INFLATION AND INFLATION UNCERTAINTY IN THE EURO AREA[1]

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Abstract

This paper estimates a time-varying AR-GARCH model of inflation producing measures of inflation uncertainty for the euro area, and investigates the linkages between them in a VAR framework, also allowing for the possible impact of the policy regime change associated with the start of EMU in 1999. The main findings are as follows. Steady-state inflation and inflation uncertainty have declined steadily since the inception of EMU, whilst short-run uncertainty has increased, mainly owing to exogenous shocks. A sequential dummy procedure provides further evidence of a structural break coinciding with the introduction of the euro and resulting in lower long-run uncertainty. It also appears that the direction of causality has been reversed, and that in the euro period the Friedman-Ball link is empirically supported, implying that the ECB can achieve lower inflation uncertainty by lowering the inflation rate.

JEL Classification: E31, E52, C22

Keywords: Inflation, Inflation Uncertainty, Time-Varying Parameters, GARCH Models, ECB, EMU

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1. Introduction

The launch of EMU in 1999 structurally changed the European macroeconomic environment and the way agents formulate their expectations. The onset of the euro, the devolution of monetary policy prerogatives from domestic authorities to the European Central Bank (henceforth ECB) and the almost complete elimination of residual barriers to financial and economic integration were all parts of this process.

Inflation and inflation expectations are among the variables which most likely were affected by this change, for three main reasons. First, the Maastricht Treaty established a new institution, the ECB, with the task of ensuring price-stability for the euro area as a whole. Second, the ECB adopted a new strategy consisting of a quantitative definition of price stability, the two pillars framework and a set of new instruments. Third, new monetary policy transmission channels emerged while others disappeared (e.g. idiosyncratic exchange rate adjustment).

This paper focuses on the analysis of the relationship between inflation and inflation uncertainty in the euro area. Surprisingly, studies on this relationship are distinctly rare. Most of them are either based on survey data (see, e.g., Giordani and Söderlind, 2003, and Arnold and Lemmen, 2008) or adopt a country-by-country approach (see Fountas *et al*. 2004, and Apergis, 2004). This motivates our decision to contribute to this area of the literature by estimating a time-varying AR-GARCH model of inflation for the euro area as a whole with the aim of producing measures of inflation uncertainty and investigating the linkages between them in a VAR framework, also allowing for the possible impact of the policy regime change associated with the start of EMU in 1999.

In achieving this goal the paper distinguishes between short-run and steady-state uncertainty. The former reflects both structural uncertainty (associated with the randomness in the time-varying parameters of the inflation process which might originate, for instance, from economic agents adapting to a new economic environment) and pure volatility (also defined impulse uncertainty). Both types of uncertainty affect forecast errors. Long-run uncertainty reflects parameter uncertainty only as variables are assumed to be at their steady state levels and shocks are shut off.

As emphasised by Evans (1991), uncertainty is not the same as variability. If individuals have very little information about inflation, they may view the future with a large amount of uncertainty even though the econometrician observes little *ex post* volatility. Conversely, there may be very little uncertainty accompanying a large change in actual inflation because individuals have a good deal of advanced information.

The need to distinguish between different types of uncertainty is consistent with economic theory and with the fact that economic agents take two types of decisions: temporal and intertemporal. Temporal decisions are more likely to be affected by the conditional variance of short-run movements in inflation, whilst intertemporal decisions might be based mainly on changes in the conditional variance of long-term inflation. MORE ON THIS QUOTING STUDIES IN EVANS AND OTHERS.

The econometric framework we use to identify the different types of uncertainty is similar to that originally proposed by Evans (1991) and recently used by Grier and Perry (1998), Berument *et al.* (2005) and Caporale and Kontonikas (2009) and consists of two-steps. First, an AR-GARCH model with time-varying parameters is estimated to generate different measures of inflation uncertainty based on lagged values of inflation only. In the second step, the relationship between inflation and inflation uncertainty is estimated in a univariate context.

We extend this framework along two directions. First, we consider the inclusions of other variables, besides lagged inflation values, which are likely to affect inflation expectations. The set of new variables includes: unemployment rate, a measure of output gap, rate of change of M3, nominal long term interest rate, nominal short term interest rate, interest rate differential, and nominal effective exchange rate index.. Second we analyse the relationship between impact inflation and inflation uncertainty in a multivariate context, better suited to deal with the possibility of reverse causality.

The choice of focusing on euro area inflation measured as the month on month rate of change of the Harmonised Index of Consumer Prices (HICP) reflects the ECB's mandate to achieve aggregate price stability in the Eurozone and the absence of instruments to fine-tune monetary policy to cyclical fluctuations in individual EMU countries.

The paper is structured as follows. Section 2 contains an essential lietarture review. Section 3 outlines the methodology. Section 4 describes the data and the empirical results. Section 5 offers some concluding remarks, highlighting in particular the policy implications of our findings.

2. Literature review

Inflation uncertainty, its linkages with actual inflation and its potential impact on real economic activity have been extensively analysed in the literature. Friedman (1977) was the first to suggest that higher average inflation could result in higher inflation uncertainty. This idea was developed by Ball (1992) in the context of a model in which higher inflation leads to increasing uncertainty over the monetary policy stance. The possibility of a negative effect of inflation on its uncertainty was then considered by Pourgerami and Maskus (1987), who pointed out that in an environment of accelerating inflation agents may invest more resources in inflation forecasting, thus reducing uncertainty (see also Ungar and Zilberfarb, 1993). Causality in the opposite direction, namely from inflation uncertainty to inflation, is instead a property of models based on the Barro–Gordon setup, such as the one due to Cukierman and Meltzer (1986).

Concerning the relationship between inflation uncertainty and real economic activity, some authors suggest that the former reduces the rate of investment by hindering long-term contracts (see, e.g., Fischer and Modigliani, 1978), or by increasing the option value of delaying an irreversible investment (see, e.g., Pindyck, 1991). Others argue that, to the extent that it is associated with increased relative price variation, it reduces the allocational efficiency of the price system (see Friedman, 1977). In contrast, Dotsey and Sarte (2000) show that inflation variability may increase investment through its impact on precautionary savings. Finally, Cecchetti (1993) suggests that a general equilibrium, representative agent model is not likely to yield a convincingly unambiguous result on the impact of uncertainty on real economic activity.

On the empirical side, a number of studies have investigated the relationship between inflation and inflation uncertainty, typically adopting an econometric framework of the GARCH type (see Engle, 1982), and providing mixed evidence (see Davis and Kanago, 2000 for a survey, and Baillie *et al*., 1996, Brunner and Hess 1993, Kontonikas 2004, Grier and Perry, 2000 for some specific contributions). Other authors take instead a VAR approach to analyse US data. In particular, Benati and Surico (2008) estimate structural VARs with time-varying parameters and stochastic volatility and report a decline in inflation predictability, showing that this can be caused by tough anti-inflation policies in the context of a sticky price model. Cogley *et al.* (2009) take a similar approach but focus instead on the inflation gap.

Empirical studies on the linkages between inflation uncertainty and real economic activity also report conflicting results both in terms of the sign (see, e.g., Holland, 1993) and of the magnitude and timing of the effects (see, e.g., Davis and Kanago, 1996, Cunningham, Tang, and Vilasuso, 1997, and Grier and Perry, 2000). Elder (2004) finds that in the US inflation uncertainty has significantly reduced real economic activity. This holds for the period prior to 1979, after 1982, and over the full post-1966 period and is robust to various specifications. This result is obtained by combining a VAR specification with a multivariate GARCH model.

The availability of reliable and easy-to-update measures of inflation uncertainty is particularly relevant for monetary policy purposes (Goodhart, 1999, and Greenspan, 2003). As Soderstrom (2002) notes, when there is uncertainty about the persistence of inflation, it is optimal for the central bank to respond more aggressively to shocks than when the parameters are known with certainty, in order to avoid undesirable outcomes in the future. According to Shuetrim and Thomson (2003), for certain shocks, taking into account parameter uncertainty can imply that a more, rather than less, activist use of the policy instrument is appropriate in contrasts with the widely held belief that the general implication of parameter uncertainty is a more conservative policy. Finally, Coenen (2007) argues that a cautious monetary policy-maker is well-advised to design and implement interest-rate policies under the assumption that inflation persistence is high when there is considerable uncertainty about its degree. Such policies are characterised by a relatively aggressive response to inflation developments and exhibit a substantial degree of inertia.

3. Econometric Framework

Usually inflation uncertainty is estimated by means of GARCH models which typically which have the drawback that they do not take into account the fact that short-run and long-run inflation uncertainty might be very different and affect inflation expectations in different ways. The econometric framework we employ has the advantage of yielding estimates of the various types of uncertainty discussed above. More specifically, inflation is specified as a *k-th* order autoregressive process, AR(k), and is also a function of unemployment, the parameters being time-varying and the residuals following a GARCH(1,1) process. The model is the following:

$$\pi_{t+1} = \mathbf{X_t}\boldsymbol{\beta}_{\mathbf{t+1}} + e_{t+1} \qquad e_{t+1} \sim \mathrm{N}(0, \mathrm{h_t}) \tag{1}$$
$$h_t = h + ae^2_{t-1} + \lambda h_{t-1} \tag{2}$$
$$\boldsymbol{\beta}_{\mathbf{t+1}} = \boldsymbol{\beta}_{\mathbf{t}} + \mathbf{V_{t+1}} \qquad \text{where } V_{t+1} \sim \mathrm{N}(0, \mathrm{Q}) \tag{3}$$

where π_{t+1} denotes the rate of inflation between t and t+1; $\mathbf{X_t}$ is a vector of explanatory variables known at time t including a constant term, inflation π, the unemployment rate υ, the rate of change of M3 in nominal terms μ, the rate of change of the nominal effective exchange rate ξ, differential between long (10 years) and short term (3 months) interest rate δ.; e_{t+1} describes the shocks to the inflation process that cannot be forecast with information known at time t, and is assumed to be normally distributed with a time-varying conditional variance h_t. The conditional variance is specified as a GARCH(p,q) process, that is, as a linear function of past squared forecast errors, e^2_{t-i}, and past variances, h_{t-j}. Further, β_{t+1} denotes the time-varying parameter vector, and $\mathbf{V_{t+1}}$ is a vector of shocks to $\boldsymbol{\beta}_{\mathbf{t+1}}$, assumed to be normally distributed with a homoscedastic covariance matrix $\mathbf{Q}$.
Consistently with our story, the economic agents form their expectations (including inflation and the updating of the parameters β)on the basis of the available information set. The optimal predictor in this context is the Kalman filter, including equations (1) to (3) and the following updating equations:

$$\pi_{t+1} = \mathbf{X_t} E_t \boldsymbol{\beta}_{\mathbf{t+1}} + \varepsilon_{t+1} \tag{4}$$
$$H_t = \mathbf{X_t}\boldsymbol{\Omega}_{\mathbf{t+1|t}}\mathbf{X_t}' + h_t \tag{5}$$
$$E_{t+1}\boldsymbol{\beta}_{\mathbf{t+2}} = E_t\boldsymbol{\beta}_{\mathbf{t+1}} + [\boldsymbol{\Omega}_{\mathbf{t+1|t}}\mathbf{X_t}' H_{t-1}]\varepsilon_{t+1} \tag{6}$$
$$\boldsymbol{\Omega}_{\mathbf{t+2|t+1}} = [\mathbf{I} - \boldsymbol{\Omega}_{\mathbf{t+1|t}}\mathbf{X_t}' H_{t-1}\mathbf{X_t}]\boldsymbol{\Omega}_{\mathbf{t+1|t}} + \mathbf{Q} \tag{7}$$

where $\boldsymbol{\Omega}_{\mathbf{t+1|t}}$ is the conditional covariance matrix of $\boldsymbol{\beta}_{\mathbf{t+1}}$ given the information set at time t, representing uncertainty about the structure of the inflation process. As Equation (5) indicates, the conditional variance of inflation (short-run uncertainty), H_t, can be decomposed into: (i) the uncertainty due to randomness in the inflation shocks e_{t+1}, measured by their conditional volatility h_t (impulse uncertainty); (ii) the uncertainty due to unanticipated changes in the structure of inflation $\mathbf{V_{t+1}}$, measured by the conditional variance of $\mathbf{X_t}\boldsymbol{\beta}_{\mathbf{t+1}}$, which is $\mathbf{X_t}\boldsymbol{\Omega}_{\mathbf{t+1|t}}\mathbf{X_t}' = S_t$ (structural uncertainty). The standard GARCH model can be obtained as a special case of this model if there is no uncertainty about $\boldsymbol{\beta}_{\mathbf{t+1}}$, so that $\boldsymbol{\Omega}_{\mathbf{t+1|t}} = \mathbf{0}$.

In this case, the conditional variance of inflation depends solely on impulse uncertainty. Equations (6) and (7) capture the updating of the conditional distribution of $\boldsymbol{\beta}_{\mathbf{t+1}}$ over time in response to new information about realised inflation. As indicated by Equation (6), inflation innovations, defined as ε_{t+1} in Equation (4), are used to update the estimates of $\boldsymbol{\beta}_{\mathbf{t+1}}$. These estimates are then used to forecast future inflation. If there are no inflation and parameter shocks, so that $\pi_{t+1} = \pi_t = ... = \pi_{t-k}$ for all t, we can calculate the steady-state rate of inflation, π^*_{t+1}, as:

$$\pi^*_{t+1} = \beta^*_{0,t+1} \left[1 - \left(\sum_{i=1}^{k} \beta^{\pi}_{i,t+1}\right)\right]^{-1} \tag{8}$$

where

$$\beta^*_{0,t+1} = \left[\beta^{\pi}_{0,t+1} + \left(\sum_{j=1}^{m} \beta^{\upsilon}_{j,t+1}\right)\upsilon^* + \left(\sum_{j=1}^{m} \beta^{\mu}_{j,t+1}\right)\mu^* + \left(\sum_{j=1}^{m} \beta^{\xi}_{j,t+1}\right)\xi^* + \left(\sum_{j=1}^{m} \beta^{\delta}_{j,t+1}\right)\delta^*\right] \tag{9}$$

and υ^* is the steady-state unemployment rate, μ^* the steady-state rate of change of M3 in nominal terms, ξ^* the rate of change of the nominal effective exchange rate, and δ^* the differential between long (10 years) and short term (3 months) interest rate.computed as the sample mean. The conditional variance of steady-state inflation is then given by:

$$\sigma^2_t(\pi^*_{t+1}) = \nabla E_t \boldsymbol{\beta}_{\mathbf{t+1}} \boldsymbol{\Omega}_{\mathbf{t+1|t}} \nabla E_t \boldsymbol{\beta}'_{\mathbf{t+1}} \tag{10}$$

where $$\nabla E_t \beta'_{t+1} = \begin{bmatrix} \left[1 - \left(\sum_{i=1}^{k} \beta^{\pi}_{i,t+1}\right)\right]^{-1} \\ E_t \beta^*_{0,t+1} \left[1 - \left(\sum_{i=1}^{k} \beta^{\pi}_{i,t+1}\right)\right]^{-2} \\ \cdots \\ E_t \beta^*_{0,t+1} \left[1 - \left(\sum_{i=1}^{k} \beta^{\pi}_{i,t+1}\right)\right]^{-2} \end{bmatrix} \tag{11}$$

is a (k + m + 1 x 1) vector.

Having obtained the three uncertainty measures: impulse uncertainty, structyural uncertainty and steady-state uncertainty, we analyse their links with current inflation by estimating a bivariate VAR model of inflation and steady-state inflation uncertainty, since the ECB focuses on long-run price stability. The model also includes a dummy variable to allow for possible structural breaks in the underlying relationship reflecting the introduction of the euro. Specifically, the estimated model is the following:

$$\begin{pmatrix} \pi_t \\ unc_t \end{pmatrix} = A(L) \begin{pmatrix} \pi_{t-1} \\ unc_{t-1} \end{pmatrix} + BD_t + \begin{pmatrix} \varepsilon^{\pi}_t \\ \varepsilon^{unc}_t \end{pmatrix} \tag{11}$$

where unc_{t+1} represents steady-state uncertainty (i.e. $\sigma^2_t(\pi^*_{t+1})$), D_t is an intercept shift dummy variable, A(L) a matrix polynomial and B a 2×1 matrix. In the model specified above, the break date is imposed exogenously to coincide with the introduction of the euro in December 1998.

Subsequently, we carry out Granger-causality tests and also apply a sequential dummy approach to detect possible breaks endogenously. The motivation for the latter type of analysis comes from the literature arguing that rational agents are likely to react to the announcement of a regime switch before its implementation, and therefore breaks in the relationship of interest could have occurred before January 1999 (see Wilfling, 2004, and Wilfling and Maennig, 2001) .

3. Empirical Analysis

3.1 Data Description

The data included in the vector of explanatory variables include, inflation, unemployment, rate of change of M3 in nominal terms, rate of change of the nominal effective exchange rate, differential between long (10 years) and short term (3 months) interest rate. The sample period is 1980:m1 – 2009:m2.

Our preferred measure of inflation is the monthly rate of change of the seasonally unadjusted Harmonised Index of Consumer Prices (HICP) for the Eurozone as a whole.[2] Chart 1 below plots this series from 1990 onwards together with the corresponding year-on-year growth rate. Visual inspection suggests declining inflation and relatively subdued variability in the run-up to EMU and stable inflation afterwards with increased variability, particularly so towards the end of the sample.

Chart 1. Euro area Inflation

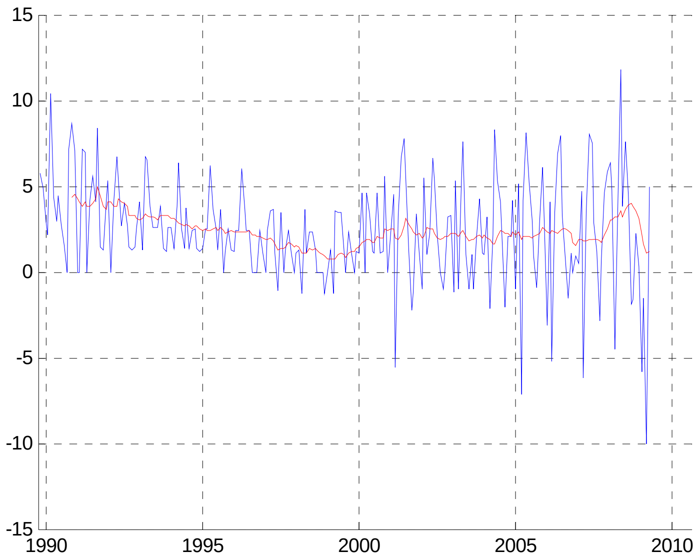
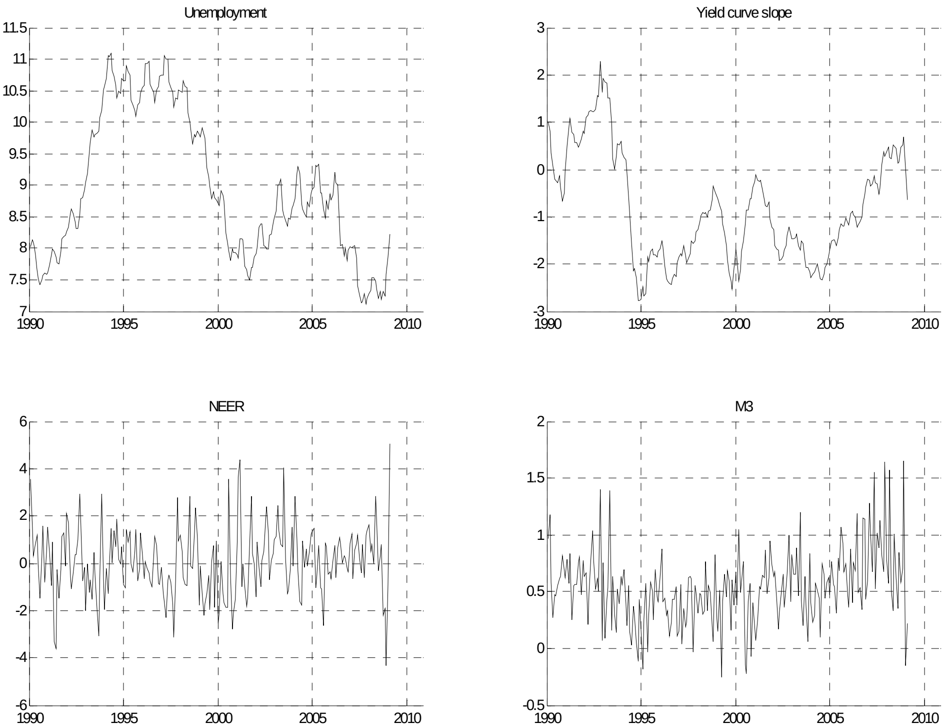


Chart 2 shows the four macroeconomic variables which we include in the model in addition to lagged inflation. The upper left panel shows the euro area seasonally unadjusted monthly unemployment rate υ.[3] The series exhibits a cyclical pattern and is clearly linked to output developments over the same period.

[2] "Euro area (changing composition) - HICP - Overall index, Monthly Index, Eurostat, neither seasonally nor working day adjusted". Eurostat code: VAL.IDX05.EMU.00. This series is available from January 1990, and has been extended backwards using a weighted average of the growth rates of the corresponding national series for France, Germany, Italy and Spain.

[3] "Euro area (changing composition) - Standardised unemployment rate, Total (all ages), Total (male & female), Eurostat, neither seasonally or working day adjusted, percentage of civilian workforce". The series is available from January 1993, with Eurostat code: VAL.EZ.CURRENT.UNEM.TOT.M_PC_UNEM_TOT.NSA. It is linked backwards until February 1982 with the series "EU12 including West Germany - Standardised unemployment rate, Total (all ages), Total (male & female), Eurostat, neither seasonally nor working day adjusted, percentage of civilian workforce", Eurostat code: VAL.UNER.T.A0_99.ORIGINAL.EC_85.M. The two remaining

Chart 2. Other data



In the upper right panel we show the diffential δ between the short and the long-term interest rate . [5] The series exhibits negative and fluctuating values over most of the sample period (positively sloped yield curve). Slope inversion is observed only at the start and at the end of the sample period, at times of heightened inflationary pressures. The lower left panel shows ξ , the logarithm of the nominal effective exchange rate in first differences. [6] The series exhibits a jagged pattern in the first part of the sample period and is consistent with appreciation in the second part. Finally, the lower right panel shows μ the logarithm of M3 in first differences. [7]

years are completed by using the yearly growth rate of the series "Euro area - UNEMPLOYMENT, STANDARDISED (EU/ILO DEFINITION)(MU16) SA", from the BIS database: Macro-economic series (Blocks A-K, Q-W).

[5] ADD REFERENCE ON INTEREST RATE DATA

[6] ADD REFERENCE ON NEER

[7] ADD REFERENCE ON M3

3.2 Trend Inflation, Steady-State Inflation and Inflation Persistence

Our benchmark univariate model of the inflation process regresses current inflation on a constant term and three lags of both inflation and the other variables as indicated above. A Bayesian approach is taken for the estimation. We start from an appropriate but weakly informative prior, and use the 1980s as a pre-sample to update it. We report the results from 1990m1 onwards, therefore including the period immediately before the Maastricht Treaty, the convergence period to meet the requirements of the Treaty, and the first decade of EMU. After the estimation, and in order to check whether there is time variation in the relevant parameters of the models, we perform ADF tests on the coefficients of the variables in the model. Twelve out of sixteen coefficients (at least one for each variable) exhbit time variation, either in the form of non- stationarity or in the form of structural breaks, which justifies the use of time-varying parameters in the AR equation (tests available on request). Similarly, we test for the significance of the ARCH and GARCH parameters of the model, finding that they are both significant (Table 1 upper panel). In Table 1 we also report the Ljung-Box test statistic for serial correlation of the residuals at lags 1 to 4, showing that there is no residual autocorrelation at 5% level.

Table 1. Tests for time variation

Coefficients of GARCH component			
	h	a	λ
Par. Val.	0.0008	0.0793	0.9060
T-stats on cov. matrix	0.7663	2.3525	19.0580

Squared standardized residuals serial correlation			
LB(1)	LB(2)	LB(3)	LB(4)
2.00	2.88	4.06	7.15

Charts 3-8 are based on the estimation results. Chart 3 shows trend inflation, namely the estimated time-varying constant from Equation (4), which declines steadily from the beginning of the 1990s up to the start of EMU, stabilising afterwards. The estimates of the individual coefficients on (lagged) unemployment, interest rate differential, nominal effective exchange rate rate of change and M3 rate of change are not particularly informative. Their sums, are shown in Chart 4 below together with confidence bands.

COMMENT CHART 4 (COEFFICIENTS)

Chart 3. EMU Trend inflation (month on month)

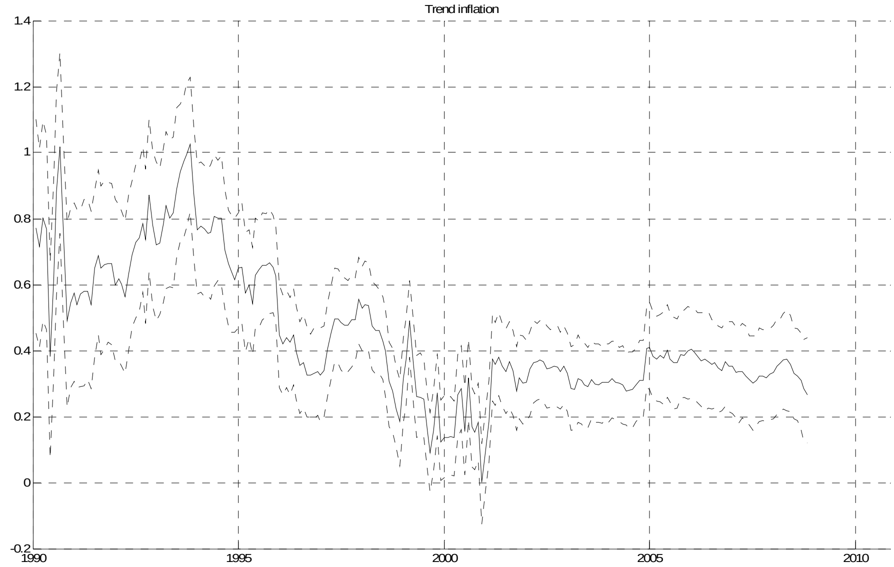


Chart 4. Time-varying beta coefficients

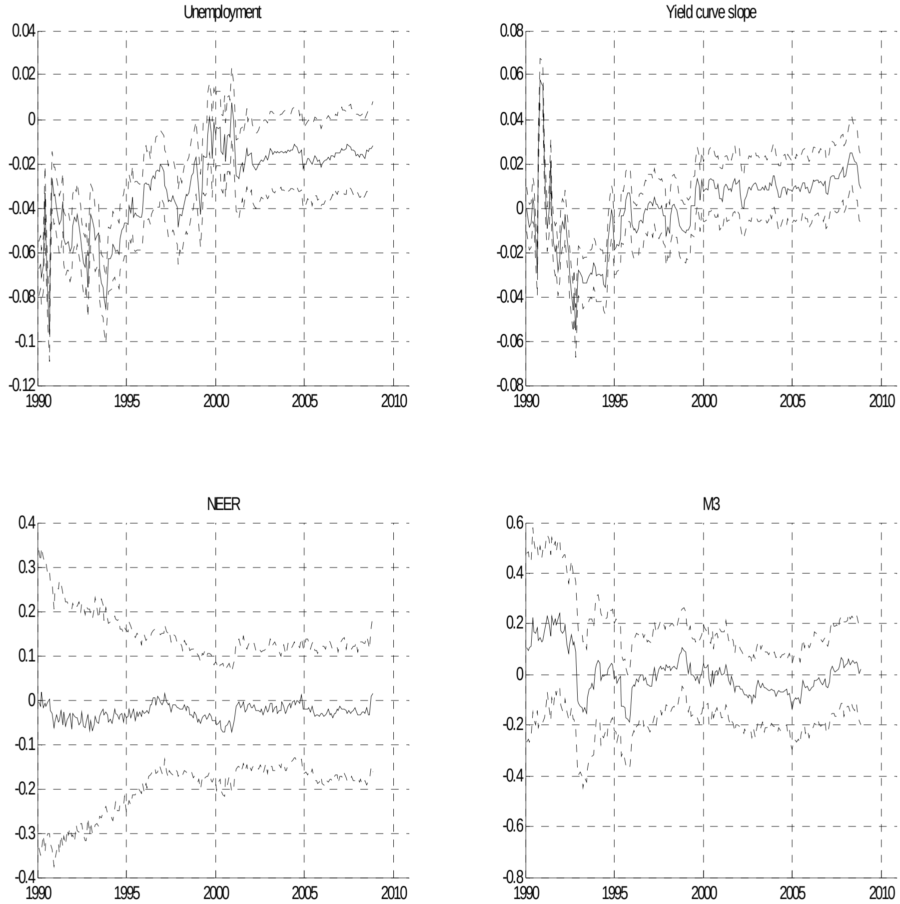
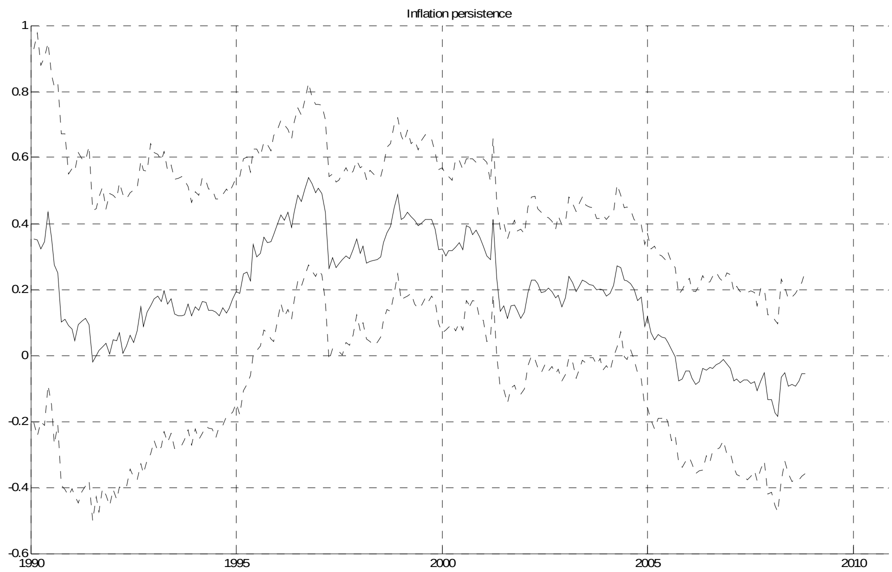


Chart 5 plots inflation persistence, defined as the sum of its autoregressive coefficients. This exhibits a positive trend becoming negative at the beginning of the third Phase of EMU, which may reflect lower and better-anchored inflation expectations in the post-1999 period, consistently with the ECB's mandate of achieving long-term price stability and with theory. For instance, Erceg and Levin (2003) show that inflation displays very little persistence if the long-run inflation target is constant. Similarly, Orphanides and Williams (2005) demonstrate that if long-run inflation expectations are well anchored, then inflation will be less persistent than if the public is uncertain about the long-run inflation target.

Chart 5. Inflation persistence



Among recent studies, O'Reilly and Whelan (2005) focus on inflation persistence and find relatively little instability in the parameters of the euro-area inflation process. Full-sample estimates of the persistence parameter are generally close to 1, and the hypothesis that this parameter has been stable over time cannot be rejected. Angeloni *et al.* (2006), using micro data on consumer prices and sectoral inflation rates from six euro-area countries spanning several years before and after the introduction of the euro, find no evidence of a shift around 1999. Finally, Altissimo *et al.* (2006) note that, for aggregate data, the degree of inflation persistence in the euro area appears to be very high for sample periods spanning multiple decades but falls dramatically once time variation in the mean level of inflation is allowed for; furthermore, the timing of the breaks generally coincides with observed shifts in the monetary policy regime.

Chart 6 plots steady-state inflation as defined by Equation (8). It shows a gradual but marked decline for most of the sample period. From 1999, whilst the downward trend gradually flattens out, volatility appears to increase, especially in the early stages of EMU and in the most recent period.

Chart 6. Steady state inflation

3.3 Short-Run and Steady-State Inflation Uncertainty

Chart 7 shows short-run inflation uncertainty and its structural component estimated using Equation (5). A sharp decline in the early part of the sample is followed by an upward shift and higher volatility around a positive trend afterwards, the biggest spike coinciding with the latest financial turmoil. Decomposing short-run uncertainty into impulse and structural uncertainty reveals that the latter dominates, i.e. exogenous shocks are the main driving force of swings in short-run uncertainty, whilst structural uncertainty (which can be interpreted as reflecting unanticipated changes in monetary policy) is relatively stable throughout the sample period and does not play a significant role.

CHECK WHETHER COMMENT OF CHART 7 IS STILL VALID

The focus of the ECB is, however, price stability in the medium term, and therefore a more relevant measure to consider is steady-state inflation uncertainty (see Chart 9). This appears to follow a downward trend with the exception of the early years of the euro, when agents were still learning about the new monetary environment. The steady decline since then can be seen as an indication of the ECB's success in fulfilling its mandate as specified in the Maastricht Treaty.

IMPROVE COMMENT OF CHART 8

Chart 7. Short-run and structural inflation uncertainty

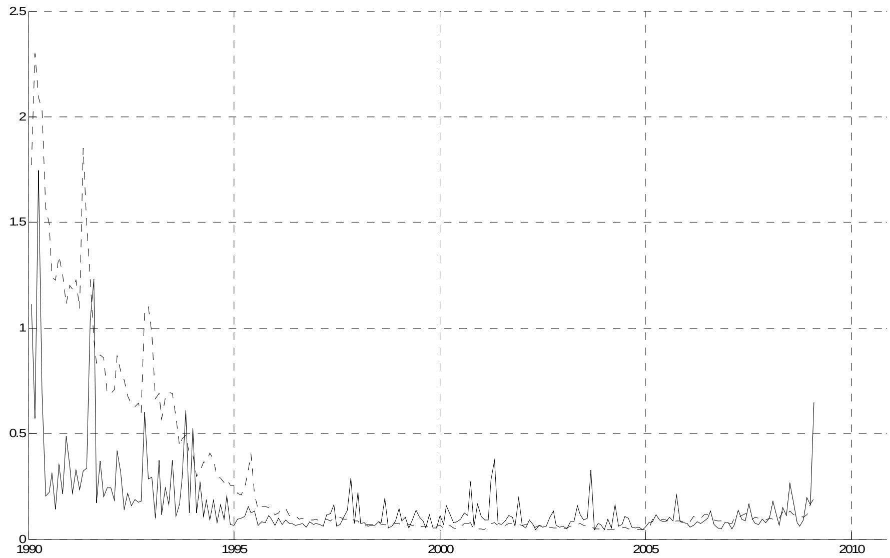


Chart 8. Steady-state inflation uncertainty

4. The Relationship between Inflation and Steady-State Inflation Uncertainty in a Bivariate VAR Framework

Next, we estimate a bivariate VAR for inflation and steady-state inflation uncertainty to test for causality and for the presence of structural breaks related to EMU. As a first step, the order of integration of the variables needs to be established. Standard ADF tests reject the null hypothesis of a unit root in levels in both cases. We then carry out the unit root tests proposed by Saikkonen and Lütkepohl (2002) and Lanne *et al.* (2002). Test results support stationarity of both series, are robust to the choice of lag length and indicate that a structural break in structural inflation uncertainty might have occurred at the start of EMU (see Table 2).

Table 2. Unit root tests on inflation and steady-state inflation uncertainty

		INFLATION		SS_UNC	
Test	Lag	Test statistic	Det. Comp.	Test statistic	Det. Comp.
ADF	14	-3.19 *	C	-1.94 *	0
EXO_SB	7	-4.86 **	C, 1998 M12	-2.84 *	C, **1998 M12**
END_SB	9	-4.21 **	C, 2008 M4	-2.97 *	C, **2001 M3***

Table 3. Cointegration tests: [infl, infl_ss_var]

Test 1: included lags (levels) 14, intercept – Johansen trace test					
Coint_rank	Test stat.	p_val	90%	95%	99%
r0 = 0	15.68	0.0453	13.42	15.41	19.62
Test 2: included lags (levels) 14, intercept – S&L cointegration trace test					
r0 = 0	17.33	0.0017	8.18	9.84	13.48

Johansen's cointegration tests confirm that both inflation and inflation uncertainty can be treated as stationary in levels (see Table 3). Therefore the remainder of the analysis is carried out under this assumption, and a VAR in levels was estimated. Standard selection criteria suggested choosing lag length 14 for the bivariate VAR in levels. The deterministic component was specified to include a constant. A shift dummy in 1998m12 to capture the introduction of the euro is found to be statistically not significant and is therefore removed from the model. Standard diagnostic tests indicate that the model is statistically adequate.

Table 4. Test for Granger-causality

H0: "infl_ss_var" does not Granger-cause "infl" – whole sample	
Test statistic = 1.1282	pval-F(l; 14, 364) = 0.3311
H0: "infl" does not Granger-cause "infl_ss_var" – whole sample	
Test statistic = 1.6885	pval-F(l; 14, 364) = 0.0559

Granger-causality tests imply uni-directional causality running from inflation to steady-state uncertainty at the 5% confidence level, consistently with the Friedman-Ball hypothesis (see Table 4).

The model was also estimated including a sequential intercept shift dummy in order to test endogenously for possible structural breaks. Chart 10 shows the sequential t-value of the corresponding coefficient in the equation for steady-state inflation uncertainty.

As can be seen, a sizeable downward shift is apparent at the end of 2000. This is consistent with the earlier finding of declining and more stable steady-state inflation uncertainty in the euro years.

Chart 10. Sequential t-value of the dummy coefficient

The results of full-sample Granger-causality tests using the specification including a shift dummy for the break detected in 2000m1 are consistent with the earlier ones. However, when carried out separately over the two sub-samples 1990m1-1998m6 and 2001m3-200m2, such tests provide evidence of a reversal in causality, implying that the Cukierman-Meltzer link has been replaced by the Friedman-Ball one in the second subsample (see Table 5), and that the ECB can effectively reduce inflation uncertainty by bringing down the inflation rate.

Table 5. Test for Granger-causality, p – values

Ho	Whole sample	1980:m1-1998:m6	2001:m3-2009:m2
Inflation does not Granger-cause inflation variability			
Inflation variability does not Granger-cause inflation			

5. Conclusions

This paper estimates a time-varying AR-GARCH model of inflation for the euro area, and investigates its linkages with the resulting measures of inflation uncertainty in a bivariate VAR framework, also modelling the possible structural break resulting from the creation of EMU at the beginning of 1999. Obtaining accurate measures of inflation uncertainty is crucial for monetary authorities, since higher uncertainty requires more active policies, as pointed out by Soderstrom (2002). Our main findings are as follows. Steady-state inflation and inflation uncertainty have both declined steadily since the inception of EMU, whilst short-run uncertainty has increased, but mainly owing to exogenous shocks. A sequential dummy procedure provides further evidence of a break coinciding with the introduction of the euro and leading to lower long-run uncertainty.

Interestingly, our analysis suggests that a tough anti-inflation stance successfully reduces long-run uncertainty in the case of the Eurozone, whilst the opposite holds for the US, where tighter policies adopted by the Fed seem to lead to lower predictability (see Benati and Surico, 2008 and Cogley *et al.*, 2009).
It also appears that the direction of causality has been reversed, and that in the euro period the Friedman-Ball link is empirically supported, implying that the ECB can achieve lower inflation uncertainty by lowering the inflation rate. This is consistent with Fountas *et al.* (2004) and Conrad and Karanasos (2005) and with the idea that, given the ECB's mandate and its record so far, any long-lasting deviations from price stability in the Eurozone would surprise market participants and lead to higher inflation uncertainty.

Overall, these results give support to the view expressed by the President of the ECB, Jean-Claude Trichet, a few years ago, when he argued that the single monetary policy and its clear focus on long-run price stability had helped anchor medium- to long-run inflation expectations in the Euro area, thus reducing inflation uncertainty (Trichet 2004). Short-run inflation uncertainty might have risen since 1999, but this does not appear to reflect higher structural uncertainty associated with unanticipated monetary policy changes, but possibly remaining differences across member states, fiscal policy, and financial and commodity market price shocks.

This analysis can be extended in several directions. First, the regression model for the inflation process can be expanded to include other possible determinants such as industrial production, money growth, the yield curve, the exchange rate and credit. Second, whether the observed patterns can indeed be attributed to the role played by the ECB can be tested by comparing our findings with those obtained for a control group of countries, such as other European countries outside the Eurozone, the US, and Canada. Third, estimation of a time-varying VAR-GARCH model could be carried out instead of treating unemployment and other possible variables as exogenous. Fourth, the forecasting properties of the model could be investigated.

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The advantages in terms of forecast accuracy deriving from including the unemployment rate as a measure of real economic activity in a model for inflation are discussed by Stock and Watson (1999) and Amisano and Giacomini (2007).

The latter authors analyse inflation uncertainty and its relation with inflation at country level in twelve EMU member states, and report that there is considerable heterogeneity across countries, even after the introduction of the euro, and also that the Friedman-Ball link appears to have weakened or even broken down in a number of cases in individual member states after the creation of EMU.