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Money in a DSGE Framework with an Application to the Euro Zone

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MONEY IN A DSGE FRAMEWORK WITH AN APPLICATION TO THE EURO ZONE

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September 2009

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ABSTRACT:

In the current New Keynesian literature, the role of monetary aggregates is generally neglected. Yet it's hard to imagine money completely "passive" to the rest of the system. By entering real money balances in a non-separable utility function, we introduce an explicit role for money via preference redefinition in a simple New Keynesian Dynamic Stochastic General Equilibrium (DSGE) model. It involves new inflation and output gap specifications where money plays a significant role. We use the General Method of Moments (GMM) to calibrate our DSGE model of the Euro area and we show that the European Central Bank –ECB) should react more strongly to economic shocks as far as the role of money is found significant.

Key-Words:

- ECB
- Inflation
- Monetary Policy
- Money

RÉSUMÉ :

Le «nouveau keynésianisme» actuel néglige le rôle des agrégats monétaires dans la détermination de l'équilibre économique. On peut se poser des questions sur cette vision tant il est difficile d'admettre que la monnaie serait une variable «passive» du système économique. En introduisant les balances réelles dans une fonction d'utilité non-séparable, cet article incorpore explicitement le rôle de la monnaie dans un modèle du type DSGE. Cette spécification débouche sur des équations d'inflation et d'output gap dans lesquelles les encaisses monétaires jouent un rôle significatif. Le modèle DSGE est calibré par la General Method of Moments (GMM) appliqué aux données de la zone Euro. Les résultats et l'analyse démontrent que dans la mesure où la croissance monétaire joue un rôle significatif, la BCE devrait réagir plus vigoureusement aux chocs économiques qu'elle ne le fait généralement.

Mots-clés :

- BCE
- Inflation
- Monnaie
- Politique monétaire

JEL classification : E31, E51, E58

Money in a DSGE framework with an application to the Euro zone

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Abstract

In the current New Keynesian literature, the role of monetary aggregates is generally neglected. Yet it's hard to imagine money completely "passive" to the rest of the system. By entering real money balances in a non-separable utility function, we introduce an explicit role for money via preference redefinition in a simple New Keynesian Dynamic Stochastic General Equilibrium (DSGE) model. It involves new inflation and output gap specifications where money plays a significant role. We use the General Method of Moments (GMM) to calibrate our DSGE model of the Euro area and we show that the European Central Bank (ECB) should react more strongly to economic shocks as far as the role of money is found significant.

Keywords: ECB, monetary policy, money, inflation.
JEL Classification: E31, E51, E58.

1 Introduction

Standard New Keynesian literature analyses monetary policy practically without reference to monetary aggregates. In this now traditional framework, monetary aggregates do not explicitly appear as an explanatory factor neither in the output gap or inflation dynamics nor in interest rate determination. Inflation is explained by the expected inflation rate and the output gap. In turn, the output gap depends mainly on its expectations and the real rate of interest (Clarida, Galí and Gertler, 1999; Woodford, 2003; Galí and Gertler, 2007; Galí, 2008). Finally, the interest rate is established via a traditional Taylor rule in function of the inflation gap and the output gap.

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Following Woodford (2003) and Ireland (2004), money becomes an irrelevant variable in this framework. Yet, it is difficult to accept the view that money has no active role to play in the economy. Assenlacher-Wesche and Gerlach (2006) confirm that money growth contains information about inflation pressures. Money may play an informational role as to the state of different non observed (or difficult to observe) variables influencing inflation or output. In a New Keynesian framework, the expected inflation rate or the output gap may "hide" the role of monetary aggregates on inflation determination, for example. Nelson (2008) shows that standard New Keynesian models are built on the strange assumption that central banks can control the long-term interest rate, while this variable is actually determined by a Fisher equation in which expected inflation depends on monetary developments. Reynard (2007) found that in the U.S. and the Euro area, monetary developments provide qualitative and quantitative information as to inflation.

Kremer, Lombardo, and Werner (2003) find that real money balances contribute significantly to the determination of output (and inflation) dynamics. In that case, money could be an explanatory variable of the output gap. A recent contribution (Andrés, López-Salido and Nelson, 2009) introduces the role of money with adjustment costs for holding real balances. Empirical analysis confirms the importance of a forward-looking behavior of money demand. Stock and Watson (1989) and Feldstein and Stock (1993) find that money contributes to predicting the fluctuations in output not already predictable from past values of output, prices and interest rates. Nelson (2002) finds that money is a significant determinant of aggregate demand, both in the U.S. and in the U.K.

How is money introduced in these models ? Mainly through the assumption that the marginal utility of consumption depends on real money balances. The standard way is to resort to money-in-the-utility (MIU) function models, whereby real money balances are supposed to affect the marginal utility of consumption. Early evidence produced by Kremer, Lombardo, and Werner (2003) in the case of Germany supports the non-separability assumption. Subsequent studies, however, reach the opposite conclusion. The empirical work undertaken by Ireland (2004), Andrés, López-Salido, and Vallés (2006), and Jones and Stracca (2008) suggests that there is little evidence that supports the inclusion of real money balances in equations in the cases of the United States, the Euro zone, and the UK.

Few studies develop micro-foundations to introduce money into the models and fewer use New Keynesian models with a Dynamic Stochastic General Equilibrium (DSGE) approach. Our paper seeks to fill this gap. It introduces the role of money via preference redefinition. Contrary to Ireland (2004) or Andrès and *al.* (2009), we define a non time-separable utility function (CES), which is a good means to introduce money into a New Keynesian model. We use a DSGE simulation to examine the consequences of such an interpretation. Even if this method may not be the only one to study the role of money, we demonstrate that such a framework can set forth transmission mechanisms generally neglected in traditional New Keynesian analyses. It highlights in particular the importance of understanding the role of money to improve economic stability and monetary policy.

The micro-fundations of our model of the economy leads to four dynamic equations explaining: the output gap, the inflation rate, money demand, and the short-term nominal interest rate. As the only major central bank that still claims to assign a significant role to monetary aggregates is the European Central Bank (ECB), it is interesting to conduct an empirical analysis that focuses on the Euro zone. We use the General Method of Moments to estimate our four equation system and to calibrate its parameters. The model so calibrated is used to simulate the behavior of the Euro zone economy. Dynamic analysis of the model, with impulse response functions following structural shocks, yields different relationships between money and other structural variables. It sheds light on the importance of money in explaining inflation and even short run fluctuations in output in the Euro zone.

2 The model

The model consists of households that supply labor, purchase goods for consumption, hold money and 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 in each period. Households and firms behave optimally: households maximize the expected present value of utility, and firms maximize profits. There is also a central bank that controls the nominal rate of interest. This model is inspired by Galí (2008), Walsh (2003) and Smets and Wouters (2003).

2.1 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.

We assume the existence of a continuum of goods represented by the interval $[0, 1]$. 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 expenditures[1]. 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 $t = 0, 1, 2...$, where W_t is the nominal wage, P_t is an aggregate price index, N_t is hours of work (or the measure of household members employed), B_t is the quantity of one-period nominally riskless discount bonds purchased in period t

[1] See Appendix 7.1

and maturing in period $t+1$ (each bond pays one unit of money at maturity and its price is Q_t where $i_t = -\log Q_t$ is the short term nominal rate) and M_t is the quantity of money holdings at time t. The above sequence of period budget constraints is supplemented with a solvency condition[2].

Preferences are measured with a CES utility function including real money balances. In the literature, utility functions are usually time-separable whereas in our model, the utility function is not time-separable. Under the assumption of a period utility given by

$$U_t = e^{\varepsilon_t^P} \left(\frac{1}{1-\sigma} \left((1-b) C_t^{1-\nu} + b e^{\varepsilon_t^M} \left(\frac{M_t}{P_t} \right)^{1-\nu} \right)^{\frac{1-\sigma}{1-\nu}} - \frac{\chi e^{\varepsilon_t^N} N_t^{1+\eta}}{1+\eta} \right) \quad (3)$$

consumption, labor, money and bond holdings are chosen to maximize (1) subject to (2) and the solvency condition. This CES utility function depends positively on the consumption of goods, C_t, positively on real money balances, M_t/P_t, and negatively on labour N_t. σ is the coefficient of relative risk aversion of households (or the inverse of the intertemporal elasticity of substitution), ν is the inverse of the elasticity of money holdings with respect to the interest rate, and η is the inverse of the elasticity of work effort with respect to the real wage. The utility function also contains three structural shocks: ε_t^p is a general shock to preferences that affects the intertemporal substitution of households (preference shock), ε_t^m is a money demand shock and ε_t^n is a shock to the number of hours worked. All structural shocks are assumed to follow a first-order autoregressive process with an *i.i.d.*-normal error term. b and χ are positive scale parameters.

This setting leads to the following conditions, which, in addition to the budget constraint, must hold in equilibrium. The resulting log-linear version of the first order condition corresponding to the demand for contingent bonds implies that

$$\begin{aligned} \hat{c}_t &= E_t[\hat{c}_{t+1}] - \frac{1}{\nu - (\nu-\sigma) a_1} (\hat{\imath}_t - E_t[\hat{\pi}_{t+1}]) \\ &\quad - \frac{(\nu-\sigma)(1-a_1)}{\nu - (\nu-\sigma) a_1} (E_t[\Delta \hat{m}_{t+1}] - E_t[\hat{\pi}_{t+1}]) + \xi_{t,c} \end{aligned} \quad (4)$$

where $\xi_{t,c} = -\frac{1}{\nu-(\nu-\sigma)a_1} \left(\frac{\nu-\sigma}{1-\nu}\right) E_t\left[\Delta \hat{\varepsilon}_{t+1}^M\right] - \frac{1}{\nu-(\nu-\sigma)a_1} E_t\left[\Delta \hat{\varepsilon}_{t+1}^P\right]$. The lower-case ($\hat{}$) denotes the log-linearized (around the steady state) form of the original aggregated variables.

The demand for cash that follows from the household's optimization problem is given by

$$-\nu(\hat{m}_t - \hat{p}_t) + \nu \hat{c}_t + \hat{\varepsilon}_t^M = a_2 \hat{\imath}_t \quad (5)$$

where real cash holdings depend positively on consumption with an elasticity equal to unity and negatively on the nominal interest rate. In what follows we

[2] Such as $\forall t \lim_{n \longrightarrow \infty} E_t[B_n] \geq 0$. It prevents from engaging in Ponzi-type schemes.

will take the nominal interest rate as the central bank's policy instrument. In the literature, due to the assumption that consumption and real money balances are additively separable in the utility function, cash holdings do not enter any of the other structural equations: accordingly, the above equation becomes recursive to the rest of the system of equations.

The first order condition corresponding to the optimal consumption-leisure arbitrage implies that

$$\eta \hat{n}_t + (\nu - (\nu - \sigma) a_1) \hat{c}_t - (\nu - \sigma)(1 - a_1)(\hat{m}_t - \hat{p}_t) + \xi_{t,n} = \hat{w}_t - \hat{p}_t \tag{6}$$

where $\xi_{t,n} = \hat{\varepsilon}_t^N - (\nu - \sigma)(1 - \nu)^{-1} \hat{\varepsilon}_t^M$.

Finally, these equations represent the Euler condition for the optimal intratemporal allocation of consumption (equation (4)), the intertemporal optimality condition setting the marginal rate of substitution between money and consumption equal to the opportunity cost of holding money (equation (5)), and the intratemporal optimality condition setting the marginal rate of substitution between leisure and consumption equal to the real wage[3] (equation (6)).

2.2 Firms

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[4],

$$Y_t(i) = A_t N_t(i)^{1-\alpha} \tag{7}$$

where A_t is the level of technology, assumed to be common to all firms and to evolve exogenously over time.

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, while the remaining firms index their prices to lagged inflation[5].

2.3 Price dynamics

Let's assume a set of firms not reoptimizing their posted price in period t. Using the definition of the aggregate price level[6] and the fact that all firms resetting prices choose an identical price P_t^*, leads to $P_t = \left[\theta P_{t-1}^{1-\varepsilon} + (1-\theta)(P_t^*)^{1-\varepsilon}\right]^{\frac{1}{1-\varepsilon}}$. Dividing both sides by P_{t-1} and log-linearizing around $P_t^* = P_{t-1}$ yields

$$\pi_t = (1 - \theta)(p_t^* - p_{t-1}) \tag{8}$$

[3] See Appendix 7.2

[4] For simplicity reasons, we assume a simple production function without capital.

[5] Thus, each period, $1 - \theta$ producers reset their prices, while a fraction θ keep their prices unchanged.

[6] As shown in Appendix 7.1

In this setup, inflation results from the fact that firms reoptimizing in any given period choose a price that differs from the economy's average price in the previous period.

2.4 Price setting

A firm reoptimizing in period t chooses the price P_t^* that maximizes the current market value of the profits generated while that price remains effective. This problem is solved and leads to a first-order Taylor expansion around the zero inflation steady state:

$$p_t^* - p_{t-1} = (1-\beta\theta) \sum_{k=0}^{\infty} (\beta\theta)^k E_t \left[\widehat{mc}_{t+k|t} + (p_{t+k} - p_{t-1}) \right] \tag{9}$$

where $\widehat{mc}_{t+k|t} = mc_{t+k|t} - mc$ denotes the log deviation of marginal cost from its steady state value $mc = -\mu$, and $\mu = \log(\varepsilon/(\varepsilon-1))$ is the log of the desired gross markup.

2.5 Equilibrium

Market clearing in the goods market requires $Y_t(i) = C_t(i)$ for all $i \in [0,1]$ and all t. Aggregate output is defined as $Y_t = \left(\int_0^1 Y_t(i)^{1-\frac{1}{\varepsilon}} di \right)^{\frac{\varepsilon}{\varepsilon-1}}$; it follows that $Y_t = C_t$ must hold for all t. One can combine the above goods market clearing condition with the consumer's Euler equation (4) to yield the equilibrium condition

$$\begin{aligned} \hat{y}_t &= E_t[\hat{y}_{t+1}] - \frac{1}{\nu + (\sigma-\nu) a_1} (\hat{\imath}_t - E_t[\hat{\pi}_{t+1}]) \\ &\quad + \frac{(\sigma-\nu)(1-a_1)}{\nu + (\sigma-\nu) a_1} (E_t[\Delta\hat{m}_{t+1}] - E_t[\hat{\pi}_{t+1}]) + \xi_{t,c} \end{aligned} \tag{10}$$

Market clearing in the labor market requires $N_t = \int_0^1 N_t(i)\, di$. By using the production function (7) and taking logs, one can write the following approximate relation between aggregate output, employment and technology as

$$y_t = a_t + (1-\alpha) n_t \tag{11}$$

An expression is derived for an individual firm's marginal cost in terms of the economy's average real marginal cost:

$$\begin{aligned} mc_t &= (\hat{w}_t - \hat{p}_t) - \widehat{mpn}_t && (12) \\ &= (\hat{w}_t - \hat{p}_t) - \frac{1}{1-\alpha} (\hat{a}_t - \alpha \hat{y}_t) && (13) \end{aligned}$$

for all t, where $\widehat{mpn}_t$ defines the economy's average marginal product of labor. As $mc_{t+k|t} = (\hat{w}_{t+k} - \hat{p}_{t+k}) - mpn_{t+k|t}$ we have

$$mc_{t+k|t} = mc_{t+k} - \frac{\alpha\varepsilon}{1-\alpha} (p_t^* - p_{t+k}) \tag{14}$$

where the second equality[7] follows from the demand schedule combined with the market clearing condition $c_t = y_t$. Substituting (14) into (9) yields

$$p_t^* - p_{t-1} = (1-\beta\theta)\,\Theta \sum_{k=0}^{\infty} (\beta\theta)^k\, E_t\left[\widehat{mc}_{t+k}\right] + \sum_{k=0}^{\infty} (\beta\theta)^k\, E_t\left[\pi_{t+k}\right] \tag{15}$$

where $\Theta = (1-\alpha)(1-\alpha+\alpha\varepsilon)^{-1} \leq 1$.

Finally, (8) and (15) yield the inflation equation

$$\pi_t = \beta E_t\left[\pi_{t+1}\right] + \lambda_{mc}\widehat{mc}_t \tag{16}$$

where β, $\lambda_{mc} = \Theta\left((1-\theta)\,\theta^{-1}\right)(1-\beta\theta)$. λ_{mc} is strictly decreasing in the index of price stickiness θ, in the measure of decreasing returns α, and in the demand elasticity ε.

Next, a relation is derived between the economy's real marginal cost and a measure of aggregate economic activity. From (6) and (11), the average real marginal cost can be expressed as

$$\begin{aligned} mc_t \;&=\; \left(\nu - (\nu-\sigma)\,a_1 + \frac{\eta+\alpha}{1-\alpha}\right)\hat{y}_t - \hat{a}_t\left(\frac{1+\eta}{1-\alpha}\right) \\ &\quad + (\sigma-\nu)(1-a_1)(\hat{m}_t - \hat{p}_t) + \xi_{t,n} \end{aligned} \tag{17}$$

Under flexible prices the real marginal cost is constant and equal to $mc = -\mu$. Defining the natural level of output, denoted by y_t^f, as the equilibrium level of output under flexible prices leads to

$$\begin{aligned} mc \;&=\; \left(\nu - (\nu-\sigma)\,a_1 + \frac{\eta+\alpha}{1-\alpha}\right)\hat{y}_t^f - \hat{a}_t\left(\frac{1+\eta}{1-\alpha}\right) \\ &\quad + \xi_{t,n}^f + (\sigma-\nu)(1-a_1)\left(\hat{m}_t^f - \hat{p}_t^f\right) \end{aligned} \tag{18}$$

thus implying

$$\hat{y}_t^f = \upsilon_a^f \hat{a}_t + \upsilon_m^f\left(\hat{m}_t^f - \hat{p}_t^f\right) + \upsilon_0^f + \upsilon_t^f \tag{19}$$

where

$$\begin{aligned} \upsilon_a^f &= \frac{1+\eta}{(\nu-(\nu-\sigma)\,a_1)(1-\alpha)+\eta+\alpha} \\ \upsilon_m^f &= \frac{(1-\alpha)(\nu-\sigma)(1-a_1)}{(\nu-(\nu-\sigma)\,a_1)(1-\alpha)+\eta+\alpha} \\ \upsilon_0^f &= \frac{-\mu(1-\alpha)}{(\nu-(\nu-\sigma)\,a_1)(1-\alpha)+\eta+\alpha} \\ \upsilon_t^f &= \frac{\alpha-1}{(\nu-(\nu-\sigma)\,a_1)(1-\alpha)+\eta+\alpha}\xi_{t,n}^f \end{aligned}$$

[7] Note that under the assumption of constant returns to scale ($\alpha = 0$), $mc_{t+k|t} = mc_{t+k}$, i.e., the marginal cost is independent of the level of production and, hence, is common across firms.

As can be seen, the natural level of output depends on real money balances with flexible prices. In our model, when $\mu = 0$ (perfect competition), the natural level of output doesn't correspond to the equilibrium level of output in the classical economy (perfect competition and fully flexible prices in all markets) due to the presence of money in the non-separable utility function. Firms market power has the effect of lowering that output level uniformly over time, without affecting its sensitivity to changes in technology.

Subtracting (18) from (17) yields

$$\widehat{mc}_t = \psi_x \left(\hat{y}_t - \hat{y}_t^f\right) + \psi_m \left((\hat{m}_t - \hat{p}_t) - \left(\hat{m}_t^f - \hat{p}_t^f\right)\right) + \psi_t \tag{20}$$

where $\psi_x = \nu - (\nu - \sigma) a_1 + (\eta + \alpha)(1-\alpha)^{-1}$, $\psi_m = (\sigma - \nu)(1 - a_1)$ and $\psi_t = \xi_{t,n} - \xi_{t,n}^f$.

By combining (20) with (16), and by taking first differences, we obtain

$$\hat{\pi}_t = \kappa_{\pi,+1} E_t[\hat{\pi}_{t+1}] + \kappa_{\pi,-1}\hat{\pi}_{t-1} + \kappa_x \Delta\hat{x}_t + \kappa_m \Delta\hat{m}_t + z_t^\pi \tag{21}$$

where $\hat{x}_t = \hat{y}_t - \hat{y}_t^f$ is the output gap, $\kappa_{\pi,+1} = \frac{\beta}{1+\beta+\lambda_{mc}\psi_m}$, $\kappa_{\pi,-1} = \frac{1}{1+\beta+\lambda_{mc}\psi_m}$, $\kappa_x = \frac{\lambda_{mc}\psi_x}{1+\beta+\lambda_{mc}\psi_m}$, $\kappa_m = \frac{\lambda_{mc}\psi_m}{1+\beta+\lambda_{mc}\psi_m}$ and $z_t^\pi = \frac{\lambda_{mc}\left(\psi_m \hat{\pi}_t^f - \psi_m \Delta\hat{m}_t^f + \Delta\psi_t\right)}{1+\beta+\lambda_{mc}\psi_m}$.

Then (21) is our first equation relating inflation to its one period ahead forecast, its one period lag value, the first difference of the output gap and the money stock growth.

The second key equation describing the equilibrium of the model is obtained by rewriting (10) so as to determine the output gap

$$\hat{x}_t = E_t[\hat{x}_{t+1}] - \kappa_r (\hat{\imath}_t - E_t[\hat{\pi}_{t+1}]) + \kappa_{mp} (E_t[\Delta\hat{m}_{t+1}] - E_t[\hat{\pi}_{t+1}]) + z_t^x \tag{22}$$

where $\kappa_r = \frac{1}{\nu - (\nu-\sigma)a_1}$, $\kappa_{mp} = \frac{(\nu-\sigma)(1-a_1)}{(\nu-\sigma)a_1 - \nu}$ and $z_t^x = \xi_{t,c} + E_t\left[\Delta\hat{y}_{t+1}^f\right]$. (22) is thus a dynamic IS equation including the money stock growth.

The third key equation describes the behavior of the money stock. Taking the first difference of (5) yields

$$\hat{m}_t = \hat{m}_{t-1} + \hat{\pi}_t + \Delta\hat{x}_t - \kappa_i \Delta\hat{\imath}_t + z_t^m \tag{23}$$

where $\kappa_i = a_2/\nu$ and $z_t^m = \nu^{-1}\Delta\hat{\varepsilon}_t^M - \Delta\hat{y}_t^f$.

The last equation determines the interest rate through a standard smoothed Taylor-type rule:

$$i_t = (1-\lambda_i)(\lambda_\pi(\pi_t - \pi^*) + \lambda_x x_t) + \lambda_i i_{t-1} + z_t^i \tag{24}$$

where λ_π and λ_x are policy coefficients reflecting the weight on inflation and on the output gap; the parameter $0 < \lambda_i < 1$ captures the degree of interest rate smoothing. z_t^i is an exogenous *ad hoc* shock accounting for fluctuations of nominal interest rate such that $z_t^i = \rho_i z_{t-1}^i + \varepsilon_{i,t}$ with $\varepsilon_{i,t} \sim N(0; \sigma_i)$. To simplify, we assume that the target inflation rate is equal to zero, i.e. $\pi^* = 0$. A decomposition of the above coefficients is provided in Appendix 7.3.

3 Calibrating the model

In our model of the Euro zone, $\hat{\pi}_t$ is the log-linearized inflation rate measured as the 12-month increase in the Euro-area Harmonized Consumer Price Index (HCPI), $\Delta\hat{m}_t$ is the log-linearized growth rate of the $M3$ monetary aggregate ($\Delta\hat{m}_t = \hat{m}_t - \hat{m}_{t-1}$), $\hat{x}_t$ is the Hodrick-Prescott (HP) trend of the log-linearized industrial output gap, i_t is the nominal interest rate and z_t^π, z_t^x, z_t^m, z_t^i, and $\hat{a}_t$ are shocks, respectively, on the inflation rate, the output gap, money growth, the nominal interest rate and the technology. Structural shocks (ε_t^P, ε_t^N, and ε_t^M), the exogenous component of the interest rate (ε_t^i) and of the productivity (ε_t^a) are assumed to follow a first-order autoregressive process with an *i.i.d.*-normal error term such as $\varepsilon_t^k = \mu_k \varepsilon_{t-1}^k + \omega_{k,t}$ where $\varepsilon_{k,t} \sim N(0; \sigma_k)$ for $k = \{P, N, M, i, a\}$.

We calibrate the model parameters by using the General Method of Moments[8] (GMM) to test our four equations (21), (22), (23) and (24). We obtain the following results:

$$\hat{\pi}_t = 0.489 E_t [\hat{\pi}_{t+1}] + 0.494 \hat{\pi}_{t-1} + 0.047 \Delta\hat{x}_t + 0.108 \Delta\hat{m}_t + z_t^\pi \tag{25}$$

$$\hat{x}_t = E_t [\hat{x}_{t+1}] - 0.013 (\hat{\imath}_t - E_t [\hat{\pi}_{t+1}]) + 0.0021 (E_t [\Delta\hat{m}_{t+1}] - E_t [\hat{\pi}_{t+1}]) + z_t^x \tag{26}$$

$$\hat{m}_t = \hat{m}_{t-1} + \hat{\pi}_t + \Delta\hat{x}_t - 0.44 \Delta\hat{\imath}_t + z_t^m \tag{27}$$

$$\hat{\imath}_t = (1 - 0.53)(2.23 \hat{\pi}_t + 0.82 \hat{x}_t) + 0.53 \hat{\imath}_{t-1} + z_t^i \tag{28}$$

4 DSGE Simulation

We simulate our model with the following shocks[9]:

$$\begin{aligned}
z_t^\pi &= \tfrac{\lambda_{mc}}{1+\beta+\lambda_{mc}\psi_m} \left(\Delta\hat{\varepsilon}_t^N - \left(\tfrac{\nu-\sigma}{1-\nu}\right) \Delta\hat{\varepsilon}_t^M - \tfrac{\psi_m}{\upsilon_m^f} \left(\hat{r}_{t-1}^n - \upsilon_a^f \Delta\hat{a}_t \right) + tip_t \right) \\
z_t^x &= -\tfrac{1}{\nu+(\sigma-\nu)a_1} \left(\tfrac{\nu-\sigma}{1-\nu}\right) E_t \left[\Delta\hat{\varepsilon}_{t+1}^M \right] - \tfrac{1}{\nu+(\sigma-\nu)a_1} E_t \left[\Delta\hat{\varepsilon}_{t+1}^P \right] + \hat{r}_t^n \\
z_t^m &= \tfrac{1}{\nu} \Delta\hat{\varepsilon}_t^M - \hat{r}_{t-1}^n \\
z_t^i &= \rho_i z_{t-1}^i + \varepsilon_t^i \\
\hat{a}_t &= \rho_a \hat{a}_{t-1} + \varepsilon_t^a
\end{aligned}$$

where tip_t are terms independents of policy containing all shocks in case of flexible prices.

It is assumed that structural shocks follow the process below:

[8] See Appendix 7.4 for the econometric analysis.
[9] See Appendix 7.5 for the decomposition of shocks.

$$\begin{aligned}
\hat{\varepsilon}_t^P &= 0.8\hat{\varepsilon}_{t-1}^P + \omega_{P,t} \\
\hat{\varepsilon}_t^N &= 0.8\hat{\varepsilon}_{t-1}^N + \omega_{N,t} \\
\hat{\varepsilon}_t^M &= 0.8\hat{\varepsilon}_{t-1}^M + \omega_{M,t} \\
\varepsilon_t^i &= 0.8\varepsilon_{t-1}^i + \omega_{i,t} \\
\varepsilon_t^a &= 0.8\varepsilon_{t-1}^a + \omega_{a,t}
\end{aligned}$$

where $\omega_{P,t}$, $\omega_{N,t}$, $\omega_{M,t}$, $\omega_{i,t}$ and $\omega_{a,t}$ are *i.i.d.* shocks with variance of 0.02^2. The model includes a common shock persistence of 0.8 as is usual in the DSGE literature. The impulse response functions in the diagrams below illustrate how the economy adjusts, i.e. how the disturbance causes each variable to move away from its steady state (zero line) and how it reverts back to it. The figures below illustrate the response of the system to a structural shock.

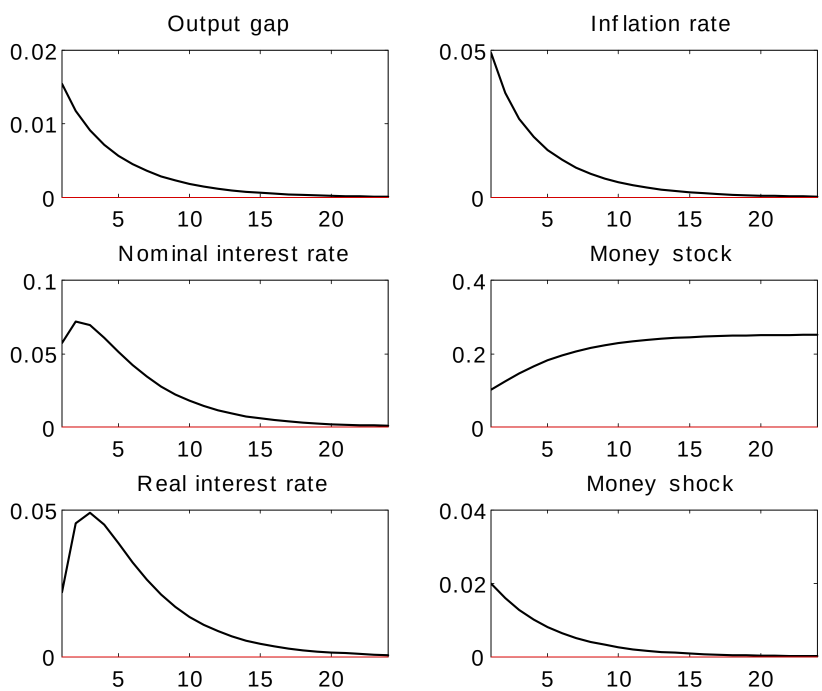


Figure 1: Impulse response functions after a money shock

A positive shock on the money stock leads to an increase in inflation, which induces a monetary policy tightening (Figure 1). The inflation rate and the output gap reach their equilibrium level while the nominal interest rate adjusts with a peak in the first periods. The output gap falls sharply due to a high interest rate adjustment then returns to its equilibrium level faster than the inflation rate.

It is important to note that the interest rate reaches a peak and its reaction is stronger than the reactions of the output gap and the inflation rate at the beginning of the adjustment period. This implies that the ECB should react strongly to a money demand shock in order to stabilize the inflation rate.

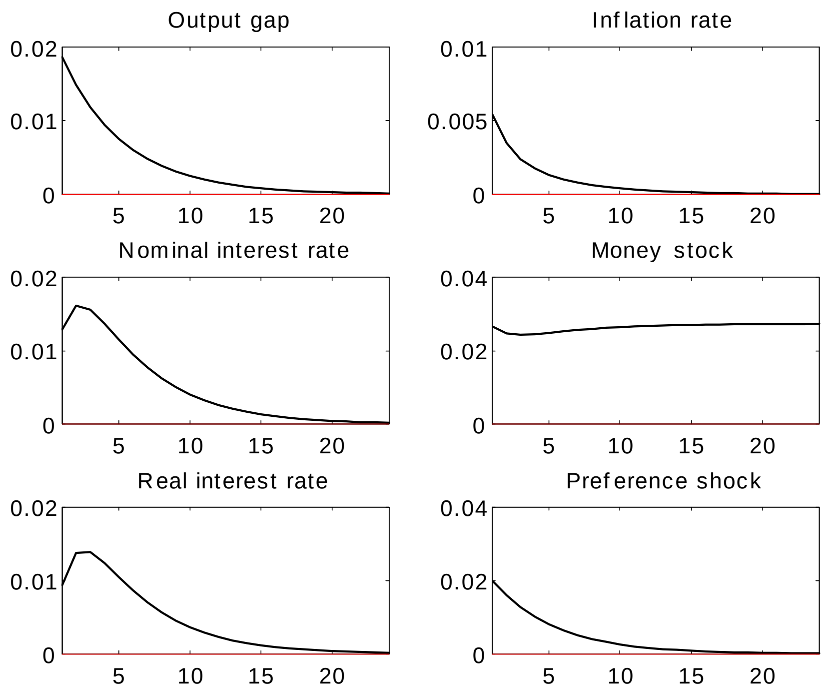


Figure 2: Impulse response functions of a preference shock

As Figure 2 shows, a positive preference (or consumption) shock leads to an increase in the nominal interest rate, which induces a short run decrease in the money stock (after an instantaneous increase), sustained by higher activity. Indeed, the output gap and the inflation rate largely increase, which explains the monetary policy tightening.

Another remark concerns the peak in the nominal interest rate response. It implies that the ECB needs to react strongly to a preference shock in order to eliminate the output gap.

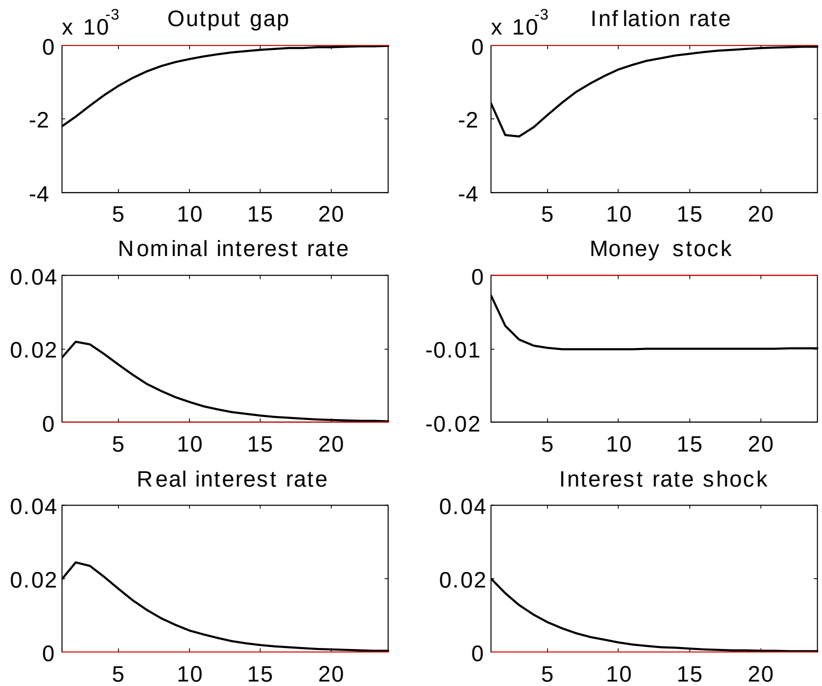


Figure 3: Impulse response functions of a nominal interest rate shock

As shown in Figure 3, a nominal interest rate shock leads to an instantaneous decrease in the inflation rate and the output gap. The results show a peak for the nominal interest rate at the beginning of the adjustment period. This means that a strong reaction by the ECB to a nominal interest rate shock in an important means to bring the inflation rate to its optimal path.

Note that the nominal interest rate goes up, though by less than its exogenous component (as a result of the downward adjustment induced by the decline in inflation and the output gap). In order to bring about the observed interest rate response, the ECB must engineer a reduction in the money supply. The calibrated model thus displays a liquidity effect.

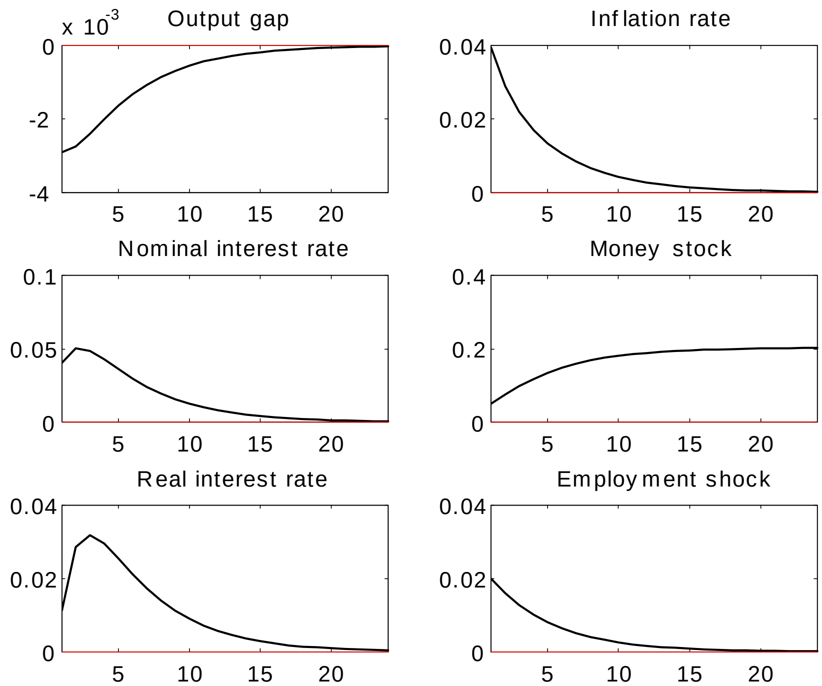


Figure 4: Impulse response functions of a worked hours shock

Figure 4 shows that a positive shock to employment leads to an instantaneous nominal interest rate tightening due to a surge in inflation. The money stock falls under its equilibrium value.

Again, our model shows a peak for the nominal interest rate. It implies that the ECB should react strongly to an employment shock at the very beginning of the adjustment period.

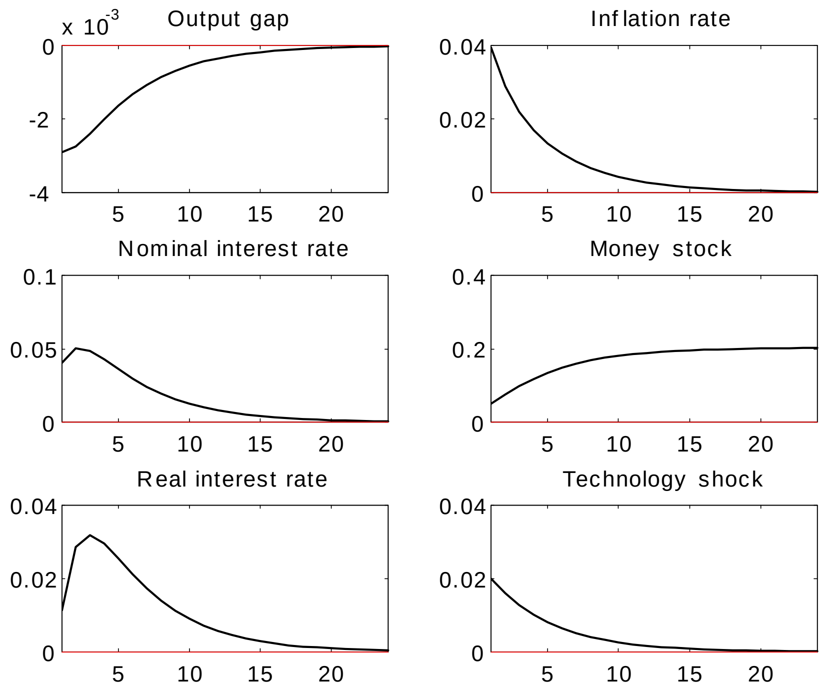


Figure 5: Impulse response functions of a technology shock

Figure 5 demonstrates that a technology shock leads to an instantaneous nominal interest rate tightening following a surge in inflation. The output gap deteriorates as well.

5 Interpretation

Kremer, Lombardo and Werner (2003) estimate a New-Keynesian DSGE model with German data (supposedly close to Euro area data) and find that real money balances contribute significantly to the determination of inflation and to the dynamics of output. Yet contrary to our findings, their impulse response function to a money demand shock does not show any peak for the nominal interest rate whereas our model magnifies the central bank reaction.

In a DSGE model calibrated for the German economy, the Deutsche Bundesbank (Eurosystem, 2008) analyses the response of selected variables to a preference shock. The results do not reveal any peak for the nominal interest rate, whereas our model highlights a significant and quick reaction. Nevertheless, our results are qualitatively similar to those stated in the Bundesbank paper even as the model utilized is built on a separable utility function.

Similarly, Bhattacharjee and Thoenissen (2007) compare two methods of introducing money in New Keynesian DSGE models (money-in-the-utility (MIU) or cash-in-advance (CIA) constraint). They observe that in response to an unexpected increase in the money growth rate, the CIA model generates hump-shaped impulse responses for output and its components. Following an interest rate shock the MIU case (completely separable money in the utility function) implies a fall of the inflation rate; but contrary to our model, it does not reveal any peak in the central bank's reaction. The main property of our model is therefore to magnify shocks and the curvature of the impulse response functions.

Casares (2006) describes a New Keynesian model calibrated on Euro area macroeconomic data. Its impulse response functions with interest rate smoothing (like in our model) don't highlight any nominal interest rate peak, except after an inflation shock. For other shocks, Casares' New Keynesian model doesn't magnify the central bank's response. Our model demonstrates this feature only because money enters the picture.

Last but not least, Galí (2008) simulates a baseline model with a separable utility function (MIU) where money does not play any role. Qualitatively, the results are similar to ours: most of the phenomena highlighted by these basic New Keynesian models are well replicated in our model, but for the nominal interest rate which peaks after the various shocks and the effects of a technology shock involving a monetary policy tightening.

Our impulse response analysis suggests that the method with which we introduce money into these type of models appears to add significant information. It clearly shows that assigning a larger role to money could be a useful tool to underpin the medium-term orientation of monetary policy and to stabilize the economy.

6 Conclusion

New Keynesian models downplay the role of monetary aggregates: the level of output, of inflation and of the interest rate can be determined without knowledge of the money stock. Our paper examines the validity of this view by studying the effects of structural shocks through a New Keynesian DSGE simulation on the Euro zone, with money included in a non-separable utility function.

Where money is introduced through an explicit CES utility function, we demonstrate that money should be a useful tool for central bankers. It incentivises monetary authorities to react more aggressively to shocks. According to our results and comparing them to other studies, our approach highlights the role of money in inflation and output gap determination. It also shows that taking money into consideration implies a stronger impact on the level of the interest rate whenever there is a shock to the system. Hence, even in New Keynesian models, money has an important role to play in terms of price and output dynamics. In accordance with our theoretical and empirical framework, the central bank should react more aggressively to shocks than when money is "forgotten".

Our approach sustains what seems to be the position of the Executive Board of the ECB (Jürgen Stark, 2006): "Taking policy decisions and evaluating their consequences only on the basis of the short-term indications stemming from the analysis of economic variables would be misguided. Assessing the trend evolution of monetary aggregates (...) allows a central bank to broaden its analysis. In particular, it often helps central banks to see beyond the transient impact of the various shocks hitting the economy. Therefore, it avoids setting monetary policy on an incompletely informed – and thus potentially destabilizing – course".

Even though the ECB may have gone as far as looking at the evolution of the money stock, it stopped short of drawing the consequences in terms of sufficiently controlling it. Regrettably, it seems the ECB ultimately did not quite practice what it preached.

7 Appendix

7.1 Aggregate consumption and price index

Let $C_t = \left(\int_0^1 C_t(i)^{1-\frac{1}{\varepsilon}}\, di\right)^{\frac{\varepsilon}{\varepsilon-1}}$ be a consumption index where $C_t(i)$ represents the quantity of good i consumed by the household in period t. This requires that C_t be maximized for any given level of expenditures $\int_0^1 P_t(i)\, C_t(i)\, di$ where $P_t(i)$ is the price of good i at time t. The maximization of C_t for any given expenditure level $\int_0^1 P_t(i)\, C_t(i)\, di = Z_t$ can be formalized by means of the Lagrangian

$$\mathcal{L} = \left[\int_0^1 C_t(i)^{1-\frac{1}{\varepsilon}}\, di\right]^{\frac{\varepsilon}{\varepsilon-1}} - \lambda\left(\int_0^1 P_t(i)\, C_t(i)\, di - Z_t\right) \tag{29}$$

The associated first-order conditions are $C_t(i)^{-\frac{1}{\varepsilon}}\, C_t^{\frac{1}{\epsilon}} = \lambda P_t(i)$ for all $i \in [0,1]$. Thus, for any two goods (i,j),

$$C_t(i) = C_t(j)\left(\frac{P_t(i)}{P_t(j)}\right)^{-\varepsilon} \tag{30}$$

which can be substituted into the expression for consumption expenditures to yield $C_t(i) = \left(\frac{P_t(i)}{P_t}\right)^{-\varepsilon} \frac{Z_t}{P_t}$ for all $i \in [0,1]$ where $P_t = \left(\int_0^1 P_t(i)^{1-\varepsilon}\, di\right)^{\frac{1}{1-\varepsilon}}$ is an aggregate price index. The latter condition can then be substituted into the definition of C_t to obtain

$$\int_0^1 P_t(i)\, C_t(i)\, di = P_t C_t \tag{31}$$

Combining the two previous equations yields the demand schedule equation $C_t(i) = \left(\frac{P_t(i)}{P_t}\right)^{-\varepsilon} C_t$ for all $i \in [0,1]$

7.2 Optimization problem

Our Lagrangian is given by

$$L_t = E_t \left[\sum_{k=0}^{\infty} \beta^k U_{t+k} - \lambda_{t+k} V_{t+k} \right] \tag{32}$$

where

$$V_t = C_t + \frac{M_t}{P_t} + Q_t \frac{B_t}{P_t} - \frac{B_{t-1}}{P_t} - \frac{W_t}{P_t} N_t - \frac{M_{t-1}}{P_t} \tag{33}$$

and

$$U_t = e^{\varepsilon_t^P} \left(\frac{1}{1-\sigma} \left((1-b)\, C_t^{1-\nu} + b e^{\varepsilon_t^M} \left(\frac{M_t}{P_t} \right)^{1-\nu} \right)^{\frac{1-\sigma}{1-\nu}} - \frac{\chi e^{\varepsilon_t^N} N_t^{1+\eta}}{1+\eta} \right) \tag{34}$$

The first order condition related to consumption expenditures is given by

$$\lambda_t = e^{\varepsilon_t^P} (1-b)\, C_t^{-\nu} \left((1-b)\, C_t^{1-\nu} + b e^{\varepsilon_t^M} \left(\frac{M_t}{P_t} \right)^{1-\nu} \right)^{\frac{1-\sigma}{1-\nu}-1} \tag{35}$$

where λ_t is the Lagrange multiplier associated with the budget constraint at time t. The first order condition corresponding to the demand for contingent bonds implies that

$$Q_t = \beta E_t \left[\frac{\lambda_{t+1}}{\lambda_t} \frac{P_t}{P_{t+1}} \right] \tag{36}$$

The demand for cash that follows from the household's optimization problem is given by

$$b e^{\varepsilon_t^M} e^{\varepsilon_t^P} \left(\frac{M_t}{P_t} \right)^{-\nu} \left((1-b)\, C_t^{1-\nu} + b e^{\varepsilon_t^M} \left(\frac{M_t}{P_t} \right)^{1-\nu} \right)^{\frac{1-\sigma}{1-\nu}-1} = \lambda_t - \beta E_t \left[\lambda_{t+1} \frac{P_t}{P_{t+1}} \right] \tag{37}$$

which can be naturally interpreted as a demand for real balances. The latter is increasing in consumption and inversely related to the nominal interest rate, as in conventional specifications.

$$\chi e^{\varepsilon_t^P} e^{\varepsilon_t^N} N_t^{\eta} = \lambda_t \frac{W_t}{P_t} \tag{38}$$

We obtain from (35)

$$U_{c,t} = e^{\varepsilon_t^P} (1-b)\, C_t^{-\nu} \left((1-b)\, C_t^{1-\nu} + b e^{\varepsilon_t^M} \left(\frac{M_t}{P_t} \right)^{1-\nu} \right)^{\frac{1-\sigma}{1-\nu}-1} \tag{39}$$

where $U_{c,t} = \left. \frac{\partial U_{t+k}}{\partial C_{t+k}} \right|_{k=0}$. Equation (39) defines the marginal utility of consumption. Hence, the optimal consumption/savings, real money balances and labor supply decisions are described by the following conditions:

- Combining (35) with (36) gives

$$Q_t = \beta E_t \left[\frac{U_{c,t+1}}{U_{c,t}} \frac{P_t}{P_{t+1}} \right] \tag{40}$$

$$Q_t = \beta E_t \left[\frac{e^{\varepsilon^P_{t+1}} C_{t+1}^{-\nu} P_t}{e^{\varepsilon^P_t} C_t^{-\nu} P_{t+1}} \left(\frac{(1-b)\, C_{t+1}^{1-\nu} + b e^{\varepsilon^M_{t+1}} \left(\frac{M_{t+1}}{P_{t+1}} \right)^{1-\nu}}{(1-b)\, C_t^{1-\nu} + b e^{\varepsilon^M_t} \left(\frac{M_t}{P_t} \right)^{1-\nu}} \right)^{\frac{1-\sigma}{1-\nu}-1} \right] \tag{41}$$

where $U_{c,t+1} = \left. \frac{\partial U_{t+k}}{\partial C_{t+k}} \right|_{k=1}$. Equation (40) is the usual Euler equation for intertemporal consumption flows. It establishes that the ratio of marginal utility of future and current consumption is equal to the inverse of the real interest rate. The above equation can be rewritten as

$$e^{-i_t} = \beta E_t \left[\frac{e^{\varepsilon^P_{t+1}} C_{t+1}^{-\nu} Z_{t+1}^{\frac{\nu-\sigma}{1-\nu}}}{e^{\varepsilon^P_t} C_t^{-\nu} Z_t^{\frac{\nu-\sigma}{1-\nu}}} \frac{P_t}{P_{t+1}} \right]$$

where $Z_t = (1-b)\, C_t^{1-\nu} + b e^{\varepsilon^M_t} \left(\frac{M_t}{P_t} \right)^{1-\nu}$. Linearizing the above equation around the steady state yields

$$-\hat{\imath}_t = E_t \left[\Delta \hat{\varepsilon}^P_{t+1} - \nu \Delta \hat{c}_{t+1} - \hat{\pi}_{t+1} + \frac{\nu - \sigma}{1-\nu} \Delta \hat{z}_{t+1} \right] \tag{42}$$

where $\hat{z}_t = Z_t - Z^{ss}$ and $\hat{z}_t = (1-\nu)\, a_1 \hat{c}_t + \hat{\varepsilon}^M_t + (1-\nu)\,(1-a_1)\,(\hat{m}_t - \hat{p}_t)$ with $a_1 = \frac{(1-b) C_{ss}^{1-\nu}}{(1-b) C_{ss}^{1-\nu} + b \left(\frac{M_{ss}}{P_{ss}} \right)^{1-\nu}}$, C_{ss} consumption in the steady state and $\frac{M_{ss}}{P_{ss}}$ real money balances in the steady state. Thus,

$$-\hat{\imath}_t = E_t \left[\begin{array}{c} ((\nu-\sigma)\, a_1 - \nu)\, \Delta \hat{c}_{t+1} - \hat{\pi}_{t+1} - (\nu-\sigma)\,(1-a_1)\, \hat{\pi}_{t+1} \\ + (\nu-\sigma)\,(1-a_1)\, \Delta \hat{m}_{t+1} + \left(\frac{\nu-\sigma}{1-\nu} \right) \Delta \hat{\varepsilon}^M_{t+1} + \Delta \hat{\varepsilon}^P_{t+1} \end{array} \right] \tag{43}$$

- Combining (35) with (37) gives

$$\frac{U_{m,t}}{U_{c,t}} = 1 - Q_t \tag{44}$$

$$\frac{b e^{\varepsilon^M_t} \left(\frac{M_t}{P_t} \right)^{-\nu}}{(1-b)\, C_t^{-\nu}} = 1 - Q_t \tag{45}$$

where $U_{m,t} = \left. \frac{\partial U_{t+k}}{\partial (M_{t+k}/P_{t+k})} \right|_{k=0}$. Equation (44) is the intertemporal optimality condition setting the marginal rate of substitution between money and consumption equal to the opportunity cost of holding money. By log-linearizing the above equation, we obtain

$$-\nu\, (\hat{m}_t - \hat{p}_t) + \hat{\varepsilon}^M_t + \nu \hat{c}_t = a_2 \hat{\imath}_t$$

where $i_t = -\log Q_t$; by using a second order Taylor approximation, with a_2 constant, yields $\log(1-Q_t) = a_2 i_t$.

- Combining (35) with (38) leads to

$$-\frac{U_{n,t}}{U_{c,t}} = \frac{W_t}{P_t} \tag{46}$$

$$\frac{\chi e^{\varepsilon_t^N} N_t^{\eta}}{(1-b)\, C_t^{-\nu}\left((1-b)\, C_t^{1-\nu} + b e^{\varepsilon_t^M}\left(\frac{M_t}{P_t}\right)^{1-\nu}\right)^{\frac{1-\sigma}{1-\nu}-1}} = \frac{W_t}{P_t} \tag{47}$$

where $U_{n,t} = \left.\frac{\partial U_{k,t}}{\partial N_{t+k}}\right|_{k=0}$. Equation (46) is the condition for the optimal consumption-leisure arbitrage, implying that the marginal rate of substitution between consumption and labor is equated to the real wage. By log-linearizing the above equation around the steady state, we obtain

$$\begin{aligned} \eta \hat{n}_t + (\nu - (\nu-\sigma)\, a_1)\, \hat{c}_t - \left(\frac{\nu-\sigma}{1-\nu}\right) \hat{\varepsilon}_t^M \\ -(\nu-\sigma)\,(1-a_1)\,(\hat{m}_t - \hat{p}_t) + \hat{\varepsilon}_t^N = \hat{w}_t - \hat{p}_t \end{aligned} \tag{48}$$

7.3 Coefficients of the model

$$\kappa_{\pi,+1} = \frac{\beta}{1+\beta+\frac{1-\alpha}{1-\alpha+\alpha\varepsilon}\left(\frac{1-\theta}{\theta}\right)(1-\beta\theta)(\sigma-\nu)(1-a_1)}$$

$$\kappa_{\pi,-1} = \frac{1}{1+\beta+\frac{1-\alpha}{1-\alpha+\alpha\varepsilon}\left(\frac{1-\theta}{\theta}\right)(1-\beta\theta)(\sigma-\nu)(1-a_1)}$$

$$\kappa_x = \frac{\frac{1-\alpha}{1-\alpha+\alpha\varepsilon}\left(\frac{1-\theta}{\theta}\right)(1-\beta\theta)(\sigma-\nu)(1-a_1)\left(\nu-(\nu-\sigma)\, a_1 + \frac{\eta+\alpha}{1-\alpha}\right)}{1+\beta+\frac{1-\alpha}{1-\alpha+\alpha\varepsilon}\left(\frac{1-\theta}{\theta}\right)(1-\beta\theta)(\sigma-\nu)(1-a_1)}$$

$$\kappa_m = \frac{1}{\frac{1+\beta}{\left(\frac{1-\alpha}{1-\alpha+\alpha\varepsilon}\right)\left(\frac{1-\theta}{\theta}\right)(1-\beta\theta)(\sigma-\nu)(1-a_1)}+1}$$

$$\kappa_r = \frac{1}{\nu-(\nu-\sigma)\, a_1}$$

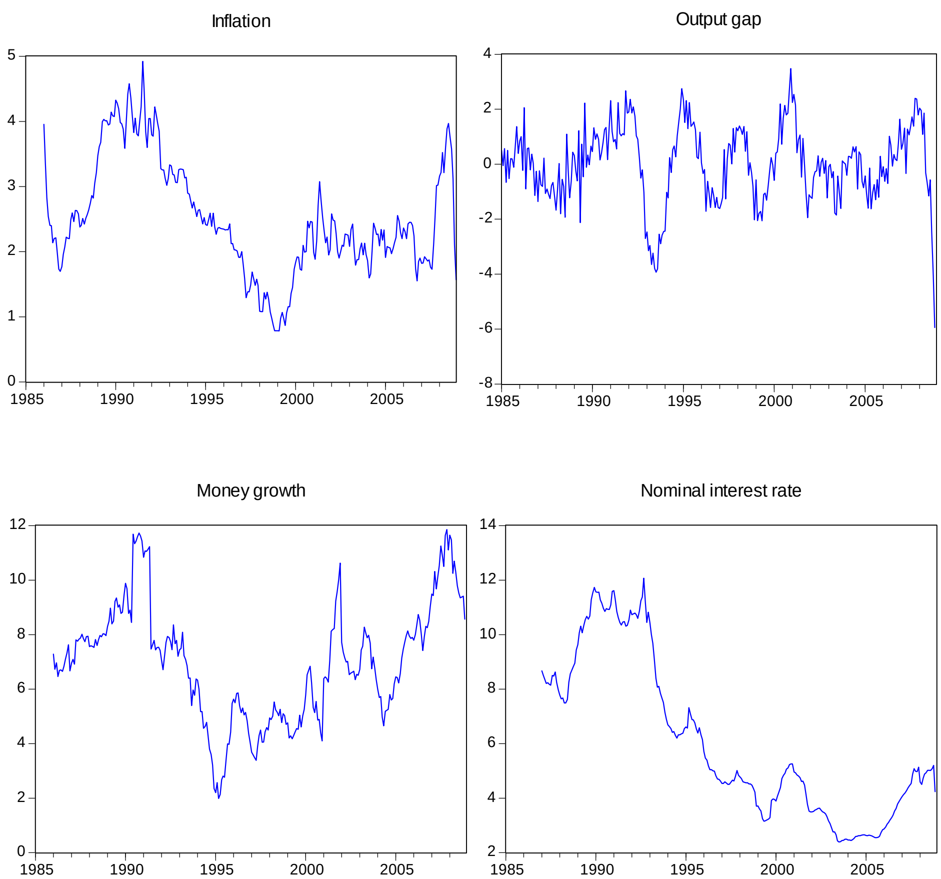
$$\kappa_{mp} = \frac{(\nu-\sigma)\,(1-a_1)}{(\nu-\sigma)\, a_1 - \nu}$$

$$\kappa_i = \frac{a_2}{\nu}$$

7.4 Estimations

The DSGE model parameters are estimated by using the General Method of Moments.

7.4.1 Data



The above data on the Euro area are of a monthly frequency from 1985 to 2008 and are extracted from the Datastream base. $\hat{x}_t$ (output gap) is the difference between the log-linearized output around the steady state ($\hat{y}_t = y_t - y$) and the log-linearized output around the steady state with flexible prices ($\hat{x}_t = \hat{y}_t - \hat{y}_t^f$). y_t is the log of the industrial production index (excluding construction) and $\hat{y}_t^f$ is the Hodrick-Prescott log of the industrial production index (excluding construction). $\Delta\hat{x}_t$ is then the detrended variation of the output gap. It corresponds to the difference between the output gap in period t

and the output gap in period $t-12$. A lag of twelve periods is chosen because it is important to compare the same months across years to avoid seasonal variations. $\hat{\pi}_t$ (inflation rate) is the difference between the log-linearized (around the steady state) price index[10] in period t and the price index in period $t-12$. $\hat{m}_t$ (money stock) is the difference between log-linearized money stock and its steady state value ($\hat{m}_t = m_t - m$).

7.4.2 Inflation equation

TABLE 1: estimation of equation (25)

$$\hat{\pi}_t = \kappa_{\pi,+1} E_t\left[\hat{\pi}_{t+1}\right] + \kappa_{\pi,-1}\hat{\pi}_{t-1} + \kappa_x \Delta\hat{x}_t + \kappa_m \Delta\hat{m}_t + z_t^{\pi}$$

$\kappa_{\pi,+1}$ (t-ratio)	$\kappa_{\pi,-1}$ (t-ratio)	κ_x (t-ratio)	κ_m (t-ratio)
0.48902** (47.33)	0.49392** (47.33)	0.04665 (1.77)	0.10843 (1.56)

R^2	J-statistic	Observations
0.70290	0.01078	252

Estimation Method: Generalized Method of Moments (GMM); Sample: January 1987 to December 2007; Kernel: Quadratic, Bandwidth: Andrews (14.97), No prewhitening; Linear estimation after one-step weighting matrix; Instruments: $\hat{x}_{t-3}$, $\hat{m}_{t-3}$, $\hat{x}_{t-6}$, $\hat{m}_{t-6}$, $\hat{x}_{t-12}$, $\hat{m}_{t-12}$.

7.4.3 Output gap equation

TABLE 2: estimation of equation (26)

$$\hat{x}_t = E_t\left[\hat{x}_{t+1}\right] - \kappa_r\left(\hat{\imath}_t - E_t\left[\hat{\pi}_{t+1}\right]\right) + \kappa_{mp}\left(E_t\left[\Delta\hat{m}_{t+1}\right] - E_t\left[\hat{\pi}_{t+1}\right]\right) + z_t^x$$

κ_r (t-ratio)	κ_{mp} (t-ratio)
0.01252** (11.23)	0.00212** (3.02)

R^2	J-statistic	Observations
0.77224	0.01297	239

Estimation Method: Generalized Method of Moments; Sample: April 1988 to November 2007; Kernel: Quadratic, Bandwidth: Andrews (25.28), No prewhitening; Linear estimation after one-step weighting matrix; Instruments: $\hat{\pi}_{t-3}$, $\hat{m}_{t-3}$, $\hat{\imath}_{t-3}$, $\hat{\pi}_{t-6}$, $\hat{m}_{t-6}$, $\hat{\imath}_{t-6}$, $\hat{\pi}_{t-9}$, $\hat{m}_{t-9}$, $\hat{\imath}_{t-9}$, $\hat{\pi}_{t-12}$, $\hat{m}_{t-12}$, $\hat{\imath}_{t-12}$.

[10] Measured as the 12-month increase in the Euro-area Harmonized Consumer Price Index (HCPI),

7.4.4 Money stock equation

TABLE 3: estimation of equation (27)
$\hat{m}_t = \hat{m}_{t-1} + \hat{\pi}_t + \Delta\hat{x}_t + \kappa_i \Delta\hat{\imath}_t + z_t^m$
κ_i (t-ratio)
0.43869 (1.57)

R^2	J-statistic	Observations
0.22181	0.06866	251

Estimation Method: Generalized Method of Moments; Sample: January 1988 to November 2007; Kernel: Bartlett, Bandwidth: Andrews (144.52), No prewhitening; Linear estimation after one-step weighting matrix; Instruments: $\hat{x}_{t-3}$, $\hat{\imath}_{t-3}$, $\hat{x}_{t-6}$, $\hat{\imath}_{t-6}$, $\hat{x}_{t-9}$, $\hat{\imath}_{t-9}$, $\hat{x}_{t-12}$, $\hat{\imath}_{t-12}$.

7.4.5 Interest rate equation

TABLE 4: estimation of equation (28)		
$\hat{\imath}_t = (1-\lambda_i)(\lambda_\pi \hat{\pi}_t + \lambda_x \hat{x}_t) + \lambda_i \hat{\imath}_{t-1} + z_t^i$		
λ_i (t-ratio)	λ_π (t-ratio)	λ_x (t-ratio)
0.533002^{**} (5.84)	2.234246^{**} (9.74)	0.824707^{**} (3.01)

R^2	J-statistic	Observations
0.87267	0.02690	251

Estimation Method: Generalized Method of Moments; Sample: January 1988 to November 2008; Kernel: Quadratic, Bandwidth: Andrews (32.89), No prewhitening; Linear estimation after one-step weighting matrix; Instruments: $\hat{x}_{t-3}$, $\hat{\pi}_{t-3}$, $\hat{x}_{t-6}$, $\hat{\pi}_{t-6}$, $\hat{x}_{t-9}$, $\hat{\pi}_{t-9}$, $\hat{x}_{t-12}$, $\hat{\pi}_{t-12}$.

7.5 Decomposition of shocks

The decomposition of shocks yields the following equations

$$z_t^\pi = \frac{\lambda_{mc}}{1+\beta+\lambda_{mc}\psi_m}\left(\Delta\left(\hat{\varepsilon}_t^N - \hat{\varepsilon}_t^{Nf}\right) - \left(\frac{\nu-\sigma}{1-\nu}\right)\Delta\left(\hat{\varepsilon}_t^M - \hat{\varepsilon}_t^{Mf}\right) - \psi_m\left(\Delta\hat{m}_t^f - \hat{\pi}_t^f\right)\right)$$
$$z_t^x = -\frac{1}{\nu+(\sigma-\nu)a_1}\left(\frac{\nu-\sigma}{1-\nu}\right)E_t\left[\Delta\hat{\varepsilon}_{t+1}^M\right] - \frac{1}{\nu+(\sigma-\nu)a_1}E_t\left[\Delta\hat{\varepsilon}_{t+1}^P\right] + E_t\left[\Delta\hat{y}_{t+1}^f\right]$$
$$z_t^m = \frac{1}{\nu}\Delta\hat{\varepsilon}_t^M - \Delta\hat{y}_t^f$$
$$z_t^i = \rho_i z_{t-1}^i + \varepsilon_t^i$$
$$\hat{a}_t = \rho_a \hat{a}_{t-1} + \varepsilon_t^a$$

We know that the natural rate of interest could be written as

$$r_t^n = \rho + \sigma E_t\left[\Delta y_{t+1}^f\right]$$

where ρ and σ are parameters and y_t^f is the production in the case of flexible prices. By using equation (19), we obtain

$$\Delta\hat{m}_t^f - \hat{\pi}_t^f = \frac{1}{\upsilon_m^f}\left(\Delta\hat{y}_t^f - \upsilon_a^f\Delta\hat{a}_t - \Delta\upsilon_t^f\right)$$

where $\hat{a}_t$ is the log of the level of technology (see equation (7)) and υ_t^f comes from (19). Then, we can assume that

$$\Delta\hat{m}_t^f - \hat{\pi}_t^f \cong \frac{1}{\upsilon_m^f}\left(\hat{r}_{t-1}^n - \upsilon_a^f\Delta\hat{a}_t\right) + tip_t$$

where tip_t includes shocks that are policy independent. Hence shocks can be rewritten as follows

$$\begin{aligned}
&z_t^\pi = \tfrac{\lambda_{mc}}{1+\beta+\lambda_{mc}\psi_m}\left(\Delta\hat{\varepsilon}_t^N - \left(\tfrac{\nu-\sigma}{1-\nu}\right)\Delta\hat{\varepsilon}_t^M - \tfrac{\psi_m}{\upsilon_m^f}\left(\hat{r}_{t-1}^n - \upsilon_a^f\Delta\hat{a}_t\right) + tip_t\right)\\
&z_t^x = -\tfrac{1}{\nu+(\sigma-\nu)a_1}\left(\tfrac{\nu-\sigma}{1-\nu}\right)E_t\left[\Delta\hat{\varepsilon}_{t+1}^M\right] - \tfrac{1}{\nu+(\sigma-\nu)a_1}E_t\left[\Delta\hat{\varepsilon}_{t+1}^P\right] + \hat{r}_t^n\\
&z_t^m = \tfrac{1}{\nu}\Delta\hat{\varepsilon}_t^M - \hat{r}_{t-1}^n\\
&z_t^i = \rho_i z_{t-1}^i + \varepsilon_t^i\\
&\hat{a}_t = \rho_a\hat{a}_{t-1} + \varepsilon_t^a
\end{aligned}$$

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