, notably with respect to monetary policy and its possible influence on output and inflation. Chadha et al. (2013) find that money conveys significant information to the central bank when there are shocks to credit supply, as may be the case during crises. Also, El-Shagi and Giesen (2013) analyze the consequences of the Federal Reserve's response to the financial crisis and find evidence of the substantial impact of money on US prices. The role of money in the US business cycle is also highlighted in El-Shagi et al. (2014).

Analyses conducted via New Keynesian DSGE models may be useful for clarifying these questions. In order to conduct this type of analysis, it is essential to introduce money explicitly into such a model, compare this model with one where money has not been explicitly introduced, and conduct empirical analyses that focus on crisis periods. This approach enables us to study the role of money and monetary policy, in order to more explicitly determine whether their impact on output and inflation is affected during crises.

The impact of money and monetary policy may change for various reasons; for instance, changes in the transmission mechanism due to variations in banks' behavior, changes in money holding and consumption/investment behaviors, changes in portfolio allocation between money and other assets, changes in expectations or risk evaluation, and more generally, increase in uncertainty, and so forth.

The purpose of this paper is to focus on the impact of money and monetary policy on the dynamics of the economy during crises.

In terms of meaningful statistical observations, crisis periods do not, in general, last very long. Hence, in order to capture the impact of short-run changes in the dynamics of the economy, there is a need to use as short sample periods as possible. Yet, one also needs to obtain a sufficient number of observations in order to achieve statistically significant sample sizes.

To deal with these two types of questions—namely, bringing forth the role of money and monetary policy and taking into consideration the short sample constraint—our research strategy consists of comparing two types of micro-founded New Keynesian models in a DSGE framework and testing them over periods short enough to capture the crisis effects, but long enough to be statistically meaningful.

The first model is a standard one, where money is omitted from the utility function and the monetary policy rule, as in the baseline model of Galí (2008). The second model introduces money in two ways. First, money is introduced in the utility function by assuming non-separability between real money balances and consumption[1]. Non-separability between consumption and real balances could be significant in the Eurozone, especially during crisis periods (Jones and Stracca, 2006). Second, money is introduced in the central bank policy rule in order to further study its role in our DSGE framework.

We apply Bayesian techniques to estimate these two models. We use Eurozone data over periods that include three different crises, namely, the beginning of the 1990s when there were speculative currency attacks on the European exchange rate mechanism (ERM); the growth and bust of the dot-com bubble in the beginning of the 2000s; and the subprime crisis and the beginning of the debt crisis from 2007 through 2011.

We analyze the dynamics of both models by studying the variance decomposition of the variables with respect to structural shocks (our focus is money and monetary policy shocks, but markup and technology shocks are also taken into consideration) over the three periods. We also study the forecasting performances of the models in each period, as well as the responses of output, flexible-price output, output gap and inflation to the shocks (IRF). Focusing on each of these periods sheds light on the specific role of money and monetary policy in crisis situations. It also provides informative results regarding output and inflation dynamics during periods of uncertainty.

The analysis shows that the impact of money on output and flexible-price output variances increases during crises. The response of output to a money shock also increases, especially during peaks of the ERM and the subprime crises. The persistence of the response of output and flexible-price output

[1] Here, the term separability must be differentiated from the terminology used in monetary aggregation literature (Barnett, 1980).

to a money shock is higher during the subprime crisis than during the other crises. The impact of conventional monetary policy on output and inflation also changes during crises. More specifically, as far as the subprime crisis is concerned, the impact of monetary policy on output and inflation constantly increases until the peak of the crisis (2008 Q3). It then decreases sharply over the next two quarters, and remains at a lower and stable level through 2011.

The response of flexible-price output to a money shock during the subprime crisis is about as strong as the response of output itself, and in addition is significantly stronger and longer lasting than during the other crises. Yet, a monetary policy shock appears to have no effect on flexible-price output for either of the crises.

Finally, our analysis demonstrates that during crises, a New Keynesian model with non-separable preferences between money and consumption and with money introduced in the monetary policy rule leads to better output forecasts than a standard New Keynesian model without money.

In Section 2, we set up the models used for the empirical analysis presented in Section 3. We analyze the ERM crisis in Section 4, the dot-com crisis in Section 5, and focus on the subprime crisis in Section 6. We compare the three crises in Section 7 and offer a conclusion in Section 8.

2 The models

Both models consist of households that supply labor, purchase goods for consumption, and hold bonds; and firms that hire labor and produce and sell differentiated products in monopolistically competitive goods markets. Each firm sets the price of the good it produces, but not all firms reset their price during each period. Households and firms behave optimally, that is, households maximize the expected present value of utility, and firms maximize profits. There is also a central bank controlling the nominal rate of interest. These models are inspired by Smets and Wouters (2007), Galí (2008), and Walsh (2010).

2.1 The baseline model without money

The following New Keynesian DSGE model is mainly inspired by Galí (2008) and serves as a baseline model (Model 1).

2.1.1 Households

We assume a representative infinitely-lived household, seeking to maximize

$$E_t\left[\sum_{k=0}^{\infty}\beta^k U_{t+k}\right], \tag{1}$$

where U_t is the period utility function and $\beta < 1$ is the discount factor.

The household decides how to allocate its consumption expenditures among the different goods. This requires that the consumption index C_t be maximized for any given level of expenditure. Furthermore, and conditional on such optimal behavior, the period budget constraint takes the form

$$P_tC_t + M_t + Q_tB_t \leq B_{t-1} + W_tN_t + M_{t-1} \tag{2}$$

for $t = 0, 1, 2....$ Here, P_t is an aggregate price index, M_t is the quantity of money holdings at time t, B_t is the quantity of one-period nominally riskless discount bonds purchased in period t and maturing in period $t+1$ (each bond pays one unit of money at maturity and its price is Q_t, where $i_t = -\ln Q_t$ is the short-term nominal rate), W_t is the nominal wage, and N_t is hours of work (or the measure of household members employed).

The above sequence of period budget constraints is supplemented with a solvency condition, such as $\forall t \lim_{n\longrightarrow\infty} E_t[B_n] \geq 0$, in order to avoid Ponzi-type schemes. Preferences are measured with a common time-separable utility function (MIU). Under the assumption of a period utility given by

$$U_t = \frac{C_t^{1-\sigma}}{1-\sigma} - \frac{\chi N_t^{1+\eta}}{1+\eta}, \tag{3}$$

where consumption, labor, money, and bond holdings are chosen to maximize Eq. 1, subject to the budget constraint Eq. 2 and the solvency condition. σ is the coefficient of relative risk aversion of households (or the inverse of the intertemporal elasticity of substitution), η is the inverse of the elasticity of work effort with respect to the real wage, and χ is a positive scale parameter.

2.1.2 Firms

Backus et al. (1992) have shown that capital appears to play a rather minor role in the business cycle. Therefore, to simplify the analysis and focus on the role of money, we do not include a capital accumulation process in the model, as in Galí (2008).

We assume a continuum of firms indexed by $i \in [0,1]$. Each firm produces a differentiated good but uses an identical technology with the following production function:

$$Y_t(i) = A_t N_t(i)^{1-\alpha}, \tag{4}$$

where $A_t = \exp(\varepsilon_t^a)$ is the level of technology assumed to be common to all firms and to evolve exogenously over time, ε_t^a is the technology shock, and α is the measure of decreasing returns.

All firms face an identical isoelastic demand schedule and take the aggregate price level P_t and aggregate consumption index C_t as given. As in the standard Calvo (1983) model, our generalization features monopolistic competition and staggered price setting. At any time t, only a fraction $1-\theta$ of firms, with $0 < \theta < 1$, can reset their prices optimally, whereas the remaining firms index their prices to lagged inflation.

2.1.3 Central bank

Finally, the model is closed by adding the following monetary policy smoothed Taylor-type reaction function:

$$\hat{\imath}_t = (1-\lambda_i)\left(\lambda_\pi(\hat{\pi}_t - \pi^*) + \lambda_x\left(\hat{y}_t - \hat{y}_t^f\right)\right) + \lambda_i \hat{\imath}_{t-1} + \varepsilon_t^i, \tag{5}$$

where λ_π and λ_x are policy coefficients reflecting the weight on inflation and the output gap, respectively; whereas the parameter $0 < \lambda_i < 1$ captures the degree of interest rate smoothing. ε_t^i is an exogenous *ad hoc* shock that accounts for fluctuations in the nominal interest rate, π^* is the inflation target, and the lowercase superscript $(\hat{\ })$ denotes log-linearized (around the steady state) variables.

2.1.4 Solution

The solution of this model leads to four equations with four variables, namely, flexible-price output $(\hat{y}_t^f)$, inflation $(\hat{\pi}_t)$, output $(\hat{y}_t)$, and nominal interest rate $(\hat{\imath}_t)$; and three structural shocks that are assumed to follow a first-order autoregressive process with an *i.i.d.*-normal error term such as $\varepsilon_t^k = \rho_k \varepsilon_{t-1}^k + \omega_{k,t}$, where $\omega_{k,t} \sim N(0;\sigma_k)$ for $k = \{p, i, a\}$.

$$\hat{y}_t^f = \frac{1+\eta}{\sigma(1-\alpha)+\eta+\alpha}\varepsilon_t^a - \frac{(1-\alpha)\ln\left(\frac{\varepsilon}{\varepsilon-1}\right)}{\sigma(1-\alpha)+\eta+\alpha}, \tag{6}$$

$$\hat{\pi}_t = \beta E_t[\hat{\pi}_{t+1}] + \frac{(1-\theta)\left(\frac{1}{\theta}-\beta\right)(\sigma(1-\alpha)+\eta+\alpha)(1+(\varepsilon-1)\varepsilon_t^p)}{1+(\varepsilon-1)(\varepsilon_t^p+\alpha)}\left(\hat{y}_t - \hat{y}_t^f\right), \tag{7}$$

$$\hat{y}_t = E_t\left[\hat{y}_{t+1}\right] - \sigma^{-1}\left(\hat{\imath}_t - E_t\left[\hat{\pi}_{t+1}\right]\right), \tag{8}$$

$$\hat{\imath}_t = (1-\lambda_i)\left(\lambda_\pi\left(\hat{\pi}_t - \pi^*\right) + \lambda_x\left(\hat{y}_t - \hat{y}_t^f\right)\right) + \lambda_i \hat{\imath}_{t-1} + \varepsilon_t^i, \tag{9}$$

where ε_t^p is the price markup shock, ε_t^i is the monetary policy shock, and ε_t^a is the technology shock.

The first baseline model is close to Galí (2008) and does not include money in the utility function, the production function, or in the Taylor rule.

2.2 The model with money

This model assumes that households gain utility from holding money (Model 2). Money could be introduced in the utility function (MIU) either in a separable or non-separable manner. In the case where money is included in a separable manner, even though households gain utility from holding money, real money balances become irrelevant in explaining the dynamics of the model. Hence, our strategy is to introduce money with a non-separability assumption between consumption and real money balances. In this case, the marginal rate of substitution between current and future consumption depends on current and future real money balances. Therefore, there is a link between holding money and consumption during the period.

As in the previous model, the representative infinitely-lived household seeks to maximize Eq. 1 with the period utility function U_t, such as

$$U_t = \frac{1}{1-\sigma}\left((1-b)\,C_t^{1-\nu} + be^{\varepsilon_t^m}\left(\frac{M_t}{P_t}\right)^{1-\nu}\right)^{\frac{1-\sigma}{1-\nu}} - \frac{\chi}{1+\eta}N_t^{1+\eta}, \tag{10}$$

where consumption, labor, money, and bond holdings are chosen to maximize Eq. 1, subject to the same budget constraint and the same solvency condition as in the baseline model. This constant elasticity of substitution (CES) utility function depends positively on the consumption of goods, C_t, positively on real money balances, M_t/P_t, and negatively on labor, N_t, as in the baseline model. ν is the inverse of the elasticity of money holdings with respect to interest rate and can be seen as a *non-separability* parameter. b and χ are positive scale parameters. We use the same production function as in the baseline model.

In addition, a money variable is introduced in the central bank policy rule in order to further explain the role of money. Generally, in the literature, money is introduced through a money growth variable (Ireland, 2003; Andrés et al., 2006, 2009; Canova and Menz, 2011; Barthélemy et al., 2011). Benchimol and Fourçans (2012) introduce a *money-gap* variable and show that, at least in the Eurozone, it is empirically more significant than other measures of the money variable. Such a rule can be derived from the optimization program of the central bank as a social planner (Woodford, 2003). We, therefore, use a *money-gap* variable in our Taylor rule.

The model leads to six equations with six macro variables, namely, flexible-price output ($\hat{y}_t^f$), flexible-price real money balances ($\widehat{mp}_t^f$), inflation ($\hat{\pi}_t$), output ($\hat{y}_t$), nominal interest rate ($\hat{\imath}_t$), and real money balances ($\widehat{mp}_t$), such that

$$\hat{y}_t^f = \upsilon_a^y \varepsilon_t^a + \upsilon_m^y \widehat{mp}_t^f - \upsilon_c^y + \upsilon_{sm}^y \varepsilon_t^m, \tag{11}$$

$$\widehat{mp}_t^f = \upsilon_{y+1}^m E_t\left[\hat{y}_{t+1}^f\right] + \upsilon_y^m \hat{y}_t^f + \frac{1}{\nu}\varepsilon_t^m, \tag{12}$$

$$\hat{\pi}_t = \beta E_t\left[\hat{\pi}_{t+1}\right] + \kappa_{x,t}\left(\hat{y}_t - \hat{y}_t^f\right) + \kappa_{m,t}\left(\widehat{mp}_t - \widehat{mp}_t^f\right), \tag{13}$$

$$\begin{aligned}\hat{y}_t \;=\;& E_t\left[\hat{y}_{t+1}\right] - \kappa_r\left(\hat{\imath}_t - E_t\left[\hat{\pi}_{t+1}\right]\right) \\ &+\kappa_{mp} E_t\left[\Delta\widehat{mp}_{t+1}\right] + \kappa_{sm} E_t\left[\Delta\varepsilon_{t+1}^m\right],\end{aligned} \tag{14}$$

$$\widehat{mp}_t = \hat{y}_t - \kappa_i \hat{\imath}_t + \frac{1}{\nu}\varepsilon_t^m, \tag{15}$$

$$\hat{\imath}_t = (1-\lambda_i)\left(\lambda_\pi\left(\hat{\pi}_t - \pi^*\right) + \lambda_x\left(\hat{y}_t - \hat{y}_t^f\right) + \lambda_m\left(\widehat{mp}_t - \widehat{mp}_t^f\right)\right) + \lambda_i \hat{\imath}_{t-1} + \varepsilon_t^i, \tag{16}$$

where

$$\begin{aligned}
\upsilon_a^y &= \tfrac{1+\eta}{(\nu-a_1(\nu-\sigma))(1-\alpha)+\eta+\alpha} & \kappa_r &= \tfrac{1}{\nu-a_1(\nu-\sigma)}\\
\upsilon_m^y &= \tfrac{(1-\alpha)(\nu-\sigma)(1-a_1)}{(\nu-a_1(\nu-\sigma))(1-\alpha)+\eta+\alpha} & \kappa_{mp} &= \tfrac{(\sigma-\nu)(1-a_1)}{\nu-a_1(\nu-\sigma)}\\
\upsilon_c^y &= \tfrac{(1-\alpha)}{(\nu-a_1(\nu-\sigma))(1-\alpha)+\eta+\alpha}\ln\left(\tfrac{\varepsilon}{\varepsilon-1}\right) & \kappa_{sm} &= -\tfrac{(1-a_1)(\nu-\sigma)}{(\nu-a_1(\nu-\sigma))(1-\nu)}\\
\upsilon_{sm}^y &= \tfrac{(1-\alpha)(\nu-\sigma)(1-a_1)}{((\nu-a_1(\nu-\sigma))(1-\alpha)+\eta+\alpha)(1-\nu)} & \kappa_i &= a_2/\nu\\
\upsilon_y^m &= 1+\tfrac{a_2}{\nu}\left(\nu-a_1\left(\nu-\sigma\right)\right) & a_1 &= \tfrac{1}{1+(b/(1-b))^{1/\nu}(1-\beta)^{(\nu-1)/\nu}}\\
\upsilon_{y+1}^m &= -\tfrac{a_2}{\nu}\left(\nu-a_1\left(\nu-\sigma\right)\right) & a_2 &= \tfrac{1}{\exp(1/\beta)-1}
\end{aligned}$$

$$\begin{aligned}
\kappa_{x,t} &= \left(\nu-a_1\left(\nu-\sigma\right)+\tfrac{\eta+\alpha}{1-\alpha}\right)\tfrac{(1-\alpha)\left(\frac{1}{\theta}-\beta\right)(1-\theta)\left(1+(\varepsilon-1)\varepsilon_t^p\right)}{1+\left(\alpha+\varepsilon_t^p\right)(\varepsilon-1)}\\
\kappa_{m,t} &= (\sigma-\nu)\left(1-a_1\right)\tfrac{(1-\alpha)\left(\frac{1}{\theta}-\beta\right)(1-\theta)\left(1+(\varepsilon-1)\varepsilon_t^p\right)}{1+\left(\alpha+\varepsilon_t^p\right)(\varepsilon-1)}.
\end{aligned}$$

As can be seen, money enters explicitly in the equations that determine output (current output, Eq. 14, and its flexible-price counterpart, Eq. 11) and inflation (Eq. 13). Money enters these equations because consumption and money are linked in the agent's utility function and $Y_t = C_t$ at equilibrium.

Notice that if $\sigma = \nu$, Eq. 10 becomes a standard separable utility function, where the direct influence of real money balances on output, inflation, and flexible-price output disappears.

3 Empirical results and analysis

3.1 Data

We use the same data set for both models of the Eurozone. $\hat{y}_t$ is the output per capita, measured as the difference between the log of the real GDP per capita and its linear trend; $\hat{\pi}_t$ is the inflation rate, measured as the yearly log difference of the GDP deflator from one quarter to the same quarter of the previous year; and $\hat{\imath}_t$ is the short-term (three-month) nominal interest rate. The latter two are linearly detrended. This data set is extracted from the (Euro) Area Wide Model database (AWM) of Fagan et al. (2001). $\widehat{mp}_t$ is the real money balances per capita, measured as the difference between the real money per capita and its linear trend, where real money per capita is measured as the log difference between the money stock per capita and the GDP deflator. We choose the $M3$ monetary aggregate from the Eurostat database. As in Andrés et al. (2006), Barthélemy et al. (2011), Benchimol and Fourçans (2012), and De Santis et al. (2013), $M3$ is used because it serves as the institutional definition of money in the Eurozone and plays a prominent role in the definition of monetary policy[2].

$\hat{y}_t^f$, the flexible-price output, and $\widehat{mp}_t^f$, the flexible-price real money balances, are entirely determined by structural shocks.

3.2 Methodology

Theoretically, only very short sample sizes (from one to a few years) are able to capture the changes in the values of parameters, owing to short-run crises.

[2] Kelly et al. (2011) suggest that official monetary aggregates, at least in the US, use an aggregation methodology that is increasingly incorrect as the aggregate becomes broader. Yet, theory-consistent monetary aggregates (Barnett, 1980) are not published by the European Central Bank (ECB).

Yet, to be reliable, statistical analyses necessitate a sufficient amount of observations. As far as we know, there is no specific statistical rule establishing the minimum number of observations necessary for reliable Bayesian tests. To deal with this issue, we follow Fernández-Villaverde and Rubio-Ramírez (2004) and choose a sample size of 48 observations (quarterly data over 12 years). Indeed, these authors demonstrate that such a sample size is sufficient to obtain valid Bayesian estimations. The confidence in such small sample size tests is reinforced by the fact that several studies have shown that the small sample performances of Bayesian estimates tend to outperform classical ones, even when evaluated by frequentist criteria (Geweke et al., 1997; Jacquier et al., 2002).

The periods of interest are presumed to contain higher uncertainty than standard periods. We choose to study three crises, as indicated earlier, in the years between 1990 Q1 and 2011 Q1. For *every* quarter of each crisis period, we run a Bayesian estimation by using the 48 observations *before* each respective quarter.

We calibrate both models as explained in the Appendix A. We also run simulations and DSGE forecasts for both models, for every quarter in each crisis period (Appendix B).

Our purpose in this paper is not to present all the results, a very cumbersome task indeed. Instead, from the estimates, we intend to draw the evolution of the variance decomposition of variables with respect to different shocks in the short and the long runs. We also intend to compare the forecasting performance of both models, and compare the main IRFs over crises.

The estimates provide values of micro and macro parameters through time that affect the dynamics of the variables. Fig. 22 through Fig. 24 show that our results are stable over the different periods. The role of each shock can be analyzed *via* the successive estimations and simulations, leading to variance decompositions of variables with respect to the shocks (the markup shock (ε_t^p), the technology shock (ε_t^a), the monetary policy shock (ε_t^i), and the money shock (ε_t^m) for the model with money). For reasons already explained, we center this analysis on money and monetary policy shocks.

After each estimation, we perform out-of-sample DSGE forecasts (each over four periods, that is, one year) to compare the forecasting performance of both models[3]. To conduct these forecasting exercises, we simulate our

[3] DSGE models are increasingly being utilized by central banks and other policy-making institutions to assist with policy decisions and forecasting, as pointed by Edge and Gürkaynak (2010). Sims and Zha (1998) introduced Bayesian methods to vector autoregressive (VAR) models to improve the accuracy of out-of-sample forecasts in a dynamic multivariate framework. More recently, researchers have started to examine the forecasting

estimated models starting with a given state and analyze the trajectories of the forecasted endogenous variables.

Finally, we analyze the responses of output, flexible-price output, output gap and inflation to money and monetary policy shocks. In order to avoid an over-cumbersome paper, we do not present all the IRFs for each crisis. We select two key points for each crisis, and for both models when appropriate, and compare the IRFs at different key points.

This analysis is done by using Metropolis–Hastings iterations on the basis of the posterior means of each estimated variable. Then, we evaluate the forecasts with respect to the actual data. Finally we compare the forecasts of both models by calculating their respective root mean-squared deviations (RMSD). After calculating the sum of the absolute values of the corresponding RMSD over four out-of-sample forecasts, we compare these values between the two models.

4 European exchange rate mechanism crisis

The first period under scrutiny includes the European exchange rate mechanism (ERM) crisis of 1992. The peak of the crisis is characterized by the so called *Black Wednesday*. This refers to the events of Wednesday, September 16, 1992, when the British government withdrew the pound sterling from the European ERM.

The period of analysis is from 1990 Q1 through 1994 Q1. Other crises also occurred during this period, such as the oil crisis following the first Gulf war[4] from 1990 Q2 through 1991 Q2; the Russian crisis[5] from 1992 Q2 through 1992 Q4; and the French real estate crisis[6] from 1992 through 1996. In addition to the ERM crisis, these episodes also affected the Eurozone.

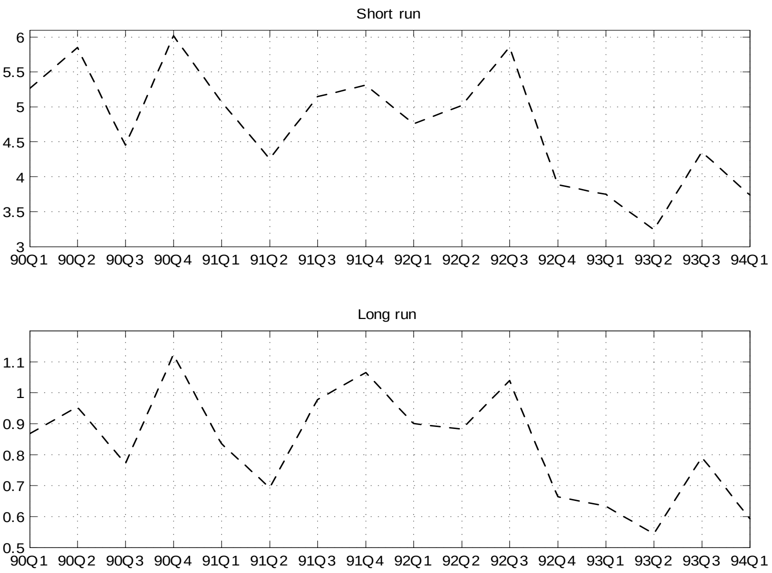

Figure 1: Variance decompositions of output with respect to the money shock (in percent) in Model 2

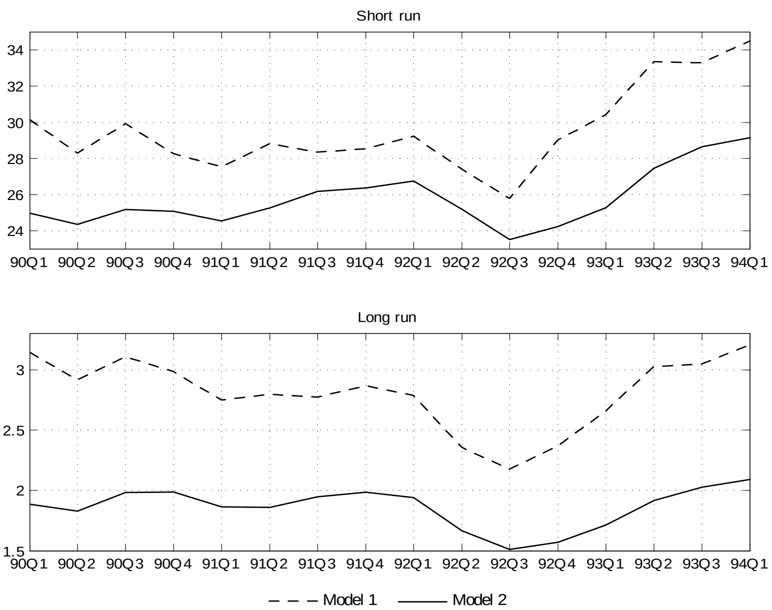

Figure 2: Variance decompositions of output with respect to the monetary policy shock (in percent) in Model 1 (solid lines) and Model 2 (dashed lines)

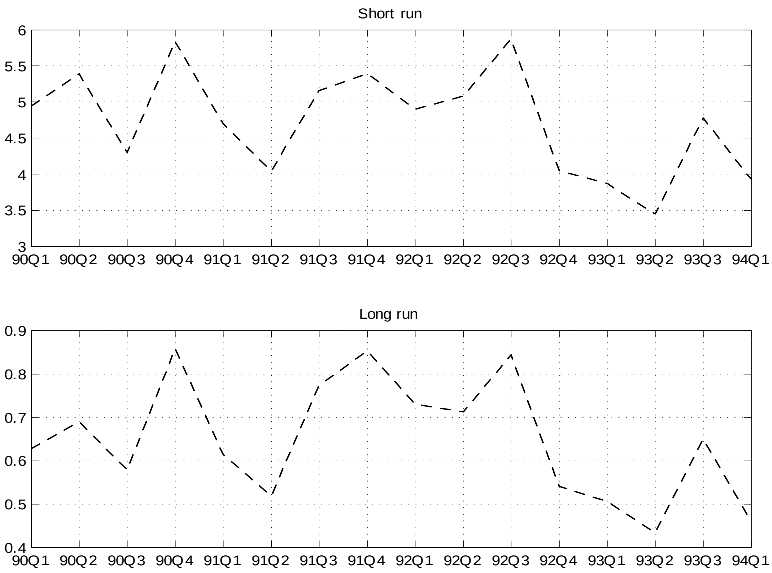

Figure 3: Variance decompositions of flexible-price output with respect to the money shock (in percent) in Model 2

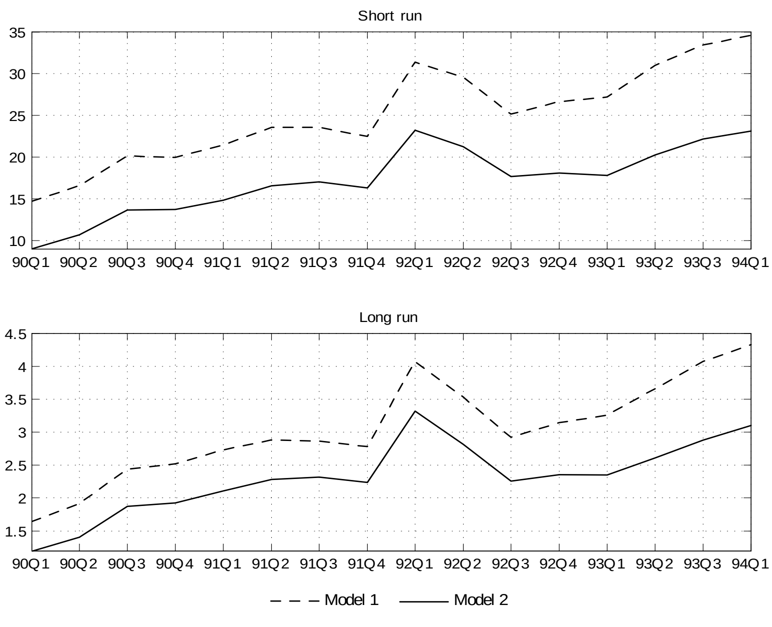

Figure 4: Variance decompositions of inflation with respect to the monetary policy shock (in percent) in Model 1 (solid lines) and Model 2 (dashed lines)

4.1 Variance decomposition

For each Bayesian estimation of each model, we compute the short-run (conditional to the first period) and long-run (unconditional) variance decomposition of the variables with respect to the shocks.

As seen in Fig. 1, the impact of money (Model 2) on output in the short run is relatively small, but not negligible. It reaches a peak in 1990 Q2, 1990 Q4, and 1992 Q3. It remains at a higher level during the ERM crisis (an impact of more than 5% on variance in the short run). The impacts in the long run are small, but follow the same pattern.

The monetary policy shock plays a significant role in output fluctuations in the short run (Fig. 2). It explains just below 30% of the output variance before 1992 Q3 for Model 2, and the percentage increases quickly from this period. The long-run impact is much smaller but non-negligible.

All in all, output variability is mainly explained by the monetary policy shock (around 30%) and the technology shock (around 60%) in the short run for both models. The technology shock explains most of the variance in the long run (around 87%) for both models. The markup shock has a negligible role on output in both the short and long runs.

Fig. 3 shows that money also plays a small but non-negligible role in explaining flexible-price output variations in the short run. The dynamics of these impacts follow a path similar to that of current output, with peaks at the same periods as far as current output is concerned. The long-run impact of money on flexible-price output remains very small.

Regardless of the model, the monetary policy shock (not shown here) has no impact on flexible-price output dynamics in either the short or long run. Flexible-price output is essentially explained by the technology shock in both runs (around 90%) for both models.

The variance decomposition of inflation shows that the money shock has a very small role to play, be it in the short or long run (less than 2%). As Fig. 4 demonstrates, the monetary policy shock has a significant impact on

performance of these models. In one such investigation, Smets and Wouters (2007) show that a DSGE model can generate forecasts that have a lower root mean-squared deviation (RMSD) than a Bayesian Vector Autoregression (BVAR). On the other hand, Edge et al. (2010) show that the out-of-sample forecasting performance of the Federal Reserve Board's new DSGE model for the US economy (EDO) is in many cases better than their large-scale macro-econometric model (FRB/US).

[4] The 1990 oil price spike occurred in response to the Iraqi invasion of Kuwait on August 2, 1990. The war lasted until February 28, 1991.

[5] The constitutional crisis of 1993 was a political stand-off between the Russian president and the Russian parliament that was resolved by using military force.

[6] From 1992 through 1996, real estate prices declined up to 40%.

inflation dynamics in the short run, but a very small one in the long run. The markup shock is important as well (around 80%) in the short run and dominates the process in the long run (around 96%) for both models.

Fig. 2 and Fig. 4 indicate that the short-run impact of monetary policy on output remained relatively constant, whereas its impact on inflation increased from the beginning of the period until the peak of 1992 Q3. It increased in both cases after 1992 Q3 and the ERM crisis, whatever the model used.

However, the role of monetary policy appears to be greater in Model 2, with stronger impacts in the short than in the long run[7].

4.2 Forecasting performances

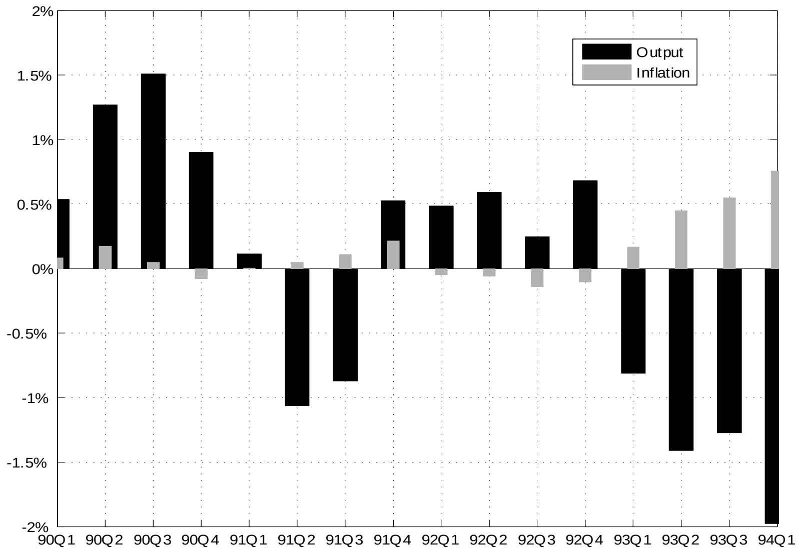

Figure 5: Comparison of output and inflation DSGE forecast errors—Model 2 is better when the bar is positive; Model 1 is better otherwise.

As mentioned previously, from each Bayesian estimation, we simulate the out-of-sample forecasts of output and inflation over the next four periods (one year) and compare these values to the historical values. This enables us to compute the RMSD of each period for each model. A negative number

[7]We do not present the decomposition of output, flexible-price output, and inflation with respect to the markup and technology shocks. As they are negligible, we present neither the decomposition of inflation with respect to the money shock nor the decomposition of the flexible-price output with respect to the monetary policy shock. However, all these variance decompositions are available upon request.

(negative bar) implies that the RMSD of the non-separable model is higher than that of the baseline model. In such cases, the forecasting performance of Model 1 is better than that of Model 2.

Fig. 5 shows that Model 2 has better predictive power for output dynamics than Model 1 when speculative attacks on currencies occurred between 1991 Q4 and 1992 Q4. It is also the case in 1990, when other crisis events impacted the Eurozone (essentially, the oil crisis following the Gulf War).

In terms of inflation, Fig. 5 shows that the predictive power of both models is quite similar, except after the ERM crisis where Model 2 dominates Model 1.

4.3 Interpretation

The previous analysis suggests that money had a stronger impact on output during this crisis than during more stable periods. Furthermore, this impact is stronger than what Ireland (2004) and Andrés et al. (2006) found.

The variation of the expected money growth parameter (κ_{mp} in Eq. 14) and of the expected money shock growth parameter on output (κ_{sm} in Eq. 14) in Model 2 are the main factors that explain this result.

The change in the impact of money on flexible-price output is very much determined by the variations in the money shock parameter (υ^{y}_{sm} in Eq. 11).

The transmission mechanism of shocks follows a complex process in our models. Such complexity is manageable when studying the impact of the money shock; an analysis of the macro-parameters is, in this case, sufficient to interpret changes in the transmission process. It is more complicated to interpret changes in the transmission mechanism of a monetary policy shock. An analysis of the values of the macro-parameters alone is not sufficient. The monetary policy shock (ε^{i}_{t} in Eq. 9 and Eq. 16) enters the model through the Taylor rule; furthermore, there is no macro-coefficient enabling a direct study of its impact. Therefore, it is hard to analyze the changes in the impact of such a shock, other than through the variance decomposition results.

Fig. 2 indicates that in 1992 Q3, at the peak of the ERM crisis, the impact of monetary policy on output reaches its lowest level. This may be due to the conduct of monetary policy, which in that period, was more focused on limiting exchange rate variations than on stabilizing output.

The RMSD errors comparison (Fig. 5) highlights two different periods, namely, from 1990 Q2 through 1991 Q1 and from 1991 Q4 through 1992 Q4. These periods, also identified in Fig. 1, show that the impact of money on output in these crisis periods and the predictive abilities of Model 2 over Model 1 are related.

Fig. 5 also reflects the fact that there is a significant difference between both models with respect to errors in growth forecasting.

5 Dot-com crisis

The bursting of the dot-com bubble in the Eurozone occurred approximately one quarter later (2000 Q3) than in the United States (2000 Q2). Our period of study is from 1999 Q1 through 2003 Q1. This enables us to analyze the peak of the bubble in the Eurozone (2000 Q2–Q3) and the period following the burst of the bubble.

5.1 Variance decomposition

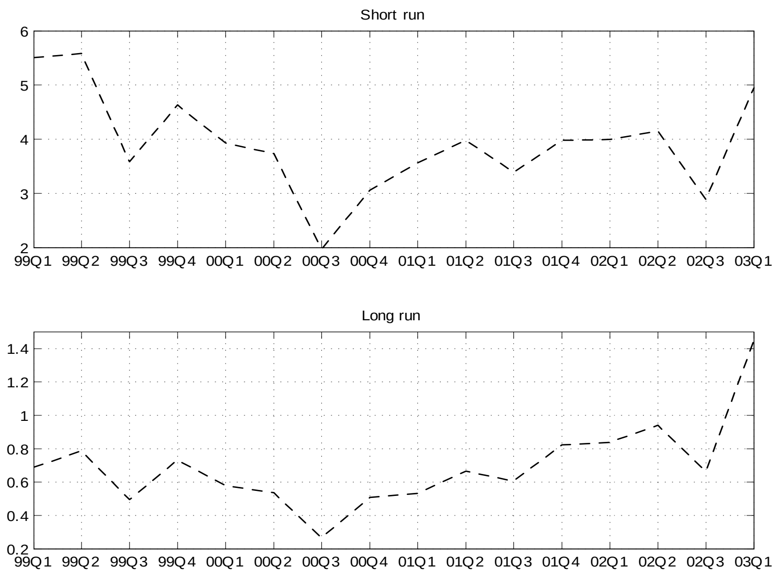

Figure 6: Variance decompositions of output with respect to the money shock (in percent) in Model 2

The impact of the money shock on output variance when the bubble was in process (between 2000 Q1 and Q4) is decreasing and small, in the short run as well as in the long run (Fig. 6). The decreasing trend from 1999 Q2 through 2000 Q3 corresponds to the bubble formation. However, the impact increases after the burst of the bubble (2000 Q3), even if not very significantly.

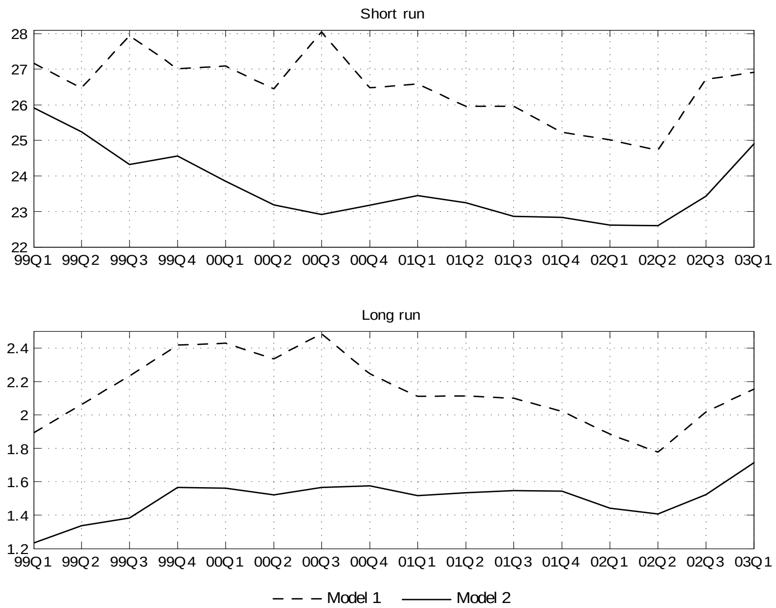

Figure 7: Variance decompositions of output with respect to the monetary policy shock (in percent) in Model 1 (solid lines) and Model 2 (dashed lines)

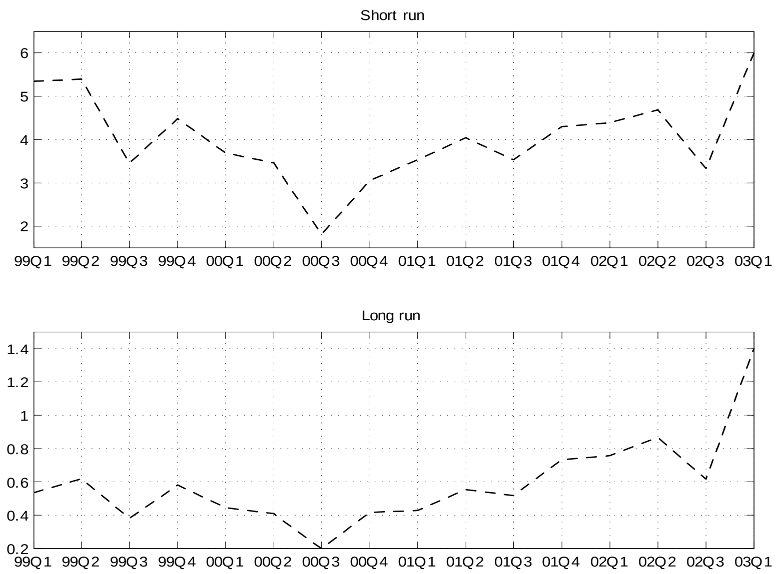

Figure 8: Variance decompositions of flexible-price output with respect to the money shock (in percent) in Model 2

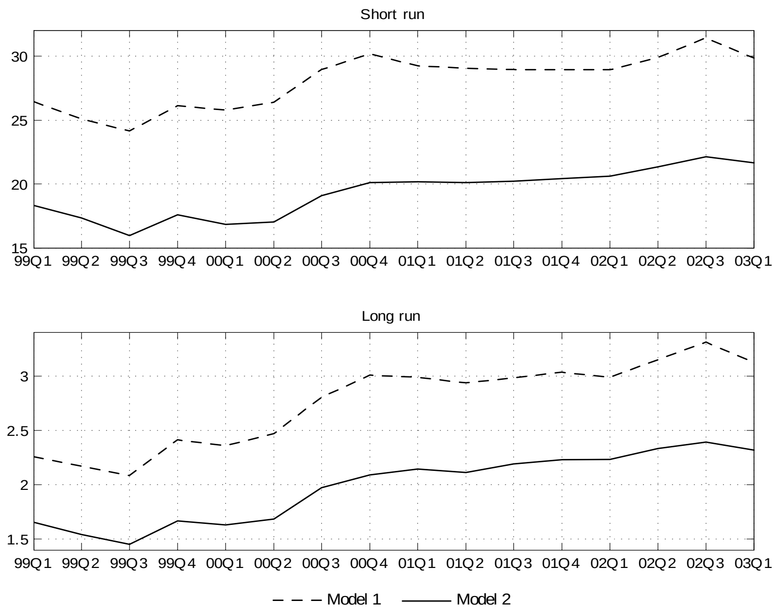

Figure 9: Variance decompositions of inflation with respect to the monetary policy shock (in percent) in Model 1 (solid lines) and Model 2 (dashed lines)

Monetary policy has a significant impact on output in the short run (around 27–28% for Model 2, Fig. 7), but this impact diminishes following the burst of the bubble. The impact in the long run is very small and negligible.

As in the previous crisis period, output is mainly explained by the monetary policy and technology shocks (respectively around 27–28% and 65% for Model 2) in the short run, but mainly by the technology shock in the long run (around 86%). The markup shock should also be taken into consideration in both runs, even though its role is less important than that of the above two shocks (11% and 14% in the short and long runs, respectively).

As far as flexible-price output is concerned, our results show that the impact of the money shock is very small in the short run and negligible in the long run. This is the case for both models (Fig. 8). These results are applicable to the monetary policy shock as well. Flexible-price output is essentially explained by the technology shock in the short as well as long run (around 90% for both models).

The money shock has a very small impact (less than 2%) on the variance of inflation. Monetary policy, on the other hand, has a significant role to play in inflation variability, at least in the short run, especially for Model 2 (Fig. 9). This impact increases a bit after the peak of the bubble.

All in all, the variance of inflation is primarily explained by the monetary policy and markup shocks in the short run (around 30% and 80% for Model 2, respectively), and by the markup shock (around 97% for Model 2) in the long run. The other shocks (money and technology) have a negligible impact in both models.

5.2 Forecasting performances

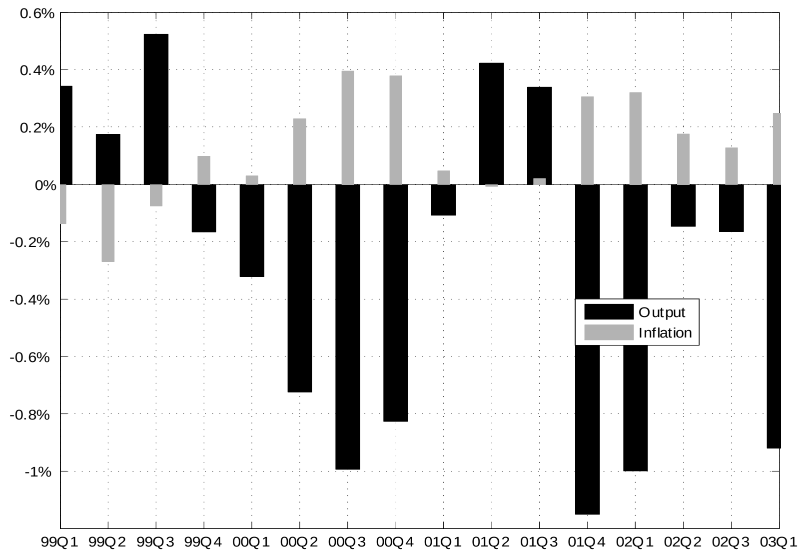

Figure 10: Comparison of output and inflation DSGE forecast errors—Model 2 is better when the bar is positive; Model 1 is better otherwise.

According to Fig. 10, between 1999 Q4 and 2000 Q4 when the bubble was building up, Model 2 does not demonstrate significantly better predictive power of output dynamics than the baseline model. The results change in the two quarters following the burst of the bubble, until the events of September 11, 2001 (2001 Q3).

In terms of inflation forecasts outside crisis periods, Model 1 is generally a better predictor than Model 2; whereas during crisis periods, the former model prevails.

5.3 Interpretation

Even if the impact of money on output and flexible-price output before 2000 Q3 (the peak of the financial bubble) is small, it does increase following that date. We believe that confidence was not completely restored after the burst of the bubble, because the impact of money on output at the beginning of the period remains a bit higher than its value at the end of the period. However small this value is, it is close to the value found by Ireland (2004) and Andrés et al. (2006). This may be due to the fact that the dot-com crisis ultimately had a rather small impact on European economies. The low impact on output is explained in Model 2 by the very low value of the expected money growth parameter (κ_{mp} in Eq. 14) and of the expected money shock growth parameter on output (κ_{sm} in Eq. 14).

The impact of money on flexible-price output is determined by the variation of the money shock parameter (υ^{y}_{sm} in Eq. 11) that reaches its lower value at the peak of the bubble in 2000 Q3.

The dot-com crisis appears to have reinforced the impact of monetary policy on inflation. This impact has increased since the beginning of the period (Fig. 9) in the long and short runs to reach a maximum level at the end of the period.

As explained in Section 4.3, the transmission of the monetary policy shock is not linked to an estimated parameter (the value multiplying the monetary policy shock is equal to one). The values of the parameters alone are, therefore, not sufficient to explain the behavior of the impact of monetary policy on output and inflation dynamics.

6 The subprime crisis

The rise in subprime mortgage delinquencies and foreclosures in the United States and the resulting decline of securities backed by these mortgages around the world started in 2007 Q3. After the subprime crisis, the debt crisis started around 2010 Q2 in the Eurozone. In order to capture the impact of these events, our period of analysis ranges from 2007 Q1 through 2011 Q1.

6.1 Variance decomposition

Fig. 11 shows that the impact of the money shock on output variance in the short run increases from 2007 Q2 and peaks in 2007 Q3 and 2008 Q3, explaining about 10% of the variance between these two peaks. The rapid decrease of the value of this impact between 2008 Q3 and 2009 Q1 is notable, after which it stabilizes. The value in the long run remains very small through the period and follows a similar pattern as in the short run. After 2009 Q1, the impact manifests a decreasing trend, to reach about 6.5% in 2011 Q1.

Figure 11: Variance decompositions of output with respect to the money shock (in percent) in Model 2

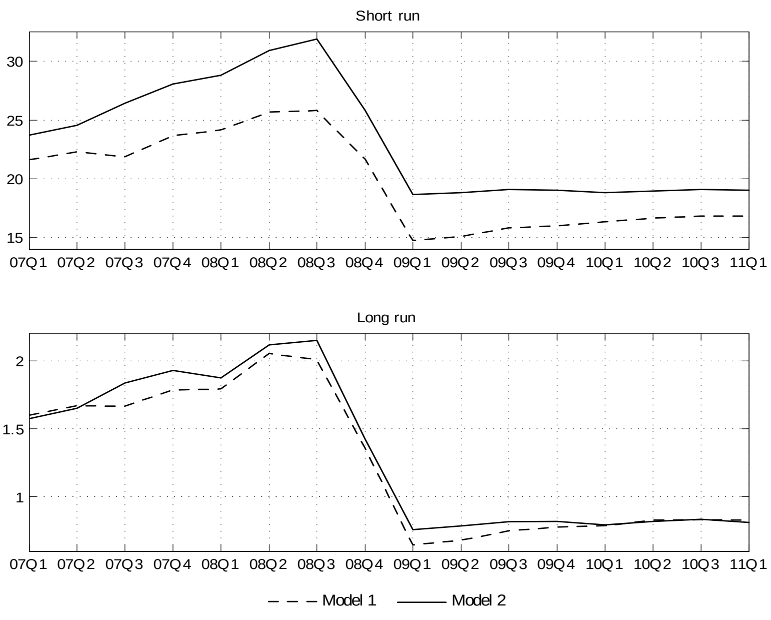

Figure 12: Variance decompositions of output with respect to the monetary policy shock (in percent) in Model 1 (solid lines) and Model 2 (dashed lines)

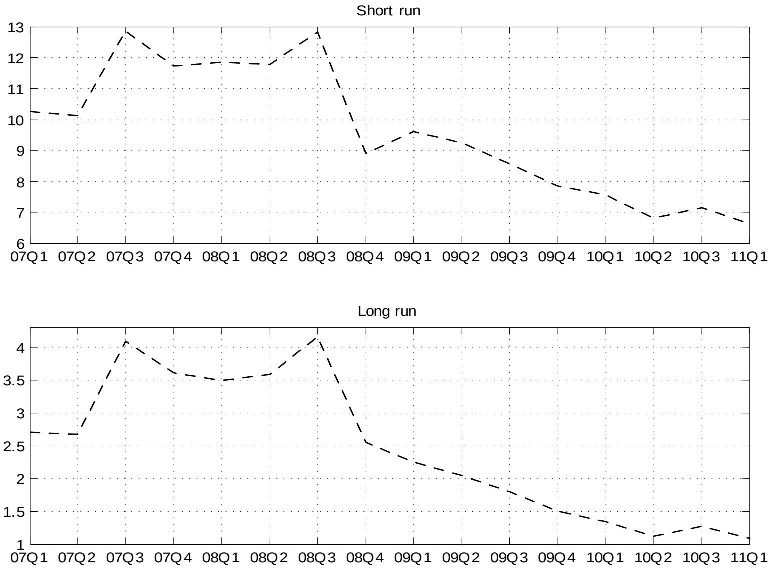

Figure 13: Variance decompositions of flexible-price output with respect to the money shock (in percent) in Model 2

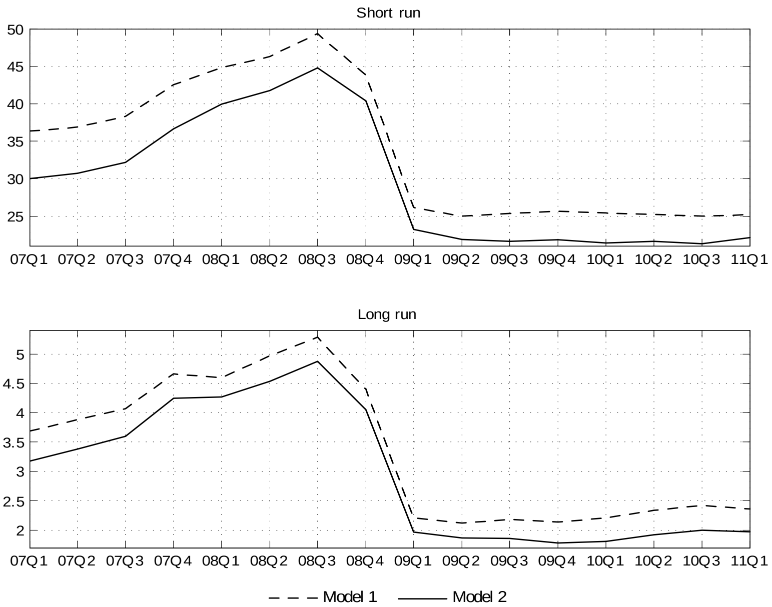

Figure 14: Variance decompositions of inflation with respect to the monetary policy shock (in percent) in Model 1 (solid lines) and Model 2 (dashed lines)

The monetary policy shock has a significant impact on output variation in the short run (Fig. 12) with a peak in 2008 Q3. At this point, it explains more than 30% and 25% of the output variance in Model 1 and Model 2, respectively. The impact of monetary policy on output increases over the first quarters of the subprime crisis and reaches its highest level at the peak of the subprime crisis (2008 Q3). Following this peak, the impact decreases fairly sharply, to reach its lowest level in the beginning of 2009.

As shown, the impact of monetary policy on output is lower for Model 2 than Model 1. The baseline model (Model 1) does not show any impact of money shocks on output, whereas Model 2 does; and the impact of the money shock is fairly strong during this period. Therefore, this impact lowers the impact of the monetary policy shock on output in Model 2, in the short as well as long runs.

As in the previous crises, output variability in the short run is primarily explained by the monetary policy shock (between 20% and more than 30%) and the technology shock (around 64%); whereas the technology shock dominates the process in the long run (around 85%). The markup shock also has a non-negligible role to play, since it accounts for 12% of the output variance in the short run and about 14% in the long run in Model 1. The result is somewhat different in the case of Model 2, because the role of the markup shock is limited to around 5%.

The impact of the money shock on flexible-price output follows the same pattern as the one on current output but with somewhat higher values, in the short as well as long runs (Fig. 13). However, the impact of the monetary policy and markup shocks on this variable become insignificant in both models, in the short and long runs (graphs not shown).

On the whole, flexible-price output is essentially explained in both models by the technology shock, in the short and long runs (with a value around 80%).

As during the other crises, the impact of the money shock on inflation is insignificant and thus not presented here. Inflation variations in the short run are driven mainly by the monetary policy shock (explaining between 20% and 50% of the variance) and the markup shock (around 79%), and by the markup shock (around 97%) in the long run, in both models. The significant change in the importance of these impacts from 2008 Q3 to 2011 Q1 is noticeable.

6.2 Forecasting performances

Fig. 15 indicates that at the core of the subprime crisis (2007 Q4 through 2009 Q4), Model 2 provides better forecasts of output than the baseline

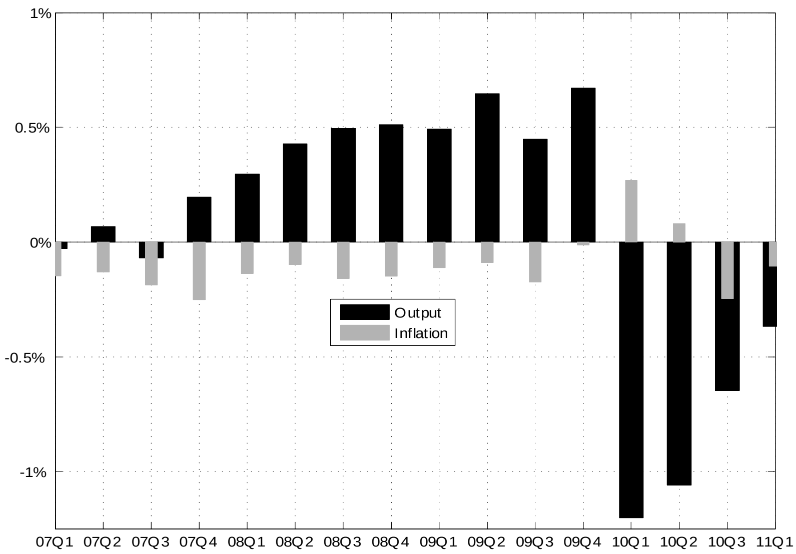

Figure 15: Comparison of output and inflation DSGE forecast errors—Model 2 is better when the bar is positive; Model 1 is better otherwise.

model. This outcome is reversed following 2010 Q1, when the debt crisis starts. Even though Model 1 is in general better than Model 2 in terms of inflation forecasts, the difference is insignificant.

6.3 Interpretation

As far as the US is concerned, Cecchetti (2009) and Mishkin (2010) consider that the crisis began in 2007 Q1, when several large subprime mortgage lenders started to report losses. The real trigger for the crisis was in 2007 Q3, when the French bank BNP Paribas temporarily suspended redemptions from three of its fund holdings that had invested in assets backed by the US subprime mortgage debt. As a result, credit spreads began widening, overnight interest rates in Europe shot up, and the European Central Bank (ECB) immediately responded with the largest short-term liquidity injection in its nine-year history.

The Euro Group heads of states and governments and the ECB held an extraordinary summit in October 2008 to determine joint action for the Eurozone. They agreed on a bank rescue plan that would entail hundreds of billions of euros—governments would inject banks with capital and guarantee interbank lending. Financial uncertainty decreased as a consequence of this action. This decrease may explain the diminishing impact of money and monetary policy on output variations after October 2008 (Fig. 11 to Fig. 13), as well as the decreasing impact of monetary policy on inflation (Fig. 14).

The change in the impact of money on output is explained in the model (from Eq. 14) by the variations in the expected money growth parameter (κ_{mp}) and the expected money growth shock parameter on output (κ_{sm}).

The impact of money on flexible-price output partly results from the variation of the money shock parameter (υ^y_{sm} in Eq. 11).

Similar to the previous crisis periods, the values of the parameters alone are not sufficient to describe the behavior of monetary policy impacts on output and inflation dynamics.

As explained in Section 4.3, the transmission mechanism or at least its consequences are better understood by analyzing the variance decomposition with respect to structural shocks, than by going through the changes in the values of parameters. The exceptions to this are parameters that directly multiply a shock in the macro-equation of a core variable (as is the case with κ_{mp}, κ_{sm}, and υ^y_{sm}).

Our monetary policy shock describes only conventional monetary policy shocks. The decreasing role of conventional monetary policies after 2008 Q3 is probably due to the emergence of unconventional monetary policy around the same period. This change in the policy regime may have influenced money related parameters in the flexible-price output equation (υ^y_{sm}, υ^y_m and υ^y_c in Eq. 11).

The output RMSD comparison (Fig. 15) is not affected by the change in policy that occurred during the last quarter of 2008. 2008 Q3 is not the end of the crisis, even if the impact of money and monetary policy on output declines. Uncertainty and risk aversion are ever-present in the economy. This probably explains why Model 2 has a better predictive power for output than Model 1 during the subprime crisis.

Contrary to other studies, such as Ireland (2004), Andrés et al. (2006), and Andrés et al. (2009), our analysis indicates that money did have a significant role to play in the subprime crisis, as it did in the two crises we have studied earlier. This confirms the predictive abilities of Model 2 during crisis periods.

To better understand the relationship between the role of money and monetary policy during the financial crisis, it may be useful to introduce the evolution of the interest rate spread over the period as an indication of the uncertainty level. This spread[8] provides an assessment of counterparty risk

[8] The spread is measured as the difference between the three-month Euribor and a short maturity bond. As a European bond does not exist, we choose the one-year Bubill

from interbank lending, reflecting both liquidity and credit risk concerns.

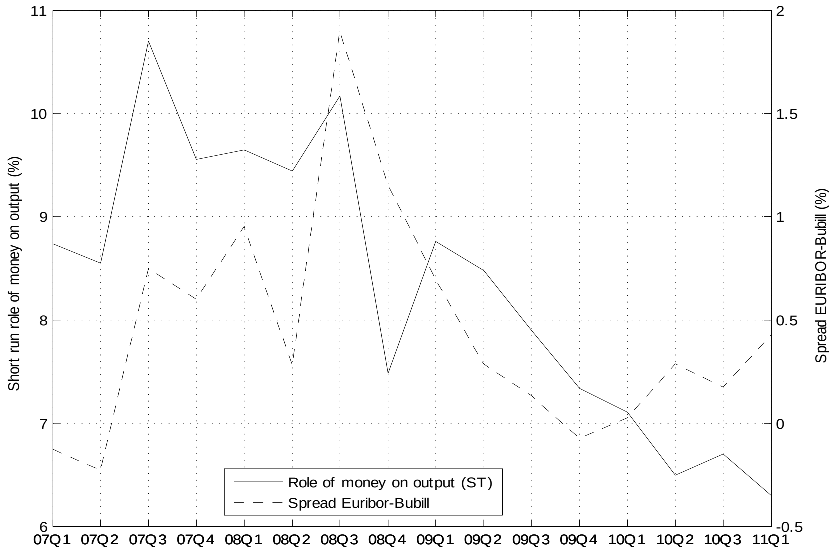

Figure 16: Comparison between the role of money on output (short-run variance decomposition, Model 2) and the Euribor–Bubill spread

Fig. 16 indicates that the dynamics of the short-run impact of money on output during the subprime crisis and the interest rate spread are positively related (except in 2009 Q1 and after 2009 Q4). This relationship underscores the link between financial risk and the role of money on output.

In the same vein, Fig. 17 and Fig. 18 show that the impact of monetary policy on output and inflation follows the same direction as the spread. These impacts are significant and increase with the crisis, from 2007 Q1 up to the peak of the subprime crisis (2008 Q3). They diminish rapidly and significantly after 2008 Q3, remaining at a lower but still meaningful level until the end of the period (2011 Q1). This sharp decline coincides with the introduction of unconventional monetary policies.

When Lehman Brothers and other major financial institutions failed in 2008 Q3, the credit freeze in the money market brought the global financial system to the brink of collapse. The Federal Reserve, the ECB, and other central banks purchased almost 3 trillions dollars of government debt and troubled private assets from banks over the last quarter of 2008. That was the largest liquidity injection into the credit market and the largest unconventional monetary policy action in world history. These measures explain

(Germany) as short-term Treasury bills.

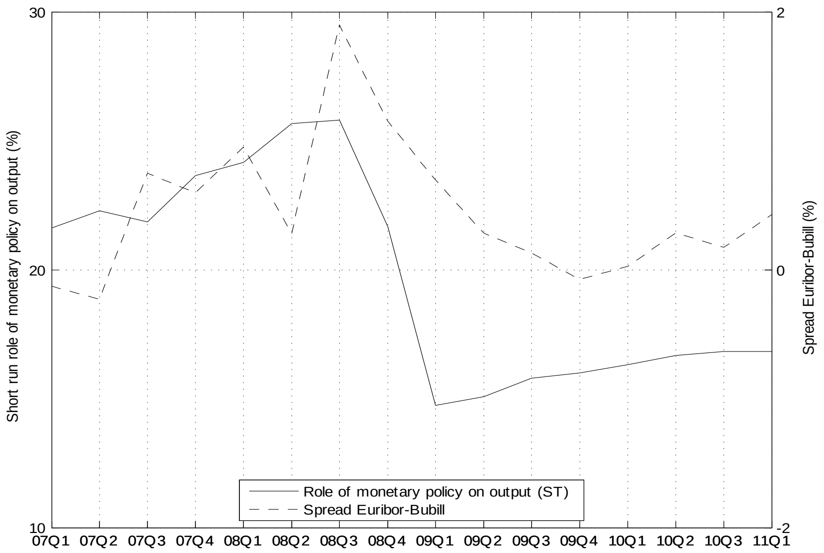

Figure 17: Comparison between the role of monetary policy on output (short-run variance decomposition, Model 2) and the Euribor–Bubill spread

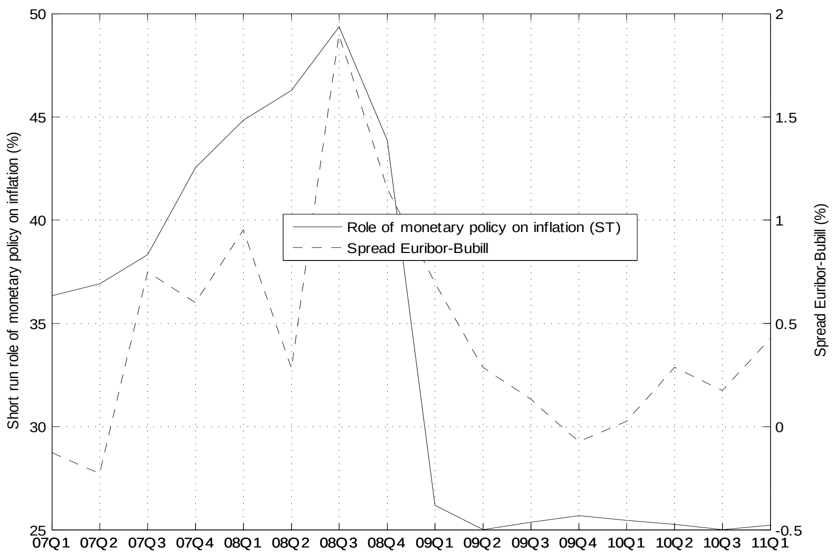

Figure 18: Comparison between the role of monetary policy on inflation (short-run variance decomposition, Model 2) and the Euribor–Bubill spread

the fall of the spread and the sharp decline in the impact of monetary policy on output and inflation after this period (Fig. 17 and Fig. 18).

Uncertainty started to decrease in the aftermath of these policy actions, decreasing the short-run impact of money on output following the peak of the spread in 2008 Q3 (Fig. 16).

7 A comparison of the three crises

In order to compare the three crises, we analyze the impulse responses of output, output gap and inflation to money and monetary policy shocks over key periods. The comparison is for both models as far as the monetary policy shock is concerned. A comparison of variance decompositions over the different crises is also useful to better understand the respective roles of the shocks.

7.1 Impulse response functions

Besides indicating the impact of different shocks, the IRF give the opportunity to quantify the persistence of the shocks over each period.

The impulse response functions of inflation are reported in percentage points, whereas the other impulse responses are reported in percentage deviations from each variable's period-specific linear trend (see Section 3). The selected dates correspond to the two most relevant peaks of each crisis[9].

[9] We do not present all the impulse response functions over the three crises, for each period, and for both models; because that would be too heavy a task. However, all these results are available upon request.

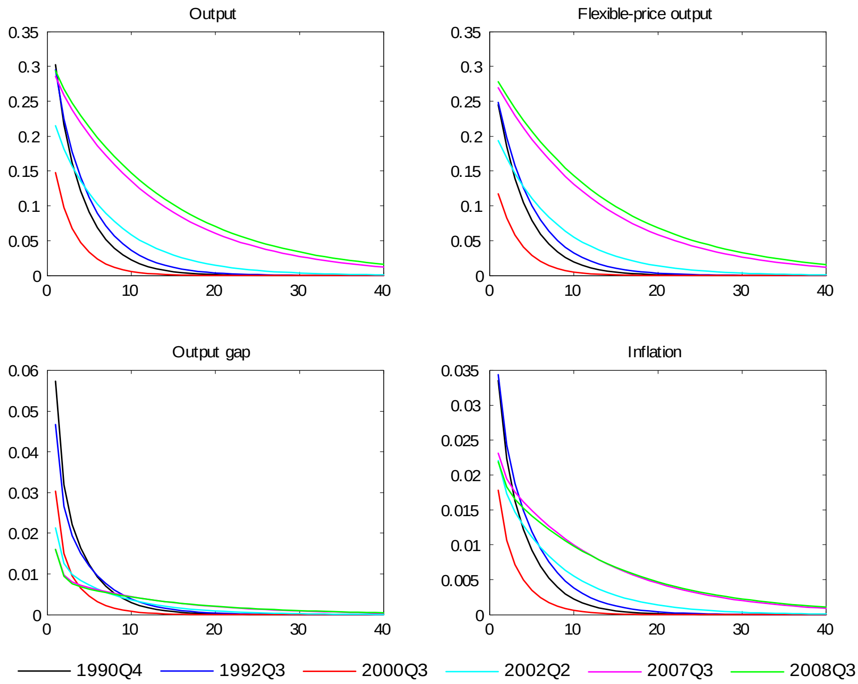

Figure 19: Comparison of impulse response functions following a 1% standard deviation money shock (Model 2) over the three crises

Fig. 19 shows the impulse response functions of output, flexible-price output, output gap and inflation following a 1% increase in the money shock's standard deviation (Model 2). Interestingly, a positive money shock implies almost the same response of output for the subprime and ERM crises (0.3%), at least on impact, whereas the on-impact response of output for the dot-com crisis is lower (0.15%–0.2%). Yet, the impact on the flexible-price output is stronger for the subprime crisis than for the other crises.

The persistence of this shock is higher for the subprime crisis than for the other crises. It is a reflection of the fact that it takes more time for output and flexible-price output to reach their steady-state values over the subprime crisis than over the other two crises.

The impact of the money shock on the output gap differs between crises. It is more significant in the first few quarters following the peaks of the ERM crisis (almost 0.06%) than in the first few quarters following the peaks of the dot-com (0.03%) and subprime (0.015%) crises.

The response of inflation to a 1% money shock is higher during the ERM crisis than during the two other crisis periods. These differences may be at least partly explained by the fact that during the ERM crisis, the uncertainty about the exchange rate was higher than for other crisis periods.

As for output and flexible-price output, the responses of inflation to a money shock are more persistent over the subprime crisis than over other crises.

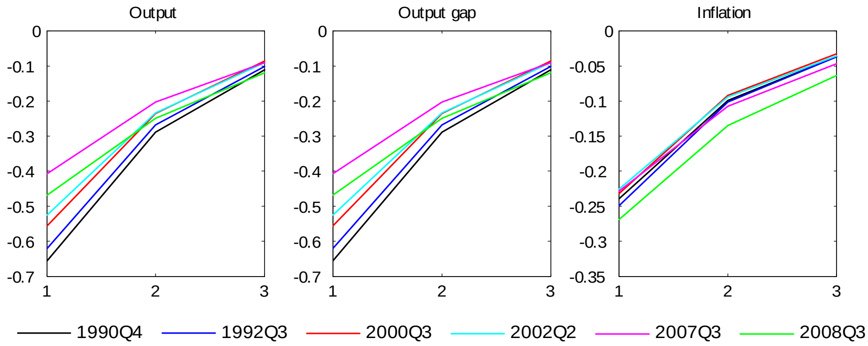

Figure 20: Comparison of impulse response functions following a 1% standard deviation monetary policy shock (Model 2) over the three crises

Fig. 20 shows an enlargement of the impulse response functions to a 1% increase in the monetary policy shock's standard deviation in the non-separable framework (Model 2).

The responses of flexible-price output to a monetary policy shock are not shown since they are about nil (of the order of 10^{-16}) for all key periods.

The response of output to a monetary policy shock differs between time periods. There is a decrease on impact from about 0.4% in 2007 Q3 to 0.65% in 1990 Q4. The impact of monetary policy on output was, therefore, stronger over the ERM crisis period than the dot-com crisis, and stronger over the dot-com crisis than the subprime crisis period. Similar implications are true for the output gap. It is also true for the inflation rate, but to a lesser extent. The exchange rate channel may have had a more significant impact on monetary policy, and on transmission channels, during the ERM crisis than during the more recent periods.

After a positive technology shock, output and flexible-price output increase, the output gap slightly decreases, and inflation decreases (figures not shown). Interestingly, the sensitivity of output to a technology shock is significantly higher during the subprime crisis (in 2008 Q4 and 2010 Q2) than during the two other crises.

The impact of a price-markup shock on output and inflation decreases from 1990 to 2010. Regardless of the period, a positive price-markup shock leads to an increase in inflation, but to a decrease in output and the output gap. The impact of a price-markup shock to flexible-price output is nil (of the order of 10^{-16}).

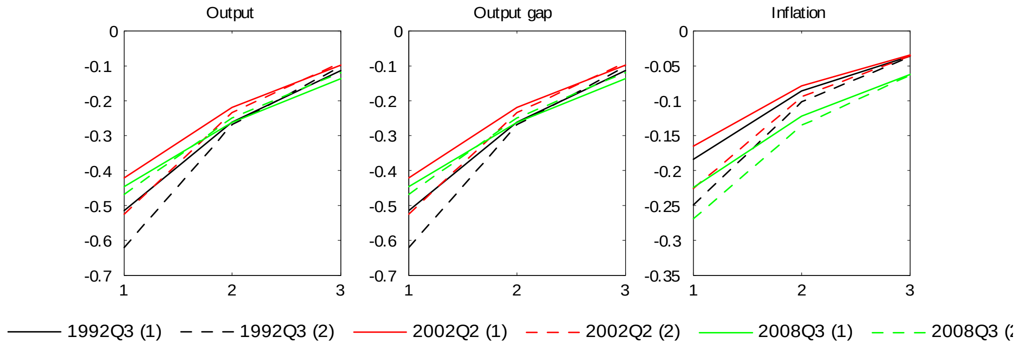

Figure 21: Comparison of impulse response functions following a 1% standard deviation monetary policy shock over the three crises (Model 1: solid lines; Model 2: dashed lines)

Fig. 21 shows an enlargement of the impulse response functions to a monetary policy shock in the separable and non-separable frameworks, that is, a comparison of the responses of output, output gap and inflation between Model 1 and Model 2. These impulse response functions are focused only on the peak-point in each crisis that appears to be more critical.

The impact of a monetary policy shock on output, output gap and inflation in the baseline model is typically smaller than in the model including money. However, the persistence of the monetary policy shock does not appear to be significantly affected by the inclusion of money in the model[10].

7.2 Variance decompositions

During the subprime crisis, money has a more significant impact on output and flexible-price output than during the ERM and dot-com crises, especially in the short term. These values must be compared to Ireland (2004), Andrés et al. (2006), and Andrés et al. (2009), who found that the impact of money on output appears to be limited and negligible (between 0–2%). However, the impact of money on inflation variability is very small.

Over all the three crises analyzed in this paper, the short-run impact of monetary policy on output remains high (around 15–30%), but its value fluctuates more during the subprime crisis, indicating the higher disruptive effect of this crisis as compared with the others.

The short-run impact of monetary policy shocks on inflation variability also remains high over the three crises (15–50%), again with higher fluctua-

[10]The responses of flexible-price output to a monetary policy shock are not shown since they are not significant (of the order of 10^{-16}) for both models.

tions during the subprime crisis (about 25–50%).

A focus on the subprime crisis (Section 6.3) confirms the link between the spreads that measure uncertainty in the financial market and the impact of the money and monetary policy shocks on the dynamics of the economy.

Finally, in terms of output forecasting, Model 2 generally performs better than Model 1 over crisis periods, especially during periods of high uncertainty. The results concerning the financial crisis are striking in that respect (Fig. 15).

8 Conclusion

The aim of this paper was primarily to study the role of money and monetary policy during crisis periods. To achieve this goal, we compared the performance of two DSGE models, namely, one baseline model without money, as in Galí (2008), and one with non-separable preferences between consumption and real money balances included in the utility function of households, and with a money augmented Taylor rule, as in Benchimol and Fourçans (2012). The study is conducted over three crisis periods running from 1990 through 2011, including the European ERM crisis (1992), dot-com crisis (2001), and subprime crisis (2007) followed by the debt crisis.

We tested both models by using successive Bayesian estimations so as to obtain empirical estimates of the variations of the micro-parameters. We ran simulations to obtain variance decompositions from both models over the three crises and capture short- and long-run dynamics that are generally hidden in longer sample sizes. We also ran DSGE forecasts to compare the forecasting performances of both models over the crises, and analyze the responses of output, output gap and inflation to shocks.

Our analysis indicates that the impact of money shocks on output variations increases during crises. This impact was higher during the subprime crises than the ERM and dot-com crises. The impact of conventional monetary policy is also affected during crises. As far as the subprime crisis is concerned, the impact appears to increase in the beginning of the crisis, but decreases sharply afterwards.

In addition, our results also demonstrate that during these periods, the model with money generally provides better forecasts of output (and sometimes inflation) than the baseline model.

The results also underscore the fact that the impact of money and monetary policy on output variability diminishes significantly following what appears to be the peak of the subprime crisis (2008 Q3). Inflation variability does not seem to be affected directly by money variables. It is mainly explained by the monetary policy and markup shocks in the short run, and essentially by the markup shock in the long run, as found in the literature.

The response of output to a money shock is stronger at the peak of the subprime and ERM crises than at the peak of the dot-com crisis. And the persistence of the output response to a money shock is higher over the subprime crisis than over the other crises.

Lastly, it is interesting to note that the response of flexible-price output to a money shock during the subprime crisis is about as strong as the response of output itself. In addition, it is significantly stronger and longer lasting than it does during other crises. Yet, a monetary policy shock appears to have no effect on flexible-price output for all crises (in both models).

The findings of our paper also support the view that New Keynesian DSGE models with non-separability between consumption and real money balances, and with money in the Taylor rule, should be preferable to separable models without money, as far as macroeconomic forecasting is concerned, at least during crisis periods and in the Eurozone.

Finally, our results also provide some clues regarding the structural dynamics of the economy that may help inform central banks, markets, and policy regulators. For example, the more significant role than generally expected of real money balances during crises, as well as the changing role of monetary policy, are important indicators.

9 Appendix

A Calibration

We calibrate all parameters of the non-separable model as in Benchimol and Fourçans (2012). The monetary policy rule is an *ad hoc* reaction function and completely dependent on the monetary authority.

Following standard conventions, we calibrate beta distributions for parameters that fall between zero and one, inverted gamma distributions for parameters that need to be constrained to be greater than zero, and normal distributions in other cases.

The calibration of σ is inspired by Rabanal and Rubio-Ramírez (2005) and by Casares (2007). They choose risk aversion parameters of 2.5 and 1.5, respectively. In line with these values, we consider that $\sigma = 2$ corresponds to a standard risk aversion. We adopt the same priors in both models with the same risk aversion calibration.

As in Smets and Wouters (2003), the standard errors of the innovations are assumed to follow inverse gamma distributions. Furthermore, we choose a beta distribution for shock persistence parameters (as well as for the backward component of the Taylor rule) that should be less than one.

The calibration of α, β, θ, η, and ε comes from Galí (2008) and Casares (2007). The smoothed Taylor-type rule (λ_i, λ_π, λ_x, and λ_{mp}) is calibrated following Andrés et al. (2009), Barthélemy et al. (2011), and Benchimol (2014a,b); analogue priors as those used by Smets and Wouters (2003) for the monetary policy parameters. In order to take into consideration possible changes in the behavior of the central bank, we assign a higher standard error for the coefficients of the Taylor rule. υ (the non-separability parameter) must be greater than one. κ_i (Eq. 15) must be greater than one, insofar as this parameter depends on the elasticity of substitution of money with respect to the cost of holding money balances, as explained in Söderström (2005); while still informative, this prior distribution is dispersed enough to allow for a wide range of possible and realistic values to be considered (that is, $\sigma > \nu > 1$).

The calibration of the shock persistence parameters and the standard errors of the innovations follows Smets and Wouters (2003), where a much lower mean is adopted for ρ_i. All the standard errors of shocks are assumed to be distributed according to inverted gamma distributions, with prior means of 0.04. The latter law ensures that these parameters have a positive support. The autoregressive parameters are all assumed to follow beta distributions. Except for monetary policy shocks, all these distributions are centered around 0.75. We take a common standard error of 0.1 for the shock persistence parameters, as in Smets and Wouters (2003).

B Estimation results

Fig. 22, Fig. 23, and Fig. 24 present the Bayesian estimations[11] of both models. The solid and dashed lines represent the results for the baseline model (Model 1) and the model with money (Model 2), respectively.

The estimation of the implied posterior distribution of the parameters for each sample size and each model is done using the Metropolis–Hastings algorithm (three distinct chains, each of 5000 draws; see Smets and Wouters (2007), and Adolfson et al. (2007)). Average acceptation rates per chain are around 0.25, as settled by the literature; priors and posteriors distributions are not presented, but are available upon request.

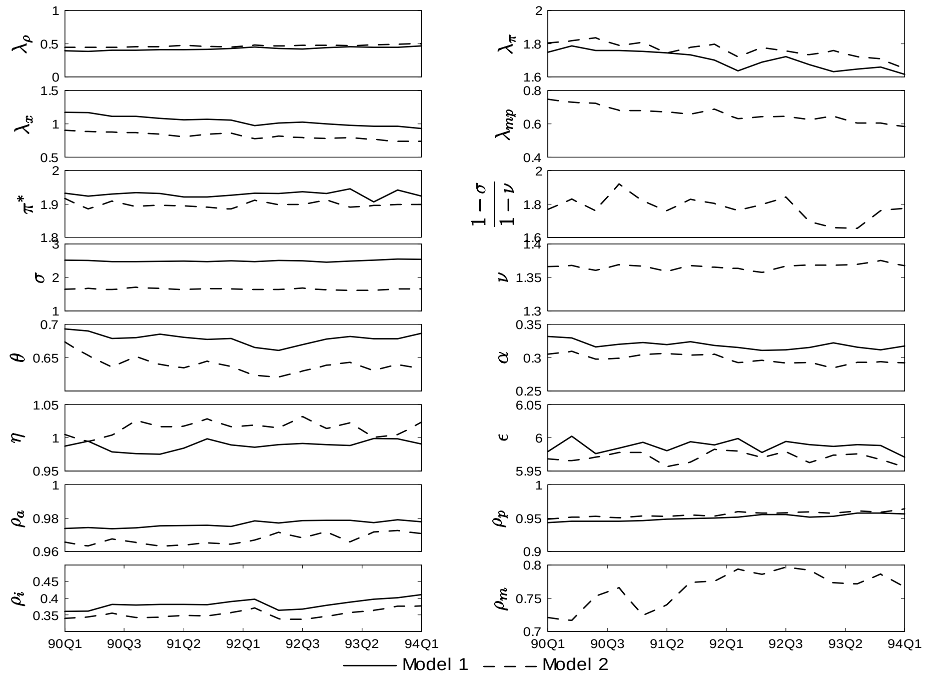

Figure 22: Parameter values for both models during the ERM crisis

[11] The results of parameter estimations and validation and robustness tests can be provided upon request. All Student tests are above 1.96 and parameter estimations are stable over time.

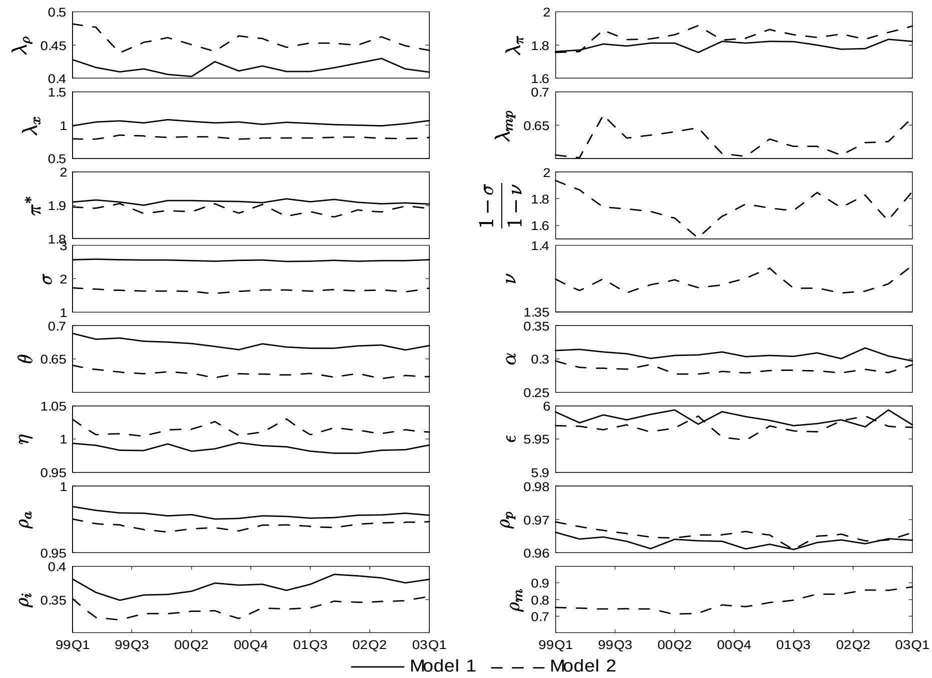

Figure 23: Parameter values for both models during the dot-com crisis

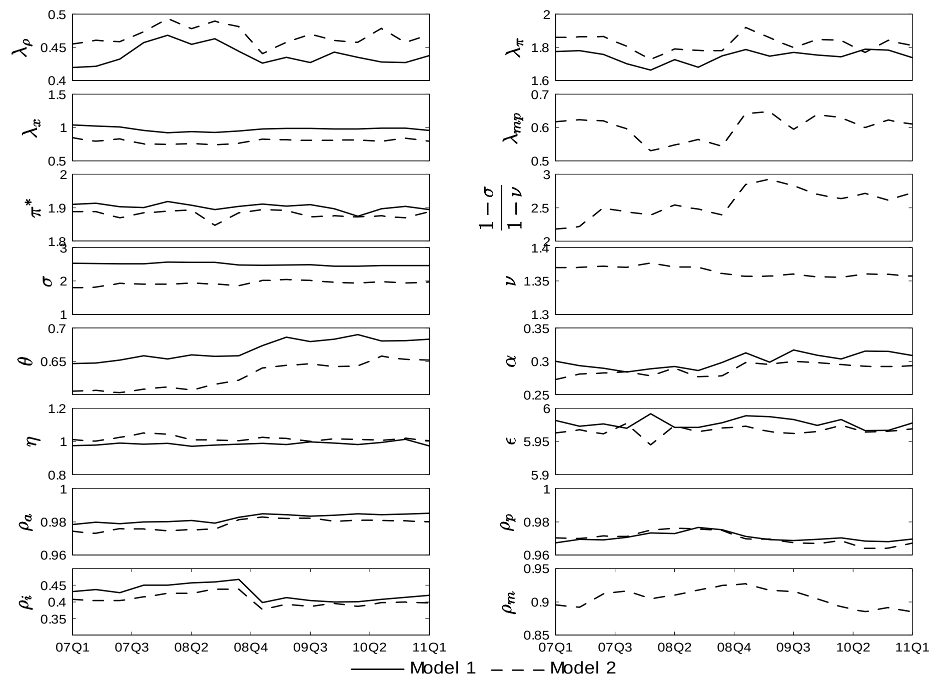

Figure 24: Parameter values for both models during the subprime crisis

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