ECB Monetary Policy in the Presence of Nonlinearities

by

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Abstract

The recent financial crisis of 2007-2009 raises several issues related to the conduct of monetary policy during the last two decades. Inflation targeting monetary strategy has been pointed as a potential source of the crisis, as its main objective of inflation stabilization might have diverted central banks from financial stability. We consider the case of ECB inflation targeting monetary policy since its inception in order to provide evidence of possible changes in its implementation after the collapse of Lehman Brothers in September 15, 2008. To this end we take into consideration the existence of nonlinearities that may exist in the estimated Taylor rule specification. We employ three alternative econometric approaches: (a) The Qu and Peron (2007) structural break model; (b) a TVP model with stochastic model and (c) a Markov-Switching VAR model using quarterly data for the ECB for the period 2001:Q1 to 2012:Q4. The main findings of our analysis show that the recent financial turmoil and the debt crisis had not led the ECB to a stronger response to inflation in its reaction function and debt crisis. From a theoretical and policy perspective our findings imply that the ECB could stabilize inflation without adopting a more aggressive set of monetary rules to combat increased inflation changes.

Keywords: ECB, monetary policy; inflation targeting; Taylor rule; risk management, financial crisis, structural breaks, Markov-Switching VAR model

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1. Introduction

The financial crisis of 2007-2009 has brought into attention again the role of monetary policy in amplifying or dampening the effects of the crisis (Taylor, 2009; Bullard, 2009; Frappa and Mesonnier, 2010). These urgent events have left aside the discussion on the inflation targeting policy as the appropriate monetary policy framework. However, inflation targeting has been adopted by ECB from its establishment as well as by the Bank of England, Bank of Canada and Bank of Sweden and it is also advocated by the Chairman of the FED, Ben Bernanke (see Bernanke *et al*., 1999). To this end the basic idea is that Central Banks which adopt inflation targeting could emphasize the inflation objective in the conduct of monetary policy at the expense of other monetary policy goals (King, 1997; Friedman, 2004; and Walsh, 2009).

There are three approaches to this direction. The first approach argues that in order to comply with its inflation target, the central bank must put more weight on inflation. We follow Creel and Hubert (2013) and we separate the inflation targeting, paradigm, which amounts to strong response to price developments to reach low and stable inflation eventually leading to stable macroeconomic conditions from the inflation targeting *framework* which amounts to a commitment to a numerical target, publication of forecasts and increased transparency. The second approach argues that inflation developments do not always depend on internal factors to an economy; hence any automatic adjustment of interest rates to inflation might prove an inefficient tool. Finally, inflation targeting adoption may be sensitive to the self-selection issue, implying that what has led actually to low inflation in countries that adopt inflation targeting was their decision to aim specifically at lower inflation than in earlier pre-inflation targeting periods. However, it is argued that the central bank's commitment to low and stable inflation may not necessarily lead to a stronger response to inflation.

Following the seminal paper by Taylor (1993) a voluminous literature emerged focusing on the derivation and estimation of linear monetary policy reaction functions in many economies. Although, the derived policy rules are simple in their nature they fit the data relatively well. Recently, researchers focus their analysis to examine whether monetary policy reacts in a nonlinear manner to economic activity and inflation. There are several factors that may lead to the existence of nonlinearities. First, as Svensson (1997), Ball and Sheridan (2003) and Clarida *et al*. (1999) among others argue that the nonlinearity is the result of deviations from the conventional minimization of quadratic loss functions subject to linear Phillips curves and aggregate demand schedule. Furthermore, it is possible that the Phillips curve may reflect more complex price-setting mechanisms than those aggregated in a linear specification (Schaling, 2004; Dolado *et al*. 2005). Finally, it is argued that the loss function of the central bank may not be quadratic because of asymmetries in the response of monetary policy to inflation in different stages of the business cycle and/or the size of deviations of actual inflation from explicit or implicit targets (Dolado *et al*. 2005; Taylor and Davradakis, 2006; Cuckierman and Muscatelli, 2008).

A second factor of potential nonlinearity in monetary policy is the existence of uncertainty in the economic environment. Therefore, as Gnabo and Moccero (2013) underline several sources of uncertainty affect the implementation of monetary policy in real time. Such sources of uncertainty that may lead to nonlinearities in the conduct of monetary policy are due to: (a) the uncertainty that policy makers face about the state of the economy as a result of data uncertainty. This is a realistic argument since measures of economic activity and inflation are subject to substantial revisions following the quarter the quarter of their release; and the same holds for potential output and the NAIRU which are often reported with measurement errors. Therefore, it is argued that these potential data measurement errors policy makers should be less aggressive with respect to incorrectly measured targets[1].

Parameter uncertainty is also an important element of the presence of nonlinearity since this is related to the uncertainty with respect to the impact of monetary policy on the economy as well about the structure of the economy. Svensson (1999) argued that uncertainty about the quantitative impact of monetary policy on the economy should lead to less aggressiveness in monetary policy. By contrast, Peersman and Smets (1999) among others found that parameter uncertainty has very limited quantitative effects on the feedback parameters. Finally, Flamini and Milas (2011) show that when the exogenous volatility related to a particular state variable increases, the optimal monetary policy should also have an increasing response with respect to this variable. It is argued that such a response will reduce the risk of large deviations of the economy from the steady state that would deteriorate the distribution forecasts of the output gap and inflation. Giannoni (2007) also shows that in the presence of parameter uncertainty in the model and about the shock

[1] See for example Peersman and Smets (1999).

process, policymakers adopt an optimal monetary rule that requires the interest rate to respond stronger to fluctuations in inflation and in changes in the output gap.

The final source of uncertainty for policy makers is related to the distribution of disturbances to the economy. As Gnabo and Moccero (2013) point out, optimal monetary policy in a linear-framework with only shock uncertainty exhibits certainty equivalence. Therefore, given that the optimal policy depends only on the expected value of the target variables the degree of uncertainty does not affect the effectiveness of this policy implying that the central bank acts as it would be in a non-stochastic economy. Essentially this is the linearity hypothesis underlying the modeling and estimation of Taylor rule. The "robust control" approach to monetary policy criticizes the implications of linearity on the grounds that the costs of being wrong is independent of whether the expected value of inflation is over or under estimated. It argues that a "risk management approach" to monetary policy should be adopted which implies that central banks choose the policy that minimizes the loss over the complete distribution of values for a given parameter within a given range. The risk management approach could lead to a more aggressive response of monetary policy to macroeconomic conditions. Minskin (2008) is an advocate of this approach arguing that when financial markets are in strain, risk management is crucial in formulating the appropriate response of monetary policy. Bernanke and Reinhart (2004) also claim that in order to implement the monetary policy effectively at very low interest rates when the economy faces deflation, it is crucial that policymakers should act preemptively and aggressively to avoid facing the complications raised by the zero lower bound.

A few studies have recently examined whether the institutional adoption of inflation targeting has modified the conduct of monetary policy. Seyfried and Bremmer (2003) have analysed six countries which adopted inflation targeting and they found a break in the monetary policy reaction function which leads them to conclude that the respective central banks focus primarily to inflationary pressures than to current inflation. Trecroci and Vassalli (2010) estimated a TVP model and found a higher response to inflation across time by the central banks. Assenmacher - Wesche (2006) estimated a two regime MS-VAR model and they found that there was no significant response to the inflation by the central bank before the adoption of inflation targeting but it becomes significant after its adoption. Taylor (2006) and Davradakis studied the response of the Bank of England to the inflation and it is shown that it responded since inflation targeting adopted in case that inflation rate was above target. Baxa *et al*. (2009) have shown that the response to inflation has decreased after inflation targeting in five countries based on the estimation of a TVP model. Creel and Hubert (2013) analyze the case of monetary policy response using data from the inflation targeting economies, Canada, Sweden and the UK and they conclude that the adoption of inflation targeting has not led to a stronger response to inflation. Finally, Fouejieu (2012) analyze the issue, using data for emerging markets, whether inflation targeting has been a potential source of the recent financial crisis. His findings hardly support the main hypothesis but do call for further macro-prudential policies to tackle the issue of financial stability.[2]

The purpose of this paper is to contribute to the empirical literature on monetary policy uncertainty in the presence of nonlinearities. Our analysis deals with a set of alternative testable hypothesis in order to examine the response of the monetary policy conducted by the ECB in an inflation targeting framework and the likelihood of this response to follow a non-linear pattern. Therefore, we follow Creel and Hubert (2013) and we test the hypothesis that inflation targeting translates into a stronger response to inflation with the adoption of three alternative econometric methodologies. These estimation approaches do not require us to identify *ex ante* the dates or the nature of the structural breaks (being either sudden switches or gradual changes). Within this context we first employ the Qu and Perron (2007) testing procedure to examine the presence of structural breaks for unknown dates and number of breaks. We then estimate a time-varying parameter (TVP) model with stochastic volatility and finally, a Markov-Switching Vector Autoregressive (MS-VAR) model developed by Hamilton (1989) and Sims and Zha (2006) which permit to date break dates and characterize regimes. These econometric methodologies have several advantages when they contrast with tests of monetary rules that do not capture multiples shifts in variance, since they do allow for heteroskedasticity. This is an important property since the sources of time variation might be both the coefficients and the variance- covariance matrix of innovations Primiceri (2005).

The rest of the paper is organized as follows. Section 2 presents and discusses the theoretical model. In Section 3 we present the alternative econometric

[2] Creel and Hubert (2013) cover sufficiently large number of studies which could be a good reference for more details.

methodologies. Section 4 presents the data and the empirical results with the summary and policy implications given in section 5.

2. Theoretical model

Taylor (1993) has been the starting point to analyze the monetary policy responses where the policy instrument is assumed to depend on a small number of macroeconomic variables. Specifically, Taylor's original specification models monetary policy feedback as a function of contemporaneous inflation and the contemporaneous output gap given by:

$$r_t = \beta_0 + \beta_1 \pi_t + \beta_2 y_t + u_t \quad (1)$$

where r_t is the central bank reference rate and π_t and y_t are the current inflation and output gap, β_1 and β_2 are the weights attributed respectively to inflation and output gap and u is a disturbance error term. This inflation target rule implies that the policy rate is assumed to respond to current levels of inflation and the output gap. Despite its simplicity, this policy rule was found very successful in tracking the evolution of the interest rate in the FRB-US and SIGMA models at the Federal Reserve Bank and the ECB's NAWN model.

There have been several arguments in favour or against this specification. Christiano *et al*., (2005) and Campell *et al*., (2012) argue that because central bank inflation and output forecasts maybe inaccurate and unexpected shocks may occur, the policy rate may have to respond to actual changes in current macroeconomic conditions. Therefore, a contemporaneous Taylor rule is useful to analyze monetary policy. Furthermore, Bernanke and Blinder (1992), Bernanke and Minhov (1998) and Goodhart (2001) demonstrated that the estimation of a contemporaneous Taylor rule when monetary policy experiences transmissions lags solves the endogeneity problem that arises in forward-looking specifications of the monetary reaction function which make realized inflation and output endogenous to interest rate changes through the transmission channels of monetary policy. Specifically, if inflation and output only respond with even a one lag to changes in the policy instrument it is shown that the real effects of monetary policy occur after 12 months for the GDP and between 18 and 24 months for inflation then the current values of inflation and output should not be affected contemporaneously by u_t and are not subject to endogeneity.

In contrast, Orphanides (2003) argues that the estimation of a policy reaction function with a misspecified horizon can yield misleading information regarding the responsiveness of policy to the outlook of inflation and economic activity. Therefore, a forecast-based approach to monetary policy, where the central bank reacts pre-emptively to changes in the economic environment has become the dominant paradigm in the literature the last decade. A second potential drawback of the original specification is that it relies on variables like potential output, which may be unreliable as a policy indicator in real time. A final limitation of the simple Taylor rule is related to the speed by which the policy interest rate is adjusted in response to new information on inflation and economic activity. As recent empirical evidence has shown several central banks adjust their policy rates in a series of small or moderate steps, a process called inertia which is modelled by including lagged values of the policy rate as an additional explanatory variable in the policy feedback rule. Recently Belke and Klose (2013) proposed an alternative way of estimating Taylor reaction functions if the zero-lower-bound on nominal interest rate is binding by focusing on the real rather than the nominal interest rate.

3. Econometric methodology

We apply three alternative econometric approaches to evaluate whether the institutional adoption of inflation targeting since the establishment of the ECB has modified the conduct of monetary policy.

3.1. Qu and Perron (2007) test for the presence of multiple structural breaks

Qu and Perron (2007) developed a multivariate testing procedure which is appropriate to estimating and testing for multiple structural breaks that occur at unknown dates. Qu and Perron (2007) test has several advantages compared to alternative tests for structural breaks. First, it allows for conditional heteroscedasticity in the error term. Second, its design allows the parameters, the covariance matrix of the errors, or both to change across regimes (i.e. periods between two structural breaks). We test the null hypothesis that there is no break in the series against an unknown number of breaks up to a maximum of K; it then identifies the number and dates of breaks using a sequential approach. This testing procedure is implemented in two stages. The first stage amounts to the identification of the date on which the most significant break in the monetary policy reaction function under the assumption that 1, 2 or 3 breaks exist over the sample. In the second stage, given the results of the tests implemented in the first stage, we set the number of breaks to a fixed number $K = 1$ and examine whether the break date can be associated with the 2007-2009 financial crisis.

3.2. Time-varying parameter model

Recent research by Boivin (2006), Canova and Gambetti (2008), Kim and Nelson (2006) and Koop *et al*. (2009), among others, show that the conduct of monetary policy may change smoothly. To account for this alternative adjustment process we estimate a Time-Varying Parameter (TVP) model which will allows us to analyse whether monetary policy undergoes possible gradual changes or its adjustment is better described by a discrete break. The TVP specification includes stochastic volatility to control for heteroskedasticity in order to account for the case that the time-varying variance of shocks may be significant when modeling monetary policy (Sims and Zha, 2006; Primiceri, 2005; Kim and Nelson; 2006 Following, Creel and Hubert (2013) the TVP specification for the conduct of monetary policy is given as follows:

$$\begin{aligned} r_t &= \beta_{0t} + \beta_{1t}\pi_t + \beta_{2t}y_t + u_t, \text{ with } u_t \sim N(0,\sigma_{ut}^2) \\ &= \Psi_t Z_t + u_t \end{aligned} \tag{2}$$

where r_t, π_t and y_t are the interest rate, the inflation rate and the output gap. The vector Ψ_t denotes the collection of time-varying parameters and Z_t the corresponding variables. All parameters have a t subscript to denote their time varying behavior. The TVP model assumes that all parameters in the Taylor rule (the measurement equation) follow a random walk without a drift, called the transition equation:

$$\Psi_{t+1} = \Psi_t + \upsilon_t \text{ with } \upsilon_t \sim N(0,\Sigma) \tag{3}$$

Furthermore, we model stochastic volatility, h_t, as follows:

$$\begin{aligned} \sigma_{u,t}^2 &= \gamma \exp(h_t) \\ h_{t+1} &= \phi h_t + \eta_t \sim N(0,\sigma_\eta^2) \end{aligned} \tag{4}$$

According to Nakajima (2011) the random walk assumption allows the inclusion both temporary and permanent shifts in the parameters. It is further assumed that any shocks to the innovations of the time-varying parameters to be uncorrelated with the parameters Ψ_t and h_t Furthermore, the value of the noise-to-variance ratio, defined as the ratio between the variance of the transition equation and the variance of the measurement equation (Σ/σ_{ut}^2) leads to the evolution of coefficients. Within this framework we can formulate a regression with time invariant coefficient which means that we are required to fix the diagonal of $\Sigma = 0$ in the transition equation, in order that the noise-to-variance ratio is zero and therefore the OLS estimation procedure could produce unbiased and efficient results. .

The estimation of equations (2) to (4) is conducted with the implementation of a Markov chain Monte Carlo (MCMC) algorithm to generate the joint posterior distribution of parameters under the assumption of a certain prior probability density. This Bayesian approach using the MCMC models is the appropriate approach to estimate the TVP model with stochastic volatility (Primiceri, 2005 and Nakajima, 2011) given in equations (2)-(4). The advantage of this method is that allows the parameters and state variables to be estimated under both linear and non-linear forms. In particular the β_t coefficients and stochastic volatility are state variables and they form the state-space model and this Bayesian approach using the MCMC method provides an efficient estimation of the TVP model.

4.3. Markov-Switching VAR model

In the final part our aim is to examine the question of the existence of switching regimes in the conduct of monetary policy by the ECB. The difference in this analysis is that we implement a backward-looking Taylor rule specification instead of a contemporaneous specification. As Sims and Zha, (2006) show while a contemporaneous (or forward-looking) monetary rule is certainly more representative of the behavior of central banks, their identification may be fragile. The estimation of this specification is based on a 3-equation VAR instead of a single equation of a monetary rule. This econometric approach allows us to identify the changes in the macroeconomic environment considered as a whole instead of considering the changes in the Taylor rule only. Therefore, following Creel and Hubert (2013) we investigate whether changes in inflation and output processes occurred with changes in the conduct of monetary policy following the collapse of Lehman Brothers in September 2008.

In order to study the dynamics of the regime switching and the stochastic processes which evolved in the conduct of monetary policy, we adopt the MS-VAR specification, introduced by Hamilton (1989) model. This model allows, in a multivariate context, for shifts in the stochastic volatility regime driving the policy rate. Thus, the change in regime should be considered as a random event and not predictable. In addition, the effect of these shifts must be considered when we investigate the stochastic properties of the short run interest rate volatility. Therefore, we selected a specification of the MS-VAR which allowed for regime shifts in the intercept and the variance-covariance matrix, We model the linkage between the interest rate and inflation and output gap by a 3-dimensional vector of endogenous variables $X' = [r_t, \pi_t, y_t]$.

Furthermore, the MS-VAR model allows the structural coefficients and the covariance matrix to be dependent on an unobserved state variable S_t which is assumed to follow a 1st order Markov chain. The joint distribution on the shocks can be non-constant across the sample periods. The general specification is given as follows:

$$X_t = z_t \delta_{s_t} + u_t \qquad t = 1, \ldots\ldots T \qquad (5)$$

$$u_t \mid s_t \sim N(0, \Sigma_{s_t}) \qquad S_t = \{1, \ldots\ldots k\} \qquad (6)$$

where, $X_t = (x_{1,t}, x_{2t}, x_{3,t})$ is a 1×3 vector of the endogenous variables, namely, the central bank interest rate, the inflation rate and the output gap, z_t is a *1 x np* vector of *p* lagged endogenous variables, S_t, is an unobserved state, β_{st} is a $np \times 1$ vector of parameters, T, k the number of states (or regimes) and u_t is the innovation process with a regime-dependent variance-covariance matrix $\Sigma(z_t)$. It is assumed that z_t follows an irreducible ergodic *m*-regime Markov process with the transition matrix

$$P = \begin{bmatrix} p_{11} & p_{12} & \cdots & p_{1M} \\ p_{21} & p_{22} & \cdots & p_{2M} \\ \cdots & \cdots & \cdots & \cdots \\ p_{M1} & p_{M2} & \cdots & p_{MM} \end{bmatrix} \qquad (7)$$

The transition probabilities p_{ij} in **P** are constant, and given by

$$p_{ij} = \Pr(z_{t+1} = j \mid z_t = i), \sum_{j=1}^{k} p_{ij} = 1, \forall i, j \in \{1, \ldots, k\} \qquad (8)$$

The MS-VAR model was estimated using the Maximum likelihood procedure based on the Expectation Maximisation (EM) algorithm.[3] Moreover, given this structure we were also able to calculate the unconditional probability that the system of the exchange rate and the respective fundamentals is in regime *i*, $i = 1,\ldots m$, at any given date, $\Pr(s_t = i)$. In addition, the 'smoothed' probabilities could be obtained, representing the ex-post inference about the system being in regime *i* at date *t*. Finally, we could provide the specific date for the regime switches. For instance, for 2 regimes, an observation was assigned to the first regime if $Pr(s_t = 1 \mid \Delta Y_T) > 0.5$, and to the second regime if $Pr(s_t = 1 \mid \Delta Y_T) < 0.5$. Our focus is on the interest rate equation for the interpretation of the results. We consider the case for changes in both coefficients and disturbance terms and we test for 2 or 3 different states (or regimes).

4. Data and empirical results

We examine the ECB monetary policy under inflation targeting which has been adopted since the introduction of the euro and the formation of the Eurozone. ECB follows simple monetary policy reaction functions by setting the main refinancing operations interest rate as a function of inflation and output gap. The data is quarterly and spans from 1999 Q1 to 2012 Q4. We follow Orphanides (2001, 2003 and 2004) and Gnabo and Moccero (2012) and use real time data to estimate monetary policy reaction functions for the Eurozone. We consider a stable sample with low inflation over which potential changes in the conduct of monetary policy would be even more striking. This consideration is important because it allows us to examine inflation targeting avoiding the link that has been argued in the literature that this type of monetary policy has been substantially effective during the period of disinflation in the 1980s and the policies implemented by most industrialized countries. The nominal short-run interest rate is the main refinancing operations interest rate. The inflation rate is the measure of inflation targeted by ECB which is the Harmonized Index of Consumer Prices (HICP). The output gap is the real GDP subtracted by its potential calculated via the state-space estimate calculated by ECB.

[3] For details about the EM algorithm see Hamilton (1989).

All data is retrieved from *Thomson Financial Datastream and the ECB Statistical Data Warehouse*.[4]

Table 1 summarizes the estimated break date and parameters of the monetary rule based on the Qu and Perron (2007) testing procedure. Following this work we perform three different tests. First we allow for a break in both regression coefficients and the covariance matrix of the errors. Second, we consider the case that a break is present only in regression coefficients. Finally we take the case that a break exists only in the covariance matrix. Creel and Hubert (2013) argue that the second test could be the appropriate specification to evaluate a change in the institutional setting or of the recent crisis. The results show that there is a break in the covariance of errors which occurs approximately around the time of the peak of the crisis.

These findings lead to the conclusion that monetary policy has changed over a sample (1999-2013) with an estimated break in the fourth quarter of 2008 at the peak of the financial crisis. A great number of papers focusing on monetary policy changes postulate or find a change at the end of the 1970s or beginning of the 1980s. Furthermore, the Great Moderation period is found or assumed to be stabled. The present analysis evidences that monetary policy has changed in the euro area. It appears that the structural break estimated for the euro area happens approximately after the peak of the financial crisis. We also note in Table 1 that the estimates of the policy coefficients of the two regimes before and after the break. Thus, the response to inflation β_{π} has decreased from 1.12 to -0.61, whereas the response to output β_{y}, has risen from 0.53 to 1.35. These results provide evidence that the response to inflation has decreased after the break date. There is no evidence of a policy change towards a greater focus on inflation. Our results are in line with those reported in Clarida *et al*. (2000) and other relevant works and more recently with Baxa *et al*. (2009), Gnabo and Moccero (2012) and Creel and Hubert (2013) for different economies which have adopted inflation targeting at some point of time. ECB along with most central banks has also been proactive after the end of their response to inflation. Finally, we also argue that the response to inflation has decreased with the

[4] Prior to the estimation of the alternative models we conduct unit root and stationarity tests to determine the stochastic properties of the data by applying standard unit root and stationarity tests. The results show that we are unable to reject the null hypothesis of a unit root in the data for the levels of all three series, whereas the first difference of the series are I(0) processes. The results are available upon request.

inflation targeting by ECB and there is no evidence, based on the estimated coefficients, of a policy change towards a policy change towards a greater focus on inflation as a result of the recent financial crisis.

We now turn our attention to the discussion of our results of the estimated TVP model. Table 2 reports the estimates for posterior means, standard deviations, the 95% credible intervals, the convergence diagnostics (CD) and inefficiency factor developed by Geweke (1992).[5] We compute the latter two coefficients in order to confirm that the MCMC algorithm converges and in addition to check that the selected number of iterations is the sufficient whereas the algorithm makes posterior draws sufficiently. From the estimates given in Table 2 we conclude that we are able to reject the null hypothesis of a stronger response to inflation in the monetary reaction function since October 2008 which implies that the conduct of monetary policy did not change significantly even with the escalation of the Eurozone debt crisis in October 2009. The inflation targeting framework of ECB conduct of monetary policy did not show significant response to output as well, a result which is line with the fact that unemployment is not an explicit variable in ECB's loss function.[6] Furthermore, the z-score of the CD statistic confirms that the convergence to the posterior distribution is satisfactory whereas the inefficiency factors given in the last column are substantially low, implying an efficient sampling for the parameters and state variables.

Finally, we provide a discussion of the estimates based on our 3-equation MS-VAR specification with four lags given that we employ quarterly data. The estimated model allows for changes in both coefficients and disturbance terms. We test the null hypothesis of no switching regime against the alternative one switching regime which is consistent with the stylized fact that the conduct of monetary policy by ECB has been stable over the period 1999-2007 and we are interested to assess the likelihood that there has been a regime switch in 2008 as a result initially of the global financial crisis and subsequently the Eurozone debt crisis.

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[5] All estimates have been made using the codes developed by Nakajima (2011) which can be downloaded at http://sites.google.com/site/jnakajimaweb/program. To compute the posterior estimates we follow Creel and Hubert (2013) and we generate L = 30000 draws after the initial 6000 draws are draws are discarded. In addition to the estimates we have also produced the respective diagrams which represent the evolution overtime of posterior estimates (posterior medians, two- and one-standard deviation bands) of the influence of inflation and of the output gap on the interest rate.

[6] We have also derived the corresponding diagrams which show the evolution overtime of posterior estimates of the responses of the interest rate to inflation rate and to the output gap (the 95% confidence interval for the posterior median). To save space these diagrams are available upon request.

Table 3 provides our results from the estimation of the MS-VAR(4) which help us to address the issue of volatility regime switching and to discriminate between low and high volatility regime in the interest rate equation before and after the financial crisis. Table 3 reports the estimated coefficients of the proposed MS-VECM along with the necessary test statistics for evaluation of the adequacy of the estimated model. The Likelihood Ratio test for the null hypothesis of linearity is statistically significant and this suggests that linearity is rejected. This is a nonstandard LR test due to Davies (1987). This outcome is reinforced from the AIC and HQIC criteria. The estimation of the equation provides asymmetrically a number of statistically significant coefficients, thereby justifying the use of regime dependent autoregressive parameters.

Table 3 also reports several other diagnostics which further highlight the use of regime switching induced nonlinearities in the relationship of the two exchange rates. First, the standard deviations σ_{int}, σ_{inf} and σ_{gap} take the values of 0.073, 0.065 and 0.060, and 0.027, 0.033 and 0.037 for regime 1 and regime 2 respectively; these values help us to identify regime 1 as the regime with higher response to inflation and regime 2 as the regime with lower response to inflation. Second, the duration measure shows that the high volatility regime lasts approximately 3.5 quarters, whereas the low volatility regime lasts approximately 12 quarters. This outcome is expected given there is no economic or financial crisis evident during most of the period under investigation except for the recent financial crisis, normal periods last more than turbulent periods. Finally, the calculated unconditional probability shows that there is a probability of 32 percent that a high volatility regime occurs and 68 percent that a low volatility regime takes place. The transition probabilities p_{11} and p_{22} explain the possibility of regime clustering and it is shown that there is 55 percent probability that a high volatility regime will be followed by a high volatility regime, while there is a 86 percent probability that a low volatility regime will be followed by a low volatility regime.[7]

Based on these estimates we may argue that in the Eurozone, the MS-VAR estimation does not show an explicit break in the conduct of monetary policy by ECB.

[7] The estimates of the MS-VAR are complemented by the derivation of the smoothed smoothed probabilities of being in the high and the low volatility regimes. It is shown that Regime 1 (high response regime) is evident during the period of crisis. To save space the smoothed probabilities are available upon request.

It rather shows a smooth transition from regime 2 to regime 1. This evidence is in line with the fact that the conduct of monetary policy followed by the ECB has been quite steady since 1999 and evidence of a possible shift of its policy during Regime 1 is rather small in magnitude. Furthermore, given that in Regime 2 the response to inflation is lower than in Regime 1 its dominance is also related to the conduct of monetary policy in the Eurozone. Finally, our results are in line with the evidence provided by our estimates of the time-varying parameters model.

5. Conclusions and policy implications

In the present paper we provide an empirical evaluation of the possible changes that may occur in the conduct of monetary policy pursued by the ECB since the formation of the Eurozone in light of the recent 2008-2009 financial crisis and the subsequent debt crisis. We employ three alternative econometric models to analyse the issue whether the recent financial crisis led into a stronger response to inflation by ECB which since its inception has adopted an inflation targeting policy.

The estimates of all three econometric models show that the unfolding of the recent financial crisis and the subsequent Eurozone debt crisis has not led to stronger response to inflation in the ECB' monetary reaction function. Furthermore, these results derived from these models are in line with the source or the nature of the potential break or the targeted real variable, i.e. the output gap. In addition, these findings may lead to the argument that during the period 2007-2013 there is limited evidence that ECB responded stronger to the output gap (which has recently increase in the Eurozone). Such a restricted policy strategy is consistent with the continuous concern by ECB of a future rise of inflation in case output is considered as a leading indicator of inflation. As possible explanations for such behaviour two arguments may be put forward (see also Assenmacher-Wesche, 2006; Baxa et al., 2009; Creel and Hubert, 2013). First, inflation targeting possibly leads to anchoring private inflation expectations, which allows the ECB to control inflation without the need to act in a more aggressive manner to smooth out inflation volatility. Second, the ECB's inflation targeting policy which reflects the architecture of monetary union in the Eurozone has led to low and stable inflation and hence to a lower response to inflation during the recent financial turmoil. As a final conclusion we also confirm the arguments made in the relevant literature discussed in the introduction that the stability of private expectations which is observed in inflation targeting economies, as

Eurozone is, implies that the inflation targeting framework allows the ECB to implements flexible strategy to respond to inflation variations in a non-aggressive way.

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Table 1. Testing for a Structural Break in Monetary Rules over (1999-2012)

	allowing break in regression coefficients & in the covariance matrix of the errors		allowing break in regression coefficients		allowing break in the covariance matrix of the errors	
Estimated break date	2008.Q4		2008.Q4		2008.Q4	
90% interval confidence	2008.Q3	2009.Q1	2008.Q3	2009.Q1	2008.Q3	2009.Q1
	β_π	β_y	β_π	β_y	β_π	β_y
Sample pre-break	1.12*	0.53*	1.12*	0.53*	1.12*	0.53*
Sample post-break	-0.61*	1.35*	-0.61*	1.35*	-0.61*	1.35*

Notes: Given the minimal length criteria of a regime (set at 20% of the total length of the sample) and 1 break allowed. Significance levels are based on OLS estimations and (*) indicates significance at the 5%

Table 2. Benchmark TVP estimation – Estimated Posteriors of coefficients

Parameters	Mean	S.D.	95% U	95% L	CD	Inefficiency
Σ11	0.0203	0.0046	0.0051	0.0173	0.533	27.61
Σ22	0.0076	0.0023	0.0046	0.0089	0.766	21.88
Σ33	0.0045	0.0009	0.0012	0.0051	0.448	17.51
ϕ	0.1224	0.0687	0.0402	0.1991	0.887	22.21
σ_η	0.3012	0.1443	0.0556	0.5513	0.322	65.41
γ	0.0298	0.0041	0.0191	0.044	0.401	19.81

Notes: S.D. denotes the standard deviation, 95% U and L denote the 95% credibility criteria, CD is the Z-score of the convergence diagnostics proposed by Geweke (1992) and inefficiency denote the inefficiency factors.

Table 3. Estimation of the MS-VAR

Regime 1			
coefficients	**interest rate**	**inflation rate**	**output gap**
Constant	-0.0012 (-0.323)		
lag1	1.3583* (4.035)	-0.01498* (4.6703)	1.3988* (3.988)
lag 2	-0.2651*(2.708)	-0.10461* (3.7981)	-1.997* (4.988)
lag 3	-0.1106(1.1971)	0.05469* (3.4951)	2.682* (4.1123)
lag 4	-0.1839*(-2.0552)	-0.0665* (2.5782)	-1.446* (3.4461)
σ	0.073	0.065	0.060
Regime 2			
Constant	1.0233* (2.988)		
lag1	0.0355 (1.6889)	-0.0225 (1.0333)	0.0567 (1.0222)
lag 2	0.0988 (1.7778)	0.0266 (1.2251)	0.0899 (0.9971)
lag 3	0.0256 (1.2333)	0.0988 (1.6881)	-0.3012 (0.3324)
lag 4	-0.09887* (3.776)	-0.09655* (3.022)	0.1123 (1.6887)
σ	0.027	0.033	0.037
Duration	3.57		12.14
Unconditional probability	0.323		0.677
p_{11}		0.55	
p_{22}		0.86	
	Null hypothesis: The variance and autoregressive parameters are equal across regimes (Linear VAR) Alternative: The variance and autoregressive parameters are different across regimes (MS-VAR)		
Likelihood LR AIC HQIC		905.40{828.70} 153.4 [0.000] -7.83 {-7.32} -7.21 {-7.03}	

Notes:

1. LR denotes the likelihood ratio test for the null of a linear VAR. The value in squared brackets next to LR is the marginal significance level of this test, based on Davies (1987).
2. The values in curly brackets report the respective values from the linear VAR(4).
3. t-statistics are reported in parentheses. * denotes statistical significance at the 5% level.