JEL Classification: E31, C22, C11, C32
Keywords: inflation persistence, new member states, time-varying mean, central bank credibility, ARFIMA model, Bayesian estimation, Kalman filter

The Role of Inflation Persistence in the Inflation Process in the New EU Member States*

Michal FRANTA – Czech National Bank (michal.franta@cerge-ei.cz)
corresponding author
Branislav SAXA – Czech National Bank
Kateřina ŠMÍDKOVÁ – Czech National Bank, and Charles University

Abstract
The aim of this paper is to compare inflation persistence between the New Member States (NMS) that joined the European Union in 2004 and 2007 and selected euro area members. If the levels of inflation persistence between the two groups are different, the NMS may encounter problems with fulfilling the Maastricht criterion on inflation and – after entering the euro area – with inflation divergence. We argue that the specific economic situation of the NMS in the last 15 years necessitates careful selection of inflation persistence measures. Two measures are estimated. The first one is based on a simple univariate statistical model of inflation with a time-varying mean. The second one assumes that inflation follows a fractionally integrated process and measures inflation persistence within an ARFIMA model. Statistical tests suggest that the model with a time-varying mean is preferable to the ARFIMA model for almost all countries. The estimation results show that inflation persistence is not an issue for all of the NMS. On the one hand, Bulgaria, Cyprus, the Czech Republic, Malta, Romania, and Slovakia exhibit persistence levels similar to those in the selected euro area countries. On the other hand, Estonia, Hungary, Latvia, Lithuania, Poland, and Slovenia encounter a problem with high persistence stemming from both high intrinsic and high expectations-based inflation persistence.

1. Introduction

Inflation persistence differences between the NMS and EAC can result in problems with fulfilling the Maastricht criterion on inflation, and, after entering the euro area with inflation divergence. Intuitively, high inflation persistence corresponds to a slow return of inflation to its long-run value after a shock occurs. Therefore, should a symmetric shock hit all the EU members, countries with high estimates of persistence could struggle to meet the Maastricht inflation criterion. It would take them longer to combat the consequences of this symmetric shock and return inflation to its long-run value. Moreover, the limit for inflation is based on the inflation average of the best EU inflation performers. This inherently implies that in the case of a symmetric positive shock to inflation, the benchmark will be set by countries with a high speed of inflation adjustment, i.e., the lowest inflation persistence. In other words, in the case of large differences in national inflation persistence

* The views expressed are those of the authors and do not necessarily represent those of the affiliated institutions. We thank Roman Horváth, Alf Vanags, Massimo Suardi, Kamil Galuščák, and all the participants of the workshop organized by the Directorate-General for Economic and Financial Affairs of the European Commission "What Drives Inflation in the New EU Member States?" for useful comments and suggestions. The paper was written with the support of the European Commission (reference ECFIN/ /C/2008/010).

values across the EU, it would be very difficult for those NMS with relatively high inflation persistence to stay close to the Maastricht inflation benchmark. Analogously, similarities in inflation persistence would increase the likelihood of symmetric reactions to common shocks.

Regarding inflation persistence in the euro area context, it has been shown that the inflation convergence achieved prior to euro introduction has not been sustained in the EAC since 1998, and inflation persistence has been identified as one of the prominent reasons.[1] It has been asserted that the euro area economies adjust unevenly to symmetric shocks due to differences in inflation persistence. Therefore, the risk of inflation divergence after the NMS enter the Eurozone is another reason why it is necessary to examine inflation persistence in the NMS.

The current literature has not reached a consensus on whether inflation persistence in the NMS is higher than in the EAC, or not. Studies dealing with the NMS are usually based on disaggregated data on prices. Approaches drawing on inflation aggregates, however, have several advantages. First, international comparisons are easier than with disaggregated evidence. Second, it is aggregate inflation that is relevant for conducting monetary policy. Third, the previous empirical work on the EAC focused on inflation aggregates, and this can serve as a useful benchmark. Working with aggregated data involves also certain disadvantages. Specifically, the results can suffer from aggregation bias, i.e., inflation aggregates can exhibit higher persistence than any of the particular components included.

In this paper, we take the aggregate data approach and estimate two measures of inflation persistence based on two univariate models of inflation. The first model is a model with a time-varying mean that is estimated using Bayesian techniques. The estimated model results in an unobserved component model estimated by the Kalman filter. The model enables identification of two types of inflation persistence: intrinsic and expectations-based inflation persistence. The second model employed, ARFIMA, assumes that inflation follows a fractionally integrated process. Both models are estimated using quarterly CPI inflation data covering approximately the last 15 years.

The choice of models draws on the discussion in Franta, Saxa, and Šmídková (2007).[2] From that paper, it follows that standard statistical approaches to measuring inflation persistence, based on constant inflation means, can yield misleading conclusions about the role that persistence plays in forming inflation in the NMS. These approaches have been primarily designed to assess the persistence in developed economies. As a result, they do not take fully into account the specific situation of the NMS (e.g., monetary policy regime switches, price deregulation, real convergence toward the euro area, and short time series) and tend to overestimate inflation persistence in the NMS by assuming a constant mean. Univariate models with a time-varying mean and ARFIMA models are preferable since they account for the specific traits of the inflation processes in the NMS. Finally, the structural measures are difficult to estimate due to the above-listed specific features of the NMS and consequent econometric problems in the estimation of the New Keynesian Phillips Curve.

[1] See Angeloni and Ehrmann (2004).

[2] In a pilot study, the NMS were represented by four countries (the Czech Republic, Hungary, Poland, and Slovakia).

Our analysis focuses on the NMS that entered the EU between May 1, 2004 and January 1, 2007. The estimation results suggest that some NMS are close to the EAC in terms of inflation persistence and the relative importance of its components (e.g. Cyprus, Malta, the Czech Republic, and Bulgaria). Other NMS, however, exhibit remarkable differences relative to the euro area. We show that some NMS economies (e.g. Hungary, Latvia, and Lithuania) face a serious problem with accommodating inflation shocks. The problem stems from a high estimated level of intrinsic inflation persistence. Moreover, expectations-based inflation persistence is found to be higher in these countries than in the EAC, which contributes to a long-lasting difference between the inflation target pursued by the central bank and public inflation expectations.

In addition, the model with a time-varying mean demonstrates why inflation persistence measures, usually employed in the case of developed countries, produce biased results in the case of the NMS. We show that in general, the estimated perceived inflation target that plays the role of a time-varying mean does not exhibit breaks for the EAC. On the other hand, breaks in the mean are frequent and significant for the NMS. Inflation persistence measures, therefore, provide upward biased measures in the case of the NMS.

Finally, we also discuss whether inflation processes in the NMS are represented better as a stationary process with parameter instability (a time-varying mean) or as a fractionally integrated process. These processes both imply mean reversion and hence can look very similar. Despite looking similar, they can imply different inflation persistence levels. Although empirical results based on the ARFIMA model suggest that persistence in some NMS may be higher than indicated by models with a time-varying mean, additional statistical tests imply that assuming a stationary process with breaks is preferable to using fractionally integrated models for almost all the countries considered.

The structure of the paper is as follows. Section 2 reviews the available literature on the topic, with a special emphasis on the relevance of inflation persistence in the NMS. Section 3 describes stylized facts and the two adopted statistical approaches to measuring and estimating inflation persistence. Section 4 reports on and discusses the results of these alternative estimates. Section 5 concludes. On the web-site of this journal (http://journal.fsv.cuni.cz/) you can find the *Appendixes 1–3*. Appendix 1 includes plots of inflation rates for all the sample countries; Appendix 2 provides the complete results of the Bayesian estimation of the time-varying mean model. Appendix 3 presents estimates of the perceived inflation targets.

2. Related Literature

In this section, we briefly review key theoretical concepts that can be employed to model the inflation process and to measure inflation persistence. We focus on those concepts which are relevant to the NMS. Then we discuss the major empirical results related to the NMS. It is important to note that not all concepts look at inflation persistence from the same angle. Specifically, some measures separate the impact of persistence in nominal contracts on inflation from the impact of persistence in the real economy (intrinsic and extrinsic inflation persistence) and also from the impact of inflation expectations and monetary policy regime changes.

A possible distinction between the models used for measuring inflation persistence can be drawn between statistical and structural approaches. Statistical measures of inflation persistence are usually based on a univariate representation of the inflation process. Marques (2004) provides a summary of such measures, e.g., measures based on the sum of autoregressive coefficients, the largest autoregressive root, half-life, and spectral density at frequency zero. Inflation persistence measures based on the structural models of inflation usually deal with some specification of the Phillips curve. Calvo (1983) introduces a model of nominal price rigidities where only a fraction of firms can adjust their prices in a given period. The Calvo model leads to a forward-looking reduced-form specification, and the persistence in inflation originates from the persistence in inflation-driving variables (e.g., the output gap, real marginal costs). This type of inflation persistence is denoted as extrinsic inflation persistence.

Since the models based on the Calvo structural approach have proved, in terms of data fit, inferior to models that incorporate a lagged value of inflation, some attempts have been made to extend the Calvo model to include backward-looking behavior of firms. Within the Calvo framework, Galí and Gertler (1999) assume that a fraction of backward-looking firms set their prices according to prices in the previous period, adjusted for inflation. Christiano, Eichenbaum, and Evans (2005) incorporate a backward-looking term by assuming indexation of prices to inflation in the previous period for firms not chosen to re-optimize in a given period. The resulting hybrid versions of the New Keynesian Phillips curve (NKPC) introduce a new type of inflation persistence that originates in the price-setting process itself and thus is qualitatively different from extrinsic inflation persistence. Inflation persistence that stems from the way wages and prices are set is called intrinsic inflation persistence.[3]

More recently, the question has arisen whether the intrinsic inflation persistence captured by the lagged values of inflation is spurious (see, for example, Sbordone, 2007). Within this debate, the attention of researchers has turned to the role of the inflation trend for modeling the inflation process and for measuring inflation persistence. Regardless of whether recent models take the form of the NKPC or are purely statistical, the focus is on the process assumed for the inflation trend, on the interpretation of inflation trend changes, and on the implications for the persistence of inflation.

Marques (2004) considers several treatments for the inflation trend that is represented by a time-varying mean of inflation. For U.S. and euro area inflation, he applies an HP filter and a moving average. Dossche and Everaert (2005) model the time-varying mean as an AR(2) process. Stock and Watson (2007) and Cogley, Primiceri, and Sargent (2008) assume a trend following a driftless random walk. In addition to Dossche and Everaert, they also impose stochastic volatility in the inflation trend. Finally, Cogley and Sbordone (2006) derive the NKPC by log-linearization of the Calvo model specification around the time-varying trend. This procedure leads to a NKPC with time-varying coefficients.

The models with a time-varying inflation trend introduce another type of inflation persistence that stems from changes in trend inflation. In general, the papers

[3] The structural character of the hybrid version of the New Keynesian Phillips curve has been questioned on the grounds of micro-evidence. It turns out, for example, that individual prices remain unchanged for several periods, contradicting the assumption of Christiano et al. (2005) on the indexation of prices.

mentioned in the previous paragraph find trend inflation to be an important contributor to overall inflation persistence. Moreover, some of the papers identify a significant influence of monetary policy on changes in the inflation trend.

Bilke (2005) and Dossche and Everaert (2005) discuss the role of monetary policy changes for the inflation mean – the unobserved component model of Dossche and Everaert includes the central bank's inflation target. The inflation mean follows a process dependent on the target. Mishkin (2007), Cecchetti, Hooper, Kasman, Schoenholtz, and Watson (2007), Sbordone (2007), Stock and Watson (1997), and Benati (2008) also discuss the significant influence of monetary policy on the decrease of overall inflation persistence in developed countries over the last two decades. Finally, note that it is not only monetary policy regime changes that are examined as a source of change in the inflation trend. Gadzinski and Orlandi (2004) and Levin and Piger (2004), for example, focus on the influence of administrative price changes on the mean of inflation.

Another stream of literature investigating inflation persistence employs a fractionally integrated process[4] to model inflation, e.g., Gadea and Mayoral (2006) and Kumar and Okimoto (2007). The motivation stems from the fact that the literature provides substantial evidence against inflation following both an I(0) and I(1) process. The common explanation is that this is the result of structural breaks in the time series. However, the other alternative is that the inflation series follow a fractionally integrated or ARFIMA process. As Gadea and Mayoral (2006) suggest, stationary processes with structural breaks and fractionally integrated processes can be easily confused, and so subsequent testing between the two approaches is necessary.

As already mentioned in the introduction, so far most of the available research on inflation persistence in the NMS is based on disaggregated-level data and on a limited sample of countries (the Czech Republic, Hungary, Poland, and Slovakia). Disaggregated-level data analyses are available for the Czech Republic in Babetskii, Coricelli, and Horváth (2006), for Hungary in Ratfai (2006), for Poland in Konieczny and Skrzypacz (2005), and for Slovakia in Coricelli and Horváth (2006). They all work with one-country data sets and this makes any international comparisons rather difficult.

Macro studies are even fewer than those based on disaggregated data. Two studies focus on a selected group from the NMS. They both work with statistical models of persistence. Darvas and Varga (2007) suggest using time-varying-coefficient models and the Flexible Least Squares estimator in order to estimate inflation persistence in the Czech Republic, Hungary, Poland, and Slovakia. They argue similarly to the second study (Franta, Saxa, and Šmídková, 2007) that models with time-varying coefficients are vital for inflation persistence analysis in the NMS. The two studies concur that inflation persistence in the NMS, at least the selected ones, is not very different from that in the EAC. In addition, Franta, Saxa, and Šmídková (2007) propose to look at the most likely causes of inflation persistence by using models that are capable of distinguishing between intrinsic and extrinsic persistence on the one hand and persistence related to monetary policy and expectations

[4] Baillie, Chung, and Tieslau (1996) surveys the applications of fractionally integrated processes in economics and finance. Applications for inflation time series, although predominantly for forecasting purposes, can be found in Baillie et al. (1996), Doornik and Ooms (2004), and Gabriel and Martins (2004).

on the other hand. This distinction might be useful to policy makers when they try to lower inflation persistence.

Moderate inflation persistence differences represent of course only one important factor in the fulfilling the Maastricht criterion on inflation and convergence within the euro area. Other streams of literature focus on alternative factors. Specifically, problems with convergence are related to rigidities inherited from the past and higher inflation expectations stemming from the chosen disinflation strategy in Bulíř, Hurník (2009), and to country-specific shocks and a lack of financial sector integration in Stavrev (2007). Empirical findings from alternative literature streams are useful complements. For example, both situations (i) moderate inflation persistence differences and large repeated country-specific shocks as well as (ii) significant inflation persistence differences and no country-specific shocks will lead to problems with convergence. While other factors have been covered by literature, the inflation persistence differences in the NMS have not been researched sufficiently yet.

3. Stylized Facts and Models for Estimating Inflation Persistence

In this section, we provide a data description and basic stylized facts on inflation in the NMS. We then discuss the two models we employ for the measurement of inflation persistence: the time-varying mean model and the ARFIMA model.

3.1 Description of Data Used in This Study

We work with two groups of countries. The first group of NMS consists of the 12 countries that joined the EU in 2004 and 2007: Bulgaria, Cyprus, the Czech Republic, Estonia, Hungary, Latvia, Lithuania, Malta, Poland, Romania, Slovakia, and Slovenia. The second group of selected EAC – the control group – consists of 4 countries: Belgium, Germany, Portugal, and Spain. For the sake of simplicity, we report the results not for all EAC, but only for the selected four countries, which represent interesting case studies from the point of view of the NMS. Specifically, Belgium is a developed, small, open economy of comparable size to most of the NMS. Germany is viewed by many as the country that anchors inflation in Europe. Portugal and Spain are small, open, converging economies that are facing, in terms of the inflation persistence, similar issues to those that the NMS may encounter in forthcoming years. We do not compare the NMS with the euro area as a whole because euro area inflation aggregates can suffer from aggregation bias.[5] The abbreviations of the countries used in the text, the number of observations available for the analysis, and the corresponding time spans are reported in *Table 1*.

The data for CPI inflation are taken from the International Financial Statistics prepared by the International Monetary Fund (IFS). We use the seasonally adjusted, annualized q-o-q rate of change of CPI, computed as $400*\ln(CPI_t / CPI_{t-1})$ Figures depicting the inflation rates for all the countries can be found in *Appendix 1*.

3.2 Some Stylized Facts: Inflation in the NMS

In the last 15 years, inflation rates have been higher in the NMS than in the EAC. *Table 2* provides the inflation rates for the period 1993Q2–2008Q1 and

[5] For a discussion of the effect of aggregation on inflation persistence differentials in the euro area, see Fiess and Byrne (2007).

TABLE 1 Country Abbreviations and Time Spans

Country	Abbreviation	Observations	Period
Bulgaria	BUL	68	1991Q2–2008Q1
Cyprus	CYP	72	1990Q2–2008Q1
the Czech Republic	CZE	60	1993Q2–2008Q1
Estonia	EST	64	1992Q2–2008Q1
Hungary	HUN	72	1990Q2–2008Q1
Latvia	LAT	68	1991Q2–2008Q1
Lithuania	LIT	63	1992Q3–2008Q1
Malta	MAL	72	1990Q2–2008Q1
Poland	POL	72	1990Q2–2008Q1
Romania	ROM	69	1991Q1–2008Q1
Slovakia	SVK	60	1993Q2–2008Q1
Slovenia	SLO	64	1992Q2–2008Q1
Belgium	BEL	72	1990Q2–2008Q1
Germany	GER	68	1991Q2–2008Q1
Spain	ESP	72	1990Q2–2008Q1
Portugal	POR	72	1990Q2–2008Q1

Table 2 Inflation Means (%)

Period	BUL	CZE	EST	HUN
1993Q2–2008Q1	36	5	10	11
2001Q1–2008Q1	6	3	5	6
	LAT	LIT	POL	ROM
1993Q2–2008Q1	10	13	10	34
2001Q1–2008Q1	6	3	3	12
	SVK	SLO	MAL	CYP
1993Q2–2008Q1	7	8	3	3
2001Q1–2008Q1	5	5	2	3
	BEL	GER	ESP	POR
1993Q2–2008Q1	2	2	3	3
2001Q1–2008Q1	2	2	3	3

Source: Author's calculations based on IMF IFS database.

the sub-period 2001Q1–2008Q1. These are samples available for all the analyzed countries, as documented by *Table 1*. Two observations are worth noting. First, the difference in inflation means between the NMS and the EAC has been decreasing over time. While the inflation rates do not change for the EAC if we restrict the sample to the sub-period 2001Q1–2008Q1, they decrease considerably for almost all the NMS. Second, the NMS are not a homogeneous group. They started the EU accession process with very different inflation rates. In the last 15 years, two NMS (Bulgaria and Romania) had inflation above 20% on average; five NMS (Estonia, Hungary, Latvia, Lithuania, and Poland) faced moderate inflation of 10–20%; three NMS (the Czech Republic, Slovakia, and Slovenia) achieved inflation relatively close to the EU average (5–10%); and two NMS (Cyprus and Malta) had inflation rates fully converging to euro area inflation.

Table 3 The Crosses of Inflation Means (% of quarters)

Period	BUL	CZE	EST	HUN
1993Q2–2008Q1	7	23	7	5
2001Q1–2008Q1	45	21	41	21
	LAT	LIT	POL	ROM
1993Q2–2008Q1	3	2	5	12
2001Q1–2008Q1	10	17	14	3
	SVK	SLO	MAL	CYP
1993Q2–2008Q1	25	35	52	40
2001Q1–2008Q1	17	52	55	52
	BEL	GER	ESP	POR
1993Q2–2008Q1	40	17	30	30
2001Q1–2008Q1	59	21	48	41

Source: Author's calculations based on the IMF IFS database.

Inflation rates in the NMS were affected by various factors connected with economic transition, real convergence, EU accession, and various external shocks. Most typically, transition factors and EU accession affected inflation in the NMS in the first two-thirds of our data sample. For example, price deregulation and tax reforms, including harmonization of taxes and excise duties, were among the common shocks contributing to higher inflation in that period. A more detailed analysis can be found in EBRD (1999).

Table 3 illustrates why it is so important to take into account specific attributes of inflation processes in the NMS when putting the definition of inflation persistence into practice. If we assume a model with a constant mean, then an inflation series that does not frequently oscillate around its statistical mean would be suspected of having high persistence.[6] To find out which NMS would fit into this category, we compute the number of times that each national inflation series switched from above to below its mean and vice versa. We consider the inflation mean over the period 1993Q2–2008Q1 and its sub-period 2001Q1–2008Q1.

There are two observations that we would like to emphasize. First, the inflation series for the NMS that are former transition economies cross their means less frequently than the inflation series for the control group – the EAC. Second, once we restrict the sample by removing the first half, during which inflation was most affected by transition and real convergence factors, and once we consider the second half of the sample (2001Q1–2008Q1) only, the means are more similar.

3.3 The Time-Varying Mean Model

To examine the persistence of inflation, we have set up a simple statistical model that reflects the recent studies which deal with the modeling of the inflation process. The model is univariate and incorporates permanent (trend) and transitory components. Moreover, it enables the distinction of intrinsic and expectations-based inflation persistence. Intrinsic inflation persistence relates to nominal rigidities and to

[6] Marques (2004) formally demonstrates the inverse relationship between inflation persistence and mean reversion in the case where the inflation process is modeled as an autoregressive process of order *k*.

the way wages and prices are set. Expectations-based inflation persistence is driven by the differences between public perceptions about the inflation target and the central bank's true (explicit or implicit) inflation target.[7] Since the model is univariate, it cannot capture extrinsic inflation persistence. The measures of real activity in the NMS are, at least for the beginning of the period considered, of questionable quality, so we do not attempt to incorporate them into the model for the purpose of extending it for measuring extrinsic inflation persistence.[8]

The model specification is close to the univariate version introduced in Dossche and Everaert (2005). Basically, the model specification consists of three equations.

$$\pi_{t+1}^{T} = \pi_{t}^{T} + \eta_t \qquad (1)$$

$$\pi_{t+1}^{P} = (1-\delta)\pi_{t}^{P} + \delta\pi_{t+1}^{T} \qquad 0 < \delta < 1 \qquad (2)$$

$$\pi_t = \left(1 - \sum_{i=1}^{4}\varphi_i\right)\pi_t^{P} + \sum_{i=1}^{4}\varphi_i\pi_{t-i} + \varepsilon_t \qquad \sum_{i=1}^{4}\varphi_i < 1 \qquad (3)$$

where π_t^T is the central bank's inflation target, π_t^P is the inflation target as perceived by the public, and disturbances η_t and ε_t are mutually independent, zero-mean, white noise processes.

In the first equation, the central bank's inflation target is modeled as a random walk and thus represents a permanent component of the modeled inflation process. It is a common practice nowadays to assume that inflation target changes have a permanent effect (see, for example, Leigh, 2005). The model assumes a random walk for the inflation target even if the central bank does not target inflation explicitly. On the other hand, if a country has adopted inflation targeting (e.g. the Czech Republic in 1997/98), we do not impose the known targets into the model.

The second equation describes the relationship between the central bank's inflation target and the target as perceived by the public. The public forms its inflation expectations based on the current inflation target announced by the central bank and on the public's expectations in the previous period. Parameter δ represents the weight on the two sources. A similar specification of inflation expectations is assumed, for example, in Bomfim and Rudebusch (2000).

Parameter δ captures the expectations-based inflation persistence – the persistence that relates to how long a central bank's inflation target and the public's inflation expectations can differ after a shock occurs to the central bank's inflation target. In the framework of heterogeneous agents, δ denotes the fraction of the forward-looking public. It could also be interpreted as a parameter capturing the credibility of the central bank. Values close to 1 indicate that changes in the inflation target pass immediately into the public's inflation expectations.

The third equation imposes an autoregressive structure on the level of inflation. The time-varying mean is represented by the perceived inflation target. The sum of autoregressive coefficients captures the intrinsic inflation persistence.

[7] For details of the definitions see Angeloni, Aucremanne, Ehrmann, Gali, Levin, and Smets (2006).

[8] The influence of real activity terms on inflation is captured by the unobserved component of the model.

The model, (1)–(3), was originally set up to measure inflation persistence net of monetary policy actions. However, in the case of the NMS, a component modeled as a random walk captures many other influences. Apart from changes in monetary policy (e.g. monetary policy regime switch), processes such as administrative price changes, deregulation, and price convergence can be viewed as processes affected by shocks with permanent effects. The interpretation of our estimates, therefore, is broader than in the original model, and we recall this in the section describing the estimation results.

Putting one-period-lagged equation (2) into equation (1) and the resulting equation back into equation (2) yields:

$$\pi_t = \left(1 - \sum_{i=1}^{q} \varphi_i\right)\pi_t^P + \sum_{i=1}^{q} \varphi_i L^i \pi_t + \varepsilon_t \qquad \varepsilon_t \sim N\left(0, \sigma_\varepsilon^2\right) \tag{4}$$

$$\pi_{t+1}^P = (2-\delta)\pi_t^P + (\delta - 1)\pi_{t-1}^P + \delta\eta_t \qquad \eta_t \sim N\left(0, \sigma_\eta^2\right) \tag{5}$$

Since the system (4)–(5) includes an unobservable component (π_t^P), we transform it into a state space form and use state space analysis methods. The state space form follows:

$$\begin{bmatrix} \pi_{t+1}^P \\ \pi_t^P \end{bmatrix} = \begin{bmatrix} 2-\delta, \delta - 1 \\ 1, 0 \end{bmatrix} \begin{bmatrix} \pi_t^P \\ \pi_{t-1}^P \end{bmatrix} + \begin{bmatrix} \delta \\ 0 \end{bmatrix} \eta_t \tag{6}$$

$$\pi_t = \left[\left(1 - \sum_{i=1}^{4} \varphi_i\right), 0\right] \begin{bmatrix} \pi_t^P \\ \pi_{t-1}^P \end{bmatrix} + \sum_{i=1}^{4} \varphi_i \pi_{t-i} + \varepsilon_t \tag{7}$$

To estimate the unobservable series of perceived inflation π_t^P, we use the exact initial Kalman filter (the case of unknown initial conditions) as described, for example, in Koopman and Durbin (2003). The Kalman filtering assumes known coefficients; therefore, we have to estimate them before we employ the filtering procedure on the system (6)–(7).

An estimation of the parameter vector $\theta = \left[\delta, \varphi_1, \varphi_2, \varphi_3, \varphi_4, \sigma_\varepsilon^2, \sigma_\eta^2\right]$ is carried out using Bayesian estimation techniques. The advantage of Bayesian estimation is that it exploits the maximum of the available information. We do not build our estimates solely on the information in data (Y) as the maximum likelihood approach does. On the other hand, we do not rely on information from other sources only, as in the case of a model calibration. So, we combine the information contained in the data on inflation with the information provided by other studies that deal with similar issues. We avoid the problem of unrealistic estimates sometimes obtained with the maximum likelihood estimation procedure. Moreover, we do not suffer from the low amount of related work for the NMS, which would provide insufficiently reliable values for the parameters.

The basic idea behind Bayesian estimation stems from Bayes' theorem:

$$p(\theta \mid Y) = \frac{p(Y \mid \theta) p(\theta)}{p(Y)} \tag{8}$$

Table 4 Priors

Parameter	Distribution	Mean	Std. dev.
φ_1	Beta	0.2	0.3
φ_2	Beta	0.1	0.3
φ	Beta	0.05	0.3
φ_4	Beta	0.05	0.3
δ	Beta	0.15	0.2
σ^2_ε	Inverse Gamma	2.0	Inf
σ^2_η	Inverse Gamma	0.5	Inf

This says that the posterior distribution of parameters, $p(\theta \mid Y)$, is proportional to the product of the likelihood of the data given the parameter vector, $p(Y \mid \theta)$, and the prior distribution $p(\theta)$. The product, the posterior kernel, is then normalized by the marginal data density, computed as

$$p(Y) = \int_{\Theta} p(\theta, Y) d\theta = \int_{\Theta} p(\theta) \times p(Y \mid \theta) d\theta \tag{9}$$

where the integrand is integrated over the whole parameter space Θ.

The likelihood function $p(Y \mid \theta)$ is estimated by using the Kalman filter, and the posterior kernel is simulated by using the Metropolis Hastings sampling algorithm. For a detailed explanation of Bayesian estimation, see, for example, An and Schorfheide (2006).

Following Dossche and Everaert (2005), we take the priors $p(\theta)$ from several studies that use various estimation techniques and underlying models to estimate particular parameters. The prior for the sum of the autoregressive coefficients (intrinsic inflation persistence) is taken from Gadzinski and Orlandi (2004) and Levin and Piger (2004), i.e., from studies that take into account breaks in the inflation mean. These studies are, however, focused on developed countries. For the NMS, we therefore use prior distributions with higher standard deviations to reflect the higher uncertainty in the priors regarding the NMS. Similarly, we assume higher variances of shocks than Dossche and Everaert (2005), since the NMS have been facing structural changes and a more volatile economic environment in general. The original variances of the shocks to the inflation target and inflation are taken from Kozicki and Tinsley (2003) and Smets and Wouters (2005).

Finally, the prior for parameter δ is taken from studies dealing with signal extraction (Erceg and Levin, 2003; Kozicki and Tinsley, 2003) and sticky information (Mankiw and Reis, 2002). The distribution of the priors, the prior means, and the standard deviations are reported in *Table 4*.

The estimation is carried out using the Matlab toolbox Dynare.[9] We simulate the posterior distribution using five blocks of the Metropolis Hastings algorithm with 20,000 replications. The acceptance ratio is between 0.2 and 0.4.[10] The results of

[9] For details on Dynare see http://www.cepremap.cnrs.fr/dynare/.

[10] Note that an acceptance ratio of between 0.2 and 0.4 is recommended in order for the simulations to cover the parameter space reasonably.

the Metropolis Hastings algorithm are assessed based on Brooks and Gelman (1998). Details are provided in the section dealing with the estimation results. Finally, note that the time series for inflation and the inflation target are used as data for the estimation. The inflation target is an HP filtered time series of inflation. The HP filtering parameter is equal to 1,600, as this is typical for quarterly data.

3.4 ARFIMA Models

As outlined earlier in this paper, not accounting for structural breaks in an inflation time series can lead to upward bias in the inflation persistence estimates. However, as Gadea and Mayoral (2006) suggest, stationary processes with breaks and fractionally integrated processes can resemble each other, and it can be difficult to distinguish between them. Therefore, we follow the approach of Gadea and Mayoral (2006) and model the inflation series of the NMS and EAC as a fractionally integrated process.

The time series π_t follows the ARFIMA(p,d,q) process if

$$\phi(L)(1-L)^d \pi_t = \theta(L)\varepsilon_t \tag{10}$$

where d is a fractional differencing parameter, $\varphi(L) = 1-\varphi_1 L - \varphi_2 L^2 - \ldots - \varphi_p L^p$ is an autoregressive polynomial, $\theta(L) = 1-\theta_1 L - \theta_2 L^2 - \ldots - \theta_q L^q$ represents a moving average polynomial, the roots of $\varphi(L)$ and $\theta(L)$ lie outside the unit circle, and ε_t is white noise.

Baillie et al. (1996), Baum, Barkoulas, and Caglayan (1999), and Gadea and Mayoral (2006) argue that the ARFIMA model can be an appropriate representation of the stochastic behavior of inflation time series for many countries. The family of ARFIMA models allows a high degree of persistence without assuming the presence of a unit root. On the other hand, modeling the inflation process within the ARFIMA framework does not allow for distinguishing between the types of inflation persistence identified by the time-varying mean models.

In the first step, we follow Gadea and Mayoral (2006) and estimate the fractional differencing parameter d using Geweke and Porter-Hudak's technique.[11] Parameter d indicates how long a shock affects the process. A value of d equal to zero describes a short memory process, and $|d| \in (0, 0.5)$ implies a long memory process. If $d \in [0.5,1)$, shocks are transitory and the variance of the process is unbounded. The process, however, still exhibits mean reversion. Finally, if $d \geq 1$, the effect of a shock is permanent.

Based on the estimated value of parameter d, we estimate the impulse response function of ARFIMA (0,d,0).[12] To compare the persistence of shocks in the time series, we report the values of the impulse response function for the time horizons of 4 and 12 quarters after the realization of a shock.

[11] Geweke and Porter-Hudak's technique is a semi-parametric approach based on spectral regression. It is implemented in STATA by Baum and Wiggins (1999).

[12] The impulse response function measures the effects of the realization of a shock on subsequent values of the time series. We used the STATA implementation for ARFIMA written by Baum (2000).

In the next step, we test the hypothesis of a time series following a fractionally integrated process of order d versus a stationary process with breaks, proposed in Mayoral (2004). In order to reflect the convergence process observed in the inflation time series of the NMS, we allow for a break in both level and trend. The test statistics have the following form:

$$R(d) = T^{1-2d} \frac{\inf_{\omega \in \Omega} \left(\sum \left(\pi_t - \hat{\alpha}_1 - \hat{\delta}_1 DC_t - \hat{\beta}_1 t - \hat{\delta}_2 DT_t \right)^2 \right)}{\sum \left(\Delta^d \left(\pi_t - \hat{\alpha}_0 - \hat{\beta}_0 t \right) \right)^2} \tag{11}$$

where T is the number of periods, $\Omega = [0.15, 0.85]$ are trimming thresholds, $DC_t = 1$ if $t>\omega T$ and 0 otherwise, and $DT_t = (t-T_B)$ if $t>\omega T$ and 0 otherwise. α_0, α_1, β_0, β_1, δ_1, and δ_2 are coefficients from the appropriate regressions. Δ^d is the operator of differencing of order d. Critical values are computed according to Mayoral (2004). The null hypothesis assumes a fractionally integrated process while the alternative hypothesis assumes a stationary process with breaks.

4. Results

In this section, we provide the estimation results for the inflation persistence measures introduced in the previous sections. First, we report the estimates of intrinsic and expectations-based inflation persistence based on the time-varying mean model. Second, we discuss the estimates obtained from the ARFIMA model.

4.1 Time-Varying Mean Models

In this sub-section, we present the estimation results of the statistical model introduced in Section 3.3. The model allows for the inflation mean to change over time. Thus, it enables us to measure inflation persistence net of the effects of monetary policy, administrative price changes, price convergence, etc. We discuss the estimation results obtained using Bayesian estimation techniques. Moreover, we touch upon the robustness of the results regarding the model specification. Finally, we also present graphically the estimates of the unobserved components of the model.

The complete results can be found in *Appendix 2*. Prior distributions and posterior means with 90% confidence intervals are reported for all coefficients and countries. Furthermore, in the appendix we also discuss the performance of the Metropolis-Hastings algorithm and the tools we employ to strengthen the reliability of the estimation results.

Here we confine ourselves to the measures of the intrinsic and expectations-based inflation persistence. Intrinsic inflation persistence is captured by the sum of the autoregressive coefficients on the lagged values of inflation, $\sum \varphi_i$, and expectations-based persistence by coefficient δ. *Table 5* suggests several general differences between and within the groups of countries.

The selected EAC exhibit a very low or even negative level of intrinsic inflation persistence.[13]

For the group of NMS, the results are more diverse. The NMS can be divided into three sub-groups with respect to the extent of intrinsic inflation persistence. The first sub-group of countries (Bulgaria, the Czech Republic, Romania, and Slo-

Table 5 Intrinsic and Expectations-Based Inflation Persistence

Country	$\Sigma\varphi_i$	δ
BUL	0.24	0.23
CZE	0.10	0.31
EST	0.91	0.19
HUN	0.92	0.17
LAT	0.94	0.13
LIT	0.94	0.12
POL	0.99	0.13
ROM	0.43	0.29
SVK	0.29	0.25
SLO	0.94	0.13
MAL	-0.30	0.30
CYP	-0.44	0.25
BEL	0.08	0.33
GER	-0.28	0.40
ESP	0.07	0.33
POR	-0.49	0.45

Note: Complete results are reported in *Appendix 2*.

vakia) attains similar or slightly higher levels of intrinsic inflation persistence than the selected EAC. The inflation process in the second sub-group of countries (Estonia, Hungary, Latvia, Lithuania, Poland, and Slovenia) follows an almost unit root process even though we impose non-stationarity in the process for the inflation mean. Finally, for Malta and Cyprus, we observe a level of intrinsic inflation persistence comparable to the group of EAC. All coefficients φ_i are not, for example, statistically different from zero for Cyprus.

Within the framework of our model, the negative estimates of intrinsic inflation persistence suggest that inflation after a shock converges to its long-run value oscillating around the value. In the case of a positive value, inflation decays without exhibiting this oscillating pattern.[14]

The NMS and EAC also differ in terms of expectations-based inflation persistence. The estimated values of coefficient δ are lower for the NMS than for the selected EAC. The cross-country differences are often statistically significant (e.g. Latvia, Lithuania, and Slovenia vs. Germany and Portugal) – see the 90% confidence intervals in *Appendix 2*. It is worth noting that δ can be viewed as a measure of the public's tendency to be forward looking. Therefore, countries with low δ can be viewed as having a high fraction of backward-looking members of the public. So, changes in

[13] Note that DYNARE provides confidence intervals for single coefficients φ_i only, not for the whole sum. Since the intrinsic inflation persistence is captured by the sum of the coefficients, it is difficult to conclude anything about the statistical significance of the estimated measure of intrinsic inflation persistence. On the other hand, the confidence intervals for single φ_is provide some evidence. For coefficient δ, we obtain a confidence interval directly.

[14] Note that since we use a statistical model of inflation, the negative values are not in conflict with any optimization problem on the micro level. This would be a problem in the case of a negative sum of the coefficients in structural measures based, for example, on some specification of the New Keynesian Phillips curve.

the random walk component of the model pass into public inflation expectations very slowly – the country exhibits a high level of expectations-based inflation persistence.

There are also differences among the NMS themselves. Again, some of the differences are statistically significant (e.g. the Czech Republic vs. Latvia). The Czech Republic, Romania, Slovakia, Malta, and Cyprus exhibit estimates of δ close to the values estimated for the selected EAC. On the other hand, some countries have δ close to zero, hence they face problems with anchoring inflation expectations (Latvia, Lithuania, Poland, and Slovenia).

In order to assess the effect of the model specification on the estimated values, we estimate two extensions of the benchmark model. First, we estimate the model from Dossche and Everaert (2005), i.e., the model where the inflation target is unobservable. We encounter a problem with identifying coefficient δ. Intuitively speaking, the coefficients on the lagged values of inflation are identified since they appeared on the observable variables (lagged values of inflation). The time-varying mean, however, consists of two unobserved components (the central bank's inflation target and the perceived inflation target). Therefore, the parameter representing the relationship between the two unobserved components need not be identified. The posterior distribution of δ closely follows the prior distribution, which may indicate a lack of identification. Therefore, we view the results of the benchmark model as more reliable. We also impose an autocorrelation structure on the disturbance η_t; the results of main interest do not change significantly.[15]

The model with estimated parameters can be re-formulated into a state space form (see system (6)–(7) in Section 3.3) and the exact initial Kalman filter method can be used to estimate the unobservable components of the system. One has to bear in mind that we do not know the exact parameter values and must work with estimates. So, the information value of the filtering exercise is lowered because of the state space model parameter uncertainty. The purpose of the filtering, however, is to point out the various profiles of the unobserved component – the perceived inflation target – for various countries. For that purpose, our knowledge of the parameter estimates is sufficient.

Figures 1–3 show the inflation rate and the filtered perceived inflation target for several countries from our sample. We present countries that represent each sub-group discussed above. Germany represents the EAC that have almost negligible intrinsic inflation persistence and a low level of expectations-based inflation persistence. Slovakia is a member of the sub-group of the NMS that exhibits a moderate level of intrinsic inflation persistence, and Hungary represents the high intrinsic inflation persistence countries with a high fraction of backward-looking members of the public. Note that the perceived inflation target serves as a time-varying mean of the inflation process and follows a non-stationary AR(2) process.

First note that we do not report the results of the filtering exercise for the whole period of available data. The exact initial Kalman filter method assumes infinite variances for the initial values of the unobserved components of the system. The confidence intervals for the perceived inflation target are therefore very large for the few first observations, and we focus on a sub-period with a reasonable width of confidence intervals for the unobserved variable.

[15] We do not report the results here. They are, however, available upon request.

Figure 1 Inflation and the Perceived Inflation Target: Germany

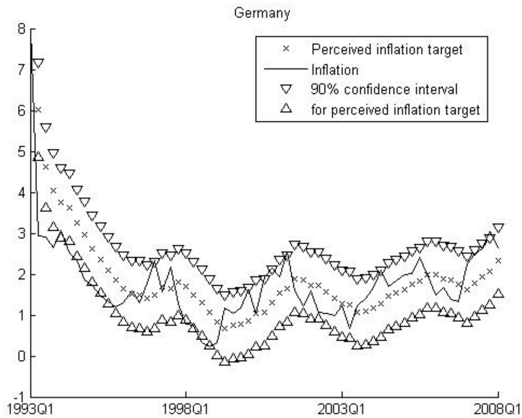
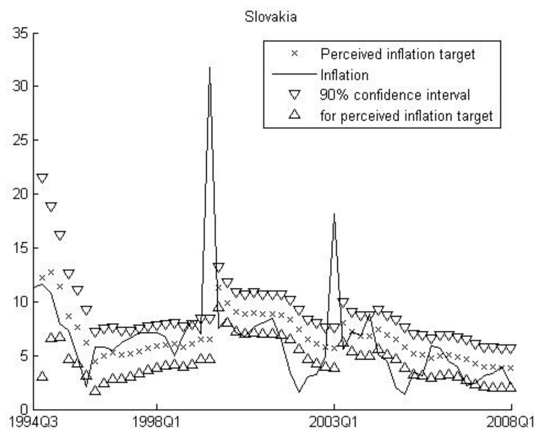


Figure 2 Inflation and the Perceived Inflation Target: Slovakia



The figures demonstrate what the recent literature has put forward as a problem in the measurement of inflation persistence and what we thoroughly discussed for the NMS above. Structural breaks in the economy lead to breaks in the inflation mean and consequently to bias in persistence measures built on models with a constant mean. While perceived inflation targets do not exhibit clear breaks for Germany, a few statistically significant breaks are observable for Slovakia, and the difference in the perceived inflation target over time attains almost 30 percentage points in Hungary.[16] So, standard measures are not appropriate for the NMS, and more flexible models of the inflation process should be employed to avoid such biased results.

In addition, the Kalman filtering results can capture the effect of introducing inflation targeting on the public's inflation expectations. *Figure 4* shows the evolution of the public's inflation expectations (perceived inflation target) for the Czech

[16] On the other hand, the confidence interval for the Hungarian perceived inflation target is very wide.

Figure 3 Inflation and the Perceived Inflation Target: Hungary

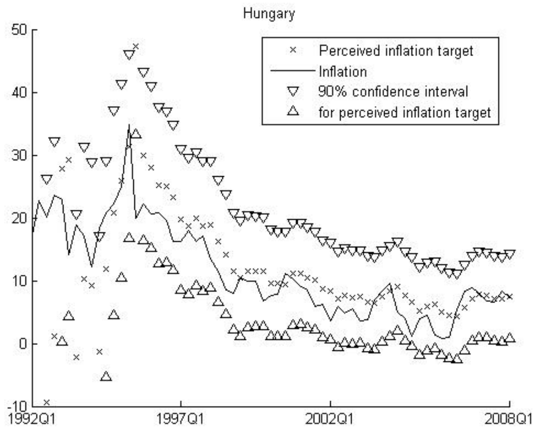
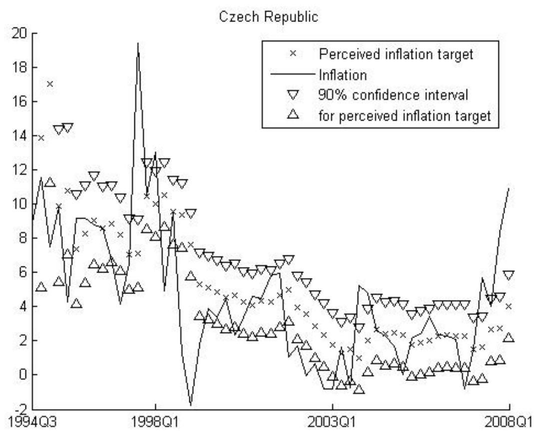


Figure 4 Inflation and the Perceived Inflation Target: the Czech Republic



Republic. The Czech Republic has been targeting inflation since 1998. According to our estimates, expectations reached the level of the announced target (3%) in 5 years and have been close to it since then. Recently, an upsurge can be observed as a consequence of higher energy and food prices and changes in indirect taxes.

The figures for the rest of the NMS and EAC are presented in *Appendix 3*.

4.2 The ARFIMA Model

In this section, we present estimation results based on the assumption that the inflation series follow a fractionally integrated process. The estimate of the parameter of fractional differencing d along with its standard error are reported in the second and the third column of *Table 6*. The last two columns of this table show the values of the impulse response function for the time horizons of 4 and 12 quarters after the realization of a positive shock of a size equal to one.

Table 6 The Estimation of the Fractional Differencing Parameter *d* and the Value of the Impulse Response Function in Selected Time Horizons

Country	*d*	SE(*d*)	IPF(4)	IPF(12)
BUL	0.19	0.11	0.07	0.03
CZE	0.50	0.37	0.28	0.16
EST	0.99	0.19	0.98	0.97
HUN	1.71	0.63	2.94	6.41
LAT	1.34	0.12	1.80	2.61
LIT	0.62	0.08	0.41	0.27
POL	1.20	0.10	1.44	1.79
ROM	0.40	0.31	0.20	0.10
SVK	0.42	0.67	0.21	0.11
SLO	0.90	0.22	0.81	0.72
MAL	-0.03	0.41	0.01	0.00
CYP	0.07	0.35	0.02	0.01
BEL	0.43	0.37	0.22	0.12
GER	0.84	0.51	0.72	0.60
ESP	1.01	0.43	1.02	1.03
POR	0.11	0.59	0.03	0.01

Table 7 Test of Fractional Integration of the Order *d* versus a Stationary Process with Breaks

Country	0.6	0.8	1	1.2
BUL	**0.293** ***	0.051 *	0.009 ***	0.001 ***
CZE	**0.346** **	0.062	0.011 ***	0.002 ***
EST	0.399	0.089	**0.018** *	0.003 ***
HUN	0.549	0.104	0.018	**0.003** ***
LAT	0.231 ***	0.085	0.026	**0.006** ***
LIT	**0.946**	0.104	0.012 ***	0.002 ***
POL	0.431	0.088	0.016 **	**0.003** ***
ROM	**0.492**	0.109	0.022	0.004 ***
SVK	**0.337** **	0.056	0.009 ***	0.001 ***
SLO	0.285 ***	0.049 **	**0.008** ***	0.001 ***
MAL	**0.287** ***	0.047 **	0.007 ***	0.001 ***
CYP	**0.296** ***	0.049 **	0.008 ***	0.001 ***
BEL	**0.280** ***	0.046 **	0.007 ***	0.001 ***
GER	0.525	**0.106**	0.019	0.003 ***
ESP	0.313 ***	0.053 *	**0.009** ***	0.001 ***
POR	**0.342** **	0.060	0.010 ***	0.002 ***
1% critical values	0.335	0.043	0.015	0.008
5% critical values	0.364	0.050	0.017	0.009
10% critical values	0.381	0.054	0.018	0.009

Notes: Critical values are based on Mayoral (2004). ***, **, and * denote significance at the 1%, 5% and 10% levels. For each country, the cell in bold determines the column closest to the value of *d* estimated using Geweke and Porter-Hudak's technique and are reported in *Table 6*.

The results demonstrate that based on the estimate of the fractional differencing parameter *d*, no general distinction can be made between the inflation persistence in the EAC and the NMS. Among the EAC, Belgium and Portugal exhibit relatively low persistence, while Germany and Spain end up with fairly high persistence estimates. Among the NMS, Malta and Cyprus exhibit very low inflation persistence and Bulgaria, the Czech Republic, Romania, and Slovakia can be considered as countries with moderate inflation persistence. On the other hand, Estonia, Hungary, Latvia, Lithuania, Poland, and Slovenia show high inflation persistence when evaluated on the basis of the fractional differencing parameter.

Table 7 summarizes the results of testing the null hypothesis of a fractionally integrated process against the alternative of a stationary process with breaks. For each country, the cell in bold determines the column closest to the estimated value of parameter *d* reported in *Table 6.* At the 10% level of significance, we can reject the null hypothesis of a fractionally integrated process for all countries except Lithuania, Romania, and Germany. Modeling the inflation time series as a stationary process with breaks is thus preferable for most of the countries considered. In light of this result, we consider the analysis employing the time-varying mean presented in the previous part of the paper to be our preferred one.

Finally, note that the alternative hypothesis to the test presented in *Table 7* is that the inflation time series follows a stationary process with *just one* break. So, if the test suggests rejecting the null of a fractionally integrated process, it follows that the model with a time-varying mean (i.e., the model allowing for more breaks) is preferable. On the other hand, if the test doesn't find enough evidence against the null, it still doesn't imply that the model with *more than one* break is not preferable.

5. Conclusions

In this paper, we examine inflation persistence in the countries that joined the European Union in 2004 and 2007. We argue that reliable estimates of inflation persistence are necessary for understanding the obstacles that the NMS can face while trying to fulfill the Maastricht criterion on inflation. Moreover recent literature points out that inflation persistence differences can cause inflation divergence within a monetary union.

We suggest that the specific economic situation of the NMS in the last 15 years requires careful consideration of methods used for the estimation of inflation persistence. First, once models with a constant mean of inflation are used, frequent breaks in the inflation time series, caused, for example, by administrative price changes or by monetary policy regime switches, lead to upward bias in the persistence estimates. Second, data availability and quality of statistics complicate estimation of inflation persistence measures based on multivariate statistical and structural models.

The estimation results based on the time-varying mean model suggest that the NMS can in general be divided into two groups. One group consists of Bulgaria, Cyprus, the Czech Republic, Malta, Romania, and Slovakia. The main traits of the inflation persistence in this group are similar to the selected euro area countries (Belgium, Germany, Portugal, and Spain). The other group of NMS (Estonia, Hungary, Latvia, Lithuania, Poland, and Slovenia) exhibits a higher level of intrinsic inflation persistence and more prominent role of backward looking element in the formation of inflation expectations.

Thus, the members of the second group could face a more difficult situation while trying to fulfill the Maastricht criterion on inflation or accommodating a common inflation shocks withing eurozone.

REFERENCES

An S, Schorfheide F (2006): Bayesian Analysis of DSGE models. *Federal Reserve Bank of Philadelphia Research Department Working Paper*, no. 06-5.

Angeloni I, Ehrmann M (2004): Euro Area Inflation Differentials. *ECB Working Paper*, no. 388.

Angeloni I, Aucremanne L, Ehrmann M, Gali J, Levin AY, Smets F (2006): New Evidence on Inflation Persistence and Price Stickiness in the Euro Area: Implication for Macro Models and Policy. J*ournal of the European Economic Association*, 4(2-3):562–574.

Babetskii I, Coricelli F, Horváth R (2007): Measuring and Explaining Inflation Persistence: Disaggregate Evidence on the Czech Republic. *CNB Working Paper*, no. 1.

Baillie RT, Chung C-F, Tieslau MA (1996): Analysing Inflation by the Fractionally Integrated ARFIMA-GARCH Model. *Journal of Applied Econometrics*, 11(1):23–40.

Baum CF (2000): FRACIRF: Stata Module to Compute Impulse Response Function for Fractionally-integrated Time Series. *Statistical Software Components S414004, Boston College Department of Economics*.

Baum CF, Wiggins V (1999): GPHUDAK: Stata Module to Estimate Long Memory in a Timeseries. *Statistical Software Components 388101, Boston College Department of Economics*, revised 25 June 2006.

Baum CF, Barkoulas J, Caglayan M (1999): Persistence in International Inflation Rates. S*outhern Economic Journal*, 65(4):900–914.

Benati L (2008): Investigating Inflation Persistence across Monetary Regimes. *ECB Working Paper Series*, no. 851.

Bilke L (2005): Break in the Mean and Persistence of Inflation: A Sectoral Analysis of French CPI. *Banque de France Working Paper*, no. 122.

Bomfim AN, Rudebusch GD (2000): Opportunistic and Deliberate Disinflation under Imperfect Credibility. *Journal of Money, Credit, and Banking*, 32(4).

Brooks SP, Gelman A (1998): Alternative methods for monitoring convergence of iterative simulations. *Journal of Computational and Graphical Statistics*, 7:434–455.

Bulíř A, Hurník J (2009): Inflation convergence in the euro area: just another gimmick? J*ournal of Financial Economic Policy*, 1(4).

Calvo G (1983): Staggered Prices in a Utility-Maximizing Framework. *Journal of Monetary Economics*, 115(1):383–398.

Cecchetti SG, Hooper P, Kasman BC, Schoenholtz KL, Watson MW (2007): *Understanding the Evolving Inflation Process*. Presentation at the U.S. Monetary Policy Forum, Washington, D.C.

Christiano L, Eichenbaum M, Evans M (2005): Nominal Rigidities and the Dynamic Effects of a Shock to Monetary Policy. *Journal of Political Economy*, 113:1–45.

Cogley T, Sbordone AM (2006): Trend Inflation and Inflation Persistence in the New Keynesian Phillips Curve. *Federal Reserve Bank of New York Staff Reports*, no. 270.

Cogley T, Primiceri GE, Sargent TJ (2008): Inflation-gap Persistence in the U.S. *NBER Working Paper*, no. 13749.

Coricelli F, Horváth R (2006): Price Setting Behaviour: Micro Evidence on Slovakia. *CEPR Discussion Paper*, no. 5445.

Darvas Z, Varga B (2007): *Inflation Persistence in the Euro-area, US, and New Members of the EU: Evidence from Time-varying Coefficient Models.* Money Macro and Finance Research Group Conference 2006.

Dossche M, Everaert G (2005): Measuring Inflation Persistence – A Structural Time Series Approach. *ECB Working Paper*, no. 495.

Druant M, Fabiani S, Kezdi G, Lamo A, Martins F, Sabbatini R (2009): How Are Firms' Wages and Prices Linked: Survey Evidence in Europe. *European Central Bank Working Paper*, no. 1084.

Erceg CJ, Levin AT (2003): Imperfect Credibility and Inflation Persistence. *Journal of Monetary Economics*, 50(4):915–944.

Fiess N, Byrne J (2007): Euro Area Inflation: Aggregation Bias and Convergence. *Department of Economics, University of Glasgow / Working Papers*.

Franta M, Saxa B, Šmídková K (2007): Inflation Persistence in New EU Member States: Is It Different from Euro Area Members? *ECB Working Paper*, no. 810.

Gadea MD, Mayoral L (2006): The Persistence of Inflation in OECD Countries: A Fractionally Integrated Approach. *International Journal of Central Banking*, 1(4).

Gadzinski G, Orlandi F (2004): Inflation Persistence in the European Union, the Euro Area, and the United States. *ECB Working Paper*, no. 414.

Galí J, Gertler M (1999): Inflation Dynamics: A Structural Econometric Analysis. J*ournal of Monetary Economics*, 44:195–222.

Konieczny J, Skrzypacz A (2005): Inflation and Price Setting in a Natural Experiment. *Journal of Monetary Economics*, 52(3):621–632.

Koopman SJ, Durbin J (2003): Filtering and Smoothing of State Vector for Diffuse State-space Models. *Journal of Time Series Analysis,* 24(1):85–98.

Kozicki S, Tinsley PA (2003): Permanent and Transitory Policy Shocks in an Empirical Macro Model with Asymmetric Information. *Federal Reserve Bank of Kansas City Working Paper*, no. 03-09.

Kumar MS, Okimoto T (2007): Dynamics of Persistence in International Inflation Rates. *Journal of Money, Credit and Banking*, 39(6):1457–1479.

Leigh D (2005): Estimating the Implicit Inflation Target: An Application to U.S. Monetary Policy. *IMF Working Paper*, no. 05/77.

Mankiw NG, Reis R (2002): Sticky Information Versus Sticky Prices: A Proposal to Replace the New Keynesian Phillips Curve. *Quarterly Journal of Economics*, 117(4):1295–1328.

Marques CR (2004): "nflation Persistence: Facts or Artefacts? *ECB Working Paper*, no. 371.

Mayoral L (2004): Testing for Fractional Integration versus Short Memory with Trends and Structural Breaks. last version from June 2006 available at http://www.econ.upf.edu/~mayoral/laura_mayoral_research.htm

Mishkin FS (2007): Inflation Dynamics. *BIS Review*, no. 29/2007.

Ratfai A (2006): Linking Individual and Aggregate Price Changes. *Journal of Money, Credit and Banking*, 38(8):2199–2224.

Sbordone AM (2007): Inflation Persistence: Alternative Interpretations and Policy Implications. *Journal of Monetary Economics*, 54:1311–1339.

Smets F, Wouters R (2005): Comparing Shocks and Frictions in US and Euro Area Business Cycles. *Journal of Applied Econometrics*, 20(2):161–183.

Stavrev E (2007): Growth and inflation dispersions in EMU: reasons, the role of adjustment channels, and policy implications. *IMF Working Paper*, no. 07/167.

Stock JH, Watson MW (2007): Why Has U.S. Inflation Become Harder to Forecast? *Journal of Money, Credit and Banking*, 39(1):3–34.