

Changes in Inflation Dynamics under Inflation Targeting? Evidence from Central European Countries

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Abstract

The purpose of this paper is to provide a novel look at the evolution of inflation dynamics in the selected central European (CE) countries. We use the lens of the New Keynesian Phillips Curve (NKPC) nested within time-varying framework. Exploiting time-varying regression model with stochastic volatility estimated via Bayesian techniques, we analyze both closed and open-economy version of the NKPC. The results point to significant differences between the inflation process in three CE countries. While inflation persistence has almost disappeared in the Czech Republic, it remains rather high in Hungary and Poland. In addition, the volatility of inflation shocks decreased quickly few years after the adoption of inflation targeting in the Czech republic and Poland, whereas it remains quite stable in Hungary even after ten years' experience in inflation targeting. Our results document that differences in practical implementation of inflation targeting can have an impact on inflation dynamics. In addition, we found some evidence that 'structural' parameters of the NKPC are somewhat related to macroeconomic environment.

JEL Codes: C11, C22, E31, E52.

Keywords: Bayesian model averaging, Central European Countries, inflation dynamics, New Keynesian Phillips curve, time-varying parameter model.

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Nontechnical Summary

Understanding the nature of short-term inflation dynamics poses a major challenge for monetary policy. The traditional Phillips curve postulated that there is a stable trade-off between inflation and economic activity. At the same time, it has almost become a common wisdom that inflation is very persistent. Consequently, taming inflation was deemed to be costly in terms of output loss. However, better understanding of the role of expectations changed the perception of monetary policy conduct. Since the inflation is believed to be affected not only by the current and past monetary policy but also by commitment to future monetary policy actions, a credible monetary policy that anchors inflation expectations can achieve disinflation at no cost in terms of real output. This idea was formalized into the New Keynesian Phillips curve (NKPC), which appeared during the 1990s. Its main ingredient is a forward-looking inflation term, tracking the effect inflation expectations on its current value.

The NKPC was proposed as a structural model of inflation dynamics in the sense that it is a result of optimization process at the micro level and thus is invariant to policy changes. However in practice, there are numerous reasons why the nature of inflation process can evolve across time. Importantly, implementation of credible monetary policy framework might accomplish to stabilize the level of inflation and can reduce its persistence and variability through anchored inflation expectations. The macroeconomic changes can in turn feed back to microeconomic environment. The countries in Central Europe went through a unique episode where both macro and microeconomic factors might have played a role in triggering changes in inflation dynamics in the last two decades. Their economies underwent significant structural changes coupled with changes in monetary and exchange rate regimes.

This paper aims to provide evidence on the evolution of inflation dynamics in some CE countries that adopted inflation targeting regime (the Czech Republic, Hungary and Poland) by means of the NKPC nested within time-varying framework. To estimate a model with time-varying parameters we resort to Bayesian techniques. We track evolution of overall inflation dynamics along with the changes in ‘structural’ parameters such as the degree of price stickiness.

We find that the nature of inflation process differs across selected CE countries. Although forward-looking component dominates the inflation dynamics in all three countries, which is a sign of (at least partially) anchored inflation expectations, inflation is considerably less persistent in the Czech Republic than in Hungary and Poland and the persistence has been constantly decreasing. In addition, the volatility of inflation shocks decreased quickly few years after the adoption of inflation targeting in the Czech Republic and Poland, while it remains rather stable in Hungary even ten years after the inflation targeting was adopted. These two results, show that the differences in practical

implementation of inflation targeting do matter, particularly in reference to the role of the exchange rate or the ability to anchor inflation expectations via transparent and credible policy. Less credible monetary policy leads economic subjects to take into account observed inflation levels rather than the inflation target.

We have found some evidence that ‘structural’ coefficients are not stable in time as it is commonly believed. We show that the average time for which prices remain fixed is negatively correlated with both the level and volatility of inflation. That is if inflation is high and volatile, firms tend to change prices more frequently. The share of backward-looking price setters, who simply adjust their prices by observed inflation rather than in forward-looking fashion, is changing smoothly with predominantly downward sloping trend. It seems that this is driven by long-term factors such as increasing competition, decrease in administratively regulated prices or the learning capacity of price setters.

1. Introduction

The New Keynesian Phillips curve (NKPC) has become a workhorse macroeconomic model to study the relation between inflation and real economic activity, notably in the domain of optimal monetary policy conduct. In broader terms, the NKPC is a core element of New Keynesian DGSE models (Smets and Wouters, 2003). The NKPC is built around a concept of staggered price-setting (or wage-setting), either motivated by staggered contracts (Taylor, 1980; Rotemberg, 1982) or probabilistic approach (Calvo, 1983). The NKPC was proposed as a structural model of inflation dynamics (Galí and Gertler, 1999; Galí et al., 2001) in the sense that it is a result of optimization process at the micro level and thus is invariant to policy changes. However, in practice, there are potentially numerous reasons why the nature of inflation process can evolve across time and related empirical evidence seems to confirm this claim.

In general terms, the (macro)economic structure is constantly changing and when we think of the past decades these changes were quite substantial. There has been a long empirical research on the changes in business cycle and inflation persistence. Kim and Nelson (2006) and McConnell and Perez-Quiros (2000) provided groundbreaking evidence for the US and Stock and Watson (2003, 2005) for other countries, which initiated a debate about the Great Moderation. Corvoisier and Mojon (2005) find that mean inflation of OECD countries was subject to two or three structural breaks since 1960's. The decrease of inflation persistence has been attributed to more aggressive monetary policy stance in the US (Davig and Doh, 2008) and implementation of credible monetary policy regimes such as inflation targeting elsewhere (Benati, 2008). The linkage between changes in inflation dynamics and monetary policy is further corroborated by evidence about structural changes in monetary policy itself (Baxa et al., 2010; Boivin, 2006; Kim and Nelson, 2006; Koop et al., 2009; Sims and Zha, 2006; Trecroci and Vassalli, 2010).

From the microeconomic point of view, there are various reasons why the agents' behavior might evolve over time, which in turn induce changes in the key 'structural' parameters of the NKPC. Some of these changes can be even triggered by changes on the macroeconomic level. The most obvious case is the firms' decisions on the frequency of price adjustment. Most microeconomic studies on price-setting find the level and variability of inflation as one of the key determinants of the frequency of price changes (Klenow and Malin, 2010). Fernandez-Villaverde and Rubio-Ramirez (2008) show within the of DSGE framework that movements of pricing parameters are indeed correlated with inflation.

The countries in Central Europe went through a unique episode where both macro and microeconomic factors might have played a role in triggering changes in inflation dynamics in the last two decades. Their economies underwent significant structural changes coupled with changes in monetary and exchange rate regimes. It is likely that

these factors implied also significant changes at the microeconomic level. In particular, the level of inflation and monetary policy credibility could have induced changes in price setting behavior of individual firms. While there is some micro evidence (Babetskii et al., 2007; Konieczny and Skrzypacz, 2005; Coricelli and Horváth, 2010), the changes in the nature of overall inflation process are practically undocumented.

The purpose of this paper is to fill this gap and provide evidence on the evolution of inflation dynamics in CE countries (the Czech Republic, Hungary and Poland) through the lens of the NKPC nested within time-varying framework. First, we estimate a standard hybrid version of the NKPC (Galí and Gertler, 1999) and track evolution of overall inflation dynamics along with the changes in 'structural' parameters such as the degree of price stickiness. Second, to study an impact of external drivers on inflation we estimate an open economy version of NKPC in the spirit of Galí and Monacelli (2005). We slightly depart from their original (purely forward-looking) model and consider a hybrid version of NKPC, just as in the case of the closed-economy form. In our two step procedure closely related to Kim (2006) we estimate time-varying regression model with stochastic volatility using Bayesian techniques. In addition, we use Bayesian model averaging in order to tackle the issue of instrument selection as it was shown to be a very relevant in forward-looking models in many previous papers.

Our results can be summarized as follows. First, we find that a nature of inflation process differs across selected CE countries. Despite the fact that forward-looking component dominates the inflation dynamics in all three countries, inflation is considerably less persistent in the Czech Republic than in Hungary and Poland. Second, changes in inflation process over time are also rather heterogeneous. Inflation persistence as tracked by the coefficient on the backward-looking term has decreased substantially in the Czech Republic, which was coupled with respective increase in the forward-looking term. Additionally, the volatility of inflation shocks decreased quickly few years after adoption of inflation targeting both in the Czech Republic and Poland, suggesting that inflation targeting and other policy changes influenced the inflation dynamics in these two countries. On the contrary, the nature of inflation process in Hungary does not seem to have changed much over the last 15 years. Third, the estimated coefficients of the domestic driving variable were often statistically insignificant. This feature can be linked to potentially important supply shocks during the transition which cannot be fully captured by the original NKPC model. The relative importance of foreign inflation factors, tracked by terms of trade, is relatively negligible as well, suggesting that the foreign factors might already be well reflected in inflation expectations themselves. Fourth, we find some evidence that both level of inflation and its volatility are negatively correlated with the average time for which prices remain fixed. Therefore, it seems that the price setting behaviour of economic agents is somewhat related to macroeconomic environment rather than being fully invariant to it as the benchmark NKPC assumes. Our findings have some noteworthy policy implications. Previous research suggested

that implementation of credible monetary policy regime contributed to a decrease of inflation persistence in the most developed countries. Although all three CE countries officially adopted inflation targeting regime a decade ago, inflation persistence has not considerably changed in Poland and Hungary and still remains at high levels when compared to the Czech Republic or developed countries. This could be related to the fact that inflation targeting in these countries is less credible and economic subjects take chiefly into account observed inflation levels rather than the inflation target.

The paper is organized as follows. In chapter 2, we review relevant literature, focusing particularly on empirical aspects of the NKPC estimation. Chapter 3 presents our empirical framework and data. All results and their interpretation appear in chapter 4. The final chapter concludes and suggests some avenues for future research.

2. Related literature

From empirical perspective, the NKPC owes its growing popularity to the seminal papers of Galí and Gertler (1999) (GG hereafter) and Galí, Gertler and López-Salido (2001, GGL). GG introduced estimation via GMM techniques and proposed a ‘hybrid’ modification of the original forward-looking model. This modification encompasses an effort to provide some structural justification for inflation persistence that the ‘pure’ version of the NKPC was unable to capture.

Despite theoretical appeal of the NKPC, consecutive studies have produced rather conflicting empirical evidence with results varying across economies, data sets and - most notably - across estimation methods. Econometric approach of GG was heavily criticized by a few later authors (e.g. Rudd and Whelan, 2005; Mavroeidis, 2005), mainly on the grounds of questionable behavior of GMM estimator in the NKPC context. The common criticism includes sensitivity to the choice of instrument set, weak identification and small sample bias. To overcome potential pitfalls related to GMM estimator, Ireland (2001) and Lindé (2005) advocate a system approach using full information maximum likelihood method as it provides more efficient parameter estimates than limited information (i.e. ‘single-equation’) methods such as GMM. In their response to Lindé and other critiques Galí et al. (2005) claim (with reference to Cochrane, 2001) that the issue of which estimation approach is preferable is completely open since there are no theorems or Monte Carlo simulations that suggest that one outperforms the other. In addition, they show that when the NKPC is correctly specified one obtains fairly robust results across estimation methods.

The stock of econometric techniques has progressively expanded. Some authors use Bayesian techniques (e.g. Smets and Wouters, 2003) or minimum distance approach (Sbordone, 2005; Christiano et al., 2005). Kleibergen and Mavroeidis (2009) proposed

robust versions of GMM estimator. Other papers stick to VAR framework and assess the validity of the NKPC by testing the set of restrictions (in the spirit of Campbell and Shiller, 1987). Fanelli (2008) analyzes the idea that forward-looking agents calculate their expectations within a VAR-like setting (with inflation and forcing variable), which allows to deal with the issue of feedback effect from inflation into forcing variables. This paper rejects validity of the NKPC for the Euro area. Carriero (2008) obtains similar negative evidence with the US data suggesting, however, that this result can indicate a failure of rational expectation hypothesis rather than NKPC-consistent forward-looking behaviour. The relevance of rational expectations is further tested by Nunes (2010), who estimates the NKPC for the US economy considering firms represented by rational expectations as well as firms represented by survey expectations. He finds that although survey expectations can be a determinant of inflation dynamics, the rational expectations seem to be predominant. Dees et al. (2009) use global VAR to solve the weak instrument problem. In particular, they construct valid instruments using weighted averages of the global variables. Harvey (2011) points to the problem that the NKPC cannot appropriately account for nonstationarity, which is usually dealt with in an ad-hoc fashion such as an application of detrended variables. Instead, he proposes a model where lagged inflation in the NKPC is replaced by unobserved random walk component. Kontonikas (2010) generalizes the NKPC using ARDL bound approach (Pesaran et al., 2001), which is suitable for variables with any order of integration. He finds with US data starting in 1960's that higher marginal cost increase inflation.

Leaving the question of estimation aside, there are two other strands of literature that seek to improve model's fit. First strand tries to find a good proxy for marginal cost or other appropriate inflation-forcing variable (notably for open economies), while the latter studies effects of changes in economic system and monetary policy on inflation dynamics.

In the empirical literature, firms' marginal cost are notoriously proxied by labour income share (LIS) - a measure based on Cobb-Douglas production technology. While the measure may be applicable for the US and other major countries, some modifications need to be made for small open economies. In general terms, there is some intuition that open trade and capital flows weaken the effect of domestic real activity on inflation (Razin and Yuen, 2002; Razin and Loungani, 2005). Galí and Monacelli (2005) derive a small open economy version of the NKPC for CPI inflation, which includes (a difference in) terms of trade as an additional forcing variable (above marginal cost). While this model assumes a complete exchange-rate pass-through, Monacelli (2005) relaxes this assumption. Mihailov et al. (2011a) provide first empirical evidence based on this model. Batini et al. (2005) propose an open economy NKPC where marginal cost is affected by import prices and external competition, confirming that this model fits well the UK data. Rumler (2007) extends marginal cost by cost of intermediate inputs (both domestic and imported) and finds some plausible evidence for the Euro area countries. Regardless

proposed corrections in marginal cost that account for external effects, some authors (e.g. Rudd and Whelan, 2007) cast severe doubts on appropriateness of LIS measure itself claiming that LIS has in fact intrinsically countercyclical nature. Consequently, Mazumder (2010) proposed new measure that corrects LIS by relaxing overly restrictive assumptions such as free adjustment of labor input at fixed wage rate. Such measure of marginal cost turns to be procyclical. Mazumder (2011) claims that the cyclicity of the selected marginal cost proxy is crucial for the sign of the corresponding coefficient in the NKPC. However, paradoxically if the marginal cost is procyclical as it is commonly believed, its coefficient in the NKPC has counter-intuitive negative sign.

A few recent studies, which are more closely related to our research, fall into the second strand of literature. They consider the effects of changes in economic system and monetary policy and explore how these changes are propagated into the changes in parameters of the NKPC. In general terms, these studies allow the nature of inflation dynamics to change over time. Most of the evidence is available for the US. Hall et al. (2009) use a time-varying model, which arguably corrects for specification bias (due to incorrect functional forms, omitted variables, and measurement errors) inherent to fixed-coefficient estimation. They conclude that lagged inflation term in the ‘hybrid’ version turns out to be insignificant. In a similar vein, Cogley and Sbordone (2008) claim that inflation persistence in the NKPC arise due to variation in the long-run trend component of inflation, which can be attributed to monetary policy shifts. Once log-linearization around time-varying inflation trend is taken (in their two-step VAR estimation), the ‘pure’ forward-looking NKPC explains the US inflation dynamics fairly well. Zhang and Kim (2008) find with inflation survey data (and recursive GMM estimation) that forward-looking behavior played a smaller role during the high and volatile inflation regime before 1981 than in the period of moderate inflation afterwards. Kang et al. (2009) employ an unobserved component model for inflation with Markov switching parameters confirming the claim that inflation persistence indeed changes across policy regimes. They find a break around the collapse of Bretton Woods in early 1970’s and another around 1981 with Volcker disinflation. Cogley et al. (2010) obtain similar results using VAR with drifting coefficients and stochastic volatility (unlike most other studies they analyze inflation gap measured as a difference between inflation and its trend). On the contrary, Stock and Watson (2007), based on unobserved component model with stochastic volatility, argue that the US inflation persistence has not changed for decades. D’Agostino et al. (2011) provide evidence that explicit modelling of structural changes in inflation dynamics (within time-varying VAR framework) can improve the accuracy of inflation forecasts.

The evidence on changes of inflation dynamics in other economies, especially that within the NKPC framework, is less abundant. There are numerous studies initiated by the ESCB Inflation Persistence Network but they mainly use micro data and do not explicitly test the NKPC. There are only a few papers tracking the issue of overall inflation

dynamics. Benati (2008) uses data for several developed inflation targeting countries (Canada, New Zealand, Sweden, Switzerland, the UK) and the Euro area concluding that inflation persistence decreased almost to zero once credible monetary regimes were implemented and, therefore, that inflation persistence is not structural. Hondroyannis et al. (2009) apply specific time-varying framework to data of France, Germany, Italy and the UK concluding consistently with previous evidence for the US (Hall et al., 2009) that backward-looking parameter of time-varying NKPC is almost negligible. Tillmann (2009) explores how the explanatory power of the forward-looking NKPC in the Euro area evolves across time (using the present-value formulation of the model in a rolling-window regression). He finds that explanatory power of the model varies substantially across the underlying monetary regimes triggered by events such as ERM crisis, the Maastricht treaty and the EMU launch. Koop and Onorante (2011) use dynamic model averaging (Raftery et al., 2010) to study the relationship between inflation and inflation expectations in the Euro area. They find strong support for the forward-looking behavior, interestingly mainly since the start of the recent financial crisis.

The research focused on the inflation dynamics and the NKPC estimation in CE countries has been gradually expanding. However, the issue of possible structural changes, which seems to be highly relevant in this case, has not been explicitly tackled, yet. The time-invariant estimates provide rather ambiguous evidence on the fit of the NKPC. Arlt et al. (2005) reject validity of the pure NKPC for the Czech economy using cointegration-based tests. Franta et al. (2007) conclude that inflation in three CE countries is more persistent than in the EMU and that the NKPC proposed in GG is not consistent with data for any of analyzed countries. Plašil (2011) estimates the NKPC for the Czech Republic by making use of advances in the area of optimal instrument selection, time series factor analysis and GMM bootstrap. He finds some support for the hybrid NKPC. Vašíček (2011) estimates the hybrid NKPC augmented for open economies for four CE countries. He confirms higher persistence of inflation in CE countries, finds that the common measures of the marginal cost perform worse than the output gap and that external rather than internal factors seem to drive inflation. Mihailov et al. (2011b) test a small economy NKPC proposed in Galí and Monacelli (2005) using data from twelve new EU member states. Although they find rather mixed evidence on the importance of external factors, the fit of this model is better for the NMSs than for the developed OECD economies (Mihailov et al., 2011a). Basarac et al. (2011) estimate the NKPC for panel of nine new EU countries obtaining a measure of expected inflation directly from consumer surveys via a probability method. They confirm that inflation in these countries is very persistent. Hondroyannis et al. (2008) provide some evidence for a group of seven new EU member states based on time-varying model. A bit surprisingly they find that the inflation persistence in these countries is practically nonexistent (and therefore similar to the Euro area), which contradicts practically all country-specific, though time-invariant, evidence. Moreover, their panel estimation for heterogenous group of seven new members does not seem to be appropriate given

that economic structure and monetary policy framework of these countries are very different.

3. Model and estimation strategy

3.1 Closed and open economy hybrid NKPC

In our empirical analysis we start with the seminal hybrid NKPC model laid out in GG:

$$\pi_t = \gamma_f E_t \pi_{t+1} + \gamma_b \pi_{t-1} + \lambda s_t + \varepsilon_t \quad (3.1)$$

where π_t denotes inflation, $E_t \pi_{t+1}$ inflation expectations conditional on information up to time t , s_t is a proxy for marginal cost (as a deviation from the steady-state) and ε_t is an exogenous inflation shock, such that $E_{t-1} \varepsilon_t = 0$. Unlike GG, we assume that parameters γ_f , γ_b and λ are potentially time-varying, i.e. they may evolve over time because of dynamic economic conditions in the converging economies under study. Reduced-form parameters are non-linear functions of three structural parameters: subjective discount factor, β , probability that prices remain fixed, θ , and a fraction of backward-looking price setters, ω .

$$\begin{aligned} \lambda &\equiv (1 - \omega)(1 - \theta)(1 - \beta\theta)\phi^{-1} \\ \gamma_f &\equiv \beta\theta\phi^{-1} \\ \gamma_b &\equiv \omega\phi^{-1} \\ \phi &\equiv \theta + \omega(1 - \theta(1 - \beta)) \end{aligned}$$

Structural parameters may provide a closer look on a nature of structural changes that have been affecting economies in question. Namely, one might be interested whether a fraction of backward-looking setters have decreased, e.g. as a result of inflation targeting regime, or how the average duration for which prices remain fixed ($1/(1 - \theta)$) drifts over time.

Given that all CE countries can be classified as small open economies we also consider a NKPC model in the spirit of Galí and Monacelli (2005) which accounts for the potential impact of external factors on inflation. Recently, Mihailov et al. (2011b) used pure small economy NKPC model of Galí and Monacelli (2005) and evaluated relative importance of domestic and external drivers in the new member states. Our version can be viewed as an extension of their approach to the hybrid NKPC and time-varying framework. In line with the open economy model, we now assume that *CPI* inflation can be expressed as:

$$\pi_t = \pi_{H,t} + \alpha \Delta IT_t \quad (3.2)$$

where $\pi_{H,t}$ is *domestic inflation*, ΔTT_t denotes current-to-past period change in the terms of trade¹ and parameter α measures openness of the economy. Dynamics of domestic inflation is analogously to (3.1) given by²:

$$\pi_{H,t} = \gamma_f E_t \pi_{H,t+1} + \gamma_b \pi_{H,t-1} + \lambda_\alpha s_t \quad (3.3)$$

Plugging (3.3) into (3.2) and making use of the fact that $\pi_{H,t} = \pi_t - \alpha \Delta TT_t$, we get:

$$\pi_t = \gamma_f E_t (\pi_{t+1} - \alpha \Delta TT_{t+1}) + \gamma_b (\pi_{t-1} - \alpha \Delta TT_{t-1}) + \lambda_\alpha s_t + \alpha \Delta TT_t$$

After some arrangements we obtain hybrid open-economy NKPC model of the form:

$$\pi_t = \gamma_f E_t \pi_{t+1} + \gamma_b \pi_{t-1} + \lambda_\alpha s_t + \alpha \{ \Delta TT_t - \gamma_f E_t \Delta TT_{t+1} - \gamma_b \Delta TT_{t-1} \}. \quad (3.4)$$

To motivate economic interpretation of the term in curly brackets in (3.4), it is useful to first consider two extreme cases when γ_f and γ_b is equal to one, respectively³. If $\gamma_f = 1$, then bracketed term becomes $(\Delta TT_t - E_t \Delta TT_{t+1})$ and model (3.4) collapses into pure open-economy model introduced by Mihailov et al. (2011b). Intuitively, as pointed out by Mihailov et al. (2011b), a current demand for domestic goods in the pure NKPC would increase when $(\Delta TT_t > E_t \Delta TT_{t+1})$ because price of domestic goods is relatively lower than that anticipated in the future, and this increased demand causes upward pressure on current inflation. Inversely, when $(\Delta TT_t < E_t \Delta TT_{t+1})$, current-period demand for domestic goods would lower as agents expect their relative price to decline in the future, and thus exerts downward pressure on current inflation.

In fully backward-looking setting, implied by $\gamma_b = 1$, bracketed term shrinks to $(\Delta TT_t - \Delta TT_{t-1})$. Again, the effect on inflation can be inferred from the comparison of the two terms in brackets, i.e. by investigating whether $(\Delta TT_t > \Delta TT_{t-1})$

¹ Galí and Monacelli (2005) use rather inverse definition of the terms of trade, i.e. they define it as import over export price index

² We use identical symbols for the forward and backward-looking term, respectively, although they are not necessarily equal to their closed-economy counterparts. We leave out the error term for expositional ease.

³ Although we do not impose restriction $\gamma_f + \gamma_b = 1$ a priori, results usually show close-to-convexity properties.

or $(\Delta TT_t < \Delta TT_{t-1})$ holds true. The crucial difference is, however, that backward-looking agents now anticipate the future path of terms of trade with respect to its past value since lagged value is used as a simple way to make a forecast. Note, that this implies, other things equal, higher inflation inertia than in closed-economy model, because terms of trade now serve as another channel contributing to persistence.

When the universe is formed by both forward and backward-looking agents, one simply compares ΔTT_t to linear combination of $E_t \Delta TT_{t+1}$ and ΔTT_{t-1} where coefficients γ_f and γ_b serve as multiplicative constants or weights. Hence, with a slight simplification, the linear⁴ combination can be viewed as a weighted average of the next-to-current difference in terms of trade anticipated by forward-looking and backward-looking agents. Since a difference in terms of trade is nothing else than a change in relative prices of imports (in terms of exports), it can be, in a certain respect, interpreted as a measure of imports' *inflation*. Thus, the hybrid open-economy NKPC consistently uses the same hybrid formation for inflation expectations, no matter whether they are defined as a rise in general level of goods and services or relative price of imports in terms of exports.

3.2 Econometric framework

Models (3.1) and (3.4) cannot be estimated directly due to fact that $E_t \pi_{t+1}$ is, in essence, latent quantity which must be proxied by some observable variable. Since inflation expectations taken from surveys cover only a very short time-span we proceed by making a common assumption that economic agents form their expectations rationally and replace the quantity $E_t \pi_{t+1}$ by π_{t+1} . Note, however, that this leads to endogeneity bias as the future inflation is by construction correlated with the error term. To see this, let $\vartheta_{t+1} \equiv \pi_{t+1} - E_t \pi_{t+1}$ be the unpredictable forecast error and rewrite (3.1) into the following form⁵:

$$\pi_t = \gamma_f \pi_{t+1} + \gamma_b \pi_{t-1} + \lambda s_t + e_t, \quad (e_t \equiv \varepsilon_t - \gamma_f \vartheta_{t+1}) \quad (3.5)$$

To obtain time-invariant parameter estimates in the model (3.5) one usually resorts to GMM techniques. Since GMM methodology with time-varying coefficients has not yet been fully developed⁶, we broadly stick to the strategy proposed by Kim (2006) who tackles the issue of endogeneity in linear models with dynamic coefficients following

⁴ If one restricts coefficients to sum up to 1, it is also a convex combination with straight interpretation of a weighted average.

⁵ For the sake of brevity, we only describe our estimation strategy for the basic NKPC model. Open economy version is estimated analogously. We make explicit reference to the open economy model only if this is necessary to avoid confusion.

⁶ See Partouche (2007) for a valuable breakthrough in this area.

random walk. In principle, Kim (2006) shows that it is possible to get consistent estimates of time-varying coefficients by employing two-step procedure. In the first step, we run the OLS regression⁷ of endogenous variables on a set of instruments that are uncorrelated with the error term in (3.5) and store standardized residuals. In the second step, standardized residuals are added as additional regressors into (3.5) and the whole system with time-varying coefficients may be cast into the state-space form and estimated with few modifications via Kalman Filter in a quite traditional fashion. Details on modifications in Kalman filter formulas are given in Kim (2006) and Kim (2008).

Despite practical appeal of the two-step procedure, there are still some thorny issues to be answered in the NKPC context: *i*) economic theory does not postulate what instruments should be used in the first step which leads to a common problem of instrument selection, *ii*) standard estimation of linear state-space models via Kalman filter assumes that gaussian shocks to the target variable are constant over the time. However, this is unlikely to hold for the inflation process (as argued e.g. in Koop and Korobilis, 2009), in particular for inflation in CE countries. Application of methods ignoring possible variation in the volatility of the error term may lead to serious bias of estimated time-varying coefficients.

To address these issues we slightly modify the procedure of Kim (2006). More specifically, we use Bayesian model averaging (BMA) instead of traditional OLS in the first step and estimate time-varying model with stochastic volatility in the second step. Bayesian model averaging (see Hoeting et al., 1999) is a relatively new method introduced to a wider audience in the mid-1990s. It provides a coherent framework to account for model uncertainty and instrument sensitivity. Unlike ‘traditional’ approach to estimation of the NKPC, where a researcher typically selects instruments (and thus conditions her model) in a quite subjective manner, BMA effectively weights all possible models based on posterior model probability. Thus, the aim of model averaging is not to find the best model or to select the best possible set of instruments but rather to use information from all models and average the outcome with respect to their ‘reliability’, induced by data and priors. To our knowledge BMA approach is new in the NKPC literature, although similar ideas have already been tossed around in the context of rational expectations models (see Wright, 2003). Let Z be the $T \times k$ matrix summarizing an information set available to the economic agents. Under standard assumptions, the unrestricted model can be represented as:

⁷ Kim (2006) assumes that the relation between endogenous variables and instruments is time-invariant. Kim (2008) also considers other alternatives. Notably, one can also assume that the relation between endogenous variables and instruments is time-varying. For reasons that will become clear later we do not adopt this approach here.

$$y_t = a + Z_t\delta + \epsilon_t \quad \epsilon \sim N(0, \sigma^2) \quad (3.6)$$

where y_t denotes the outcome variable (such as π_{t+1}), a is an intercept and δ is a vector of parameters. Since economic theory leaves us rather agnostic about the ‘true’ model, the researcher may have some uncertainty over which instruments to include or exclude. All possible combinations of instruments form the model universe $M = [M_1, M_2, \dots, M_K]$ where $K = 2^k$. BMA solution to the problem is to weight outcomes of all models by their posterior probability. Fitted value \hat{y}_t^{BMA} can be then expressed as:

$$\hat{y}_t^{BMA} = \sum_{k=1}^K \hat{y}_{t,k} p(M_k|y, Z) \quad (3.7)$$

where $\hat{y}_{t,k}$ denotes a fitted value conditional on the model k and weights $p(M_k|y, Z)$ are posterior model probabilities that arise from Bayes theorem:

$$p(M_k|y, Z) = \frac{p(y|M_k, Z)p(M_k)}{p(y|Z)} = \frac{p(y|M_k, Z)p(M_k)}{\sum_{s=1}^K p(y|M_s, Z)p(M_s)} \quad (3.8)$$

where $p(y|M_k, Z)$ denotes the marginal likelihood of the model, $p(M_k)$ prior probability that M_k is the ‘true’ model and the denominator represents integrated likelihood which is constant over the model universe. Expressions for marginal likelihood $p(y|M_k, Z)$ depend on the problem at hand and vary across different kind of models. In linear regression setting, marginal likelihood has a closed-form solution or can be obtained via approximation (depending on the nature of priors on coefficients)⁸. Before running BMA, the researcher needs to specify the model universe (set of instruments), the model priors, $P(M_k)$, and the parameter priors, $P(\varpi|M_k)$ with $\varpi \equiv (a, \delta', \sigma^2)'$.

In our setting y_t represents endogenous variables in (3.5)⁹ and instrument set includes four lags of inflation, output gap, unit labour cost, long term interest rates, interest

⁸ BMA for linear models has been implemented in several statistical products. Here, we make use of BAS package (Clyde et al., 2010) which is freely available in R.

⁹ As we have shown above endogeneity problem enters the model by replacing inflation expectations with the observable value of future inflation. Forcing variable (unit labour cost or output gap) is usually considered exogenous. However, we believe that endogeneity of the output gap cannot be apriori rejected. For this reason we formally treat the output gap as endogenous in the first-step regression and test for the presence of endogeneity in the second step by inspecting statistical significance of the coefficient on the endogeneity correction term. Terms of trade in all specifications are considered exogenous.

rate spread, unemployment, nominal effective exchange rate and crude oil price. We aimed to include the most comprehensive set of instruments consistently with previous paper subject to data availability. We use hyper-g prior on coefficients proposed by Liang et al. (2008) and run Bayesian adaptive sampling algorithm (Clyde et al., 2010) to obtain posterior probabilities over models.

Note that BMA assumes time-invariant relation between a target variable and the set of instruments. In the light of our considerations above, it may seem necessary (or reasonable) to account for time-varying nature of parameters rather than model uncertainty. Recent evidence, however, suggests that traditional time-varying parameter models perform rather poorly in inflation forecasting exercises and are outbeaten by the procedures accounting for the latter (see Koop and Korobilis, 2009).¹⁰

To finish the first-step we get residuals $\hat{v}_t = y_t - \hat{y}_t^{BMA}$, estimate Σ_v by $\hat{\Sigma}_v = \sum_{t=1}^T \frac{1}{T} \hat{v}_t \hat{v}_t'$ and obtain the standardized residuals $\hat{v}_t^* = \hat{\Sigma}_v^{-1/2} \hat{v}_t$. These residuals are used as the auxiliary regressors in the second step and may be viewed as the endogeneity correction terms.

The hybrid NKPC (3.5) with added correction terms, time-varying coefficients and stochastic volatility can be expressed as follows (see Nakajima, 2011, for general representations of time-varying regression and VAR models with stochastic volatility):

$$\pi_t = c_t' \kappa + x_t' \alpha_t + \psi_t, \quad \psi_t \sim N(0, \sigma_t^2) \quad (3.9)$$

$$\alpha_{t+1} = \alpha_t + u_t, \quad u_t \sim N(0, \Sigma) \quad (3.10)$$

$$\sigma_t^2 = \gamma \exp(h_t) \quad (3.11)$$

$$h_{t+1} = \rho h_t + \eta_t, \quad \eta_t \sim N(0, \sigma_\eta^2) \quad (3.12)$$

where $c_t \equiv (v_{t,\pi}^*, v_{t,gap}^*)'$ is a vector of the endogeneity correction terms, $x_t \equiv (\pi_{t+1}, \pi_{t-1}, s_t)'$ is a vector containing key model covariates, κ is a vector of constant parameters and $\alpha_t \equiv (\gamma_{f,t}, \gamma_{b,t}, \lambda_t)'$ represents a vector of time-varying coefficients.

Evolution of the time-varying coefficients is confined to follow random walk which allows for both permanent and transient shifts. Such a specification is designed to capture gradual changes and/or structural breaks in coefficients. Disturbances in (3.9), de-

¹⁰ Recently, Raftery et al. (2010) proposed a new method called dynamic model averaging (DMA) that accounts for both model uncertainty and parameter evolution. Since forecasting exercises have shown comparable performance of BMA and DMA at short horizons and given that DMA is still computationally unfeasible for larger instrument sets, we regard BMA as a reasonable option. Note, that DMA requires full enumeration of all models which is memory and time consuming for K greater than 2²⁰.

noted ψ_t , are normally distributed with the time-varying variance σ_t^2 . The log-volatility, $h_t = \log(\sigma_t^2/\gamma)$, is modelled as AR(1) process.

System of equations (3.9)-(3.12) forms a non-linear state space model with state variables α_t and h_t . Presence of stochastic volatility (the source of non-linearity) makes traditional estimation difficult because likelihood function is intractable. However, Bayesian inference is still possible and we can estimate the model efficiently using Markov chain Monte Carlo (MCMC) methods¹¹. To obtain results, we have drawn $M = 55.000$ samples from posterior distribution and discarded first 5000 samples as a burn-in period. Below we report results for default (quite loose) coefficient priors implemented by Nakajima (2011) in his code. As a robustness check we also experimented with other parameter settings in prior densities, but results do not seem to be severely affected by the choice of prior. Nevertheless, mixing properties of the Markov chain improved with the priors getting tighter. To check convergence, we computed inefficiency factors (Geweke, 1992) which measure how well the Markov chain mixes. In all estimated models inefficiency factors were usually quite low (well below 50), occasionally, however, they reached values close to 200 for some coefficients (close to 100 for tighter priors). Nevertheless, this still implies that we get about $M/200 = 250$ uncorrelated samples which is considered enough for posterior inference (see Nakajima, 2011).

As indicated above, one may also be interested in structural parameters of the NKPC model. Note, that their direct estimation leads to a system of equations which are highly non-linear in parameters. Since under quite mild conditions there exists one-to-one mapping between reduced-form coefficients and structural parameters, we avoid direct estimation of structural parameters and instead use non-linear solver to obtain their value from estimated reduced-form coefficients¹².

3.3 Data

Our dataset combines time series taken from several data sources (ECB, EUROSTAT, OECD and IMF). They were all downloaded from the E(S)CB data warehouse which integrates series collected by the key supranational data providers. We use seasonally-adjusted (SA) data or perform our own adjustment based on X12 ARIMA, when SA series was not directly available and statistical tests detected seasonality. Due to limited data availability induced by the transition from command to free-market economy we are forced to use relatively short time span, running from 1995 Q1 (CZ) and 1996 Q1 (HU, POL), respectively, to 2010 Q4. One has also to take into account lower data quality - especially at the beginning of the sample - as the statistical service in CE

¹¹ Nakajima (2011) shows how to sample from the posterior distribution of coefficients using a Gibbs sampler and provides all necessary computational details. See Nakajima (2011) also for the reference to his Ox and Matlab codes which were used for the estimation.

¹² We fixed subjective factor β to 0.99.

countries still faced some difficulties to meet newly adopted statistical standards. In this respect, results should be interpreted with some caution. In line with Galí and Monacelli (2005) the inflation rate is measured as the annualized quarter-on-quarter (log) difference in harmonized index of consumer prices. To proxy marginal cost we stick to the output gap taken from OECD Economic Outlook¹³ rather than to commonly used unit labour cost (labour share of income). Latter measure performed rather poorly in cross-correlation pre-analysis and in the pre-estimation exercise. Terms of trade series are calculated as a ratio of import over export price indices which have been taken from the EUROSTAT database.

In addition to the lags of variables described above our instrument set includes (lags of) unit labour cost, unemployment, nominal effective exchange rate, crude oil price, long term interest rate and interest rate spread. The spread is defined as a difference between 3M and overnight interbank interest rate.¹⁴ As noted above, number of four lags corresponds to that in the most of previous studies (see for example Galí et al., 2005). Results of the BMA procedure which document relative strengths of individual instruments are relegated to Appendix. R-square of the models with the highest posterior probability reached the value of 0.8 for all three countries.

It is important to note that inflation rate (notably for Hungary and Poland) along with some other variables show clear non-stationary pattern. Since it is not evident whether non-stationarity is a result of time-varying environment or it rather is of intrinsic nature, we rendered inflation stationary by shortening estimation period to 1999 Q1 - 2010 Q4 and re-estimated models (3.1) and (3.4)¹⁵. Given the fact that overall results remained largely identical we report only the outcomes for a longer time span.

4. Results

4.1 Benchmark NKPC (GG, 1999. GGL, 2001) with time-varying parameters

Czech Republic

Figure 1 presents estimated time-varying reduced form coefficients for the Czech republic. In general terms we can observe that Czech inflation is mainly forward-looking process. While the coefficient γ_f oscillated from 0.6 to 0.7 between 1995 and 2005, we can observe a slight tendency for its gradual increase since 2004, reaching value of 0.8, recently. The increase is quite pronounced especially since the onset of the global

¹³ It seems to correspond by and large to the output gap obtained by HP filter.

¹⁴ We resort to this rather simplistic definition due to limited availability of other interest rate data in the given period.

¹⁵ Other variables were HP filtered, if necessary, to achieve stationarity.

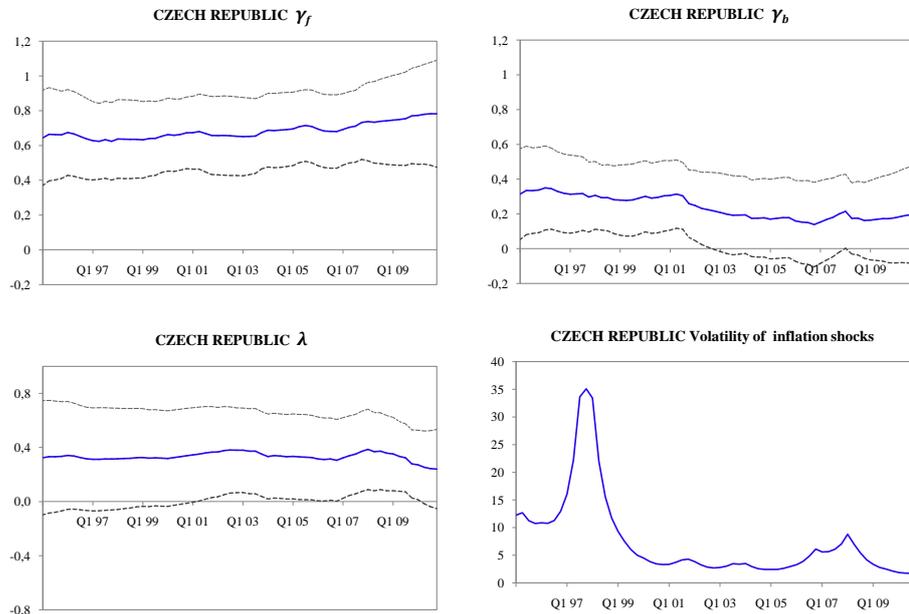
recession in 2008, which is consistent with recent evidence for euro area (Koop and Onorante, 2011). On the other hand, backward-looking term γ_b decreased over time, from 0.3 to less than 0.2. Moreover, since 2003 the estimates of γ_b are insignificant with the exception of the first quarter of 2008 when the inflation jumped up due to combined effect of increased food and energy prices and an increase of the value added tax.¹⁶ A possible explanation behind an increase in the backward-looking parameter in response to an increase in VAT might be the following: an increase in VAT increases the volatility of inflation, which translates into higher uncertainty about the future path of inflation. Thus, as the formation of inflation expectations becomes more complicated, both firms and households pay higher attention to past inflation rather than to possibly biased forecasts. On the other hand, it seems that inflation expectations were firmly anchored and the effect of this shock was rather time limited.

Interestingly, we cannot observe any peak or change in trend around 1998 when the inflation targeting was adopted by the Czech National Bank. However, several years after, a clear decline in the value of γ_b appears. The decrease of inflation persistence started in the last quarter 2001 and till the beginning of 2003 the coefficient γ_b dropped by 0.1. This decrease appeared after the inflation rate slumped significantly below the inflation target from the previous values between 4-6%. This disinflation appeared shortly after the Czech National Bank changed the approach towards the inflation target setting. In particular, the CNB decided to move from periodic setting of targets for the end of the year in terms of the net inflation rate, towards continuous targeting of the headline inflation within the predefined target range. Initially, the target was continuously decreasing, from 3-5% to 2-4% between 2002 and 2005. However, since the inflation rate already often crawled below the inflation target, the effects of subsequent shift to point targets in 2005 or the change of the targeted inflation rate from 3% to 2% in 2009 on the inflation dynamics, were negligible.

The coefficient λ measuring the impact of the real economic activity on the inflation rate is insignificant till 2001. This seems to suggest that the effects of large disinflation in the early years of transition dominated the effects of the real economic activity. Since then, the coefficient is positive and significant with the exception of the very last quarters of the sample.

The last subplot shows the estimated volatility of inflation shocks. First of the two conspicuous peaks in volatility can be associated with depreciation of the Czech koruna

¹⁶ The estimated impact of lagged inflation is in accordance with Babetskii et al. (2007) who estimated the inflation persistence on disaggregated data roughly between 0.2 to 0.3, depending on the time range included in the sample. Their results for the aggregate CPI were slightly larger but still below 0.5. From this perspective, it seems that either the results from the time-varying model do not suffer from the aggregation bias or the micro data on inflation persistence would suggest that inflation persistence could have disappeared.

Figure 1: Czech Republic: Reduced-form coefficients

following the currency crisis in the mid of 1997 as well as administrative changes in regulated prices. The second peak can be linked to an increase in import prices and value added tax in 2007/2008. Clearly, these policy shocks were short lived and do not seem to have affected the properties of inflation dynamics.

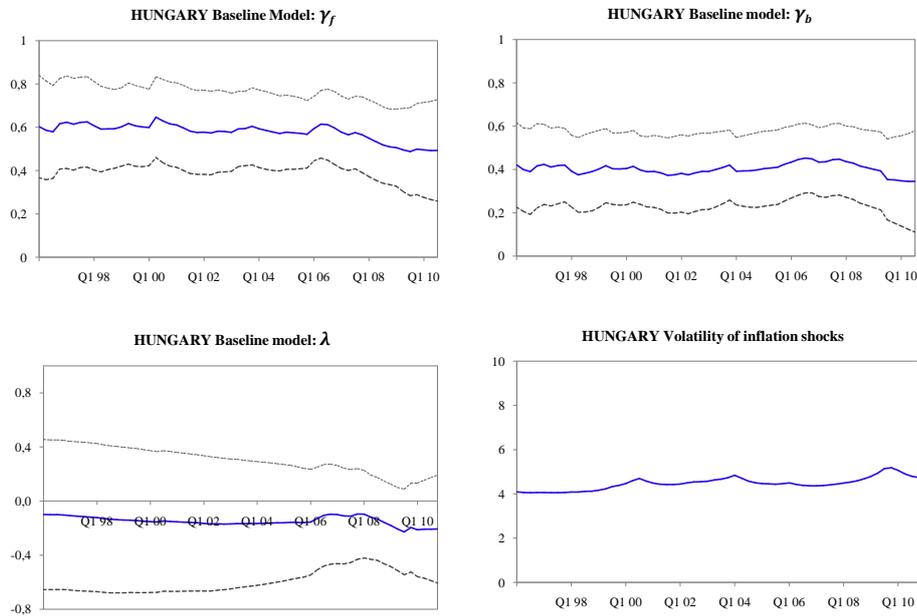
To sum up, the evidence from the time-varying coefficients suggests that characteristics of inflation process in the Czech Republic converged to those in developed countries. A predominantly forward-looking nature of inflation process is commonly reported in recent studies on the US or large EU countries (Hondroyannis et al., 2009; Cogley and Sbordone, 2008; Benati, 2008). These studies argue that inflation turns mainly forward-looking once the inflation rate stabilized under credible monetary policy regime. The timing of a gradual decrease in the backward-looking term suggests, that it was jointly caused by low inflation rate and simultaneous switch to more transparent inflation targeting regime that anchored inflation expectations at low levels.

Hungary

The evolution of the inflation dynamics in Hungary shows rather different picture in comparison to that in the Czech Republic. First, the forward-looking term γ_f is relatively stable over time with only a slight decrease since 2007. The backward-looking

term γ_b does not decrease and it is significant during the whole time span. Hence, inflation persistence still seems to be important phenomenon in Hungary. Our results with significant forward-looking term correspond to Menyhért (2008), who provides the first evidence on significant forward-looking term in Hungary. However, it must be also noted that the coefficient λ is negative, though insignificant, on the entire sample with a weak evidence of its increase since 2007. This result can be explained either by poor reliability of the output gap estimate for Hungary or it can reflect the fact that output gap is not a driving factor of inflation as suggested by the NKPC model. In addition, we have tested alternative domestic forcing variables such as unit labor cost or unemployment rate with very similar results.

Figure 2: Hungary: Reduced-form coefficients



Stability of coefficients is somewhat surprising as, at least formally, monetary policy in Hungary changed significantly since 1996. Inflation targeting was adopted in 2001¹⁷ and at the same time the crawling band was replaced by the ‘shadow’ ERM II regime of fixed exchange rate with fluctuation band $\pm 15\%$ around the central parity to euro. However, despite announcement of the shadow ERM II exchange rate regime, several pro-inflationary depreciation periods followed. The most significant one in terms of its effect on inflation occurred in 2004 when inflation increased from 3% to 7%. Nevertheless, formal changes in monetary policy did not lead to lower inflation persistence

¹⁷ Inflation targets were announced at the end of the year for the following one until 2007. The policy based on predefined medium term target (set at 3%) was implemented in 2008.

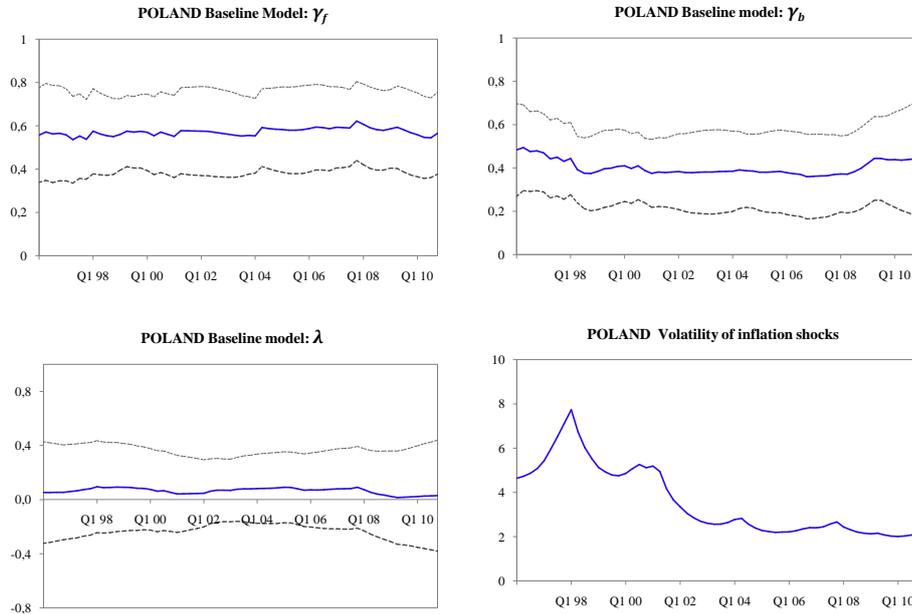
and also the volatility of inflation remained high. This seems to be related to lower credibility of inflation targeting regime in Hungary, which is in turn related to certain inconsistency between inflation and exchange rate targets. Vonnak (2008) argues that exchange rate was in fact believed to be the most effective channel of monetary policy transmission in Hungary. The hypothesis of lower credibility seems to be supported by the estimated volatility of inflation shocks that is stable over the sample as well as by the fact that exchange rate was identified as one of the most important factors of inflation expectations (see Appendix). Hence, despite the adoption of inflation targeting and diminishing effects of transition, we cannot identify any important changes neither in the parameters of the NKPC nor in the volatility of shocks.

Poland

Poland adopted explicit inflation targeting in 1999. Already before the adoption the inflation persistence decreased as indicated by the backward-looking term γ_b that moved from values close to 0.5 below 0.4. Since 2001 till 2009 the coefficient γ_b stays below 0.4 with no tendency to move and the forward-looking term γ_f remained stable as well with just small variations between 0.55 and 0.60. The overall dynamics of inflation was stable with significant role of both, forward and backward-looking components. The observed stabilization of driving factors of inflation dynamics can be linked to stabilization of inflation expectations: Lyziak (2003) and Orłowski (2010) document that inflation expectations anchored to the target path about 2 years after the inflation targeting was adopted by the National Bank of Poland, that is in 2001/2002. Correspondingly, our results suggest that volatility of inflation shocks decreased sharply and since 2001 inflation in Poland is characterized by stable monetary policy regime, stable coefficients of the NKPC and low volatility of inflation shocks. However, the estimate of λ is close to zero (never exceeds 0.1) and never significant. Hence the dynamics of inflation, when the closed economy specification of the NKPC is considered, is not driven by (the estimate of) output gap. Again, this points to some problems with finding a good proxy for firms' marginal cost or, potentially, to the empirical failure of the model.

Overall Assessment of Results

In general, we find evidence that the forward-looking inflation term is more important than the backward-looking one. This implies that inflation expectations play a substantial role and they are (at least partially) anchored in the CE countries. Consequently, monetary policy might be able to affect the future inflation also by influencing inflation expectations as such, for example by a credible commitment to future policy actions, and that the central banks do not need to rely on interest rate changes only.

Figure 3: Poland: Reduced-form coefficients

When the time-averages of estimated time-varying coefficients are considered (Table 1), the coefficient for expected inflation γ_f is significant at two standard deviations¹⁸ in all three countries. The backward looking term is lower and significant at one standard deviation only. The coefficients γ_f and γ_b for Poland and Hungary are similar, with γ_f close to 0.55 and γ_b slightly over 0.4. The results for the Czech Republic are somewhat different suggesting higher importance of inflation expectations for the overall inflation dynamics with time average of estimated coefficient γ_f at 0.68. Correspondingly, the role of the backward-looking term is lower, as the associated coefficient γ_b equals to 0.24. Hence, the Czech inflation persistence is roughly one half relatively to other countries¹⁹.

The impact of the output gap on inflation is rarely significant on the entire sample. Actually, just in case of the Czech Republic, the estimated coefficient λ is significant at one standard deviation. This result can have number of explanations. First, the Phillips curve might flatten at lower levels of inflation as the relationship between output or unemployment and inflation is likely nonlinear. This idea already appears in the original article by Phillips (1958) and was further acknowledged by number of authors (an

¹⁸ Standard deviation is again calculated as a time-average of its time-varying counterpart.

¹⁹ Note, that the time-averages can be interpreted as a result from a 2SLS model with stochastic volatility, where the first step equation is replaced by a BMA model.

Table 1: Time average of estimated coefficients (Reduced-form NKPC)

	Czech Republic	Poland	Hungary
γ_f	0.68 (0.23)	0.57 (0.19)	0.58 (0.19)
γ_b	0.24 (0.22)	0.40 (0.18)	0.40 (0.18)
λ	0.33 (0.33)	0.06 (0.30)	-0.15 (0.45)

overview can be found in Stock and Watson, 2010). Second, the slope of the Phillips curve might depend on the size of the output gap: in normal times without recessions and with only mild output gaps, the relationship implied by the Phillips curve is small, but when larger recessions occur, the curve steepens (Stock and Watson, 2010). All countries in our sample were characterized with relatively low volatility of growth rates and although in a number of periods the output gap was negative, the output growth remained positive or it decreased by few percents below zero (with the exception of the current crisis). Third, and perhaps most importantly within the context of the CE countries represented in our sample, the low λ can be associated with factors specific to transition countries (such as fading impact of changes in regulated prices) that cause shifts of the Phillips curve rather than movement along it. Since the volatility in the time-varying λ is relatively small and no systematic correlations either with inflation or output gap appear, it seems that the hypothesis of shifts of the Phillips curve in response to supply shocks seems to be the most likely. However, the first step BMA results suggest that real factors are often relevant for the inflation forecasts (inflation expectations), though the relationship can be more complicated than standard NKPC suggests.

Our time-average results are in line with existing studies that estimate time-invariant NKPC (Arlt et al., 2005; Franta et al., 2007; Basarac et al., 2011; Danišková and Fidrmuc, 2011; Vašíček, 2011) and confirm the hybrid nature of the NKPC. However, when time-varying responses are allowed, the estimated degree of inflation persistence is somewhat smaller²⁰. It is arguable whether omission of potential changes in inflation process implies some upward bias in the backward-looking term, nevertheless these results are in line with Hondroyiannis et al. (2009). In summary, we show that inflation dynamics differs substantially between the three CE countries and imposing slope homogeneity in panel of rather heterogeneous group of CE countries might not be appropriate. Our findings also confirm rather ambiguous evidence on the importance of

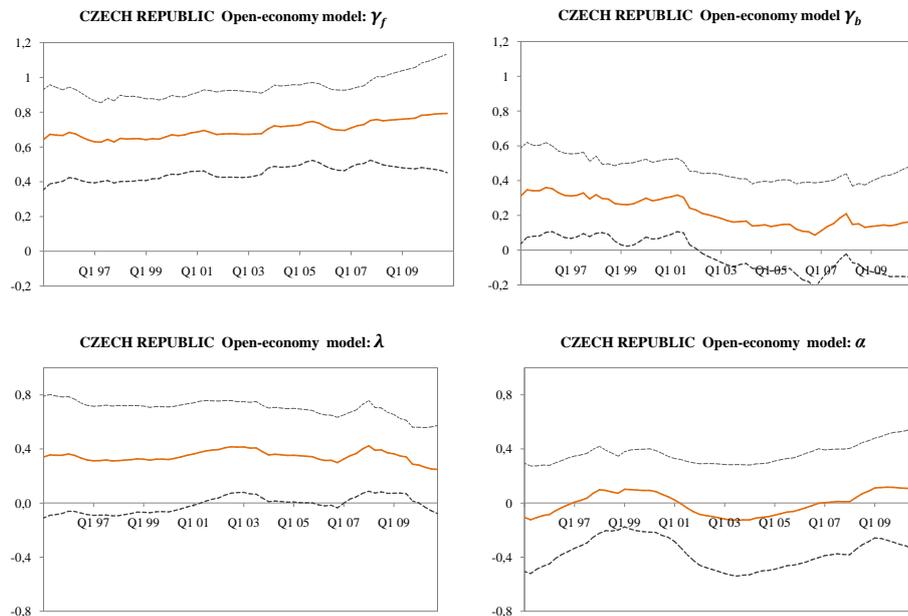
²⁰ Additionally, Vašíček (2011) reports the estimates of the hybrid NKPC in all countries under study finding that forward-looking term dominates the inflation process but the lagged inflation is still important. Also his estimates of λ are close to zero for Poland, often negative for Hungary and about 0.2 for the Czech Republic, but with high variation across different variables representing economic activity.

domestic forcing variables. Mihailov et al. (2011a) and Vašíček (2011) provide some evidence that external factors can be more important as inflation forcing variables. In the following, we extend this evidence to time-varying framework.

4.2 Open-economy NKPC with time-varying parameters

All three countries under study are small open economies highly integrated with international markets, in particular with the euro area. The CE countries liberalized their foreign trade in the early nineties and their integration further increased since the EU accession in 2004. As a result a decisive share of domestic production is aimed at foreign markets and a major share of both intermediate and final products is imported. Therefore, domestic consumer inflation is likely affected (at least partially) by external factors. As advocated by Galí and Monacelli (2005) and subsequent works, the terms of trade that track relative changes in import and export prices can be thus considered a second forcing variable for the inflation dynamics. From this perspective the model without terms of trade is likely to be misspecified.

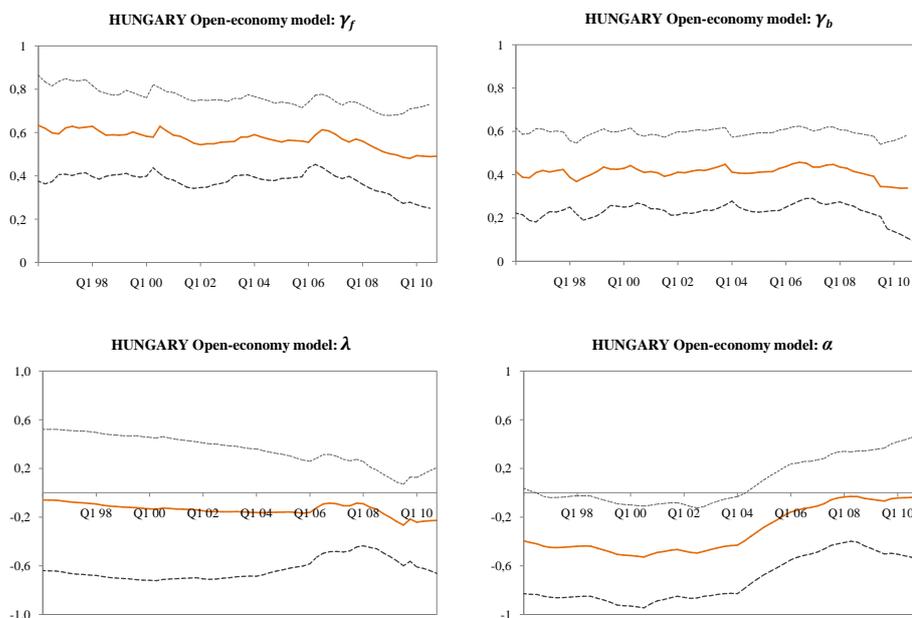
Figure 4: Czech Republic, open economy NKPC coefficients



The estimated coefficients of time-varying open economy NKPC are shown in Figures 4-6. Key observation is that the dynamics of the reduced-form coefficients remains

almost untouched. Second, the coefficient α has certain dynamics alike λ , notwithstanding it is usually insignificant²¹.

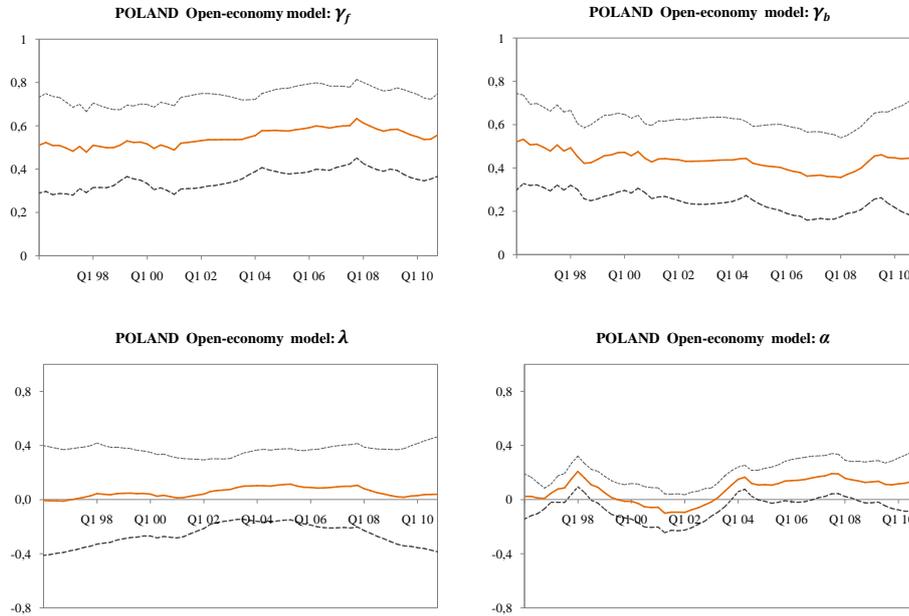
Figure 5: Hungary, open economy NKPC coefficients



Presented results suggest that the open economy NKPC improved above the benchmark NKPC only marginally. The terms of trade seem to be a driving factor of inflation only in Poland, where the coefficient α is significant in several periods following large depreciations (1997Q4-1998Q2, 2003Q4-2004Q3) and then on the onset of the late 2000's recession (2007Q1-2008Q2) again. In the Czech Republic the terms of trade are not significant and the information from foreign prices seems to be already well reflected in domestic inflation expectations themselves.

As far as Hungary is concerned, the results for the open economy NKPC are puzzling in a similar manner as for the closed economy model. The estimated coefficient α is negative and significant till 2003 despite the fact that negative values are not allowed by theory. Note, that these rather baffling results are in line with findings of Mihailov et al. (2011b). Later on, the coefficient α approaches zero and the inflation turns to be driven only by its expected and lagged values.

²¹ Given that the bracketed term in the equation (3.4) is rather complicated, we checked robustness of our results using simple deviation of terms of trade from the HP-filtered trend but the results were qualitatively similar to those presented in Figures 4-6.

Figure 6: Poland, open economy NKPC coefficients

The overall insignificance of the additional term tracking the external sources of inflation can seem a bit counterintuitive for small open economies. An intuitive explanation can be that the factors effecting terms of trade are already reflected in inflation expectations. For instance, if domestic firms are engaged in foreign trade, their inflation expectations are influenced by the foreign price level as well as the exchange rate.

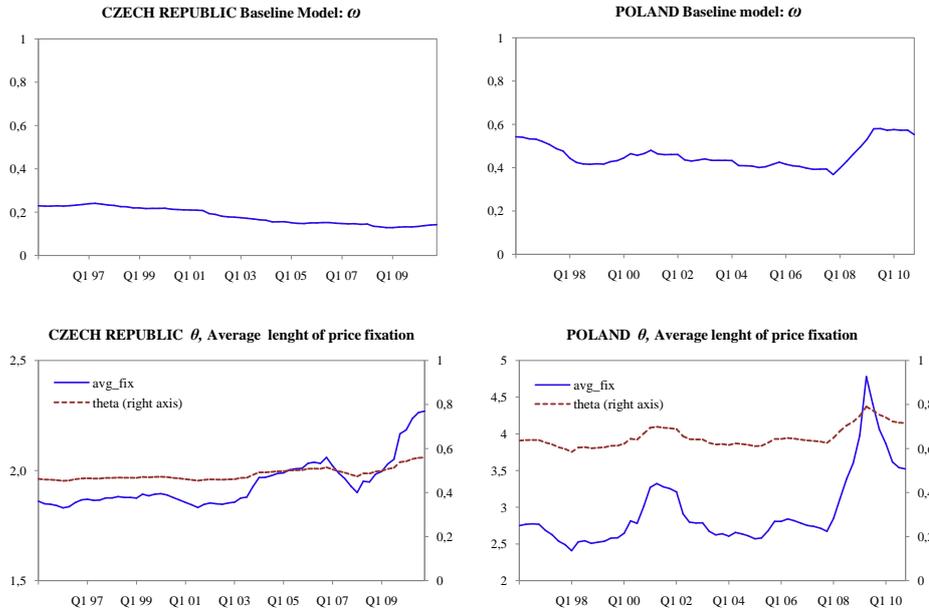
4.3 Are the NKPC structural coefficients truly structural in CE countries?

There has been a certain controversy in the existing empirical work hovering over structural coefficients in the NKPC model. While they are typically reported in papers based on time-invariant framework, time-varying studies usually do not go that far. Indeed, the idea that deep structural coefficients vary in time is rather controversial. However as put forth above, there are numerous reasons why it can be the case in CE countries. Consequently, we use the estimates of reduced form coefficients to obtain a sequence of structural coefficients corresponding to benchmark hybrid NKPC, namely *i*) the share of backward-looking price setters ω and *ii*) the average time for which the prices remain fixed as being the function of θ . As mentioned in subsection (3.2), structural coefficients were derived under the assumption of fixed β equal to 0.99²².

²² We do not estimate structural coefficient from open economy NKPC because *i*) mapping between reduced-form and structural coefficients is more complicated in this case, *ii*) while the coefficient of the

Results for the Czech republic and Poland are reported in Figure 7. For Hungary, the reduced-form coefficient of the output gap λ is negative on the whole sample, which does not allow to obtain structural parameters.

Figure 7: Structural parameters, baseline model

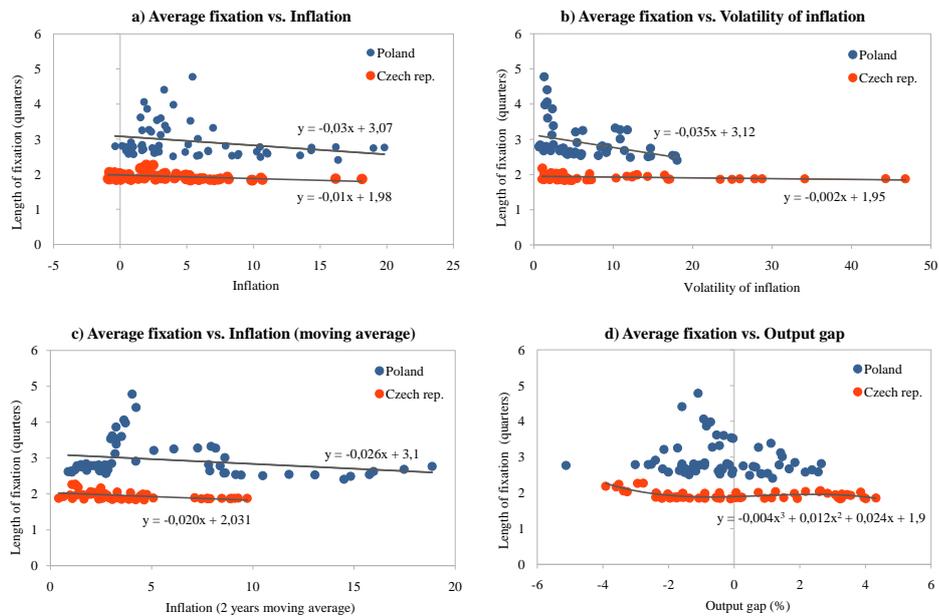


The structural coefficients for the Czech NKPC are depicted in the left panel of the Figure 7. Parameter θ was stable till 2003 and has been slowly increasing since then. Correspondingly, the average length of price fixation co-moves. This result can be associated with decreased volatility of inflation which in turn translates into longer periods when prices do not change. On average, the length of fixation was 1,94 quarters over the sample. A share of the ‘rule of thumb’ firms ω decreased by 10 percentage points from 24% to 14% during the transition, especially after 2001/2002. The decrease corresponds to our expectations. First, during the transition, firms faced continuously increasing competition and needed to change their pricing policy with respect to the market conditions. Second, over time, the role of the administratively regulated prices (which are typically set in backward-looking manner) in overall inflation decreased. Third, the forward-looking price setting is arguably subject to learning. Therefore, decreasing share of backward-looking price setters can signal that firms are becoming more sophisticated and form their expectations in rational (i.e. forward-looking) rather than adaptive (i.e. backward-looking) fashion.

open-economy component is mostly insignificant, other coefficients are largely similar to the benchmark case.

As far as Poland is concerned, the overall stability of the structural coefficients ends on the onset of the late 2000's recession (Figure 7, right panel). All structural coefficients rose sharply between 2007 Q4 and 2009 Q2, when a peak occurs and the trajectories of structural coefficients reversed. This dynamics reflects a decrease in the backward-looking term γ_b that rose due to oil and food prices. However, till the end of our sample (2010 Q4) the values of structural coefficients did not arrived to pre-recession levels. The average share of backward-looking ('rule of thumb') firms is 46% and average time for which prices remain fixed reaches 2,94 quarters. The increase of both structural parameters θ and ω at the end of the sample is clearly linked to the late 2000's recession. Concurrent upward shift in structural parameter θ capturing price rigidity and a deep slump in output suggests existence of downward price rigidities. Nevertheless, validity of these results needs to be corroborated with microeconomic data.

Figure 8: Relation between average price fixation and macroeconomic variables, baseline model



To assess, whether the derived time evolution in θ or average length of fixation can be linked to economic intuition, we present scatter plots between the average length of fixation and key macroeconomic variables: inflation, average inflation, volatility of inflation and output gap (Figure 8a-d)²³. The economic intuition says that under the situation of higher and more volatile inflation it becomes more complicated for economic agents to

²³ In case of the share of backward-looking firms ω , we argued above that its variation is rather related to institutional changes.

distinguish changes in relative prices from the changes of overall price level. Given this hypothesis, negative relationship between average length of fixation and inflation rate or the volatility of inflation should exist (discussion on this issue can be found in Taylor, 1999). Figure 8a) shows that the negative relationship indeed is observable in data as the negative slope is significant for both the Czech Republic and Poland. There is also a significant negative relationship between average length of price fixation and volatility of inflation (measured as 2-year rolling standard deviation)²⁴.

A potential negative relationship between the average length of fixation and the size of the output gap can be related to the presence of downward price rigidities. Figure 8d) shows that especially for the Czech Republic the periods with largest negative output gap are truly also periods with longest length of the fixation. Nonlinear regression of the third order supports this claim as all estimated coefficients are highly significant and the R-square of the regression is almost 50%. In case of Poland, the evidence of a significant relationship between size of the output gap and average length cannot be observed using this simple approach. Nevertheless even in Poland periods with the longest price fixation are connected with negative output gaps.

5. Conclusions

This paper analyzed the dynamics of inflation through the lens of the New Keynesian Phillips curve nested within time-varying framework. Although originally, the NKPC was proposed as a structural model of inflation dynamics which is invariant to policy changes it is likely that substantial changes on macroeconomic level coupled with large restructuring of the whole economies resulted also in significant changes at the microeconomic level. We aimed to shed some light on this issue estimating a standard hybrid version of the NKPC and its open economy counterpart for the CE countries.

The changes in inflation dynamics are usually linked to monetary policy actions. In particular, the recent decrease in inflation persistence was commonly related either to more aggressive reaction of central banks or to anchoring inflation expectations to the long term inflation target. In the period under study countries in the Central Europe went through a unique episode where monetary and exchange rate regimes changed substantially. All three countries in our sample adopted the inflation targeting framework, which is generally believed to drive down inflation persistence.

In general, we have found evidence that the forward-looking inflation term is more important than the backward-looking one. This implies that inflation expectations play a substantial role and they are (at least partially) anchored in the CE countries. In this re-

²⁴ In addition, the negative relationship was also identified with respect to the moving average of inflation and the estimated stochastic volatility of residuals.

spect, our results favour the hybrid NKPC over specifications without forward-looking term. However, a nature of inflation process differs considerably across selected CE countries. In particular, inflation is substantially less persistent in the Czech Republic than in Hungary and Poland. The almost negligible inflation persistence in the Czech Republic implies that lower inflation can be achieved via proper communication of inflation expectations and does not need to be accompanied by output or employment loss. The estimated volatility of inflation shocks decreased quickly few years after adoption of inflation targeting both in the Czech Republic and in Poland, whereas it remains stable in Hungary. Results above clearly show that the differences in practical implementation of inflation targeting do matter. In particular, it seems that simultaneous stabilization of exchange rate and price level limits the ability of central bank to anchor the inflation expectations.

The NKPC model postulates that the inflation dynamics is determined not only by inflation persistence and inflation expectations, but with the real activity, too. However, finding proper forcing variable of inflation in the CE countries has proved to be a non-trivial task. This fact seems to be related to factors specific to transition countries, such as diminishing impact of administratively regulated prices, gradually increasing productivity of labour, trade integration with the EU or higher vulnerability of the CE countries to shocks on financial markets in the 90's. All these factors lead to weaker link between evolution of output gap and inflation.

At last, we have found some evidence that 'structural' coefficients are not stable across time as it is commonly believed. We showed that the average time for which prices remain fixed is negatively correlated with both the level and volatility of inflation. The share of backward-looking price setters is changing smoothly with predominantly downward sloping trend. Unlike in the case of average fixation, the reasons should be rather sought in long-term determinants such as increasing competitions, decrease of administratively regulated prices or in the learning capacity of price setters.

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Appendix: BMA results (first step)²⁵

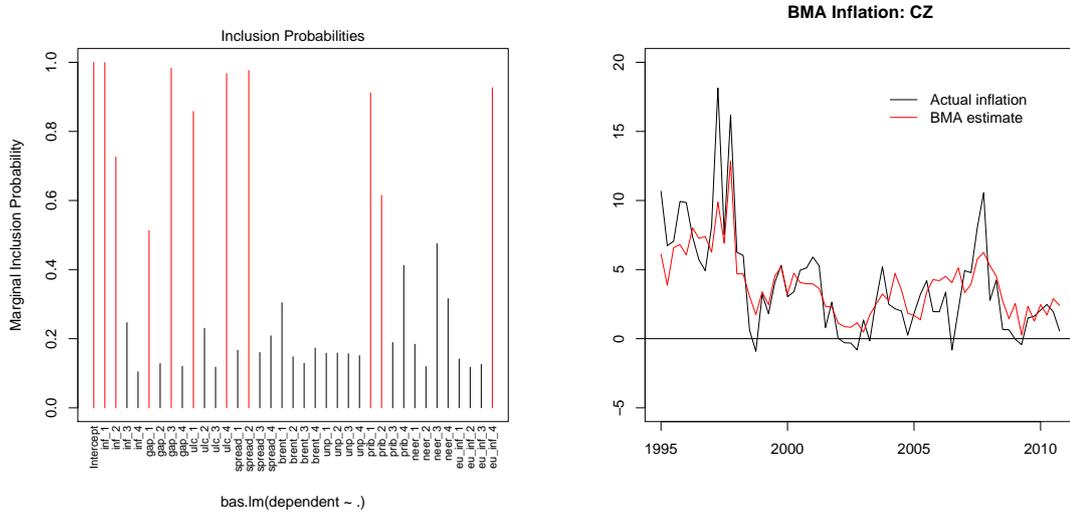


Figure A1: Czech Republic

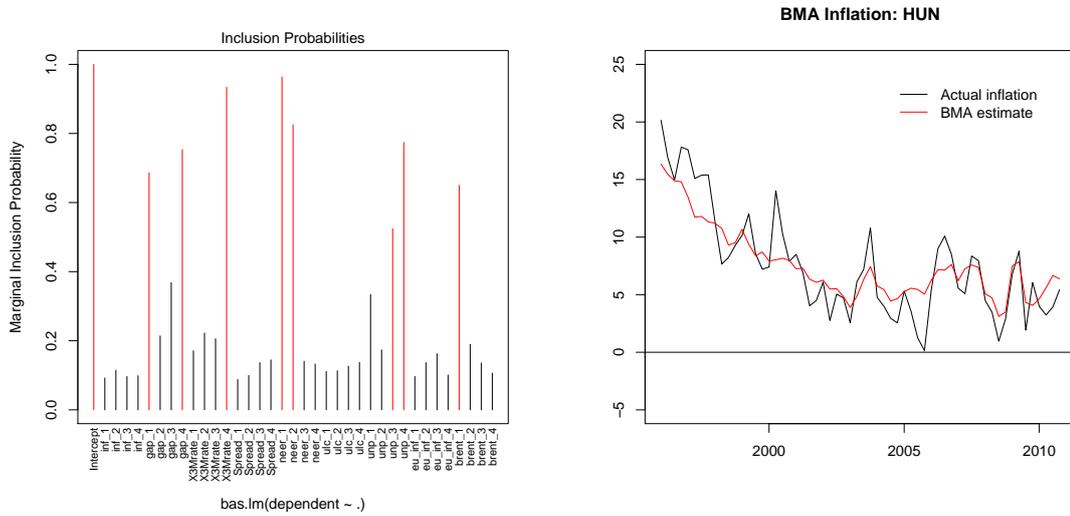


Figure A2: Hungary

²⁵ Red bars indicate posterior inclusion probability higher than 0.5.

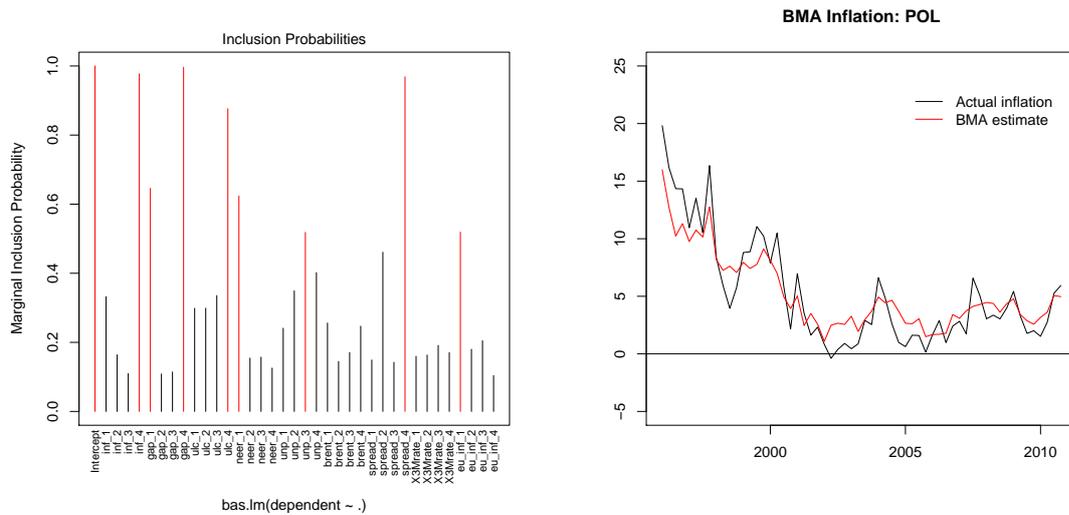


Figure A3: Poland