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A Two-Pillar DSGE Monetary Policy Model for the Euro Area [§]

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Abstract

Whereas the bulk of the literature on DSGE models provides a rationale for inflation targeting strategies, there is no model doing such a job for the strategy implemented for almost ten years now by the Eurosystem and known as the "two-pillar monetary policy strategy". We try to address this issue by developping a small "two-pillar" DSGE model for the euro area. In this paper: 1) we allow real balances to appear both in the IS and Phillips curves; 2) we find some evidence that money plays a non-trivial role in explaining the euro area business cycle; 3) this provides a rationale for the central bank (the European Central Bank) to factor in monetary developments, by exploiting the long-run relationship between money growth and inflation, eventually accounting for structural shifts in velocity; 4) we found some evidence that the ECB has reacted systematically to a filtered measure of money growth and weaker evidence it has reacted more aggressively during high money growth periods ("excess liquidity").

JEL classification: E52; E58;

Keywords: Monetary policy, Monetary aggregates, Monetary Policy Rules, Non-linearity, ECB

Résumé

Alors que la majeure partie de la littérature consacrée aux modèles DSGE fournit une justification à l'adoption de stratégies de ciblage d'inflation, aucun modèle de ce type ne permet de le faire pour la stratégie mise en oeuvre depuis dix ans par l'Eurosystème et connue sous le nom de « stratégie de politique monétaire à deux piliers ». Nous essayons de pallier ce manque en développant un modèle DSGE à « deux piliers » pour la zone euro. Dans ce papier, 1) la monnaie apparaît dans la courbe IS et la courbe de Phillips ; 2) nous montrons que la monnaie joue un rôle non trivial dans l'explication de l'évolution économique de la zone euro ; 3) cela légitime la prise en compte des évolutions monétaires dans la réaction de la banque centrale, d'une part en exploitant la relation de long terme entre croissance monétaire et inflation, d'autre part en prenant en compte les ruptures structurelles dans la vitesse de circulation de la monnaie; 4) enfin, nous montrons que la BCE a réagi à une mesure filtrée de la croissance monétaire et, dans une moindre mesure, de manière plus agressive lors des périodes de forte croissance monétaire (« excès de liquidité »).

JEL classification: E52; E58;

Mots clés : Politique monétaire, agrégats monétaires, Règles de politique monétaire, Non linéarité, BCE

Non-technical summary

The most distinctive feature of the European Central Bank's (ECB) monetary policy framework has become known as the two-pillar strategy for assessing risk to price stability. In this very specific framework, money is given an important role, which, since the inception of the ECB, has been signalled by the announcement of a reference value for the growth of a broad monetary aggregate (M3). The revision of the strategy in May 2003 and the discontinuance of an annual review may appear as a downgrading of the role of money in this strategy. The aim of the paper is to develop and estimate a two-pillar DSGE monetary policy model for the euro area that intend to reflect both the essence of the Eurosystem monetary policy framework and the effective role of money in the conduct of monetary policy. Our model elaborates on the seminal paper by Ireland (2004), who develops a small structural model of the monetary policy business cycle. A key feature of this model is that it allows real balances to play an active role in explaining the euro area business cycle. We find some evidence that money plays indeed a significant role and enters in particular both in the IS and Phillips curves of our model. In such a context, it is optimal for the central bank to factor in monetary developments into its monetary policy decisions. Taking money into account is a very challenging task as money and inflation are not necessarily closely related in the short run as they are in the long run. Therefore, the central bank seeks to exploit such a long-term relationship and should disregard short-term fluctuations in money growth. This is the essence of the "reference value", the concept developed by the Eurosystem in order to identify "excess liquidity" periods, i.e. risks to future price stability. Bearing this in mind, we suppose that the ECB sets its policy rate according to an augmented Taylor-type rule incorporating, beside the traditional inflation and output gaps, a filtered money growth gap. We suppose that the reference value should account for structural shifts in the income velocity of money and for that reason compute it as the average money growth rate over a moving window of about five years. We find some evidence that the ECB has reacted in a systematic way to monetary developments and weaker evidence that it has reacted in a non-linear way. One reason may be that, in practise, the reference value has remained unchanged since the inception of the ECB in a context where M3 growth has systematically exceeded its level. As a consequence, we only find slight support for the presence of shifts between two monetary policy regimes in the euro area. Another reason may be that what we call money in our set-up might not correspond exactly to what is meant and measured by money in reality and by the ECB, in particular because of the absence of a banking sector in our model.

Résumé non-technique

La spécificité de la BCE en matière de politique monétaire réside dans sa stratégie à 2 piliers pour évaluer les risques pour la stabilité des prix à moyen terme. Dans ce cadre d'analyse, la BCE donne un rôle prépondérant à la monnaie, qui est signalée par l'annonce d'une valeur de référence pour la croissance de l'agrégat large M3 depuis 1999. La révision de la stratégie en 2003 et l'abandon du suivi de la valeur de référence ont pu apparaître comme une dévalorisation du rôle de la monnaie. Le but du papier est de développer et d'estimer un modèle d'équilibre général modélisant à la fois le rôle de la monnaie et la stratégie de politique monétaire à 2 piliers de l'Eurosystème. Notre modèle s'appuie sur le papier fondateur d'Ireland (2004), dans lequel l'auteur développe un petit modèle structurel de politique monétaire. Un aspect crucial de ce modèle est qu'il intègre la monnaie pour expliquer certains faits stylisés de l'économie de la zone euro. Nous montrons que la monnaie joue en effet un rôle significatif et intervient à la fois dans la courbe IS et dans la courbe de Phillips. Au vu de ces résultats, il apparaît optimal pour la Banque Centrale de prendre en compte la croissance monétaire. La prise en compte de la monnaie est une tâche assez délicate car si la monnaie et l'inflation sont corrélées sur le long terme, leur relation à court terme est beaucoup moins claire. Par conséquent, la banque centrale doit exploiter la relation de long terme en s'affranchissant des fluctuations de court terme de la croissance monétaire. C'est le sens du concept de « valeur de référence » développé par l'Eurosystème pour identifier les périodes d' « excès de liquidité », facteurs de risque pour la stabilité des prix. Dans cet esprit, nous supposons que la banque centrale fixe son taux d'intérêt selon une règle de Taylor élargie, intégrant en plus de l'inflation et de la production, l'écart de la croissance monétaire filtrée à une valeur de référence. Pour que cette valeur de référence reflète les ruptures structurelles dans la vitesse de la monnaie, nous la calculons comme la moyenne mobile sur cinq ans du taux de croissance monétaire. Nos résultats montrent clairement que la BCE a réagi de manière systématique aux évolutions monétaires et qu'elle a réagi de façon non-linéaire. L'une des raisons est sans doute que la valeur de référence de la croissance de M3 est restée inchangée depuis 1999. La croissance monétaire a ainsi été

systématiquement supérieure à la valeur de référence. Dès lors, il est difficile de mettre en évidence un changement significatif entre deux régimes pour la zone euro. Une autre explication peut être liée à l'absence de secteur bancaire dans notre modélisation : ce que nous appelons monnaie ne correspond peut-être pas exactement à la définition de la monnaie telle que retenue par la BCE.

1 Introduction

The most distinctive feature of the European Central Bank's (ECB) monetary policy framework has become known as the two-pillar strategy for assessing risk to price stability. In this very specific framework, money is given an important role, which, since the inception of the ECB, has been signalled by the announcement of a reference value for the growth of a broad monetary aggregate (M3).

The two-pillar strategy was reviewed in May 2003. While confirming the use of the two-pillar framework, the ECB's Governing Council also emphasized that the "monetary analysis" (the former "first pillar" of the strategy) will mainly serve as a mean of cross-checking, from a long-term perspective, the indication stemming from the "economic analysis" (the former "second pillar"). In addition, and to underscore the long-term nature of the reference value, the Governing Council decided to discontinue the practice of an annual review. In practise, the reference value has not been reviewed since the inception of the ECB (it has remained unchanged at 4.5% since December 1998). This decision was interpreted by most observers as a downgrading of the role of money.

Does money still have an active role in the ECB's monetary policy strategy and how is it factored in in practise?

As far as the strategy is concerned, the role given to money acknowledges the fact that monetary growth and inflation are closely related in the medium to long run. Indeed, empirical studies carried out at the euro area level seem to confirm the monetarist statement according to which "inflation is always and everywhere a monetary phenomenon" (Friedman, 1956). In a recent contribution, Bordes and Clerc (2007) try to set out the need to announce a monetary growth reference value in the context of a two-pillar small backward-looking macroeconomic model. Their main point is that, contrary to the assumption usually made in New Keynesian frameworks, the central bank's influence over the nominal interest rate does not operate in the same way in the short term and in the long term. In the short term, the central bank can influence the nominal interest rate by increasing the quantity of money. This increases real balances and lowers the real interest rate and, consequently, the nominal interest rate through a liquidity effect. The liquidity effect however does not come into play in the medium to long run and, consequently, the central bank cannot influence the real interest rate. Its only means of action with regard to the nominal rate is to influence inflation expectations. This can be done through the announcement of a money supply growth target, which is derived in a way as to ensure the consistency between short-term and long-term inflation expectations. In this context, the reference value helps to reduce long-term price level uncertainty and acts as an error-correction mechanism ensuring the trend stationarity of the price level. Similarly, in the context of inaccurate estimates or imperfect knowledge regarding un-observables such as the output gap, Woodford (2007) and Beck and Wieland (2007) both argue that the ECB's computation of excess liquidity (i.e. deviation of actual M3 from the reference value), the cross-checking and finally the possibility to change interest rates in response to sustained deviations of long-run money growth are similar to the commitment to error-correction and therefore can have some stabilisation properties.

In practice, money seems to play a crucial role in the setting of monetary policy in the euro area. As an illustration, the ECB's President, J. C. Trichet, recently declared: "I consider the monetary pillar has been probably decisive when we decided to increase rates in December 2005, against the advice of the OECD, the IMF, and a number of observers", (Financial times, 17 May 2007). However, implementing "monetary analysis" in the euro area has proven difficult and very challenging over the recent years as the economy was hit by several shocks: financial instability in the aftermath of the stock market collapse in 2000, exceptionally high economic and geopolitical uncertainty between 2001 and 2003. In addition, there are some signs that a money demand shock occurred at the beginning of the 2000s in the euro area, as illustrated by an apparent structural shift in the trend velocity of money as evidenced by Bordes *et al.* (2007). Certainly, the uncertainties surrounding the assumed underlying trend in M3 income velocity have led the ECB to downplay the role of the reference value, which, indeed, has not been referred to in any introductory statement by the ECB's President since December 2002.

The aim of this paper is to develop and estimate a two-pillar DSGE monetary policy model for the euro area that intend to reflect both the essence of the Eurosystem monetary policy framework and the effective role of money in the conduct of monetary policy. To our knowledge, this contribution is novel to the literature as most DSGE models for the euro area simply do not factor in money or monetary analysis, in particular (and paradoxically) those developed at the ECB (see for instance Smets and Wouters, 2003, or more recently Christoffel *et al.*, 2007). One exception is the model by Christiano, Rostagno and Motto (2006) who explicitely introduce a banking system as well as financial frictions in their DSGE model. In their framework, the European Central Bank sets the short-term interest rates according to a standard Taylor-type rule augmented to account for the deviations of actual M3 growth from steady state.

By contrast, we allow, at least in the setup of our model, for an active role of money on output and inflation. Consequently, the central bank may react to monetary developments but not necessarily in a linear fashion, accounting for the fact that benign monetary developments should not necessarily trigger significant changes in the policy rate. We also suppose that the European Central Bank tries to exploit the long-term relationship linking monetary developments and inflation. Finally, in order to isolate and quantify the effects of changes in real balances on output and inflation but also to account for recent monetary developments in the euro area, our model involves that the measure of money must be adjusted for velocity shifts.

The paper proceeds as follows. Section 2 of the paper presents the main features of our two-pillar DSGE model for the euro area. Section 3 provides some indications on the model resolution while section 4 deals with the estimation of the model on euro area data and comments the main results. Unlike Ireland (2004) and Andrés *et al.* (2006), we estimate our model resorting to Bayesian techniques rather than by maximum likelihood methods. We do not impose any constraints on key parameters, in particular on the parameter measuring the effect of real balances on output and inflation. Indeed, both Ireland and Andrés *et al.* impose some constraints on that parameter, which in the end artificially bias the coefficient toward zero and lead them to conclude that real balances have a limited, if any, role in explaining business cycle fluctuations. Section 5 draws some monetary policy implications and concludes.

2 A Two-Pillar DSGE monetary policy model for the euro area

Our model elaborates on the seminal paper by Ireland (2004), who develops a small structural model of the monetary policy business cycle. A key feature of this model is that it allows real balances to appear both in the IS and the Phillips curves. This direct effect of money on output and inflation provides us with a justification to include a measure of money growth into the monetary policy rule. Relative to the model of Ireland, in the model used here, prices are set on a staggered basis as in Calvo (1983) rather than according to a quadratic cost of price adjustment à la Rotemberg (1982). This is done so as to bring nominal rigidities into the model in a way that is consistent with and that provides micro-foundations to the two-pillar Phillips curve's representation proposed by Gerlach (2004).

As in Ireland, our economy consists of a representative household, a representative finished goods-producing firm, a continuum of intermediate goods-producing firms indexed by $i \in [0,1]$ and a monetary authority featuring the European Central Bank. This model displays sufficient symmetry for the analysis to focus on the behaviour of a representative intermediate goods-producing firm.

2.1 Households

The representative household enters period t with money M_{t-1} and bonds B_{t-1} and receives from the monetary authority a lump sum nominal transfer T_t. Next, bonds mature providing B_{t-1} additional units of money. The household uses some of this money to purchase B_t new bonds at a nominal cost B_t/r_t where r_t stands for the gross nominal interest rates between period t en period $t+1$.

During period t, the household supplies $h_t\,(i)$ units of labour to each intermediate good-producing firm $i \in [0,1]$ for a total of $h_t = \int_0^1 h_t\,(i)\,di$.

The representative household is paid at the nominal wage rate W_t. She consumes c_t units of the finished good purchased at the nominal price P_t from the representative finished goods-producing firm. At the end of the period, the household receives nominal profit $D_t\,(i)$ from each intermediate goods-producing firm $i \in [0,1]$ for a total of $D_t = \int_0^1 D_t\,(i)\,di$.

The household then carries M_t units of money into period $t+1$, subject to the following budget constraint:

$$\frac{m_{t-1}}{\pi_t} + \frac{T_t}{P_t} + \frac{B_{t-1}}{P_t} + w_t h_t + \frac{D_t}{P_t} \geq m_t + \frac{B_t}{r_t P_t} + c_t \tag{1}$$

where $m_t = M_t/P_t$ denotes real balances, $\pi_t = P_t/P_{t-1}$ the inflation rate and $w_t = W_t/P_t$ the real wage. The household chooses c_t, h_t, B_t and m_t to maximise the following expected utility function:

$$E \sum_{t=0}^{\infty} \beta^t a_t \{u[c_t, m_t/e_t] - \eta h_t\}, \tag{2}$$

where the discount factor $\beta \in]0,1[$ and $\eta > 0$. In this setup, which is directly borrowed from Ireland (2004), we assume that money yield utility and that money and consumption in the utility of the representative household may be non-separable. The latter assumption has the consequence that real balances may enter into the IS curve, i.e. opens up a channel through which money can affect both output and inflation.

The preference and money demand shocks, a_t and e_t, follow the autoregressive processes

$$\ln(a_t) = \rho_a \ln(a_{t-1}) + \epsilon_{a,t}, \qquad \epsilon_{a,t} \sim \text{N}\ (0, \sigma_a), \qquad \rho_a \in]-1,1[\tag{3}$$

$$\ln(e_t/e) = \rho_e \ln(e_{t-1}/e) + \epsilon_{e,t}, \qquad \epsilon_{e,t} \sim \text{N}\ (0, \sigma_e), \qquad \rho_e \in]-1,1[, \qquad e > 1 \tag{4}$$

Letting λ_t denote the nonnegative multiplier on (1), the first order conditions for this problem are:

$$a_t u_1(c_t, m_t/e_t) = \lambda_t \tag{5}$$

$$\eta a_t = \lambda_t w_t \tag{6}$$

$$\lambda_t = \beta r_t E_t(\lambda_{t+1}/\pi_{t+1}), \tag{7}$$

$$(a_t/e_t) u_2(c_t, m_t/e_t) = \lambda_t - \beta E_t(\lambda_{t+1}/\pi_{t+1}). \tag{8}$$

where u_1 and u_2 are the derivatives of u with respect to the first and second variables.

2.2 Firm Behaviour and Price setting

2.2.1 The representative finished goods-producing firm

During each period, the representative finished goods-producing firm uses $y_t\,(i)$ units of each intermediate good $i \in [0,1]$, purchased at the nominal price $P_t\,(i)$ to manufacture y_t units of the finished good according to the constant-returns-to-scale technology describes by

$$y_t = \left(\int_0^1 y_t(i)^{(\theta-1)/\theta} di \right)^{\theta/(\theta-1)} \tag{9}$$

where $\theta > 1$. The finished goods-producing firm chooses $y_t(i)$ for all i $\in [0,1]$ to maximise its profits, given by $P_t \left[\int_0^1 y_t(i)^{(\theta-1)/\theta} di \right]^{\theta/(\theta-1)} - \int_0^1 P_t\,(i)\, y_t(i) di$, for all t=0,1,2,... The first order conditions for this problem are

$$y_t(i) = \left(\frac{P_t(i)}{P_t} \right)^{-\theta} y_t, \tag{10}$$

which reveal that θ measures the constant price elasticity of demand for each intermediate good i $\in [0,1]$. As competition drives the finished goods-producing firm's profit to zero in equilibrium, P_t is determined by $P_t = \left(\int_0^1 P_t(i)^{1-\theta} di\right)^{1/(1-\theta)}$.

2.2.2 The representative intermediate goods-producing firm

During each period, the representative intermediate goods-producing firm hires $h_t(i)$ units of labour from the representative household to manufacture $y_t(i)$ units of intermediate good i according to the following production function:

$$y_t(i) = z_t F(h_t(i)), \tag{11}$$

where F is increasing and concave and z_t is the aggregate productivity shock, which is assumed to follow the autoregressive process

$$\ln(z_t/z) = \rho_z \ln(z_{t-1}/z) + \varepsilon_{z,t}, \qquad \varepsilon_{z,t} \sim \mathrm{N}\ (0, \sigma_z) \tag{12}$$

where $1 > \rho_z > 0$, $z > 0$. In equilibrium, this supply side disturbance acts as a shock to the Phillips curve.

The representative intermediate goods-producing firm sells its output in a monopolistically competitive market and sets nominal prices on a staggered basis, as in Calvo (1983). During each period, each firm resets its price with probability $1 - \alpha_p$, independently of the time elapsed since the last price adjustment. The remaining firms, with probability α_p, set prices according to the following rule:

$$P_T(i) = \pi^{1-\gamma_p} \left[\frac{P_{T-1}}{P_{T-2}}\right]^{\gamma_p} P_{T-1}(i) = \Gamma_T P_{T-1}(i). \tag{13}$$

that is to say that a firm that can not optimally adjust its prices sets it as a convex combination, Γ_T, of past inflation and steady state inflation π. This framework implies that lagged inflation will enter into the linearized Phillips curve. Note that setting the inflation persistence parameter, γ_p, to zero would result in the standard Calvo model (i.e. a setup in which non-optimally adjusting firms would simply change their prices at the pace of steady state inflation). Equation (13) can also be expressed as:

$$P_T(i) = \Gamma_{T,t} P_t(i) \tag{14}$$

where

$$\Gamma_{T,t} = \begin{cases} \pi^{(1-\gamma_p)(T-t)} \prod_{j=t}^{T-1} (\pi_j)^{\gamma_p} & \text{if } T-t>0 \\ 1 & \text{otherwise} \end{cases} \tag{15}$$

The firms that do adjust their prices at date t do so to maximise the expected discounted value of current and future profits. Profits at some future date $t+j$ are affected by the choice of price at time t only if the firm has not received another opportunity to adjust between t and $t+j$. The probability of this is given by α_p^j. Let $P_t^\star$ denotes the price chosen at date t and $y_{t,T}^\star(i)$ the production of good i at date T if the firm has not reset its price since date t. The firm's pricing decision problem them involves picking $P_t^\star$ to maximise

$$\Pi_t = E_t \sum_{T=t}^{\infty} (\beta\alpha_p)^{T-t} \lambda_T \left\{ \Gamma_{t,T} \frac{P_t^\star(i)}{P_T} y_{t,T}^\star(i) - w_T F^{-1}(y_{t,T}^\star(\zeta)/z_t) \right\} \tag{16}$$

with respect to (10):

$$y_{t,T}^\star(i) = \left(\Gamma_{t,T} \frac{P_t^\star(i)}{P_T} \right)^{-\theta} y_T \tag{17}$$

where λ_t/P_t in equation (16) measures the marginal utility value to the representative household of an additional euro in profits received during period t and w_t measures the real wage paid by the firm.

For all $t = 0, 1, 2, ...$ the first-order conditions for this problem are:

$$E_t \sum_{T=t}^{\infty} (\beta\alpha_p)^{T-t} \lambda_T \left[\frac{\theta-1}{\theta} \left(\frac{y_{t,T}^\star}{y_T} \right)^{-1/\theta_p} - \frac{w_T}{z_t} (F^{-1})' \left(\frac{y_{t,T}^\star}{z_t} \right) \right] y_{t,T}^\star = 0 \tag{18}$$

i.e. :

$$E_t \sum_{T=t}^{\infty} (\beta\alpha_p)^{T-t} \lambda_T \left[\Gamma_{t,T} \frac{P_t^\star(i)}{P_t} \frac{P_t}{P_T} - \mu \frac{w_T}{z_t} (F^{-1})' \left(\frac{y_{t,T}^\star}{z_t} \right) \right] = 0 \tag{19}$$

where μ the mark-up rate is given by $\mu = \frac{\theta}{\theta-1}$.

2.3 The European Central Bank

The aim of this section is to formalise a monetary policy rule featuring the ECB's two-pillar approach, as clarified in the context of the review of the monetary policy strategy carried out in May 2003. The main aspects that we try to encapsulate in our setup are:

- a role for money in the setting of euro area policy rates. The reason is twofold: first, as our model allows real balances to appear both in the IS and the Phillips curves, it may be optimal for the central bank to adjust key policy rates with respect to monetary developments; second, monetary analysis is one of the two pillars of the strategy. As such, it complements the information stemming from the economic analysis, usually summarized by both the inflation and the production stabilisation objectives in standard versions of the Taylor rule;

- a medium to long-term orientation, as initially signalled by the announcement of a reference value for M3. Indeed, the Governing Council of the ECB seeks to exploit the long-term relationship between monetary growth and inflation, that is to say tries to see through the noise in monetary data to recover those underlying trends which are relevant for monetary policy decisions.

- finally, as money is not an intermediate target in the ECB's strategic framework, strong monetary developments or deviations of M3 growth from the reference value should not trigger a mechanistic policy reaction. Therefore, in contrast with Ireland (2004), Christiano *et al.* (2006) or Bordes and Clerc (2007), who model the policy rule as an augmented Taylor rule embedding actual monetary growth and assume a systematic response of the central bank to monetary developments, we allow for a non-linear or an asymmetric response of the central bank. In "normal time", when the monetary analysis carried by the Governing Council of the ECB does not signal risk for price stability in the medium run, the central bank may not or little react to on-going monetary developments. By contrast, when too strong monetary developments bear some risks to future price stability, i.e. in the presence of "excess liquidity", the central bank may react much stronger to money growth so as to bring prices to the appropriate or targeted price level path.

In order to reflect these different aspects of the two-pillar strategy, we first allow money growth to enter into a standard Taylor rule, in addition to the inflation and production stabilisation objectives. However, we assume that the central bank, in contrast to the private sector - households in particular - focuses on a filtered measure of money growth. As in Beck and Wieland (2007), we assume that the central bank regularly tests whether filtered money growth still hovers around its long-term average. More specifically, we suppose that the central bank checks the following inequality:

$$\frac{1}{N_c}\sum_{k=1}^{N_c}\frac{\left|\widehat{\mu_{t-k}^f}-\overline{\mu_t}\right|}{\sigma_{\mu,t}}\geq\kappa_c \tag{20}$$

where

$$\mu_t^f=\mu_{t-1}^f+\lambda\left(\mu_t-\mu_{t-1}^f\right) \tag{21}$$

is the filter used to approximate long-run values of money growth. μ_t stands for real money growth (Δm_t). The smoothing parameter λ could be chosen so as to select a frequency at which long-run money growth is highly correlated with long-run inflation (see Marx, 2007). As suggested in Gerlach (2004), we choose $\lambda = 0.15$. κ_c corresponds to the critical value considered by the central bank. $\overline{\mu_t}=\frac{1}{20}\sum_{k=1}^{k=20}\widehat{\mu_{t-k}^f}$ is the mean of the filtered money growth computed over the last 20 periods (i.e. the last five years in our model), while $\sigma_{\mu,t}$ stands for the standard deviation of $\widehat{\mu_{t-k}^f}$ computed over the same period. Therefore, the central bank assesses monetary developments using a time-varying window in order to capture medium to long-run shifts in monetary trends or velocity.

If the central bank obtains successive signals of a sustained deviation of filtered money growth from its medium to long-term average (i.e. if $\left|\widehat{\mu_{t-k}^f}-\overline{\mu_t^f}\right|\geq\kappa_c\sigma_{\mu,t}$ on average over the last N_c periods), it responds by adjusting its key policy rate stronger than would have been the case otherwise. Therefore, the central bank sets the nominal interest rate according to the following augmented Taylor-type rule:

$$\widehat{r_t}=\rho_r\widehat{r_{t-1}}+(1-\rho_r)[\rho_y\widehat{y_{t-1}}+\rho_\pi\widehat{\pi_{t-1}}+\rho_1\mathbf{1}_1\widehat{\mu_{t-1}^f}+\rho_2\mathbf{1}_2\widehat{\mu_{t-1}^f}]+u_{r,t} \tag{22}$$

where $\mathbf{1}_1$ and $\mathbf{1}_2$ are two dummy variables such that:

$\mathbf{1}_1=1$ if $\left|\widehat{\mu_{t-k}^f}-\overline{\mu_t^f}\right|<\kappa_c\sigma_{\mu,t}$ on average over the last N_c periods, $\mathbf{1}_1$ =0 otherwise;

$\mathbf{1}_2=1-\mathbf{1}_1$

Therefore, the central bank seeks to distinguish between "normal" periods and inflationary ones, the state of the economy depending upon monetary dynamics. In this setup, we expect that $\rho_2>\rho_1\geq 0$. Despite this state-contingent rule, the model has a unique, stationary solution. [1] As an illustration, figure 1 in the appendix displays the corridor corresponding to the "normal" state, for a choice of $(\kappa_c, N_c) = (1.1, 5)$. According to this set of parameters, the euro area economy was during 59 periods out of 109 in the strong monetary growth state.

2.4 Equilibrium

In our model, $c_t = y_t$ for all t. In absence of shocks, the economy converges to a steady state in which $y_t = y$, $\pi_t = \pi$, $m_t = m$, $r_t = r$,$a_t = a$, $e_t = e$ and $z_t = z$. The symmetric equilibrium can be log-linearized around the steady-state $(y,\ \pi,\ r,\ m)$ to yield the following set of equations:

$$\widehat{y_t} + \omega_2(1-\rho_e)\widehat{e_t} - \omega_1(1-\rho_a)\widehat{a_t} = E_t(\widehat{y_{t+1}}) - \omega_1(\widehat{r_t} - E_t(\widehat{\pi_{t+1}})) + \omega_2(\widehat{m_t} - E_t(\widehat{m_{t+1}})) \tag{23}$$

$$\widehat{\pi_t} - \gamma_p\widehat{\pi_{t-1}} = \beta E_t(\widehat{\pi_{t+1}} - \gamma_p\widehat{\pi_t}) + \kappa_p(\omega_p + \frac{1}{\omega_1})\widehat{y_t} - \kappa_p\frac{\omega_2}{\omega_1}\widehat{m_t} + \kappa_p\frac{\omega_2}{\omega_1}\widehat{e_t} - \kappa_p(1+\omega_p)z_t \tag{24}$$

$$\widehat{m_t} = \gamma_1\widehat{y_t} - \gamma_2\widehat{r_t} + \gamma_3\widehat{e_t} \tag{25}$$

$$\widehat{r_t} = \rho_r\widehat{r_{t-1}} + (1-\rho_r)[\rho_y\widehat{y_{t-1}} + \rho_\pi\widehat{\pi_{t-1}} + \rho_1\mathbf{1}_1\widehat{\mu^f_{t-1}} + \rho_2\mathbf{1}_2\widehat{\mu^f_{t-1}}] + u_{r,t} \tag{26}$$

$$\widehat{\mu_t} = \widehat{m_t} - \widehat{m_{t-1}} \tag{27}$$

$$\widehat{a_t} = \rho_a\widehat{a_{t-1}} + \epsilon_{a,t} \tag{28}$$

$$\widehat{e_t} = \rho_e\widehat{e_{t-1}} + \epsilon_{e,t} \tag{29}$$

$$\widehat{z_t} = \rho_z\widehat{z_{t-1}} + \epsilon_{z,t} \tag{30}$$

$$\widehat{u_{r,t}} = \rho_\epsilon\widehat{u_{r,t-1}} + \epsilon_{r,t} \tag{31}$$

[1] This property follows from the assumption that m_t is stationary and thus $\bar{\mu} = 1$.

where

$$
\begin{aligned}
\beta r &= \pi \\
r u_2 &= (r-1) e u_1 \\
\omega_1 &= \frac{-u_1}{c u_{11}}, \\
\omega_2 &= -\frac{(m/e) u_{12}}{c u_{11}}, \\
\gamma_1 &= \left(\frac{c r \omega_2}{m \omega_1} + \frac{r-1}{\omega_1}\right) \gamma_2, \\
\gamma_2 &= \frac{r}{(r-1)(m/e)} \left[\frac{u_2}{(r-1) e u_{12} - r u_{22}}\right], \\
\gamma_3 &= 1 - (r-1)\gamma_2 \\
\omega_p &= -\frac{F"(n) F(n)}{(F'(n))^2} \\
\kappa_p &= \frac{(1-\alpha_p)(1-\beta\alpha_p)}{\alpha_p (1+\vartheta\omega_p)}
\end{aligned}
$$

and where $u_1 = u_1(c, m/e)$, $u_2 = u_2(c, m/e)$, $u_{11} = u_{11}(c, m/e)$, $u_{12} = u_{12}(c, m/e)$, and $u_{22} = u_{22}(c, m/e)$.

Equation (23) represents a forward-looking IS curve. It allows changes in real balances to directly affect the dynamics of output. All of the parameters, with the possible exception of ω_2, ought to be nonnegative. The parameter ω_2 measures the effect of real balances on aggregate output. It is sometimes used in the literature (cf. Ireland (2004) or Andrés *et al.* (2006)) to explicitly test for non-separability ($\omega_2 \neq 0$). ω_2 ultimately depends upon the properties of the utility function of the representative household, and more specifically on u_{12}. It might be positive, in which case money and consumption are complements as it is assumed in the mainstream of the literature, or negative, meaning that the marginal utility of consumption is decreasing with respect to real balances. [2] Equation (24) is a forward-looking Phillips curve that allows changes in real balances to also have an impact on the dynamics of inflation when $\omega_2 \neq 0$. As in Ireland, it is worth pointing out, first, that real money balances enter into the IS curve if and only if they enter into the forward-looking phillips curve and, second, that what really matters for the dynamics of output and inflation are fluctuations in real balances once shifts in velocity have been factored in: indeed in our model, output and inflation in equations (23) and (24) can be written as functions of $(\widehat{m}_t - \widehat{e}_t)$. Equation (25) is a money demand

[2] As an example, we can think of the non separable utility function $u(c, m) = \frac{c^{1-\sigma_1}}{1-\sigma_1} \frac{m^{1-\sigma_2}}{1-\sigma_2}$. The condition $\omega_2 < 0$ corresponds to a value $\sigma_2 > 1$, and a strong concavity of the utility function with respect to money.

function with income elasticity γ_1 and interest semi-elasticity γ_2. Finally, equation (26) is the non-linear augmented Taylor rule, featuring the two-pillar monetary policy reaction function of the ECB.

Using (27) and (21), the model can finally be written as:

$$E_t(\widehat{y_{t+1}})(1-\gamma_1\omega_2)+\omega_1 E_t(\widehat{\pi_{t+1}})-\widehat{y_t}(1-\gamma_1\omega_2-\gamma_2\omega_2(1-\rho_r)\rho_y)+\omega_2(1-\rho_r)\rho_\pi\gamma_2\widehat{\pi_t}-[\gamma_2\omega_2(1-\rho_r)+\omega_1]\widehat{r_t}$$
$$+\omega_2\gamma_2(1-\rho_r)\rho_t\widehat{\mu_t^f}+(\gamma_3-1)\omega_2(1-\rho_e)\widehat{e_t}+\omega_1(1-\rho_a)\widehat{a_t}=0$$

$$\beta E_t(\widehat{\pi_{t+1}})+\kappa_p[\omega_p+\tfrac{1}{\omega_1}-\tfrac{\omega_2\gamma_1}{\omega_1}]\widehat{y_t}-(1+\beta\gamma_p)\widehat{\pi_t}+\kappa_p\tfrac{\omega_2\gamma_2}{\omega_1}\widehat{r_t}+\gamma_p\widehat{\pi_{t-1}}+\kappa_p\tfrac{\omega_2}{\omega_1}(1-\gamma_3)\widehat{e_t}-\kappa_p(1+\omega_p)\widehat{z_t}=0$$

$$\tfrac{1}{\lambda}\widehat{\mu_t^f}-\widehat{\pi_t}-\gamma_1\widehat{y_t}+\gamma_2\widehat{r_t}+\gamma_1\widehat{y_{t-1}}-\gamma_2\widehat{r_{t-1}}-\tfrac{1-\lambda}{\lambda}\widehat{\mu_{t-1}^f}-\gamma_3\widehat{e_t}+\gamma_3\widehat{e_{t-1}}=0$$

$$-\widehat{r_t}+\rho_r\widehat{r_{t-1}}+(1-\rho_r)\rho_y\widehat{y_{t-1}}+(1-\rho_r)\rho_{t-1}\widehat{\mu_{t-1}^f}+(1-\rho_r)\rho_\pi\widehat{\pi_{t-1}}+\widehat{u_{r,t}}=0$$

$$\widehat{a_t}=\rho_a\widehat{a_{t-1}}+\epsilon_{a,t}$$

$$\widehat{e_t}=\rho_e\widehat{e_{t-1}}+\epsilon_{e,t}$$

$$\widehat{z_t}=\rho_z\widehat{z_{t-1}}+\epsilon_{z,t}$$

$$\widehat{u_{r,t}}=\rho_\epsilon\widehat{u_{r,t-1}}+\epsilon_{r,t}$$

3 Model resolution

In this section, we briefly outline the methodology which is implemented to solve the model. We mimic Uhlig (1999) and we suppose that the log-linearized equilibrium relationship can be written as:

$$E_t(FX_{t+1}+G_tX_t+H_{t-1}X_{t-1}+RZ_t+SZ_{t-1})=0 \tag{32}$$

where the vectors X_t and Z_t are given by:

$$X_t=\begin{bmatrix}\widehat{y_t}\\ \widehat{\pi_t}\\ \widehat{r_t}\\ \widehat{\mu_t^f}\end{bmatrix},\qquad Z_t=\begin{bmatrix}\widehat{e_t}\\ \widehat{a_t}\\ \widehat{z_t}\\ \widehat{u_{r,t}}\end{bmatrix}$$

and where the matrices F, G_t, H_{t-1}, R and S are the matrices collecting the coefficients.[3] At this point, it should be noted that G_t and H_{t-1} are time-dependent and respectively take two values g_1, g_2 and h_1, h_2 depending on the state of the economy in t and $t-1$.

In Barthélemy and Marx (2008), we study in details some theoretical aspects of equation (32) which are not developped in this paper. We only provide the main principles of our resolution method. We adopt an approximation method and consider two separate models, one associated with the policy reaction coefficient ρ_1 (state 1, model 1) and the other with the policy reaction coefficient ρ_2 (state 2, model 2). Owing to Uhlig, we can compute the transition matrices $p_1,\ q_1,\ l_1$, respectively $p_2,\ q_2,\ l_2$, which correspond to the version of the model in state 1, respectively in state 2.

The solutions of model 1, and model 2 are then given by:

$$X_{t+1} = p_1(X_t + l_1 Z_t) + q_1 Z_{t+1}, \tag{33}$$

$$X_{t+1} = p_2(X_t + l_2 Z_t) + q_2 Z_{t+1}, \tag{34}$$

To solve the model described by equation (32), we assume that the transition matrices only depend on the state of the economy at time t and not on previous periods ; precisely, if the state at time t is 1, transition equation is given by (33), if the state at time t is 2, transition equation is given by (34), depending on past filtered money growth. It should be noted that this approach differs from a Markov-switching model, as the implicit probability of switching from one state to the other is endogenous in our setup. Contrary to the standard Markov-switching approach, which assumes a random jump between the different states, we feel that our setup better fits the two-pillar framework of the ECB.

[3] The matrices F, G_t and H_{t-1} are given by : $F = \begin{bmatrix} 1-\gamma_1\omega_2 & \omega_1 & 0 & 0 \\ 0 & \beta & 0 & 0 \\ 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 \end{bmatrix}$,

$G_t = \begin{bmatrix} -(1-\gamma_1\omega_2-\gamma_2\omega_2\rho_y) & \omega_2\rho_\pi\gamma_2 & -[\gamma_2\omega_2(1-\rho_r)+\omega_1] & \omega_2\gamma_2\rho_t \\ \kappa_p[\omega_p+\frac{1}{\omega_1}-\frac{\omega_2\gamma_1}{\omega_1}] & -(1+\beta\gamma_p) & \kappa_p\frac{\omega_2\gamma_2}{\omega_1} & 0 \\ -\gamma_1 & -1 & \gamma_2 & 1/\lambda \\ 0 & 0 & -1 & 0 \end{bmatrix}$ and $H_{t-1} = \begin{bmatrix} 0 & 0 & 0 & 0 \\ 0 & \gamma_p & 0 & 0 \\ \gamma_1 & 0 & -\gamma_2 & -1/\lambda+1 \\ \rho_y & \rho_\pi & \rho_r & \rho_{t-1} \end{bmatrix}$.

The matrices R and S satisfy: $R = \begin{bmatrix} (\gamma_3-1)\omega_2(1-\rho_e) & \omega_1(1-\rho_a) & 0 & 0 \\ \kappa_p\omega_2(1-\gamma_3)/\omega_1 & 0 & -\kappa_p(1+\omega_p) & 0 \\ -\gamma_3 & 0 & 0 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix}$ and $S = \begin{bmatrix} 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 \\ \gamma_3 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 \end{bmatrix}$.

4 Estimation

As in recent papers by Schorfheide (1999) or Smets and Wouters (2003), we apply Bayesian techniques to estimate the model presented in section 2. Contrary to Ireland (2004) or Andrès *et al.* (2006), we did not choose to compute the maximum of likelihood as such computation hardly converges toward a global maximum. Moreover, using Bayesian approach allows us to compare different models through their marginal densities as proposed by Geweke (1998).

4.1 Data

In order to estimate the parameters of our DSGE model, we use data over the period 1980:2-2007:2 on four key macroeconomic variables: real GDP per capita, the growth of real money M3 per capita, CPI inflation rate and the 3-month short-term nominal interest rate. These Data are extracted from the Euro Area Wide Model database (Fagan *et al.*, 2001). We also use the labour force data to normalize output and money growth. We use Eurostat data and linear projection (for 2006-2007) to update the labour force data. All the data are linearly detrended before the estimation.

4.2 Methodology

In section 3, we have modelled our problem with the transition law of motion (33) or (34), depending on μ_t^f. Because of the introduction of a non-linear monetary policy reaction function, the Kalman Filter has to be adapted by including time-varying matrices for the update phases so as to compute the likelihood.

With the notations introduced in section 3, we define $\xi_t = \begin{bmatrix} X_t \\ Z_t \end{bmatrix}$ and rewrite the model in a convenient state-space form:

$$\xi_t = A_{t-1}\xi_{t-1} + B_{t-1}\epsilon_t$$

and

$$X_t = H'\xi_t$$

where $A_{t-1} = \begin{bmatrix} P_{t-1} & Q_{t-1}N \\ 0 & N \end{bmatrix}$, $B_{t-1} = \begin{bmatrix} Q_{t-1} & 0 \\ 0 & I_4 \end{bmatrix}$ and $H' = \begin{bmatrix} I_4 & 0 \\ 0 & 0 \end{bmatrix}$

Note that the model is time-dependent unlike the one described by Hamilton (1994). By adapting the computation, we get that the sample log likelihood equals to:

$$\log L(y) = -\frac{nN}{\log(2\pi)} - \frac{1}{2}\sum_{t=1}^{N} |\det(T_{t|t-1})| - \frac{1}{2}\sum_{t=1}^{N}(y_t - \xi_{t|t-1})' T_{t|t-1}(y_t - \xi_{t|t-1}),$$

where n is the dimension of y, N the sample size, $\xi_{t|t-1}$ the best forecast of ξ_t at time $t-1$. What could appear as more complicated in our model is the time-dependence of transition matrices. However, the time-dependence is completely backward, so that the best prediction of ξ_t knowing state $t-1$ is the same than the benchmark model without any threshold. Thus, it is possible to compute recursively the chain of predicted values, $\xi_{t|t-1}$, and the covariance of prediction errors, $T_{t|t-1}$.

The sample log-likelihood conjugated with the prior distributions of parameters provides us with the posterior kernel distribution of a set of parameters. We compute the posterior kernel thanks to a Random Walk Metropolis Hastings Algorithm.[4]

We can approximate the log-marginal density of the data by the Laplace Approximation and use it to compare different models (Geweke, 1998). Moreover, we can assess the ability of these different models to replicate euro area stylised facts by comparing the theoretical and empirical autocovariances. While the log-marginal density provides us a single value to rank alternative models, we can discuss the limits and the differences between different models by comparing the autocovariances.

4.3 Assumptions and priors

In our benchmark estimation, four parameters are calibrated. The long-run nominal interest rate, $r = \frac{\gamma_2+\gamma_3-1}{\gamma_2}$, and the long-term inflation rate π are calibrated to 1.018 and 1.009 corresponding to their average values on our sample. This implies a discount factor, β equal to 0.991. We fix the technology production function such that the labour income share in total output is of 60%, so that $\omega_p = 0.43$. Finally, we set the slope of the Phillips curve $\kappa_p = 0.05$.[5] We directly estimate $\sigma = 1/\omega_1$, as prior is easier to define for this parameter.

As in Smets and Wouters (2003), the standard errors of the innovations are assumed to follow inverse gamma distributions (see Table 2). We choose Beta distributions for shock persistence parameters with mean 0.5 and standard error 0.2 as well as for the backward component of the Taylor rule. Indeed this kind of distribution covers the whole

[4] We reject the first 100 000 iterations before keeping around 160 000 iterations from the MCMC algorithm. We check the convergence of the distribution by looking at real-time moments of the chain.

[5] Precisely, we calibrate $\alpha_p = 0.63$ because of difficulties in estimation of this parameter, which gives for a standard value of $\theta = 8$, $\kappa_p = 0.05$.

interval $]0,1[$. For the same reason, the prior for the indexation of non-optimized prices is set to follow a Beta distribution with mean 0.24 and standard error 0.1, which is consistent with Ireland's results for the US economy. Other priors follow Gaussian distributions. The prior for γ_1 is consistent with the estimates of Ireland, slightly smaller than in the literature. We choose a positive prior mean for ω_2, as suggested in the literature but a very large standard error equal to 10 to allow for the possibility of ω_2 being positive or negative. Because the introduction of a non-linear Taylor rule is novel in the literature, priors for ρ_1 and ρ_2 are assumed to be equal. The mean of the prior arbitrarily equals 1.2 because we assume that money matters for the ECB. This prior is slightly higher than in Andrès *et al.* (2006) but is consistent with the results of Poilly (2007). Robustness of this choice has been checked.

4.4 Results

4.4.1 The fit of the different models to the data

We first estimate four different versions of the model presented above: in version 1, we estimate the model by imposing that both $\omega_2 = 0$ and $\rho = 0$, i.e. a situation in which money does not have an active role in the business cycle. This model corresponds to the standard new keynesian model as presented in Woodford (1999) and is consistent with the estimations of Ireland (2004) for the US and Andrès *et al.* (2006) for the Euro area. In version 2, we relax the assumption on ω_2 and only impose that $\rho = 0$ (i.e. we suppose a model in which money may matter for the business cycle but the central bank decides to not directly react to monetary developments). In the remaining versions, we relax the assumption that $\rho = 0$ and introduce a non-linear reaction function for the ECB, considering different cases: first, we consider the case where $\rho_1 = \rho_2$, i.e the central bank reacts to monetary development but not in a state-contingent way; second, we introduce a state contingent-policy rule and consider a set of different values for (κ_c, N_c), mainly for robustness checks.

The main results are presented in Table 1 in the appendix.

The first question we want to deal with relates to the relevance of monetary developments to explain euro area data. The log marginal posterior difference between model 2 ($\rho = 0$ only) and model 1 ($\omega_2 = 0$ and $\rho = 0$) is 18.9. Therefore, to choose model 1 over model 2, we need a prior probability over model 1 1.6×10^8 (=exp(18.9)) times larger than our prior probability over model 2. This evidence supports the assumption that money matters for the business cycle in the euro area.

As regards the parameters of interest, the response of aggregate demand ($\omega_1 = 1/\sigma$) to changes in the real rate is significant and broadly in line with the estimates provided by Andrès *et al.* (2006) for the euro area but far above the estimates provided by Ireland for the United States. As far as money demand is concerned, the elasticity with respect to interest rates ($\gamma_2 = 0.7$) is broadly in line with other estimate in the literature, but the income elasticity is very small ($\gamma_1 = 0.01/0.02$) in sharp contrast with standard estimate for the euro area, generally slightly above 1. However, this may reflect the instability of money demand functions estimated on euro area data and evidenced over the last five years.[6]

The posterior mode of ω_2, the parameter measuring the importance of real balances in the IS and Phillips curves, is negative and significant, whatever the version of the model. Therefore, this estimate associates an increase in real balances with a decrease in output and an increase in inflation. Though this result may seem at odd with the related literature, in particular Ireland (2004) and Andrès *et al.* (2006), few points are worth mentioning. First, both Ireland and Andrès and co-authors, who basically replicate Ireland's approach to euro area data, constrain that parameter to be positive and thereby artificially bias the coefficient estimate toward zero. As a consequence, these authors conclude that real balances have a limited, if any, role in explaining business cycle fluctuations. Second, the sign of ω_2 ultimately depends upon the properties of the utility function of the representative household and therefore can take either a positive or a negative sign. We leave open that possibility by assuming a flatter as possible prior distribution for ω_2. Thus, we let data decide which role of money is predominant between means of transaction and a store of value. A negative sign would imply that money acts as a substitute to consumption and that the store value effect is dominant. In such a case, a rise in inflation increases the nominal interest rate and leads to a decrease in money demand. As consumption and money are substitutes, consumption rises and leisure falls. Work effort then rises and with it output.

We turn now to the monetary policy rule. As money seems to matter to understand the dynamic of euro area data and as the Eurosystem's monetary strategy rely on a monetary pillar, it may be optimal for the European Central Bank to systematically take into account a measure of money growth in its reaction function.[7] In the version 3 of

[6] Indeed, our estimates are very sensitive to the assumptions made on the priors of the parameters entering the money demand function.

[7] see the pre-version of Beck and Wieland (2007). Even though they integrate money as a proxy of expected inflation, their result tends to prove that including money growth in Philipps Curve implies a monetary policy depending on money growth.

our model (see table 1, column 6), we suppose a constant and systematic reaction to the filtered money growth, μ_{t-1}^{f}. We set the value of the smoothing parameter λ to 0.15. This implies that the half of a one-off rise in actual money growth would disappear after 4.5-quarters.[8] The weight of money growth in the policy rule is estimated around $(1-\rho_r)\rho = (1-0.651) * 1.33 = 0.46$. Andrès *et al.* (2006) finds a slightly smaller result (0.35) for the euro area over a similar sample period. However, they suppose that the ECB reacts to actual money growth whereas we assume it reacts to the deviations of filtered money growth to its long-term average.

The introduction of monetary growth into the Taylor rule has a sizeable impact on the key parameters of the rule. For instance, the weight of the inflation decreases and becomes smaller than in Taylor-type rules without money. The gain of adding money growth into monetary policy rule is clearly identified by the log-marginal density. The log marginal likelihood difference between model 3 and model 2 is 29.2. This result implies that we need a prior probability over model 2 4.8×10^{12} times larger than our prior probability over model 3 in order to reject the fact that including money into the policy reaction function is relevant.

Does the ECB react stronger to high monetary growth or put another way to "excess liquidity"? To answer this question, we estimate our model including a non-linear state-dependent monetary policy reaction function that factors in filtered money growth. Although we assume the same priors for the both coefficients, the mode of the posterior distribution indicates that $\rho_1 = 1.01$ and $\rho_2 = 1.57$ for the parameters (κ_c, N_c) set to $(1.1, 5)$. In the last two lines of Table 1, the mean of the posterior distribution of $\rho_2 - \rho_1$ and the ratio of draws where ρ_1 is higher than ρ_2 are indicated. According to the posterior distribution, this difference is positive for 99.94% of posterior draws (see Table 1). Besides, there is a difference of 2.6 between the log-data density of this setup and the previous one without threshold, which shows that, for this choice of parameters (κ_c, N_c), to chose model 3 over model 4, we need a prior probability over model 3 $13.6 = \exp(2.6)$ times larger than our prior probability over model 4. This would tend to show that, indeed, the European Central Bank tends to react more aggressively when money growth moves away from its long-term average. [9] The fact that ρ_1 is strictly positive is consistent with the fact that money matters for the euro area economy. Though ρ_1 is significantly different from ρ_2, such difference doesn't seem to matter a lot as far as the model simulations are concerned.

[8] see Gerlach (2004) for more discussion about the value of λ.

[9] This result depends on the choice of (κ_c, N_c), but remains in most of likely cases.

4.4.2 Is the model convincingly reproducing the dynamics of the euro zone economy ?

This section is devoted to the analysis of the ability of our model to replicate the euro area economy dynamics. To this aim, we study the impulse response functions to a velocity shock, a preference shock, a productivity shock and a monetary policy shock in different cases. We also consider the autocovariances in our analysis. Since the marginal likelihood is higher for model 4, we consider that the estimates obtained for the parameters in this model are the most relevant. We want to underline the impact of taking money into account into monetary policy rule and we consider alternative policy rules without money. The considered monetary policy rules are those with monetary growth of model 4, a monetary policy rule estimated on the euro area over the period 93-04 by Gerdesmeier et al. (2007), and a Taylor rule without money estimated when we fix the other parameters of the model.[10]

Concerning the impulse response functions, the introduction of money in the policy rule affects the response of the economy to a money demand shock (see figure 4). A velocity shock leads to a less than proportional increase in filtered monetary growth μ_t^f, so that money adjusted for velocity shifts decreases. In a "standard" Taylor rule, the substitution effect between consumption and money adjusted from velocity shift implies a positive effect on y. The impact on inflation is the combination of two effects: first, the marginal propensity to consume increases implying the fall of real wage and finally a downward pressure on prices, second the inflationist effect stemming from the widening of the output gap. The former effect is dominating in this case, and inflation reacts negatively. When money growth is accounted for by the central bank, the substitution effect between money adjusted from velocity shift and consumption is more than compensated by the surge in the anticipated interest rate due to the inclusion of money growth in the Taylor rule. The overall impact on output is therefore negative too. Then, the central bank increases its nominal interest rate, since μ_t^f enters with a one-period lag into the Taylor-type rule, while both output and inflation increase due to the mechanical decrease of money growth. The growth effect is preponderant in the response of inflation. For this kind of shock, the response to money growth implies a higher volatility of both output and inflation, and a higher standard quadratic loss for the central bank. This result is consistent with Poole's analysis (1970), suggesting that a central bank that would react to money demand shocks without adjusting the money supply to keep its key interest rate unchanged would indeed generate greater output and inflation volatility.

[10] The coefficients for the Taylor rule given by Gerdesmeier et al., respectively for the Taylor rule without money, are $\rho_r = 0.9$, $\rho_y = 0.83$ and $\rho_\pi = 1.5$, respectively $\rho_r = 0.74$, $\rho_y = 0.088$ and $\rho_\pi = 1.24$.

The responses to a preference shock are quite similar when money is taken into account or not in the Taylor Rule. This kind of shock leads to an intertemporal change in the structure of preferences. Then, consumption and money rise, inflation rises due to the widening of the output gap. A productivity shock leads to standard responses for supply shocks. Consumption reacts positively and inflation is decreasing owing to downward pressures on marginal costs. In the case of the Gerdesmeier et al. Taylor rule, the response of output is lower but strictly positive. Indeed, due to the higher weight of output in the Taylor rule, expectations of consumption are lower implying a lower increase of current output. The responses to a preference shock and a productivity shock are consistent with other studies like Smets and Wouters (2003).

In case of a monetary policy shock, money is decreasing as a consequence of the money demand curve. The substitution effect implies that consumption is increasing, while intuition would expect a fall due to the negative relation between consumption and interest rate. Contrary to the previous case, the growth effect on inflation is largely dominated by the decrease of marginal costs.

Finally, including money in the policy rule is always stabilizing for inflation and money growth except when the economy is facing a velocity shock. However, the inclusion of money generally increases the volatility of output. Consequently, as far as autocovariances are concerned, the ECB two-pillar strategy seems would reduce the volatility of inflation, of money growth and of interest rate but increased the volatility of output (see figure 3). In terms of welfare, taking money into account in the Taylor rule may be welfare improving if the weight of stabilizing inflation and interest rate is predominant in the CB's objective function. Besides, figure 3 indicates that the persistance of our model is consistent with real data, whereas certain covariances are not perfectly replicated.

5 Conclusion

In this paper, we try to find a rationale for the "two-pillar" monetary policy strategy of the ECB by constructing a small DSGE model that allows real balances to play an active role in explaining the euro area business cycle. We find some evidence that money plays indeed a significant role and enters in particular both in the IS and Phillips curves of our model. In such a context, it is optimal for the central bank to factor in monetary development into its monetary policy decisions. Taking money into account is a very challenging task as money and inflation are not necessarily closely related in the short run as they are in the long run. Therefore, the central bank seeks to exploit such a long-term relationship and should disregard short-term fluctuations in money growth. This is the essence of the "reference value", the concept developed by the Eurosystem in order to identify "excess liquidity" periods, i.e. risks to future price stability. Bearing this in mind, we suppose that the ECB sets its policy rate according to an augmented Taylor-type rule incorporating, beside the traditional inflation and output gaps, a filtered money growth gap. We suppose however that the reference value should account for structural shifts in the income velocity of money and for that reason compute it as the average money growth rate over a moving window of about five years.

We find some evidence that the ECB has reacted in a systematic way to monetary developments and weaker evidence that it has reacted in a non-linear way. One reason may be that, in practise, the reference value has remained unchanged since the inception of the ECB in a context where M3 growth has systematically exceeded the reference value. As a consequence, we only find slight support for the presence of shifts between two monetary policy regimes in the euro area. Another reason is that what we call money in our set-up might not correspond exactly to what is meant and measured by money in reality and by the ECB, in particular because of the absence of a banking sector in our model.

Further extensions should consider the introduction of financial frictions and of a banking sector, in the line of research by Christiano *et al.* (2006), to better replicate the multi-dimensional aspects of the monetary analysis carried out by the Eurosystem.

Appendix

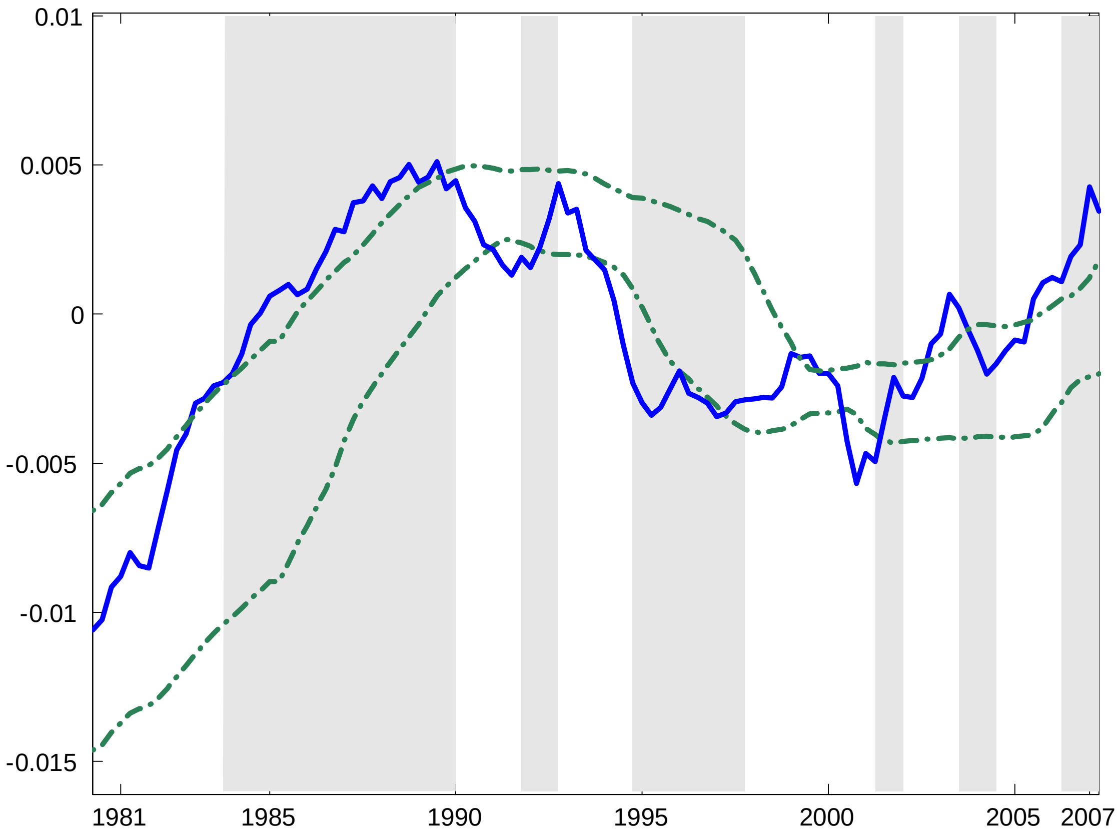

Figure 1: Money growth and thresholds for $(\kappa_c, N_c) = (1.1, 5)$.
The filtered money growth with $\lambda = 0.15$ is in thick line.The corridor defining the state 1 is in dash line. In grey, we represent the state 2 which corresponds to excessive money growth.

Table 1: Estimation results

parameters	prior law	prior mean	prior std	posterior modes $\omega_2=0$	$\rho=0$	$\rho_1=\rho_2$	Case 1	Case 2
$(\kappa_c.N_c)$							$(1.1,5)$	$(1.4,4)$
β	calibrated	0.991	0	0.991	0.991	0.991	0.991	0.991
σ	normal	1.5	0.38	2.382	1.337	1.814	1.917	1.903
				(0.285)	(0.306)	(0.337)	(0.310)	(0.302)
ω_2	normal	0.1	10	0	-4.885	-2.843	-3,123	-3.095
				(-)	(1.22)	(0.81)	(0.93)	(0.82)
γ_1	normal	0.014	0.010	0.013	0.016	0.025	0,019	0.017
				(0.009)	(0.0053)	(0.0062)	(0.0047)	(0.0072)
γ_2	normal	0.72	0.1	0.732	0.724	0.695	0,702	0.707
				(0.101)	(0.090)	(0.089)	(0.1026)	(0.096)
r	calibrated	1.018	0	1.018	1.018	1.018	1.018	1.018
ρ_e	beta	0.5	0.2	0.906	0.943	0.931	0,918	0.924
				(0.021)	(0.014)	(0.014)	(0.019)	(0.019)
ρ_a	beta	0.5	0.2	0.980	0.976	0.989	0,980	0.984
				(0.0095)	(0.0065)	(0.0026)	(0.0078)	(0.0057)
ρ_z	beta	0.5	0.2	0.937	0.872	0.888	0,908	0.905
				(0.029)	(0.048)	(0.040)	(0.031)	(0.032)
ρ_ϵ	beta	0.5	0.2	0.281	0.346	0.567	0,506	0.504
				(0.081)	(0.092)	(0.15)	(0.16)	(0.15)
σ_e	invgamma	0.1	2*	0.023	0.022	0.021	0,019	0.020
				(0.0035)	(0.0049)	(0.0036)	(0.0033)	(0.0035)
σ_a	invgamma	0.1	2*	0.009	0.009	0.009	0.009	0.009
				(0.00018)	(0.00010)	(0.00011)	(0,00013)	(0.00016)
σ_z	invgamma	0.1	2*	0.013	0.013	0.014	0,014	0.014
				(0.0011)	(0.0018)	(0.0013)	(0.0013)	(0.0013)
σ_r	invgamma	0.1	2*	0.002	0.002	0.002	0.002	0.002
				(8.2e-005)	(5.08e-005)	(4.27e-005)	(5.3e-005)	(4.13e-005)
γ_p	beta	0.24	0.1	0.147	0.135	0.108	0,079	0.100
				(0.065)	(0.06)	(0.049)	(0,043)	(0.044)
α_p	calibrated	0.63	0	0.63	0.63	0.63	0.63	0.63
ω_p	calibrated	0.43	0	0.43	0.43	0.43	0.43	0.43
ρ_r	beta	0.5	0.2	0.766	0.776	0.651	0,673	0.687
				(0.04)	(0.033)	(0.069)	(0.082)	(0.068)
ρ_y	normal	0.125	0.05	0.111	0.147	0.134	0,115	0.104
				(0.04)	(0.048)	(0.031)	(0.033)	(0.0342)
ρ_π	normal	1.7	1	1.535	1.091	0.677	0,736	0.776
				(0.175)	(0.12)	(0.16)	(0.16)	(0.19)
ρ_1	normal	1.2	0.5	0^+	0^+	1.327^{++}	1,095	1.222
				(-)	(-)	(0.24)	(0.21)	(0.22)
ρ_2	normal	1.2	0.5	0^+	0^+	1.327^{++}	1,569	1.519
				(-)	(-)	(-)	(0.27)	(0.27)
marginal density				1895	1913.9	1943.1	1945.7	1942.9
$<\rho_2-\rho_1>$							0,474	0.30
$\%(\rho_1>\rho_2)$							0.06%	4.9%

+ : calibrated parameter, ++ : coefficients ρ_1 and ρ_2 are assumed to be equal.

* : for the inverted gamma function, the degree of freedom is indicated.

Table 2: Estimation results in details

parameters	prior law	prior mean	prior st. error	estimated maximum posterior	posterior distribution MH mean	std	5%	median	95%
β	calibrated	0.991	0	0.9910	0.9910	0.0000	0.9910	0.9910	0.9910
σ	normal	1.5	0.38	1.8836	1.9168	0.3098	1.4129	1.9102	2.4363
ω_2	normal	0.1	10	-2.7977	-3.1227	0.9260	-4.8421	-3.0194	-1.7562
γ_1	normal	0.014	0.01	0.0190	0.0185	0.0047	0.0103	0.0184	0.0265
γ_2	normal	0.72	0.1	0.7108	0.7022	0.1026	0.5370	0.7000	0.8757
r	calibrated	1.018	0	1.0180	1.0180	0.0000	1.0180	1.0180	1.0180
ρ_e	beta	0.5	0.2	0.9232	0.9182	0.0188	0.8868	0.9191	0.9470
ρ_a	beta	0.5	0.2	0.9843	0.9800	0.0078	0.9684	0.9802	0.9932
ρ_z	beta	0.5	0.2	0.9224	0.9083	0.0306	0.8568	0.9094	0.9565
ρ_ϵ	beta	0.5	0.2	0.5640	0.5056	0.1554	0.2617	0.4964	0.7815
σ_e	invgamma	0.1	2*	0.0184	0.0193	0.0033	0.0142	0.0192	0.0250
σ_a	invgamma	0.1	2*	0.0090	0.0091	0.0001	0.0089	0.0091	0.0093
σ_z	invgamma	0.1	2*	0.0131	0.0138	0.0013	0.0117	0.0137	0.0161
σ_r	invgamma	0.1	2*	0.0016	0.0016	0.0001	0.0016	0.0016	0.0017
γ_p	beta	0.24	0.1	0.0785	0.1010	0.0430	0.0431	0.0950	0.1874
α_p	calibrated	0.63	0	0.6300	0.6300	0.0000	0.6300	0.6300	0.6300
ω_p	calibrated	0.43	0	0.4300	0.4300	0.0000	0.4300	0.4300	0.4300
ρ_r	beta	0.5	0.2	0.6534	0.6734	0.0818	0.5236	0.6871	0.7800
ρ_y	normal	0.125	0.05	0.1142	0.1152	0.0334	0.0583	0.1157	0.1701
ρ_π	normal	1.7	1	0.6651	0.7357	0.1606	0.4730	0.7335	1.0087
ρ_1	normal	1,2	0,5	1.0461	1.0950	0.2070	0.7757	1.0808	1.4559
ρ_2	normal	1,2	0,5	1.4749	1.5687	0.2497	1.1756	1.5564	2.0026

* : for the inverted gamma function, the degree of freedom is indicated.

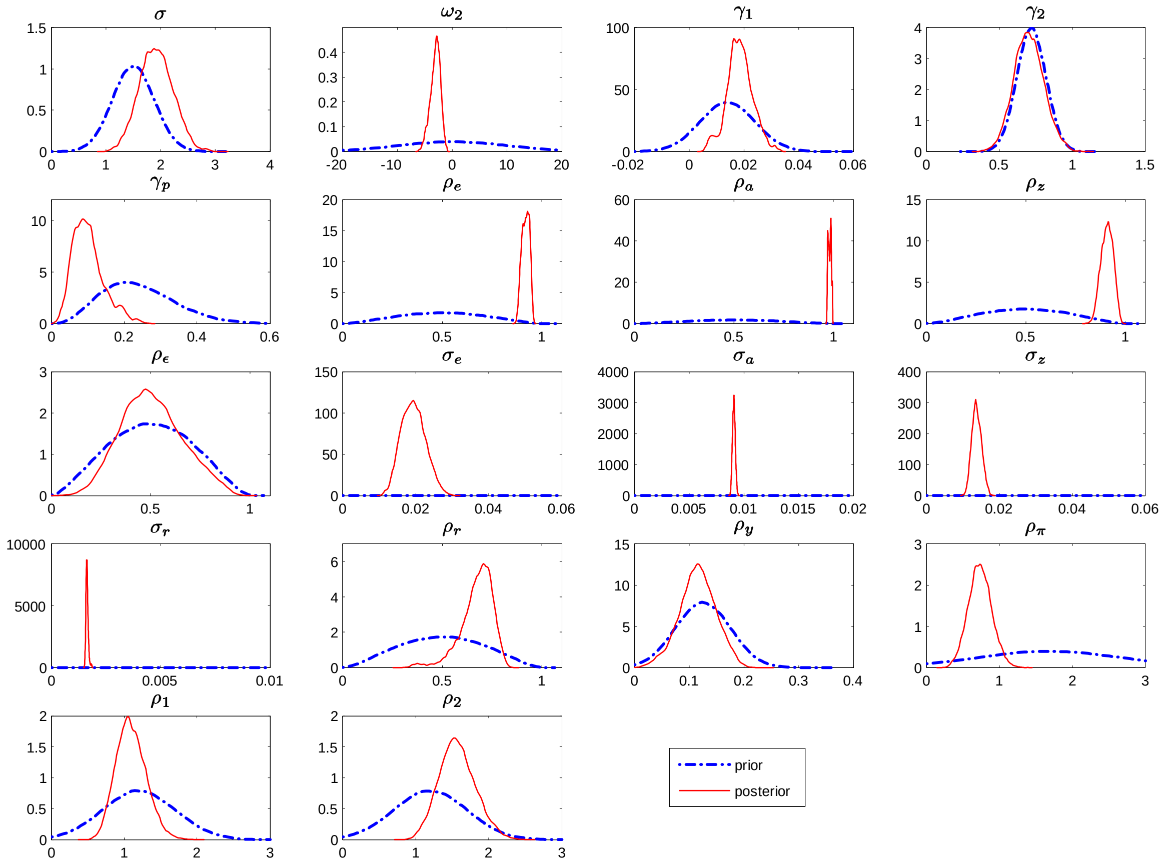

Figure 2: Priors and Posteriors for $\rho_1 \neq \rho_2$ (Case 1)

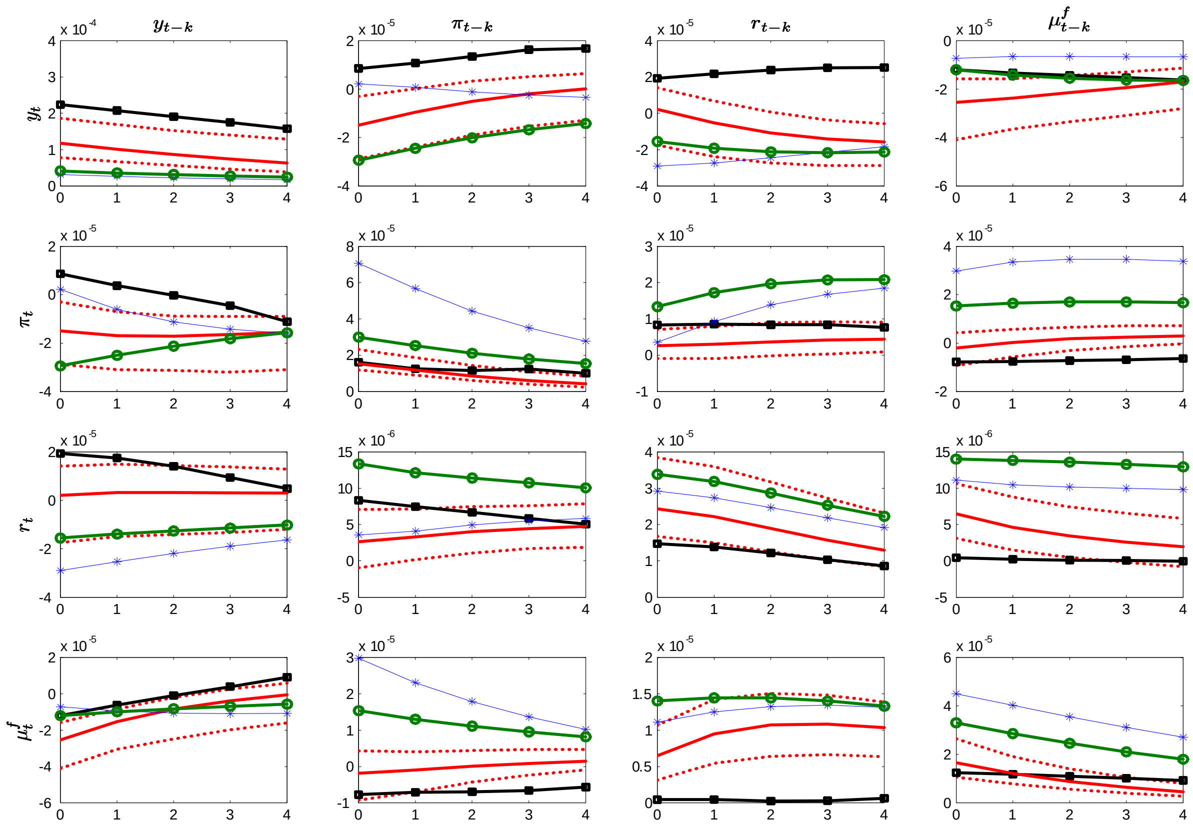

Figure 3: Comparison of empirical and theoretical autocovariances

empirical —□—, Gerdesmeier et al. —★—, TR without money —○— and model 4 —— with confident interval - - - -

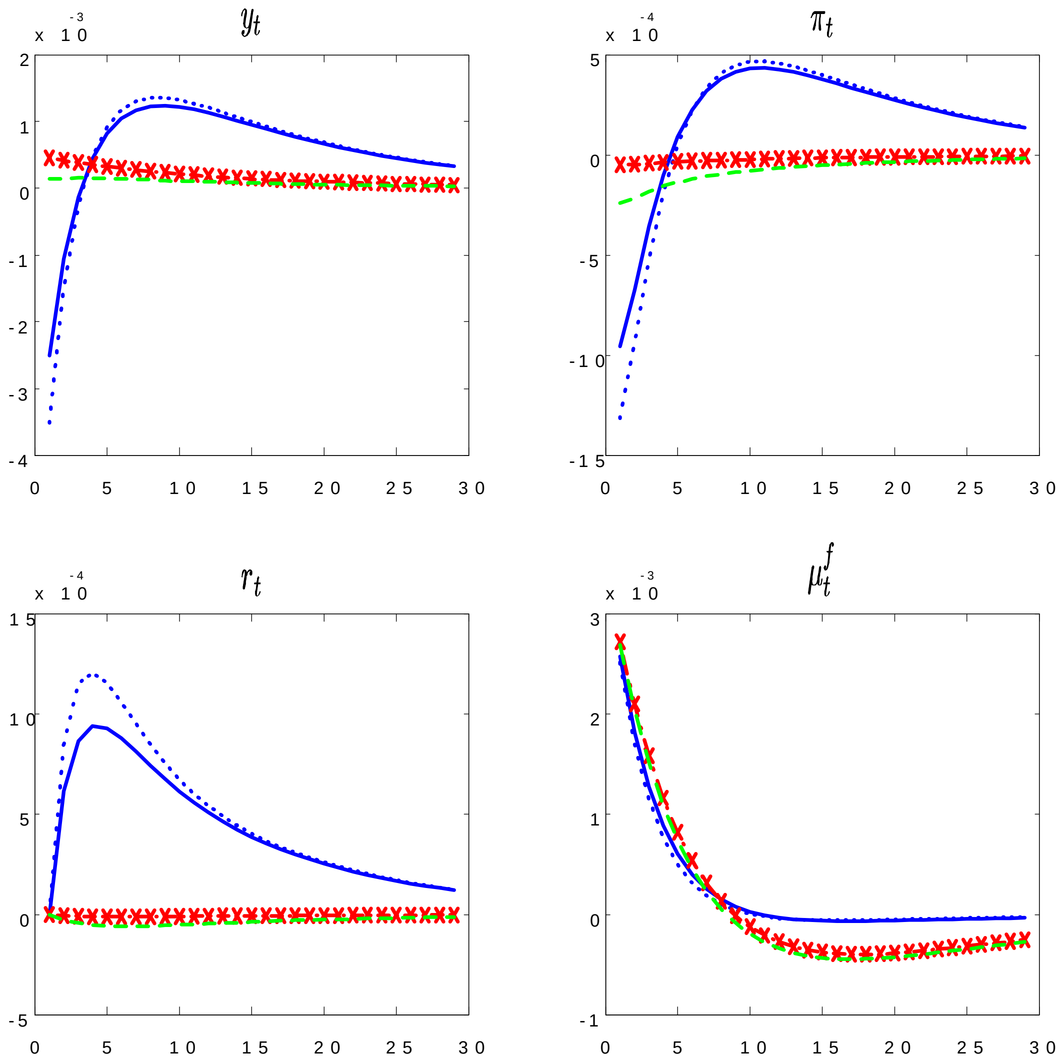

Figure 4: Impulse Response Function to a velocity shock (ϵ_e)

Case 1, $\rho = \rho_1$ ——, Case 1, $\rho = \rho_2$ ······, TR without money - -⋆- -, Gerdesmeier et al. - - - -

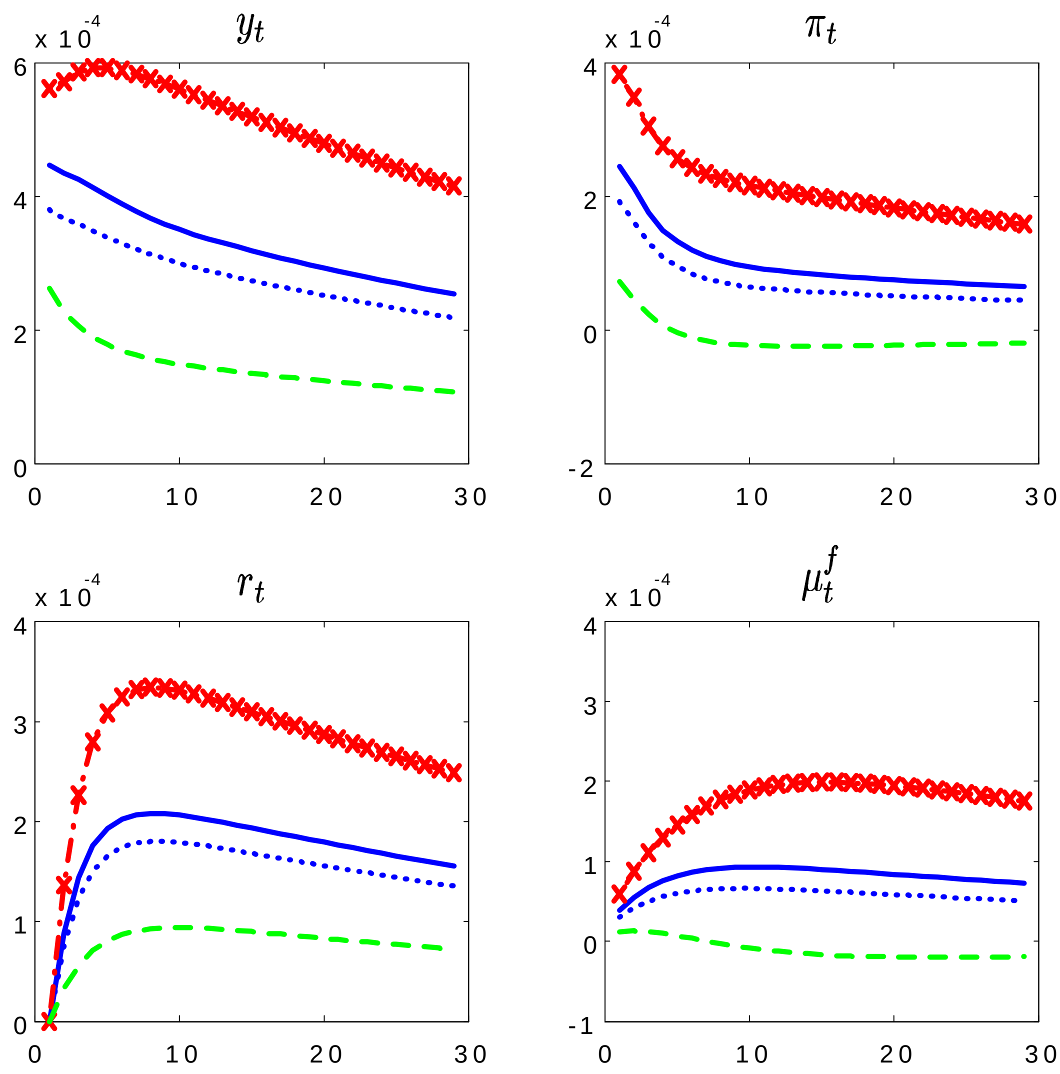

Figure 5: Impulse Response Function to a preference shock (ϵ_a)

Case 1, $\rho = \rho_1$ ——, Case 1, $\rho = \rho_2$ $\cdots\cdots$, TR without money - -⋆- -, Gerdesmeier et al. - - - -

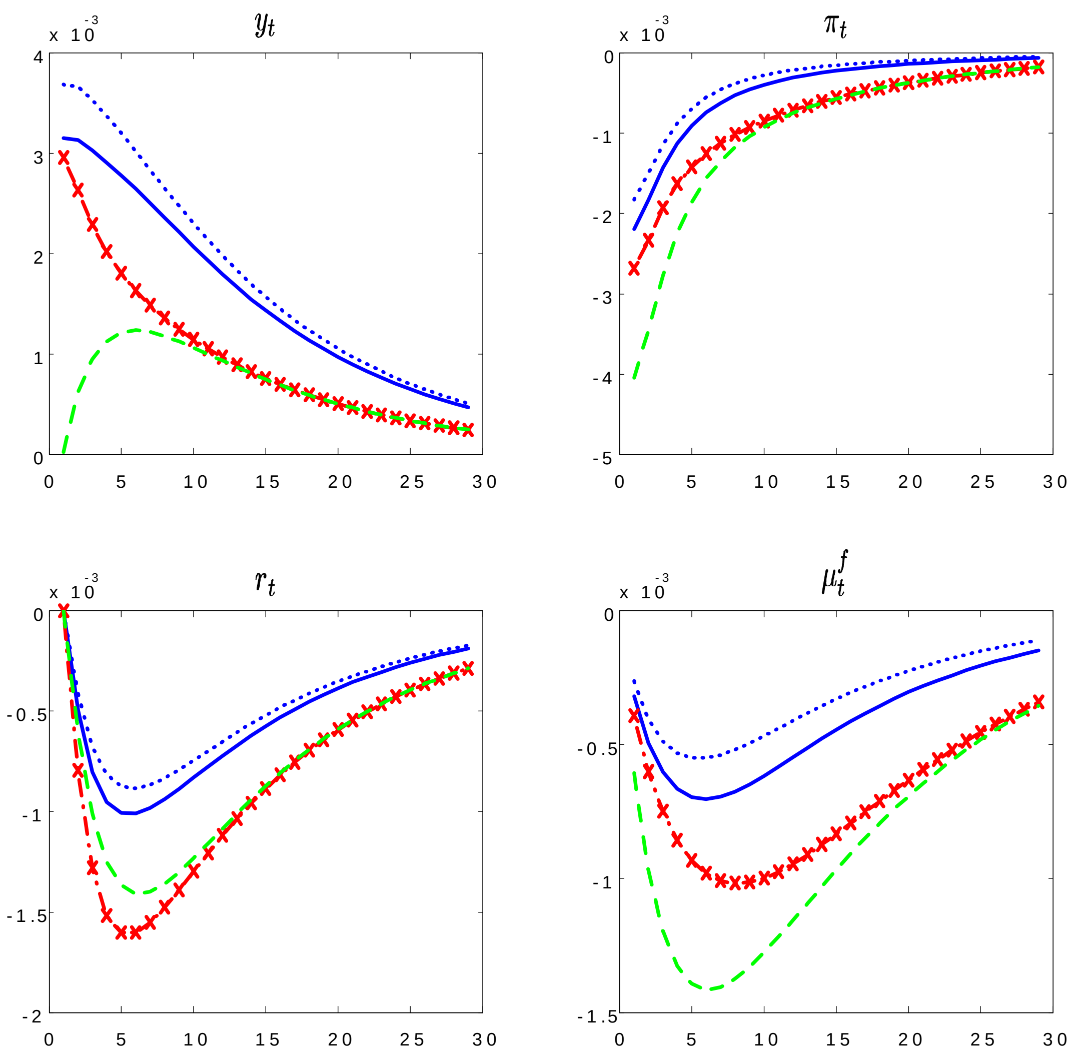

Figure 6: Impulse Response Function to a productivity shock (ϵ_z)

Case 1, $\rho = \rho_1$ ——, Case 1, $\rho = \rho_2$ · · · · · ·, TR without money - -⋆- -, Gerdesmeier et al. - - - -

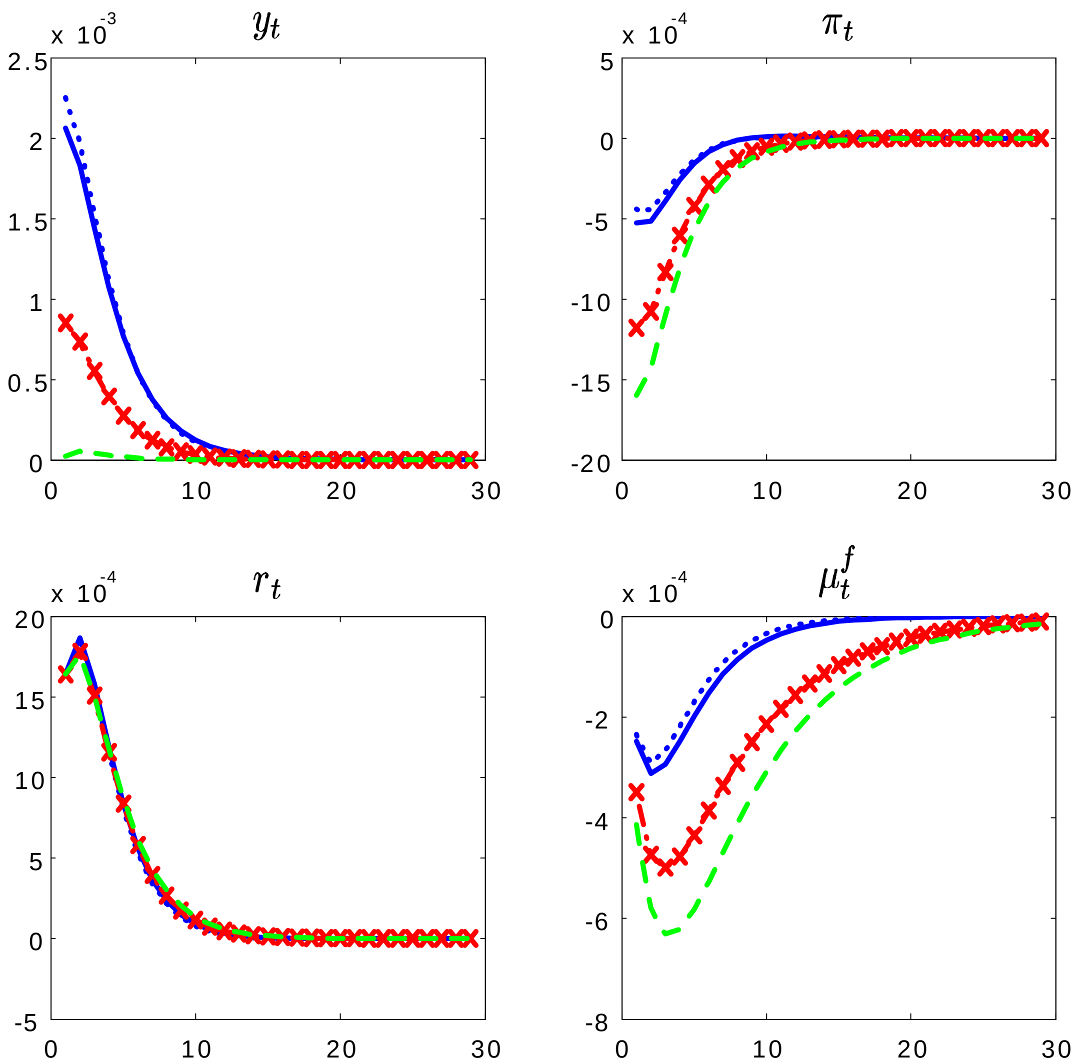

Figure 7: Impulse Response Function to a monetary policy shock (ϵ_r)

Case 1, $\rho = \rho_1$ ——, Case 1, $\rho = \rho_2$ $\cdots\cdots$, TR without money - -⋆- -, Gerdesmeier et al. - - - -

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