Money and risk in a DSGE framework: A Bayesian application to the Eurozone

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Layout

- Introduction
- The model
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The question of money

- In the current New Keynesian literature, the role of monetary aggregates is generally **neglected**.
- The main economic variables of this kind of models are: the output gap, inflation and the interest rate.
- Yet it's hard to imagine money completely "passive" to the rest of the system !

Brunner and Meltzer

- As individuals re-allocate their portfolio of assets, the behavior of real money balances induces relative **price adjustments** on financial and real assets.
- In the process, **aggregate demand** changes, and thus output.
- By affecting aggregate demand, real money balances become part of the transmission mechanism.
- The interest rate alone is thus not sufficient to explain the impact of monetary policy and the role played by credit and financial markets.
- This monetarist transmission process may also imply a specific role to real money balances when dealing with **risk aversion**.

Money and new Keynesian models

- Most of studies about New Keynesian models ignore money because of separable utilities, such as following:

$$E_t \sum_{i=0}^{\infty} \beta^i \left[\frac{C_{t+i}^{1-\sigma}}{1-\sigma} + \frac{\gamma}{1-b} \left(\frac{M_{t+i}}{P_{t+i}} \right)^{1-b} - \chi \frac{N_{t+i}^{1+\eta}}{1+\eta} \right]$$

- Solving this problem makes money completely recursive to the rest of the system of equations.
- Yet, real money holdings could affect household's consumption.
- In other words, real money balances are supposed to affect the marginal utility of consumption, i.e. we have to assume **non-separable utility** between consumption and real money balances.

Selected papers

- Andrés, López-Salido and Vallés, 2006, **Money in an Estimated Business Cycle Model of the Euro Area**, *Economic Journal*.
- Barthélemy, Clerc, and Marx, 2011, **A two-pillar DSGE monetary policy model for the euro area**, *Economic Modelling*.
- Ireland, 2004, **Money's Role in the Monetary Business Cycle**, *Journal of Money, Credit and Banking*.
- Smets and Wouters, 2003, **An Estimated Dynamic Stochastic General Equilibrium Model for the Euro Area**, *Journal of the European Economic Association*.

New Keynesian framework

Economic agents of 3 types :

- **Households**
  Purchase goods for consumption, hold money and bonds, supply labor, and maximize the expected present value of utility.
- **Firms**
  Hire labor, produce and sell differentiated products in monopolistically competitive goods markets, and maximize profits.
- **Central bank**
  Controls the nominal rate of interest.

Non-separable money in the utility

- Preferences of the representative household are defined over a composite consumption good C_t, real money balances $\frac{M_t}{P_t}$, and leisure $1 - N_t$, where N_t is the time devoted to market employment.
- CES utility function:

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

- Budget constraint:

$$P_t C_t + Q_t B_t + M_t \leq B_{t-1} + M_{t-1} + W_t N_t$$

- Production function:

$$Y_t = A_t {N_t}^{1-\alpha}$$

Solving the model

- By using Lagrangian method in order to optimize the utility function with respect to the budget constraint and the solvency condition, we obtain three first-order optimal conditions.
- We log-linearize around the steady state these conditions.
- We add an ad-hoc Taylor type rule equation to close our model.
- Finally, we have 6 equations of 6 unknown variables for our economy: output gap ($\hat{y}_t$) and its flexible-price counterpart ($\hat{y}_t^f$), inflation rate ($\hat{\pi}_t$), real money balances ($\widehat{mp}_t$) and its flexible-price counterpart ($\widehat{mp}_t^f$) and nominal interest rate ($\hat{\imath}_t$).
- Structural shocks are assumed to follow a first-order autoregressive process with an *i.i.d.*-normal error term such as $\varepsilon_t^k = \rho_k \varepsilon_{t-1}^k + \omega_{k,t}$ where $\varepsilon_{k,t} \sim N(0; \sigma_k)$ for $k = \{p, m, i, a\}$.

$$\hat{y}_t^f = \upsilon_a^y \varepsilon_t^a + \upsilon_m^y \widehat{mp}_t^f - \upsilon_c^y + \upsilon_{sm}^y \varepsilon_t^m \tag{1}$$

$$\widehat{mp}_t^f = \upsilon_{y+1}^m E_t \left[\hat{y}_{t+1}^f\right] + \upsilon_y^m \hat{y}_t^f + \frac{1}{\nu}\varepsilon_t^m \tag{2}$$

$$\hat{\pi}_t = \beta E_t \left[\hat{\pi}_{t+1}\right] + \kappa_{x,t}\left(\hat{y}_t - \hat{y}_t^f\right) + \kappa_{m,t}\left(\widehat{mp}_t - \widehat{mp}_t^f\right) \tag{3}$$

$$\begin{aligned} \hat{y}_t \quad = \quad & E_t\left[\hat{y}_{t+1}\right] - \kappa_r\left(\hat{\imath}_t - E_t\left[\hat{\pi}_{t+1}\right]\right) \\ & + \kappa_{mp} E_t\left[\Delta \widehat{mp}_{t+1}\right] + \kappa_{sm} E_t\left[\Delta \varepsilon_{t+1}^m\right] \end{aligned} \tag{4}$$

$$\widehat{mp}_t = \hat{y}_t - \kappa_i \hat{\imath}_t + \frac{1}{\nu}\varepsilon_t^m \tag{5}$$

$$\begin{aligned} \hat{\imath}_t \quad = \quad & (1-\lambda_i)\left(\lambda_\pi\left(\hat{\pi}_t - \pi_c\right) + \lambda_x\left(\hat{y}_t - \hat{y}_t^f\right) + \lambda_m \tilde{M}_{t,k}\right) \\ & + \lambda_i \hat{\imath}_{t-1} + \varepsilon_t^i \end{aligned} \tag{6}$$

Micro-funded model

$$\upsilon_a^y = \frac{1+\eta}{(\nu-(\nu-\sigma)a_1)(1-\alpha)+\eta+\alpha} \qquad \kappa_r = \frac{1}{\nu-a_1(\nu-\sigma)}$$

$$\upsilon_m^y = \frac{(1-\alpha)(\nu-\sigma)(1-a_1)}{(\nu-(\nu-\sigma)a_1)(1-\alpha)+\eta+\alpha} \qquad \kappa_{mp} = \frac{(\sigma-\nu)(1-a_1)}{\nu-a_1(\nu-\sigma)}$$

$$\upsilon_c^y = \frac{(1-\alpha)}{(\nu-(\nu-\sigma)a_1)(1-\alpha)+\eta+\alpha}\log\left(\frac{\varepsilon}{\varepsilon-1}\right) \qquad \kappa_i = a_2/\nu$$

$$\upsilon_{sm}^y = \frac{(\nu-\sigma)(1-a_1)(1-\alpha)}{((\nu-(\nu-\sigma)a_1)(1-\alpha)+\eta+\alpha)(1-\nu)} \qquad \kappa_{sm} = -\frac{(1-a_1)(\nu-\sigma)}{(\nu-a_1(\nu-\sigma))(1-\nu)}$$

$$\upsilon_{y+1}^m = -\frac{a_2}{\nu}\left(\nu-(\nu-\sigma)a_1\right) \qquad a_1 = \frac{1}{1+(b/(1-b))^{1/\nu}(1-\beta)^{(\nu-1)/\nu}}$$

$$\upsilon_y^m = 1+\frac{a_2}{\nu}\left(\nu-(\nu-\sigma)a_1\right) \qquad a_2 = \frac{1}{\exp(1/\beta)-1}$$

$$\kappa_{m,t} = (\sigma-\nu)(1-a_1)\frac{(1-\alpha)\left(\frac{1}{\theta}-\beta\right)(1-\theta)(1+(\varepsilon-1)\varepsilon_t^p)}{1+(\alpha+\varepsilon_t^p)(\varepsilon-1)}$$

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

Money in the Taylor rule ?

$\tilde{M}$ is a money variable: when $k = 0$, money does not enter the Taylor rule; $k = 1$ to 3 corresponds respectively to the real money gap (difference between real money balances and its flexible-price counterpart), the nominal money growth and the real money growth.

Methodology

- As in Smets and Wouters (2003), and An and Schorfheide (2007), we apply **Bayesian techniques** to estimate our DSGE model.
- We use **Eurozone data** like Andrès et *al.* (2006) and Barthélemy, Clerc and Marx (2011) from the Euro Area Wide Model database (AWM) of Fagan, Henry and Mestre (2001).
- We use the $M3$ monetary aggregate from the Eurostat database.
- To make output and real money balances stationary, we use first detrended data, as in Ireland (2004), Andrés, López-Salido and Vallés (2006), and Barthélemy, Clerc and Marx (2011).

Data

- $\hat{\pi}_t$ is the log-linearized detrended **inflation** rate measured as the yearly log difference of detrended GDP Deflator from one quarter to the same quarter of the previous year;
- $\hat{y}_t$ is the log-linearized detrended **output** per capita measured as the difference between the log of the real GDP per capita and its trend;
- $\hat{\imath}_t$ is the short-term (3-month) detrended **nominal interest rate**.
- $\widehat{mp}_t$ is the log-linearized detrended **real money balances** per capita measured as the difference between the real money per capita (log difference between the money stock per capita and the GDP Deflator) and its trend.
- $\hat{y}_t^f$, the **flexible-price output**, and $\widehat{mp}_t^f$, the **flexible-price real money balances**, are completely determined by structural shocks.

Calibration

- Following standard conventions, we calibrate **beta** distributions for parameters that fall between zero and one, **inverted gamma** distributions for parameters that need to be constrained to be greater than zero, and **normal** distributions in other cases.
- The calibration of σ is inspired by Rabanal and Rubio-Ramírez (2007) and by Casares (2007), respectively of 2.5 and 1.5.
- $\sigma = 2$ corresponds to a standard risk aversion.
- $\sigma = 4$, twice the standard value, represents a high level of risk aversion, around twice the estimated value.
- As our goal is to analyze two different configurations of risk, we adopt the same priors in the two models with different risk aversion calibration.
- A detailed calibration description is provided in the paper.

Methodology

- Sample: 117 observations from 1980 (Q4) to 2009 (Q4) in order to avoid high volatility periods before 1980.
- Algorithm: Metropolis-Hastings of 10 distinct chains, each of 100000 draws (Smets and Wouters, 2007; Adolfson et *al.*, 2007).
- Average acceptation rate per chain for the benchmark model (σ estimated) are included in the interval $[0.2601; 0.2661]$ and for ($\sigma = 4$) in the interval $[0.2587; 0.2658]$.

Bayesian estimation of structural parameters (1)

	Priors			Posteriors	
				σ estimated	$\sigma = 4$
	Law	Mean	Std.	Mean	Mean
α	beta	0.33	0.05	0.378	0.484
θ	beta	0.66	0.05	0.710	0.726
v	normal	1.25	0.05	1.447	1.528
σ	normal	2.00	0.50	2.157	
b	beta	0.25	0.10	0.252	0.246
η	normal	1.00	0.10	1.053	1.120
ε	normal	6.00	0.10	5.978	5.979
λ_i	beta	0.50	0.10	0.573	0.614
λ_π	normal	3.00	0.50	3.494	3.491
λ_x	normal	1.50	0.50	1.872	1.923
λ_m	normal	1.50	0.50	1.011	0.964
π_c	normal	2.00	0.10	1.903	1.908

Bayesian estimation of structural parameters (2)

	Priors			Posteriors	
				σ estimated	$\sigma = 4$
ρ_a	beta	0.75	0.10	0.992	0.994
ρ_p	beta	0.75	0.10	0.973	0.972
ρ_i	beta	0.50	0.10	0.460	0.560
ρ_m	beta	0.75	0.10	0.971	0.984
σ_a	invgamma	0.02	2.00	0.013	0.019
σ_i	invgamma	0.02	2.00	0.018	0.012
σ_p	invgamma	0.02	2.00	0.004	0.004
σ_m	invgamma	0.02	2.00	0.026	0.027

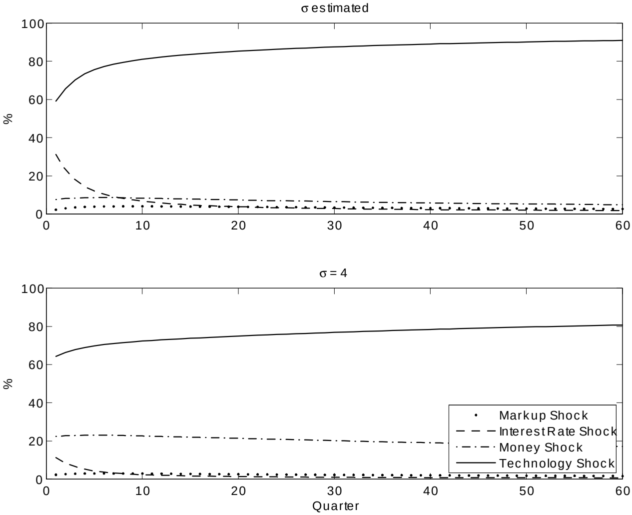
First period variance decomposition (percent)

	estimated σ				$\sigma = 4$			
	ε_t^p	ε_t^i	ε_t^m	ε_t^a	ε_t^p	ε_t^i	ε_t^m	ε_t^a
$\hat{y}_t$	2.16	31.17	**7.50**	59.16	2.23	11.19	**22.38**	64.20
$\hat{\pi}_t$	77.72	22.16	0.08	0.03	83.73	16.08	0.13	0.06
$\hat{\imath}_t$	16.35	83.44	0.14	0.07	16.66	82.99	0.23	0.13
$\widehat{mp}_t$	1.28	13.76	69.46	15.49	1.09	5.46	77.25	16.20
$\hat{y}_t^f$	0.00	0.00	**10.56**	89.44	0.00	0.00	**24.89**	75.11
$\widehat{mp}_t^f$	0.00	0.00	81.72	18.28	0.00	0.00	82.62	17.38

Unconditional variance decomposition (percent)

	estimated σ				$\sigma = 4$			
	ε_t^p	ε_t^i	ε_t^m	ε_t^a	ε_t^p	ε_t^i	ε_t^m	ε_t^a
$\hat{y}_t$	1.65	1.09	**3.07**	94.18	0.83	0.28	**10.38**	88.51
$\hat{\pi}_t$	97.66	2.14	0.09	0.12	97.64	1.79	0.24	0.33
$\hat{\imath}_t$	78.53	19.64	0.64	1.19	74.41	20.67	1.86	3.07
$\widehat{mp}_t$	1.85	0.91	52.49	44.75	0.83	0.26	60.87	38.04
$\hat{y}_t^f$	0.00	0.00	**3.06**	96.94	0.00	0.00	**10.23**	89.77
$\widehat{mp}_t^f$	0.00	0.00	54.42	45.58	0.00	0.00	62.04	37.96

Conditional variance decomposition of output



Alternative ECB's Taylor rules (1)

	estimated σ			
	$\tilde{M}_{t,0}$	$\tilde{M}_{t,1}$	$\tilde{M}_{t,2}$	$\tilde{M}_{t,3}$
λ_i	0.527	0.573	0.561	0.547
$(1-\lambda_i)\,\lambda_\pi$	1.594	1.491	1.463	1.537
$(1-\lambda_i)\,\lambda_x$	1.066	0.799	1.018	1.042
$(1-\lambda_i)\,\lambda_m$		0.431	0.136*	0.084*
ST_m^y (%)	7.05	7.50	2.23	3.66
LT_m^y (%)	2.75	3.07	2.24	2.36
LMD	-629.8	**-618.2**	-634.9	-635.3

* estimations are not significant in terms of student tests (t<1.645)

Alternative ECB's Taylor rules (2)

	$\sigma = 4$			
	$\tilde{M}_{t,0}$	$\tilde{M}_{t,1}$	$\tilde{M}_{t,2}$	$\tilde{M}_{t,3}$
λ_i	0.545	0.614	0.546	0.547
$(1-\lambda_i)\,\lambda_\pi$	1.579	1.345	1.585	1.575
$(1-\lambda_i)\,\lambda_x$	1.034	0.741	1.038	1.039
$(1-\lambda_i)\,\lambda_m$		0.371	-0.012*	-0.018*
ST_m^y (%)	22.61	22.38	23.20	23.28
LT_m^y (%)	9.56	10.38	9.29	9.15
LMD	-639.8	**-626.5**	-646.1	-646.1

* estimations are not significant in terms of student tests (t<1.645)

Comments

- Whatever the formulation of the Taylor rule, the estimated parameters of the whole model are quite similar. This is true with both levels of risk aversion.
- The impact of a money shock on output, as shown through the short term (ST_m^y, in the first period) and the long term (LT_m^y) variance decomposition of output with respect to a money shock, are also rather similar whatever the Taylor rule

Interpretation

- The weight of the money shock on output dynamics, κ_{sm}, and on flexible-price output, υ^{y}_{sm}, increases with risk aversion.
- **The higher the risk aversion, the higher the role of money on output.**
- The central bank strives for financial stability in crisis periods. The smoothing parameter in the Taylor rule equation, λ_i, increases with risk aversion.
- **The higher the risk aversion, the stronger the smoothing of the interest rate.** This reflects probably the central bankers' objective not to agitate markets.
- The introduction, or not, of a money variable in the ECB monetary policy reaction function does not really appear to change significantly the impact of money on output and inflation dynamics.

Policy implications

- Money is an important variable, at least during high uncertainty periods.
- A real money gap variable appears to be justified in the Taylor rule.
- During crisis, monetary authorities should pay attention on this variable.

Conclusion

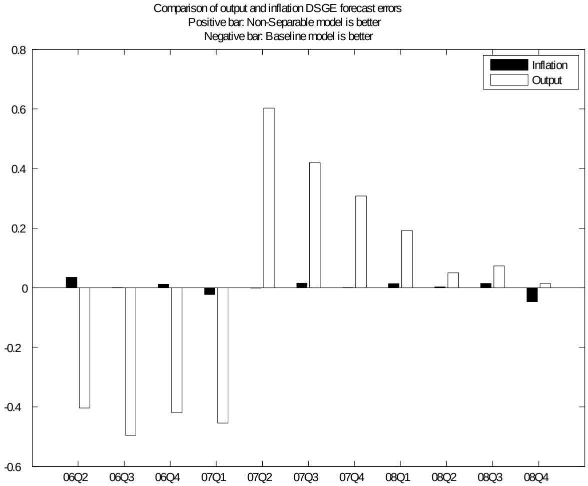
- Under a standard risk aversion: money plays a minor role in explaining output variability, as in the literature.
- **Under a higher risk aversion: money plays a non-negligible role in explaining output and flexible-price output fluctuations.**
- The explicit money variable does not appear to have a notable direct role in explaining inflation variability.
- Our results suggest that a nominal or real money growth variable does not improve the estimated ECB monetary policy rule. Yet, a **real money gap** variable significantly improves the estimated Taylor rule.
- One may infer that by **changing economic agents' perception of risks**, the last financial crisis may have increased the **role of money** in the transmission mechanisms and in output changes.

Further research

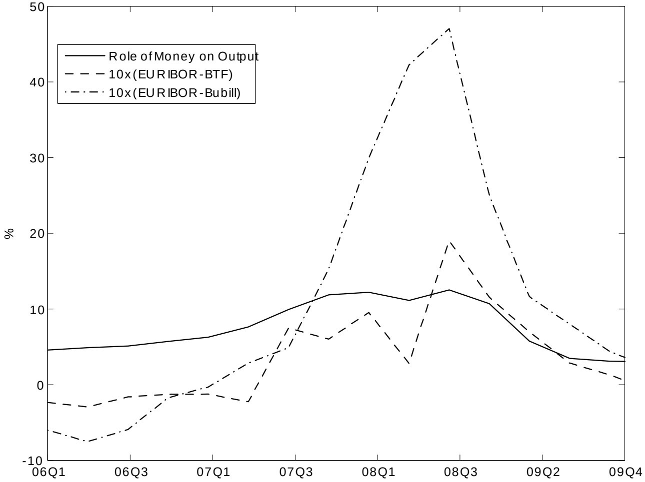
- Compare the baseline model (Gali 2008) versus our model.
- Use different data sets (demeaned, detrended).
- Enhance the model (capital, investment, central bank preferences...).
- Moving window estimations with small sample.
- Forecasting performances.

Productivity shock model (thesis)

Out-of-sample forecasting errors (DSGE Forecast)

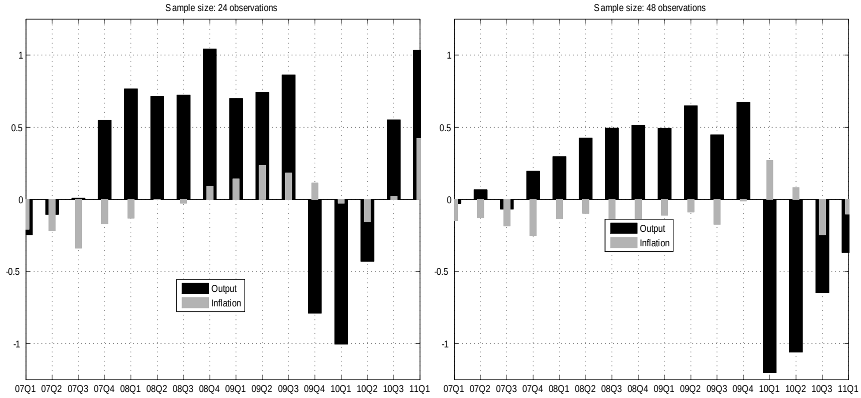


Comparison between the role of money on output and the spreads between the Bubill/BTF and the Euribor

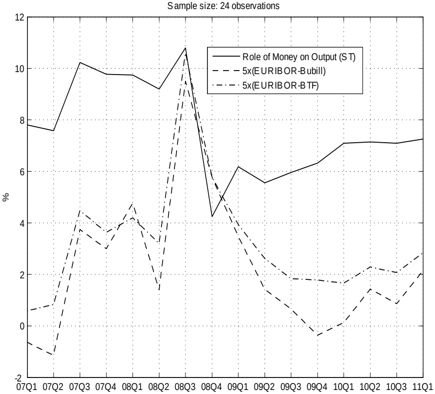


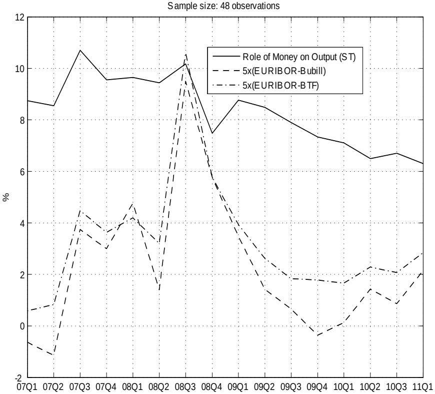
Markup shock model (JMacro)

Comparison of output and inflation DSGE forecast errors. Our model is better when the bar is positive, the baseline is better otherwise.



Comparison between the role of money on output (short run variance decomposition) and the spreads





Comparison between the role of monetary policy on output (short run variance decomposition) and the spreads