Risk aversion in the Eurozone

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Abstract

We propose a New Keynesian Dynamic Stochastic General Equilibrium (DSGE) model where a risk aversion shock enters a separable utility function. We analyze five periods from 1971 through 2011, each lasting for twenty years, to follow over time the dynamics of several parameters such as the risk aversion parameter; the Taylor rule coefficients; and the role of the risk aversion shock in output, inflation, interest rate, and real money balances in the Eurozone. Our analysis suggests that risk aversion was a more important component of output and real money balance dynamics between 2006 and 2011 than it was between 1971 and 2006, at least in the short run.

Keywords: Risk aversion, Output, Money, Eurozone, New Keynesian DSGE models, Bayesian estimation.

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1 Introduction

The New Keynesian model, as developed by Galí (2008) and Walsh (2017), brings together three equations to characterize the dynamic behavior of three key macroeconomic variables: output, inflation, and the nominal interest rate. The output equation corresponds to the log-linearization of an optimizing household's Euler equation, linking consumption and output growth to inflation-adjusted return on nominal bonds—that is, to the real interest rate. The inflation equation describes the optimizing behavior of monopolistically competitive firms that either set prices in a randomly staggered fashion (Calvo, 1983), or face explicit costs of nominal price adjustment (Rotemberg, 1982). The nominal interest rate equation, a monetary policy rule of the kind proposed by Taylor (1993), dictates that the central bank should adjust the short-term nominal interest rate in response to a trade-off between changes in inflation and output, and changes in the past interest rate.

Following optimization of household preferences, relative risk aversion explicitly enters the first two equations. It has often been calibrated, estimated, and analyzed as a simple and constant parameter in the literature (Christiano et al., 2014). Although they deal with issues largely related to risk aversion by considering log-utilities, some studies are not able to analyze constant relative risk aversion (Iacoviello, 2005). Yet, its role in the economic dynamics of the Eurozone has not been analyzed further, at least not including a relative risk aversion shock in a microfounded new Keynesian Dynamic Stochastic General Equilibrium (DSGE) model.

Alpanda (2013) highlights the important role played by risk aversion shocks in the US between 2006 and 2011. However, few studies quantify this link, or even consider risk aversion as a shock in a New Keynesian DSGE framework applied to the Eurozone. No studies use Bayesian techniques—as Fernández-Villaverde (2010) does—to analyze the role of the risk aversion shock in output, inflation, interest rate, and money dynamics in the Eurozone.

Constant relative risk aversion may change across different time periods. Evidence of time-varying risk aversion can be found in simple applied analysis carried out by Donadelli and Prosperi (2012). For instance, risk aversion varies in response to news about inflation (Brandt and Wang, 2003). However, what is the contribution of a risk aversion shock to the dynamics of output, inflation, and money, over time? Building a simple New Keynesian DSGE model including a time-varying relative risk aversion variable should be able to answer this question.

As relative risk aversion measures the willingness to substitute consumption over different periods, lower the level of risk aversion, more willing the households are to substitute consumption over time. Results on the relationship between relative risk aversion and equity risk premium can be found in Bansal and Yaron (2004). Additionally, Wachter (2006) and Bekaert et al. (2010) show that an increase in risk aversion involves an increase in equity and bond premiums, and may either increase or decrease the real interest rate through a consumption smoothing effect or a precautionary savings effect, respectively. Bommier et al. (2012) further show that risk aversion enhances precautionary savings. These studies confirm the potential link between money holdings, output, and risk aversion.

However, most new Keynesian DSGE models do not include money in agents' utility (MIU). Ireland (2004), Andrés et al. (2006), and Barthélemy et al. (2011) do not analyze the link between relative risk aversion of households and the dynamics of key macroeconomic variables.

However, Benchimol and Fourçans (2012) establish a significant link between money, output, and risk aversion. They show that real money has a significant role with regard to output if the relative risk aversion level is sufficiently high. Even though they study the role of the level of risk aversion in a non-standard MIU function (CES), they do not include a study of the microfounded risk aversion shock for the Eurozone, without non-separabilities.

As in other studies, we consider a new Keynesian DSGE model including standard shocks: a price-markup shock, a monetary policy shock, and a technology shock. To analyze the role of risk aversion in the dynamics of other variables, we consider a time-varying relative risk aversion including a risk aversion shock.

Additionally, we consider a money equation to take account of the behaviors of national central banks (before 1999) and the European Central Bank (after 1999), and to close the model with as many historical variables as exogenous shocks.

This article contributes to the literature in several ways. First, we analyze the role of a microfounded risk aversion shock in the dynamics of a New Keynesian DSGE model. Second, a completely microfounded model with a risk aversion shock is an original development, both in terms of findings as well as an estimation technique.

Mainly inspired by Smets and Wouters (2007) and Galí (2008), our model explores the role of risk aversion in inflation, output, interest rates, real money balances, as well as in flexible-price output.

Specific emphasis will be placed on how the risk aversion shock impacts the dynamics of these key variables over time. We use Bayesian techniques, as in An and Schorfheide (2007), to estimate five subsamples of the Eurozone between 1971 and 2011, each for a period of twenty years. This framework allows us to successively analyze the informational content of the last two crises (subprime and sovereign debt crises) in comparison with other crises that occurred between 1971 and 2006 in the Eurozone.

Bayesian estimations and dynamic analyses of the model, with impulse response functions and short- and long-run variance decomposition following structural shocks, yield different relationships between risk aversion and other variables. This approach sheds light on the importance of risk aversion, and its impact on output and real money balances during the last five years (2006 to 2011).

This original focus on the last forty years highlights that the effect of risk aversion shocks on output and real money balances are stronger in recent years than in the distant past. It also shows that the role of monetary policy with regard to output in the short run has decreased in recent years.

Finally, using modern theoretical and empirical tools, this study explores a fundamental question about the role of the perception of economic risks—the ability of households to consume now or later—in the dynamics of the main economic variables for the Eurozone.

The remainder of the paper is organized as follows. Section 2 describes the theoretical setup. In Section 3, the model is calibrated and estimated using Eurozone data. Impulse response functions and variance decompositions are analyzed in Section 4. Section 5 concludes, and the Appendix presents additional theoretical and empirical results.

2 The model

The model consists of households that supply labor, purchase goods for consumption, and 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 during each period. Households and firms behave optimally: households maximize the expected present value of utility, and firms maximize profits. Additionally, there is a central bank that controls the nominal rate of interest.

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. The household decides allocation of its consumption expenditure among different goods. This requires that the consumption index C_t be maximized for any given level of expenditure (Galí, 2008). Furthermore, conditional on such optimal behavior, the period budget constraint takes the form

$$P_t C_t + M_t + Q_t B_t \leq B_{t-1} + W_t N_t + M_{t-1} \tag{2}$$

where $t = 0, 1, 2...$, P_t is an aggregate price index; M_t is the quantity of money holdings at time t; B_t is the quantity of one-period nominally riskless discount bonds purchased in period t and maturing in period $t+1$ (each bond pays one unit of money at maturity and is priced at Q_t, where $i_t = -\ln Q_t$ is the short-term nominal rate); W_t is the nominal wage; and N_t denotes hours of work (or the measure of household members employed). The above sequence of period budget constraints is supplemented with a solvency condition.[1]

Preferences are measured with a common time-separable utility function (MIU). Under the assumption of a period utility given by

$$U_t = \frac{C_t^{1-\sigma_t}}{1-\sigma_t} + \frac{\gamma}{1-\nu}\left(\frac{M_t}{P_t}\right)^{1-\nu} - \frac{\chi N_t^{1+\eta}}{1+\eta} \tag{3}$$

consumption, money demand, labor supply, and bond holdings are chosen to maximize Eq. 1, subject to Eq. 2 and the solvency condition. This MIU utility function depends positively on the consumption of goods, C_t, and real money balances, $\frac{M_t}{P_t}$; and negatively on labor, N_t. $\sigma_t > 0$ is the time-varying coefficient of the relative risk aversion of households (or the inverse of the intertemporal elasticity of substitution), defined as $\sigma_t = \sigma + \varepsilon_t^r$, where ε_t^r is a risk aversion shock (detailed in Section 3.1). 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. γ and χ are positive scale parameters.

This setting leads to the following conditions[2], which must hold in equilibrium, in addition to the budget constraint. The resulting log-linear version of the first-order condition corresponding to the demand for contingent bonds implies that

$$c_t = E_t\left[c_{t+1}\right] - \frac{1}{\sigma_t}\left(i_t - E_t\left[\pi_{t+1}\right] - \rho_c\right) \tag{4}$$

where $c_t = \ln\left(C_t\right)$ is the logarithm of aggregate consumption, i_t is the nominal interest rate, $E_t\left[\pi_{t+1}\right]$ is the expected inflation rate in period $t+1$ with knowledge of the information in period t, and $\rho_c = -\ln\left(\beta\right)$.

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[1] Such as $\forall t \lim\limits_{n\longrightarrow\infty} E_t\left[B_n\right] \geq 0$, in order to avoid Ponzi-type schemes.

[2] See Appendix 6.A

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

$$\sigma_t c_t - \nu m p_t - \rho_m = a_2 i_t \tag{5}$$

where $mp_t = m_t - p_t$ are the log linearized real money balances, $\rho_m = -\ln(\gamma) + a_1$, and a_1 and a_2 are resulting terms of the first-order Taylor approximation of $\ln(1 - Q_t) = a_1 + a_2 i_t$.

Real cash holdings depend positively on consumption with an elasticity equal to $\frac{\sigma_t}{\nu}$ and negatively on the nominal interest rate.[3] We consider nominal interest rate as the policy instrument of the central bank.

The resulting log-linear version of the first-order condition corresponding to the optimal consumption-leisure arbitrage implies that

$$w_t - p_t = \sigma_t c_t + \eta n_t - \rho_n \tag{6}$$

where $w_t - p_t$ corresponds to the log of the real wage, n_t denotes the log of hours of work, and $\rho_n = -\ln(\chi)$.

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

2.2 Firms

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

We assume a continuum of firms indexed by $i \in [0, 1]$. Although each firm produces a differentiated good, they all use identical technology, represented by the following production function

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

where $A_t = \exp(\varepsilon_t^a)$ represents the level of technology, assumed to be common to all firms, and which evolves exogenously over time, and ε_t^a is a technology shock.

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

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[3] Since $\frac{1}{\beta} > 1$, $a_2 > 0$.

standard Calvo (1983) model, our generalization features monopolistic competition and staggered price setting. At any time, t, only a fraction of firms, $1-\theta$, with $0<\theta<1$, can reset their prices optimally, while the remaining firms index their prices to lagged inflation.

2.3 Central bank

The central bank is assumed to set its nominal interest rate according to an augmented smoothed Taylor (1993) rule such as:

$$i_t = (1-\lambda_i)\left(\lambda_\pi(\pi_t-\pi_c)+\lambda_x\left(y_t-y_t^f\right)+\lambda_m(mp_t-mp_c)\right)+\lambda_i i_{t-1}+\varepsilon_t^i \tag{8}$$

where λ_π, λ_x, and λ_m are policy coefficients reflecting the weight assigned to the inflation gap, the output gap, and the real money gap, respectively; the parameter $0<\lambda_i<1$ captures the degree of interest rate smoothing; and ε_t^i is an exogenous *ad hoc* shock accounting for fluctuations of the nominal interest rate. π_c is an inflation target and mp_c is a money target, essentially included to account for changes in policies targeting inflation (Svensson, 1999) and monetary aggregates (Fourçans, 2007). Other studies introduce a relevant money variable in the Eurozone Taylor rule (Andrés et al., 2006, 2009; Barthélemy et al., 2011; Benchimol and Fourçans, 2012).

Additionally, λ_m takes into account the potential money targeting of the national central bank before the creation of the European Central Bank (ECB, 1999). After 1999, the ECB followed an explicit money targeting policy until 2004, called the *Two Pillars* policy (Barthélemy et al., 2011), and might have even followed an implicit money targeting policy after that (Kahn and Benolkin, 2007).

3 Empirical results

3.1 DSGE model

Our macro model consists of five equations and five dependent variables: inflation, nominal interest rate, output, real money balances, and flexible-price output. Flexible-price output is completely determined by shocks.

$$y_t^f = \frac{1+\eta}{\sigma_t(1-\alpha)+\eta+\alpha}\varepsilon_t^a + \frac{(1-\alpha)\left(\ln(1-\alpha)+\rho_n-\ln\left(\frac{\varepsilon}{\varepsilon-1}\right)\right)}{\sigma_t(1-\alpha)+\eta+\alpha} \tag{9}$$

$$\pi_t = \beta E_t[\pi_{t+1}] + \frac{(1-\theta)(1-\beta\theta)(\sigma_t(1-\alpha)+\eta+\alpha)}{\theta(1-\alpha+\alpha\Lambda_t)}\left(y_t-y_t^f\right) \tag{10}$$

$$y_t = E_t\left[y_{t+1}\right] - \sigma_t^{-1}\left(i_t - E_t\left[\pi_{t+1}\right] - \rho_c\right) \tag{11}$$

$$mp_t = \frac{\sigma_t}{\nu} y_t - \frac{a_2}{\nu} i_t - \frac{\rho_m}{\nu} \tag{12}$$

$$i_t = (1-\lambda_i)\left(\lambda_\pi\left(\pi_t - \pi_c\right) + \lambda_x\left(y_t - y_t^f\right) + \lambda_m\left(mp_t - mp_c\right)\right) + \lambda_i i_{t-1} + \varepsilon_t^i \tag{13}$$

where $a_1 = \ln\left(1 - e^{-\frac{1}{\beta}}\right) - \frac{\frac{1}{\beta}}{e^{\frac{1}{\beta}}-1}$ and $a_2 = \frac{1}{e^{\frac{1}{\beta}}-1}$.

All structural shocks are assumed to follow a first-order autoregressive process with an *i.i.d.* (independent and identically distributed) normal error term, such as $\varepsilon_t^k = \mu_k \varepsilon_{t-1}^k + \omega_{k,t}$, where $\varepsilon_{k,t} \sim N\left(0; \sigma_k\right)$ for $k = \{p, i, a, r\}$.

3.2 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 at greater than zero, and normal distributions in other cases.

The parameters of the utility function are assumed to be distributed as follows. Only the discount factor is fixed at 0.98 in the estimation procedure. The intertemporal elasticity of substitution (i.e., the level of relative risk aversion) is set at 2, a mean between the calibrations of Rabanal and Rubio-Ramírez (2005) and Casares (2007), and consistent with the calibrated value used by Kollmann (2001) and the value estimated by Lindé et al. (2009). The inverse of the Frisch elasticity of labor supply is assumed to be approximately 1, as in Galí (2008), and the scale parameters on money and labor are assumed to be approximately 0.2, as in Benchimol and Fourçans (2012).

The calibration of α, θ, and ε comes from Smets and Wouters (2007), Casares (2007), and Galí (2008). The smoothed Taylor rule (λ_i, λ_π, λ_x, and λ_m) priors are calibrated following Smets and Wouters (2003), Andrés et al. (2009), and Barthélemy et al. (2011). To observe both the behavior of the central bank and risk aversion, we assign a higher standard error (0.2) and a Normal prior law for the relative risk aversion level and for the Taylor rule coefficients (including inflation and money targets), except for the smoothing parameter, which is restricted to be positive and less than one (Beta distribution). The inflation target, π_c, is calibrated to 2 percent, and the money target, mp_c, is assumed to be approximately 4 percent.

The calibration of the shock persistence parameters and the standard errors of the innovations follow Smets and Wouters (2007). All the standard errors of shocks are assumed to be distributed according to inverted Gamma distributions, with prior means of 0.01. The latter ensures that these parameters have positive support. The autoregressive parameters are all assumed to follow Beta distributions. All of these distributions are centered around 0.75, except for the autoregressive parameter of the monetary policy shock and the risk aversion shock, which are centered around 0.50, as in Smets and Wouters (2007). We take a common standard error of 0.15 for the shock persistence parameters, which is a mean between that of Benchimol and Fourçans (2012) and Smets and Wouters (2007).

	Law	Mean	Std.		Law	Mean	Std.
α	beta	0.33	0.10	λ_m	normal	1.00	0.20
θ	beta	0.66	0.10	π_c	normal	2.00	0.20
σ	normal	2.00	0.20	mp_c	normal	4.00	0.20
υ	normal	1.50	0.10	ρ_a	beta	0.75	0.15
ε	normal	6.00	0.10	ρ_p	beta	0.75	0.15
η	normal	1.00	0.10	ρ_i	beta	0.50	0.15
γ	beta	0.20	0.05	ρ_r	beta	0.50	0.15
χ	beta	0.20	0.05	σ_a	invgamma	0.01	2.00
λ_i	beta	0.50	0.10	σ_p	invgamma	0.01	2.00
λ_π	normal	3.00	0.20	σ_i	invgamma	0.01	2.00
λ_x	normal	1.50	0.20	σ_r	invgamma	0.01	2.00

Table 1: Calibration summary

3.3 Eurozone data

In our Eurozone model, π_t is the detrended inflation rate measured as the yearly log difference of the detrended GDP deflator from one quarter to the same quarter of the previous year; y_t is the detrended output per capita measured as the difference between the log of real GDP per capita and its trend; and i_t is the short-term (3-month) detrended nominal interest rate. These data are extracted from the AWM (Area Wide Model) database (Fagan et al., 2001). mp_t is the detrended real money balance per capita measured as the difference between real money per capita and its trend, where real money per capita is measured as the log difference between money stock per capita and the GDP deflator. We use the $M3$ monetary aggregate from the Eurostat database.

3.4 Results

The model is estimated with 160 observations from the first quarter of 1971 to the first quarter of 2011, with Bayesian techniques, as in Smets and Wouters (2007). However, to capture different policies and risk perceptions in the Eurozone between 1971 and 2011, and more specifically between 2006 and 2011, we divide this large sample into five subsamples, each consisting of 80 observations (20 years).

This procedure allows us to analyze five different periods with a sufficiently large sample, as specified in Fernández-Villaverde and Rubio-Ramírez (2004). Accordingly, we estimate our model over five different periods: from 1971 Q1 to 1991 Q1 (P1); from 1976 Q1 to 1996 Q1 (P2); from 1981 Q1 to 2001 Q1 (P3); from 1986 Q1 to 2006 Q1 (P4); and from 1991 Q1 to 2011 Q1 (P5).

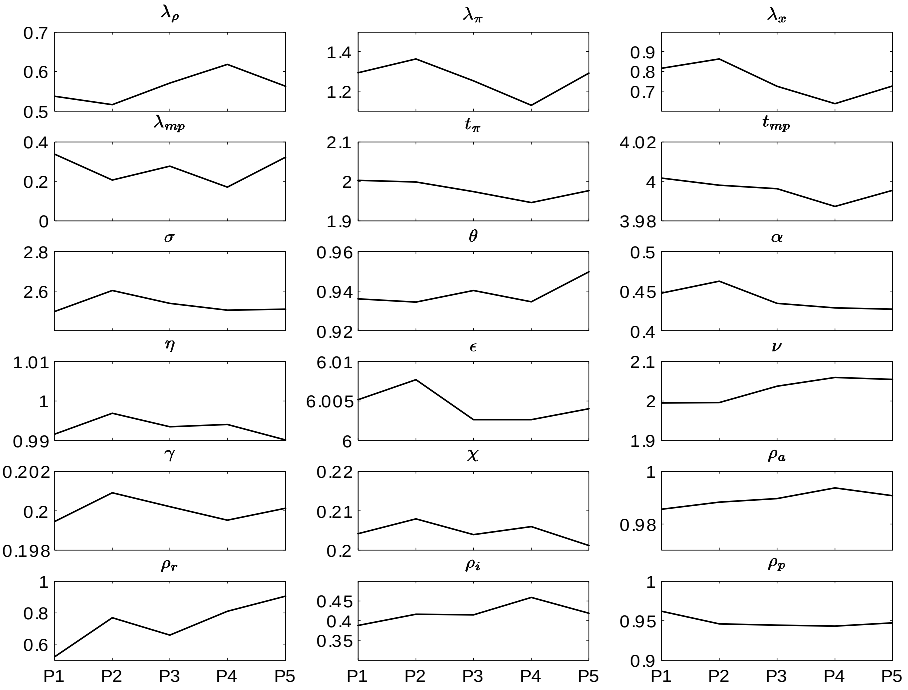

Figure 1: Bayesian estimation of parameters over the selected periods

The estimation of the implied posterior distribution of the parameters across the five periods (Fig. 1) is performed using the Metropolis-Hastings algorithm (10 distinct chains, each of $100,000$ draws). The average acceptance rates per chain are included in the interval $[0.19; 0.22]$, and the Student's t-tests are all above 1.96 in absolute terms.

To assess the model validation, we ensure convergence of the proposed distribution to the target distribution for each period. Appendix 6.B shows that the estimation results are valid and that convergence is obtained for all estimations and all moments.

Distribution of priors and posteriors are presented in Appendix 6.C. It shows that the maximum posterior distribution reaches the posterior mean of each estimated parameter. The estimation is relatively well identified, and the data is quite informative for most of the estimated microparameters.

4 Interpretation

We analyze the forecast error variance decomposition of each variable following exogenous structural shocks.

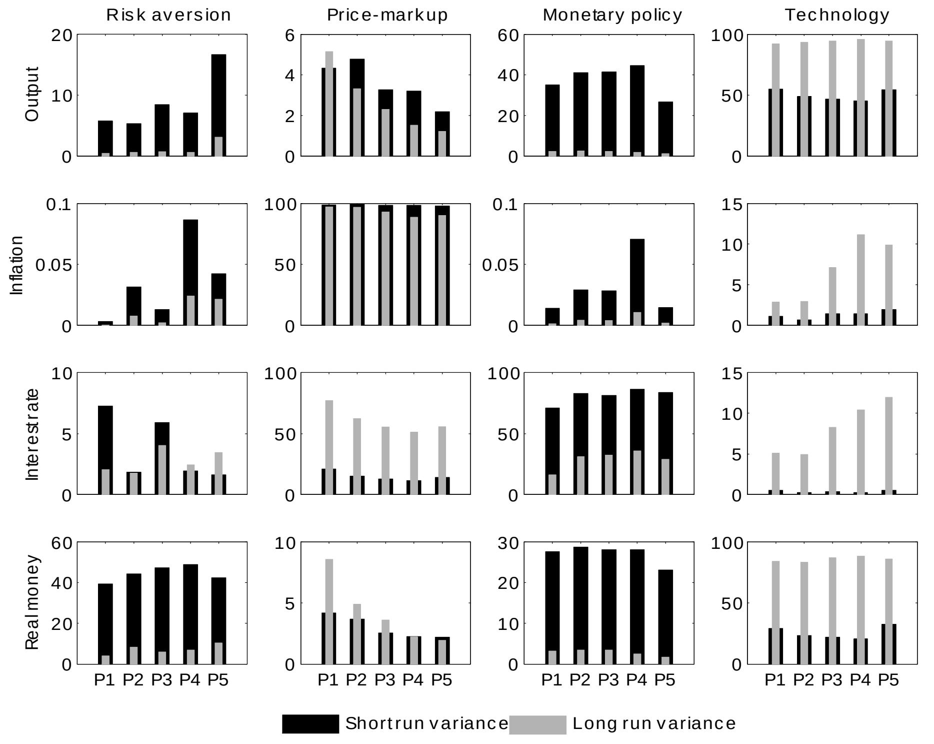

Figure 2: Variance decomposition over the selected periods

The analysis is conducted via an unconditional variance decomposition to analyze long-term variance decomposition (the gray bar in Fig. 2), and conditional variance decomposition, conditionally to the first period, to analyze short-run variance decomposition (the black bar in Fig. 2).

Fig. 2 shows that output is mainly explained by the technology shock in the long run (approximately 90%), and by the monetary policy shock (approximately 35%) and the technology shock (approximately 50%) in the short run. Rest of the variance in output is explained by the risk aversion shock (approximately 5% from P1 to P4, and more than 15% for P5) in the short term, whereas risk aversion shock has a limited role in output variance in the long run.

Fig. 2 also shows that, in accordance with the literature, inflation is mainly explained by the price-markup shock, and interest rate variance is mainly driven by monetary policy in the short run and monetary policy and price-markup in the long run. Furthermore, most of the variance in real money balances is induced by the risk aversion shock (approximately 40%) and the monetary policy shock (approximately 25%) in the short run, whereas in the long run, real money balance variance is mainly driven by the technology shock. All these results are in line with the literature.

Sections 4.1 to 4.4 present the role of each shock in the fluctuations of the macroeconomic variables, and the response of these key variables to structural shocks over the study period.

4.1 Price-markup shock

Fig. 2 shows that the price-markup shock explains almost all of the variability in the inflation rate, at least in the short run. Its role in the long run on real money balance fluctuations is halved across the study period.

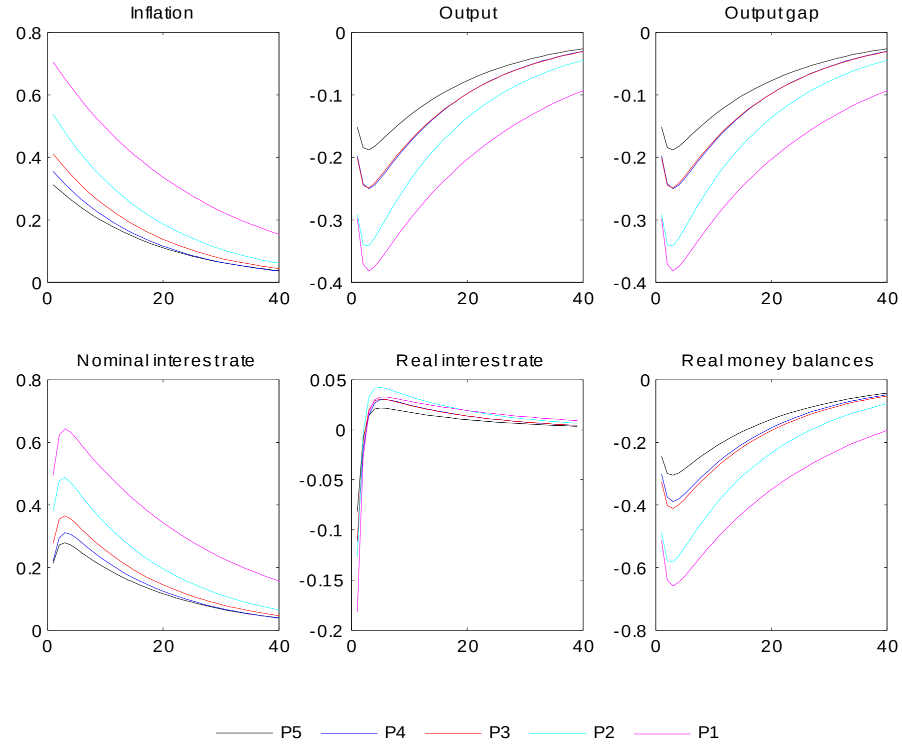

Figure 3: Impulse response function with respect to a price-markup shock

Fig. 3 shows that from P1 to P5, the impact of the price-markup shock on output, inflation, nominal interest rate, and real money balances is at least halved. While transitioning from one period to another, the impact of the price-markup shock on the overall economy reduces. Regardless of the period under study, after a positive price-markup shock, inflation rate increases, thus, nominal interest rate increases, decreasing real interest rate, output, output gap, and real money balances.

4.2 Technology shock

Fig. 2 indicates that technology plays an increasingly important role in the short term for the inflation rate and, thus, for the interest rate in the selected period.

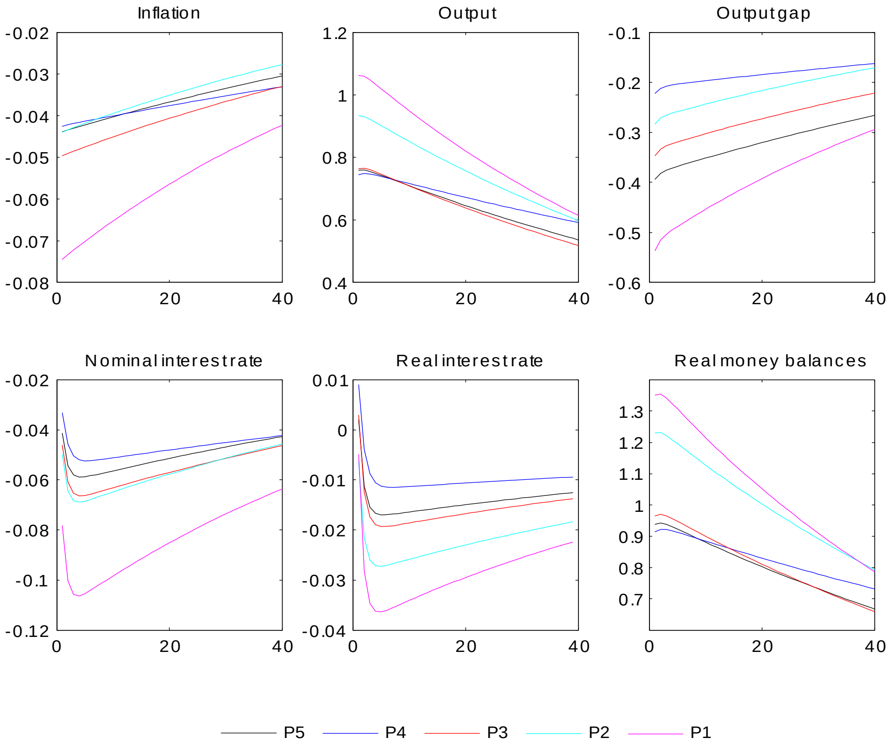

Figure 4: Impulse response function with respect to a technology shock

Fig. 4 highlights that in response to a positive technology shock, output increases but inflation decreases, resulting in an increase in real money holding, and a slight decrease in nominal interest rate and output gap. The improvement in technology is partly accommodated by the central bank, which lowers the nominal and real interest rate, while increasing the quantity of money in circulation.

Interestingly, note that maximum sensitivity of output to a technology shock was observed in P1 and P2.

4.3 Monetary policy shock

Fig. 2 shows that compared to the previous periods (P1 to P4), monetary policy has a smaller role in the short run output variability over the last period (P5)–from around 37% to 22%, respectively. This highlights a switch from the role of the monetary policy to the role of risk aversion during recent years. This confirms the declining influence of European monetary policy relative to the influence of risk aversion shocks in recent years.

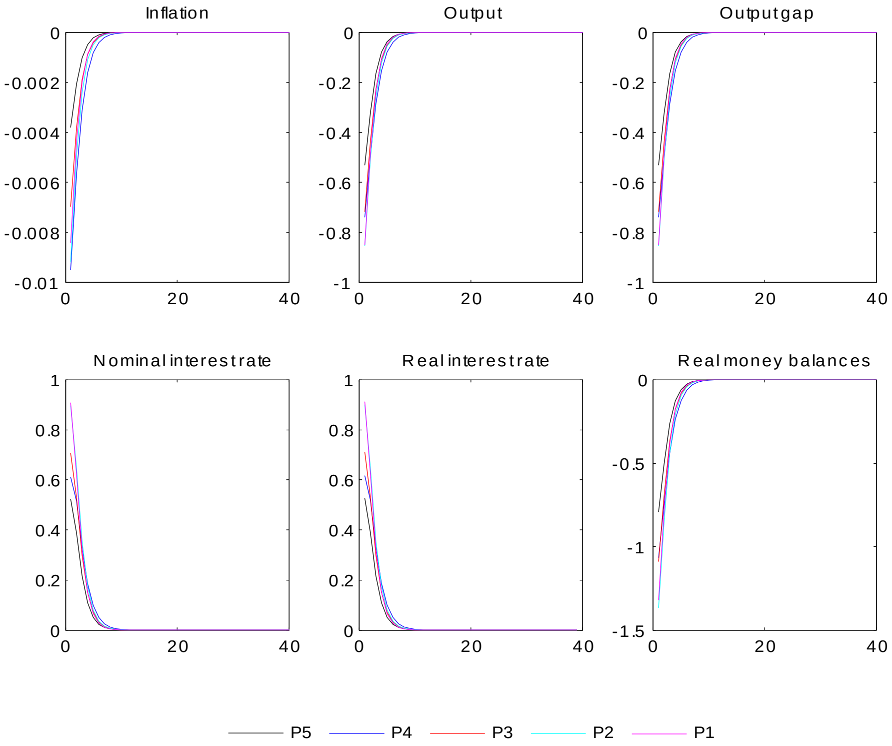

Figure 5: Impulse response function with respect to a monetary policy shock

Fig. 5 indicates that in response to an interest rate shock, inflation rate, output, output gap, and real money balances fall. The nominal and real interest rates rise. A positive monetary policy shock could also induce a fall in interest rates due to a low enough degree of intertemporal substitution (i.e., the risk aversion parameter is high enough), which generates a large impact response of current consumption relative to future consumption (Jeanne, 1994; Christiano et al., 1997). Note that in P5, nominal and real interest rates are the least sensitive of all other periods, suggesting the largest relative risk aversion compared to all other periods.

4.4 Risk aversion shock

Fig. 2 shows that output and real money balance variances have an important risk aversion shock component. This finding shows the leading role of relative risk aversion in the dynamics of output (Black and Dowd, 2011) and real money balances (Benchimol, 2011).

Although inflation rate, nominal interest rate, and flexible-price output are strong components of output, risk aversion has a minor role to play in the variance of inflation and interest rate, and it does not play a role with regard to the flexible-price output (less than 0.2% in the short- and long-run), which is completely determined by the technology shock. It also shows that inflation and interest rate variances are quasi-unaffected by the introduction of the risk aversion shock, allowing these variables to be mainly explained by the price-markup shock and the monetary policy shock, respectively.

Additionally, Fig. 2 shows that risk aversion plays a more significant role in output dynamics in the last period (P5) than in other periods (P1 to P4) in the short run. This finding reflects the increasing role played by risk aversion in more recent years (between 2006 and 2011) as compared to the past (between 1971 and 2006).

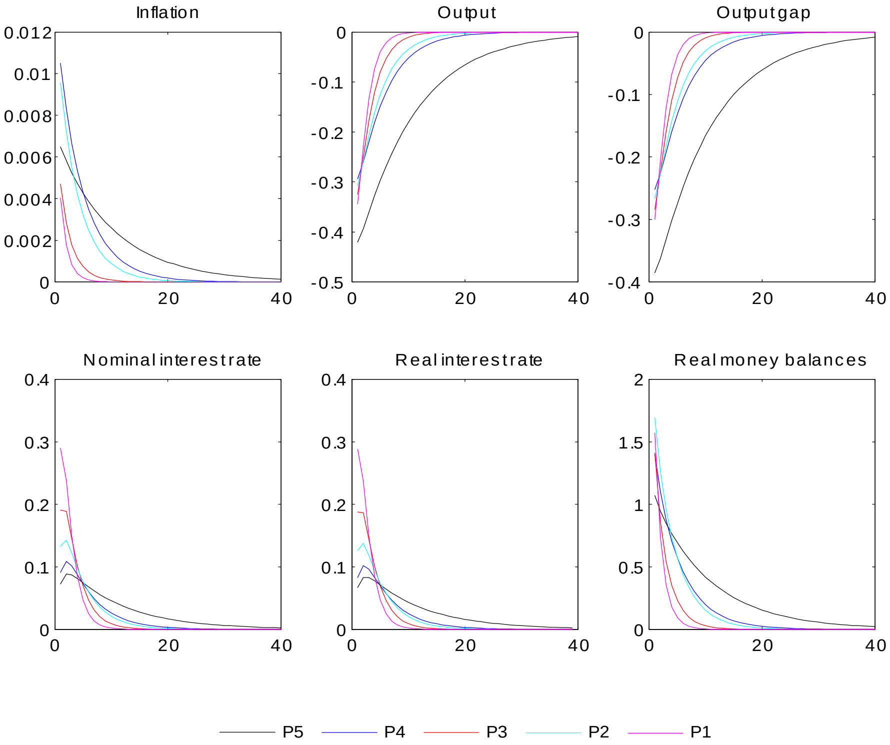

Figure 6: Impulse response function with respect to a risk aversion shock

This case is very interesting because Fig. 6 shows that a risk aversion shock leads to a decrease in output and an increase in inflation. This implies a tightening of monetary policy (because of the strong weight that the central bank places on inflation) and its strength depends on the period (strong monetary policy tightening in P1 and low monetary policy tightening in P5). The risk aversion shock also implies an increase in real money balances and real money growth, and a decrease in the output gap. Our risk aversion shock also suggests that uncertainty is counter cyclical (Baker and Bloom, 2013).

Household consumption reduces (decreasing output), and companies increase their price (to face high risk aversion and possibly, low consumption), which implies an increase in the inflation rate, constrained by a tightening of monetary policy.

Fig. 6 exhibits that the risk aversion shock has a longer impact in P5 than it does in the other periods. This is due to the increase of the autoregressive parameter of the risk aversion shock, ρ_r, over the periods, as shown in Fig. 1. Although the sensitivity of monetary policy with respect to risk aversion shock is lower in P5 than during other periods, it is more persistent in P5 than in the other periods. This highlights that the central bank reacts less strongly after a risk aversion shock, but the persistence of the impact of this risk aversion shock on nominal interest rate is stronger over time.

Bloom (2009) simulates a macro uncertainty shock, which produces a rapid drop in aggregate output, mainly because higher uncertainty causes firms to temporarily pause their investment and hiring. Our results suggest that the impact of the risk aversion shock—a micro uncertainty shock—on output and output gap is very important during the last period, P5, as compared to the other periods. As a matter of fact, an important part of the variation in output is dependent, through the risk aversion shock, on major shocks such as crises, news, and disasters (Bloom, 2009; Baker and Bloom, 2013). Controlling these media-parameters—for instance, by communication–could attenuate their impact on growth.

The leading role of the risk aversion shock in the dynamics of real money balance in the short run is another important finding. Fig. 2 indicates that real money balances are mainly explained by the technology shock (approximately 80%) in the long run, whereas in the short run, real money balances are mainly explained by the risk aversion shock and the monetary policy shock. Last but not the least, in line with Benchimol and Fourçans (2012), a risk aversion shock drastically increases real money balances response, despite increasing inflation and nominal interest rate responses (Fig. 6).

5 Conclusion

Risk aversion as a concept in economics and finance is based on the behavior of consumers and investors who are exposed to uncertainty. It is the reluctance of a person to accept a bargain with an uncertain payoff, rather than one that offers a more certain, but possibly lower, expected payoff.

This paper presents a standard New Keynesian DSGE model that includes a risk aversion shock. It shows the involvement of this risk aversion shock in the dynamics of the economy: it increases inflation, decreases output (Fig. 6), and diminishes the impact of the action by the central bank on output variance, at least in the short run (Fig. 2).

Additionally, risk aversion plays an important role in output and real money balance dynamics. It is clearly identified that risk aversion plays a negative role in determining output, whereas it increases real money balances and real money growth in the initial period (Fig. 6).

Moreover, while estimations are quite robust (Fig. 7 to Fig. 12), they show that risk aversion shock has a stronger impact on output dynamics during the last twenty years (P5) as compared to other analyzed periods (P1 to P4). This result is explained by the inclusion of the subprime and sovereign debt crises in P5 from 2007 to 2011.

This enhanced baseline model shows the importance of such a parameter to the economy, especially its impact on output, money, and monetary policy. It also serves to show the importance of controlling shocks to the agents' risk aversion, for instance, by communication.

6 Appendix

A Solving the model

- **Price dynamics**

Let us assume a set of firms not reoptimizing their posted prices in period t. Using the definition of the aggregate price level and the fact that all firms resetting prices choose an identical price P_t^*, leads to

$$P_t = \left[\theta P_{t-1}^{1-\Lambda_t} + (1-\theta)\left(P_t^*\right)^{1-\Lambda_t}\right]^{\frac{1}{1-\Lambda_t}} \tag{14}$$

where $\Lambda_t = 1 + \frac{1}{\frac{1}{\varepsilon - 1} + \varepsilon_t^p}$ is the elasticity of substitution between consumption goods in period t, and $\frac{\Lambda_t}{\Lambda_t - 1}$ is the markup of prices over marginal costs (time varying). Dividing both sides by P_{t-1} and log-linearizing around $P_t^* = P_{t-1}$ yields

$$\pi_t = (1-\theta)\left(p_t^* - p_{t-1}\right). \tag{15}$$

In this setup, we do not assume inertial dynamics of prices. Inflation results from firms reoptimizing their price plans in any given period, and choosing a price that differs from the economy's average price in the previous period.

- **Price setting**

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

$$p_t^* - p_{t-1} = (1-\beta\theta)\sum_{k=0}^{\infty}(\beta\theta)^k E_t\left[\widehat{mc}_{t+k|t} + (p_{t+k} - p_{t-1})\right] \tag{16}$$

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 $\mu = \ln\left(\frac{\varepsilon}{\varepsilon-1}\right)$ is the log of the desired gross markup.

- **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 $Y_t = \left(\int_0^1 Y_t(i)^{1-\frac{1}{\Lambda_t}}\,di\right)^{\frac{\Lambda_t}{\Lambda_t - 1}}$; 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

$$y_t = E_t[y_{t+1}] - \sigma_t^{-1}\left(i_t - E_t[\pi_{t+1}] - \rho_c\right) \tag{17}$$

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

$$y_t = \varepsilon_t^a + (1-\alpha)\,n_t \tag{18}$$

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

$$\begin{aligned} mc_t &= (w_t - p_t) - mpn_t \\ &= w_t - p_t - \frac{1}{1-\alpha}\left(\varepsilon_t^a - \alpha y_t\right) - \ln(1-\alpha) \end{aligned} \tag{19}$$

for all t, where mpn_t defines the economy's average marginal product of labor. As $mc_{t+k|t} = (w_{t+k} - p_{t+k}) - mpn_{t+k|t}$, we have

$$mc_{t+k|t} = mc_{t+k} - \frac{\alpha\Lambda_t}{1-\alpha}\left(p_t^* - p_{t+k}\right) \tag{20}$$

where the second equality follows from the demand schedule combined with the market clearing condition $c_t = y_t$. Substituting (20) into (16) yields

$$p_t^* - p_{t-1} = (1-\beta\theta)\sum_{k=0}^{\infty}\Theta_{t+k}(\beta\theta)^k E_t\left[\widehat{mc}_{t+k}\right] + \sum_{k=0}^{\infty}(\beta\theta)^k E_t\left[\pi_{t+k}\right] \tag{21}$$

where $\Theta_t = \frac{1-\alpha}{1-\alpha+\alpha\Lambda_t} \leq 1$ is time varying to take into account the markup shock.

Finally, (15) and (21) yield the inflation equation

$$\pi_t = \beta E_t\left[\pi_{t+1}\right] + \lambda_{mc_t}\widehat{mc}_t \tag{22}$$

where β, $\lambda_{mc_t} = \frac{(1-\theta)(1-\beta\theta)}{\theta}\Theta_t$. λ_{mc_t} is strictly decreasing in the index of price stickiness θ, in the measure of decreasing returns α, and in the demand elasticity Λ_t.

Next, a relationship is derived between the economy's real marginal cost and a measure of aggregate economic activity. From (6) and (18), the average real marginal cost can be expressed as

$$mc_t = \left(\sigma_t + \frac{\eta+\alpha}{1-\alpha}\right)y_t - \frac{1+\eta}{1-\alpha}\varepsilon_t^a - \log\left(1-\alpha\right) - \rho_n \tag{23}$$

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

$$mc = \left(\sigma_t + \frac{\eta+\alpha}{1-\alpha}\right)y_t^f - \frac{1+\eta}{1-\alpha}\varepsilon_t^a - \log\left(1-\alpha\right) - \rho_n \tag{24}$$

thus, implying

$$y_t^f = \upsilon_a\varepsilon_t^a + \upsilon_c \tag{25}$$

where $\upsilon_a = \frac{1+\eta}{\sigma_t(1-\alpha)+\eta+\alpha}$ and $\upsilon_c = \frac{(1-\alpha)\left(\ln(1-\alpha)+\rho_n-\ln\left(\frac{\varepsilon}{\varepsilon-1}\right)\right)}{\sigma_t(1-\alpha)+\eta+\alpha}$. Subtracting (26) from (25) yields

$$\widehat{mc}_t = \left(\sigma_t + \frac{\eta+\alpha}{1-\alpha}\right)\left(y_t - y_t^f\right) \tag{26}$$

where $\widehat{mc}_t = mc_t - mc$ is the *real marginal cost gap* and $y_t - y_t^f$ is the *output gap*. Combining the above equation with (24), we obtain

$$\pi_t = \beta E_t\left[\pi_{t+1}\right] + \psi_t\left(y_t - y_t^f\right) \tag{27}$$

where $\psi_t = \frac{(1-\theta)(1-\beta\theta)(\sigma_t(1-\alpha)+\eta+\alpha)}{\theta(1-\alpha+\alpha\Lambda_t)}$, and $y_t - y_t^f$ is the *output gap*.

The second key equation describing the equilibrium of the model is obtained by rewriting (20) to determine output

$$y_t = E_t\left[y_{t+1}\right] - \sigma_t^{-1}\left(i_t - E_t\left[\pi_{t+1}\right] - \rho_c\right) \tag{28}$$

Equation (28) is thus, a dynamic IS equation including real money balances.

The third key equation describes the behavior of *real money balances*. From (5), we obtain

$$mp_t = \frac{\sigma_t}{\nu} y_t - \frac{a_2}{\nu} i_t - \frac{\rho_m}{\nu} \tag{29}$$

B Model validation

The red and blue lines in Fig. 7 represent an aggregate measure based on the eigenvalues of the variance-covariance matrix of each parameter both within and between chains. Each graph represents specific convergence measures and has two distinct lines that represent the results within and between chains. These measures are related to the analysis of the parameter's mean (first moment), variance (second moment), and third moment of the model for the relevant period. Convergence requires both lines for each of the three measures to become relatively constant and converge to each other.

Diagnoses of the numerical maximization of the posterior kernel indicate that the optimization procedure was able to obtain a robust maximum for the posterior kernel. A diagnosis of the overall convergence for the Metropolis-Hastings sampling algorithm is provided in Fig. 7.

Diagnoses for each individual parameter were also obtained, following the same structure used for overall convergence. Most of the parameters do not seem to exhibit convergence problems, notwithstanding that this evidence is stronger for some parameters than it is for others.

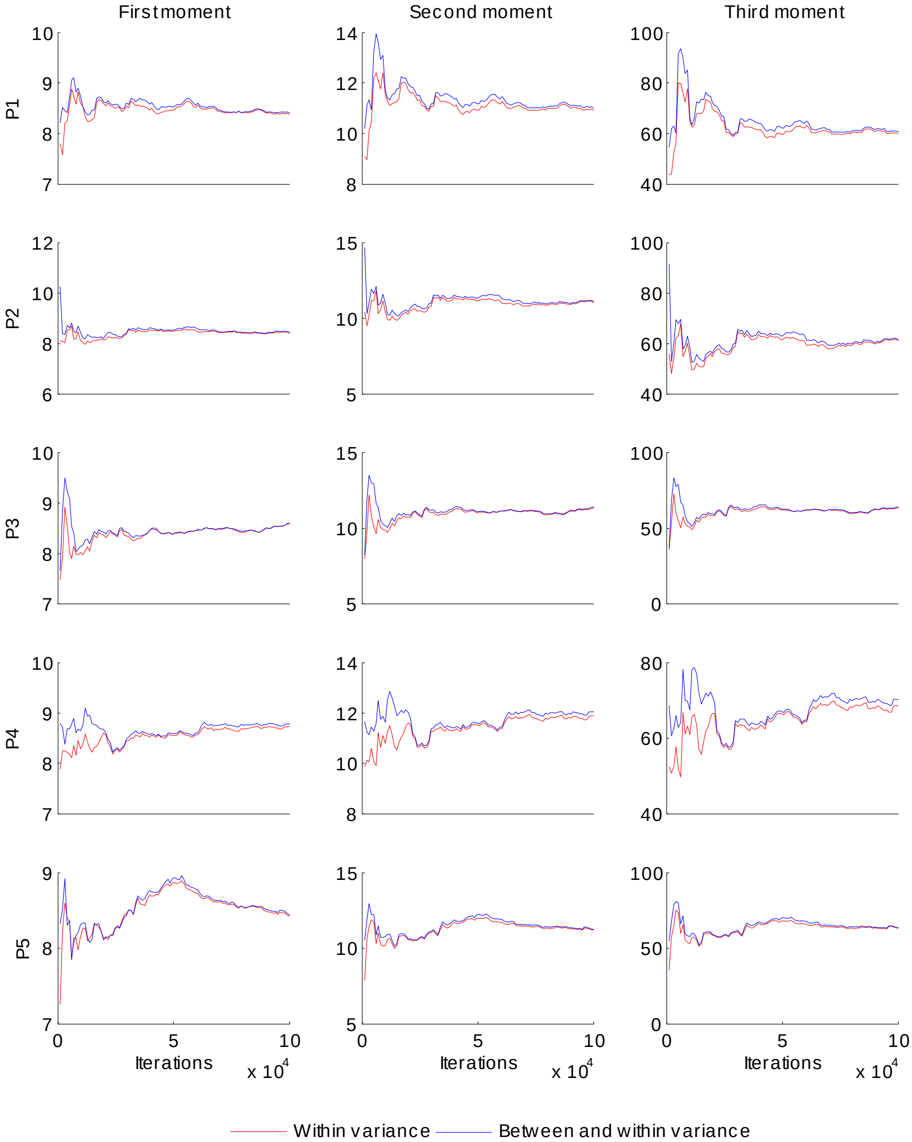

Figure 7: Multivariate Metropolis-Hastings convergence diagnosis

C Priors and posteriors

The following figures present the priors and posteriors of the estimated structural parameters over the study period.

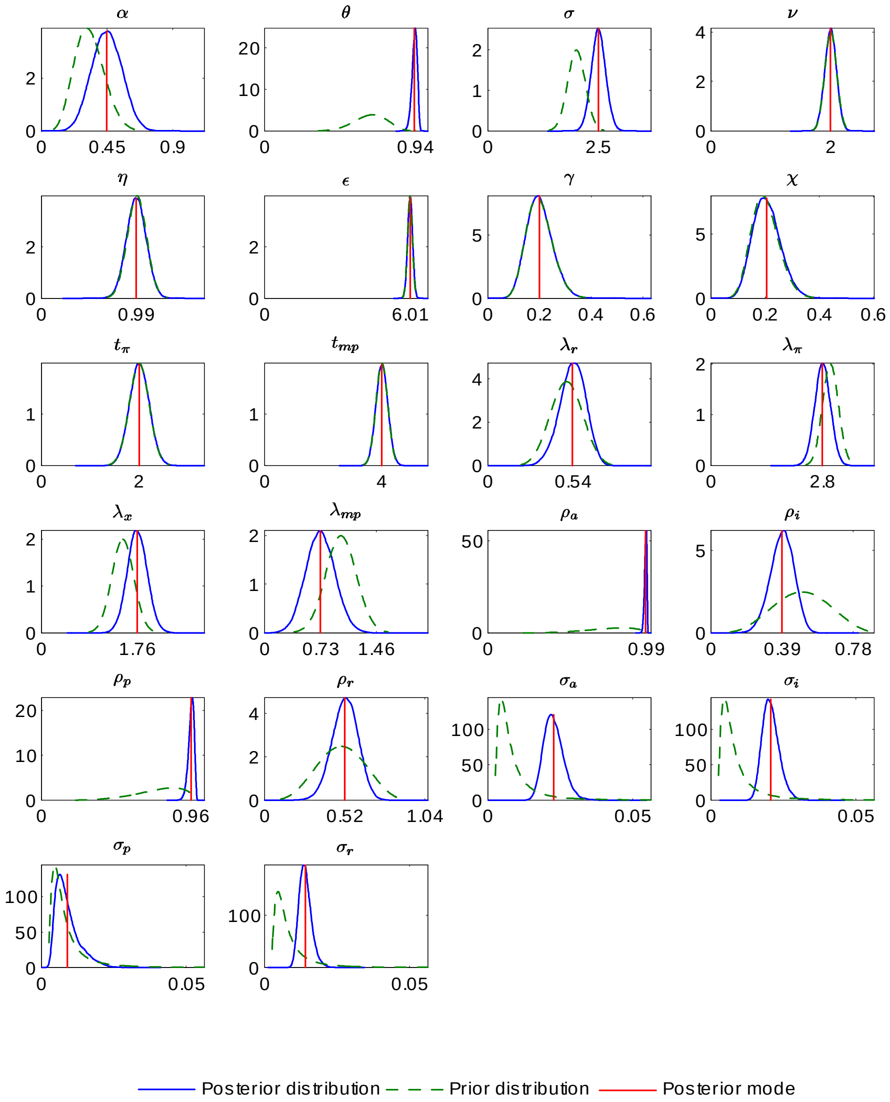

Figure 8: Priors and posteriors of the estimated parameters (P1)

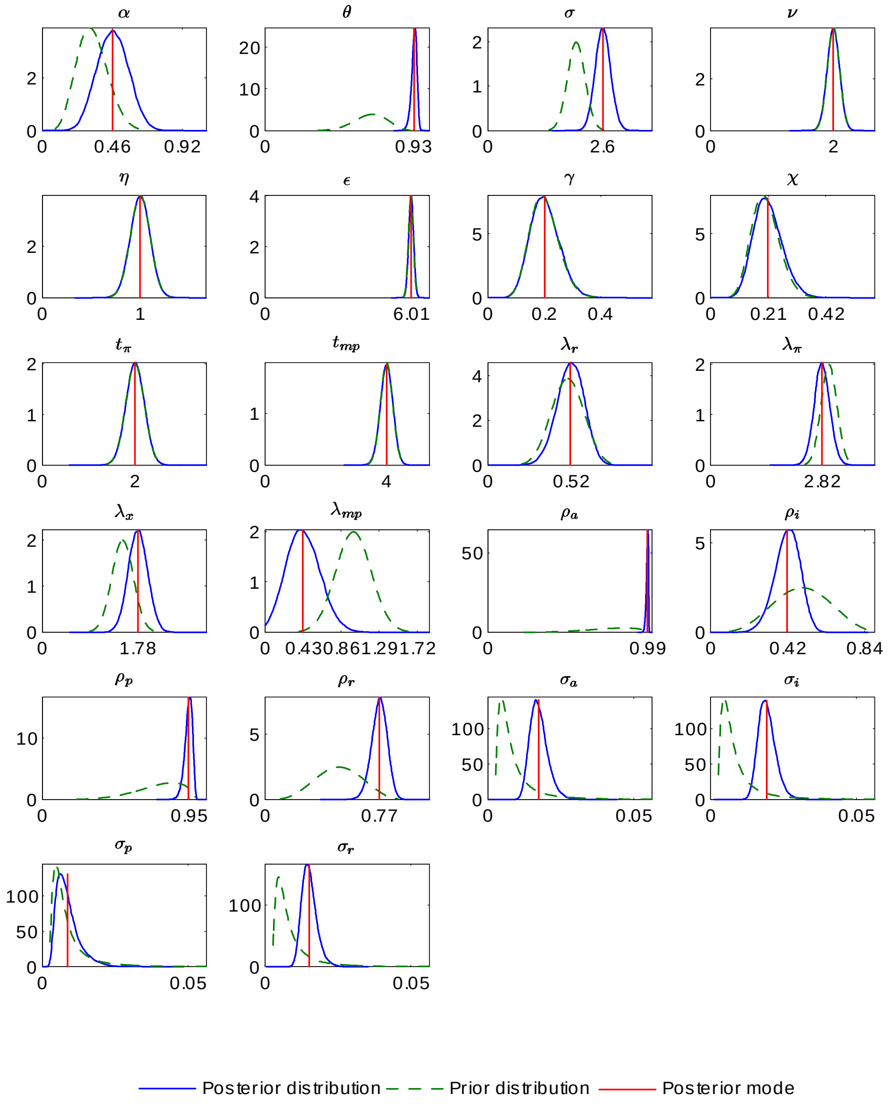

Figure 9: Priors and posteriors of the estimated parameters (P2)

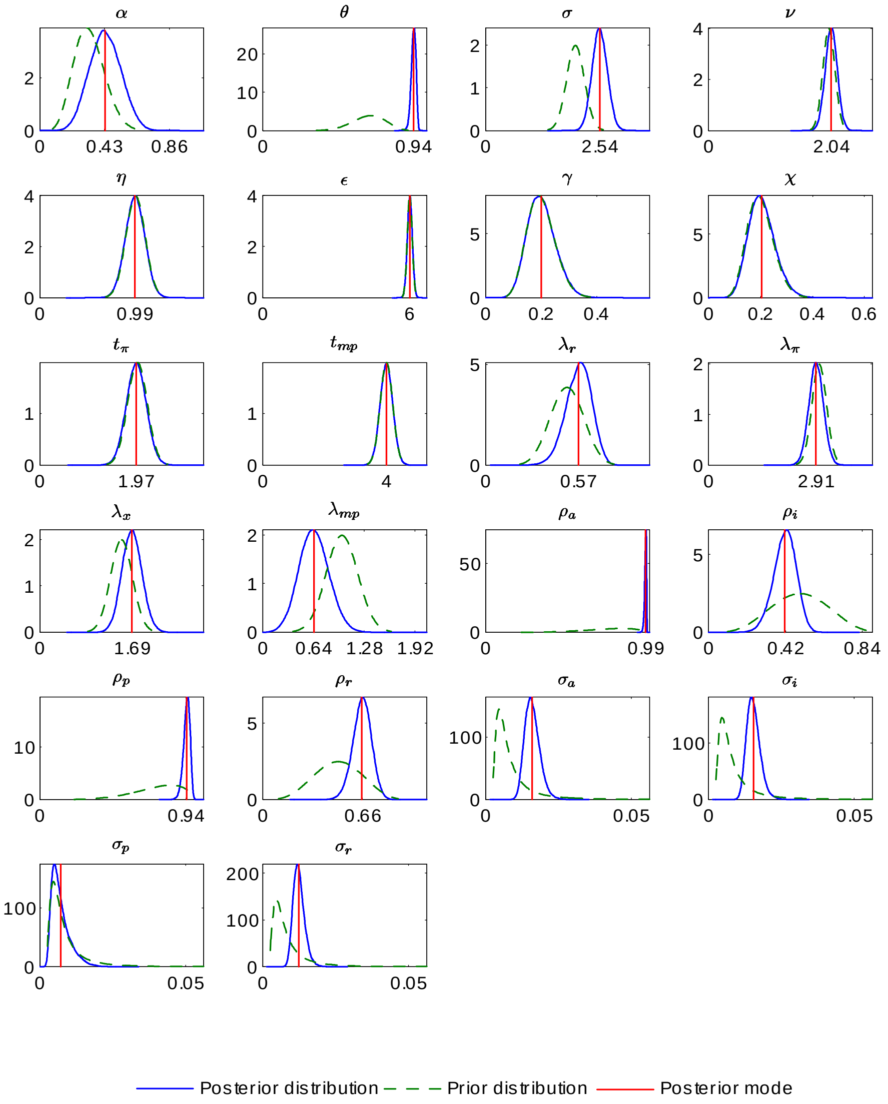

Figure 10: Priors and posteriors of the estimated parameters (P3)

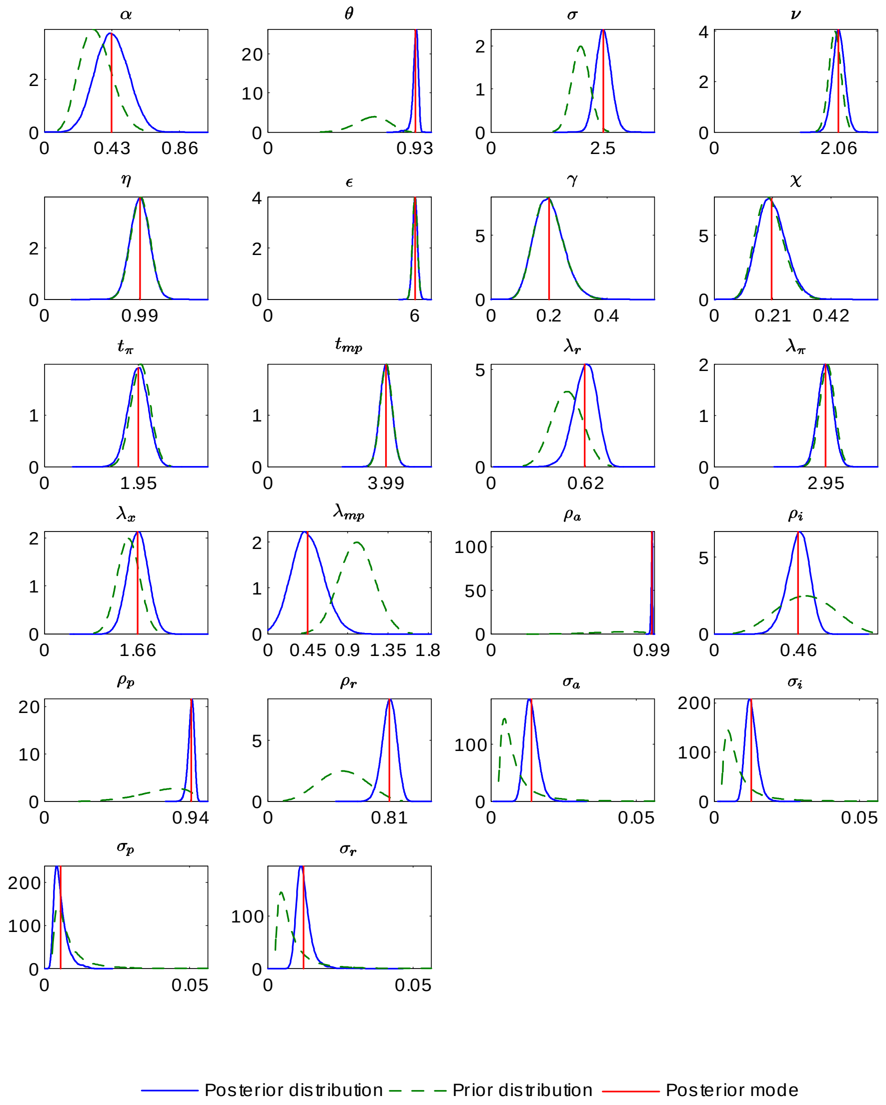

Figure 11: Priors and posteriors of the estimated parameters (P4)

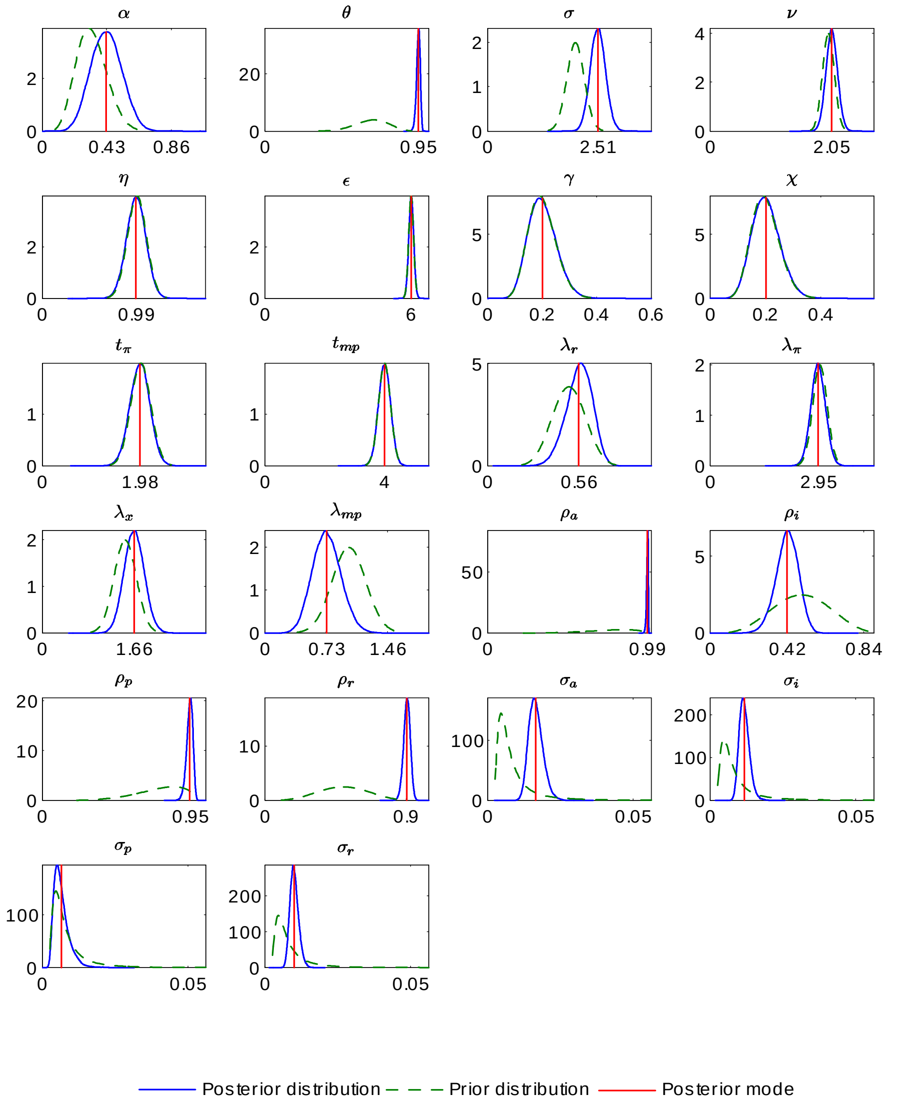

Figure 12: Priors and posteriors of the estimated parameters (P5)

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