Time Varying Parameter Taylor Rule for the Hungarian Monetary Policy

Preliminary Version – Please do not quote

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Abstract

We estimate a forward-looking time-varying monetary policy reaction function for the Hungarian economy. We estimate two different Taylor-type equations to find empirical evidence for our retrospective, narrative analysis. An important feature of our study is that estimation procedures are mainly based on data published by the Hungarian National Bank. The short-term (one-year-ahead) inflation forecasts and the contemporaneous output gap estimates are collected from the central bank's quarterly Inflation Report. While we were searching for the best possible specification, assumed the existence of an implicit and also time-varying exchange rate target. Our results point to substantial fluctuation of the parameters. The **evidence** suggests that three largely distinct subperiods can be distinguished in the history of Hungarian inflation targeting regime. These subperiods are mainly determined by the economic conditions and possibly by preferences of the Board. According to our results the first subperiod starts from Q3 2001 and lasts until the outbreak of the 2008 crisis. The second subperiod can be characterized by deep crisis and ends in 2012. The third subperiod is about recovery. We estimate the time-varying parameters of our Taylor-type equations by using the methodology of the extended Kalman filter because of the presence of a non-linear term in the measurement equation.

Keywords: Kalman Filter, Interest Rate, Monetary Policy, Taylor Rule, Time Varying Parameter

JEL Classification: E43, E52, E58

1 Introduction

After **Taylor (1993)** the monetary reaction function has become a basic cornerstone of the rational expectations models in macroeconomics. We see that both DSGE models and the less micro-founded gap models contain a Taylor-type equation to close the structure. As simulations and scenario analyzes are based on the rule, today's monetary policy decisions are also affected by it - at least to a certain extant. However, the original concept offers an other, no less important area of application: It offers the narrative interpretation of the monetary policy practice. In this study we will estimate two different Taylor-type equations to map how the focus of the Hungarian monetary policy has developed during the inflation targeting regime (Q3 2001 – Q3 2015). In order to do so we assume time-varying parameters in the equations. We first employ a linear Kalman filter, and then an extended one which allows for non-linearity. Non-linearity will be present because of anecdotal evidence of an implicit (latent) exchange rate targeting in the Hungarian monetary policy.

The primary declared goal of the Hungarian National Bank (Hungarian: Magyar Nemzeti Bank, hereinafter MNB) is to ensure price stability. Accordingly, in 2001 the MNB adopted the inflation targeting (IT) regime as a framework of its monetary policy. In an IT framework the monetary policy maker determines the policy rate on the basis of future developments of inflation and economic growth. The ultimate goal of the rate-setting decisions is to stabilize the consumer price inflation around a declared mid-term target value. Previously inflation forecasts made of the MNB were mainly based on macro-econometric models. These macro-econometric models, which lack microeconomic foundations, are based on macro-level stylized facts and typically contain a lot of equations. While these models also reflect on many relevant economic relationships, their behavior is determined solely by the past, that is by empirical correlations. Due to the good in-sample performance of these models, the so-called *conditional* inflation forecasts were based on them for many years. In this context *conditional* refers to the forecast technique which assumes stable interest rate on the forecast horizon (i.e. ceteris paribus). For many years this technique was the best practice in monetary policy and for the MNB as well. Conditional forecasts was seen to assist the policy makers in that it provided information as to whether a given central bank could achieve its target with monetary conditions remaining unchanged. However, it was unable to identify that interest rate path, which would be necessary for achieving the inflation target.

To deal with this problem in 2010 the MNB started to develop a new rational expectations gap model. The working process ended in March 2011. The introduction of the new Monetary Policy Model (hereinafter MNB) represents a paradigm shift in both inflation forecasting and monetary policy decision support. Given the forward-looking nature of this model, expectations by economic agents play a key role in monetary transmission; therefore, instead of one-off interest rate measures, the achievement of inflation target is guaranteed by the entire interest rate path over the forecast horizon.

Major transmission channels of monetary policy are incorporated into the model's behavioural (structural) equations, in which expectations by economic agents play a crucial role. The path for the policy rate is defined by a dynamic monetary policy reaction function. While we were searching for the best possible specification, the reaction function defined in MPM was a very useful reference point for us. Even though it was defined by the MNB staff, that is an important participant of the policy-making process, we found a significantly better specficifvation, in terms of in-sample performance. Evidently, our retrospective analysis is based on that specification whose in-sample performance was rated as best by the information criteria.

Section 2 will give the literature review on TVP monetary policy rules in detail. Section 3 will describe the data used for our analysis. Section 4 will present two different Taylor-type rules. The arguments for these specifications will be also presented here. Section 5 will give brief information about the estimation method, that is state space representation and basic characteristics of extended Kalman filter. Section 6 will conclude the study.

2 Literature Review on TVP Monetary Policy Rules

The following literature review is based on the comprehensive, detailed work of Yüksel et al. (2012).

Substantial effort is devoted to monetary policy changes and TVP specification of monetary policy rules. The changes in policy implementation were tried to be captured by subsample analysis, generalized method of moments (GMM), least squares (LS), maximum likelihood estimation (MLE), vector autoregression (VAR), Markov switching and Kalman filter.

Judd and Rudebusch (1998) illustrated how the Fed's reaction function has changed over time using ordinary least squares (OLS) and subsample analysis. The study resulted in that parameters of Taylor-type rule significantly differed for each sub period considered, indicating that monetary policy regime varies in time. This study also pointed out dependency of monetary policy on the attitude of policymakers towards the structure of the economy. Similarly, Clarida et al. (2000) presented that the US monetary policy has changed significantly before and after Paul Volcker was the chairman of the Fed using another estimation technique GMM. Parallel to these studies, Orphanides (2004) provided evidence about the changes in the interest rate rule of the US using the estimations of a forwardlooking Taylor rule for two subperiods.

The studies that use Kalman filter to estimate TVPs of Taylor rule include Elkhoury (2006), Trecroci and Vassalli (2006), Trehan and Wu (2007) and Hatipoglu and Alper (2009). Elkhoury (2006) examined the TVP monetary policy rule for an open economy, Switzerland. The study used Kalman filter to embed policy shifts and structural changes into the model and found that uncertainty associated with the policy rule was mostly due to time-varying characterization of the parameters and, to a lesser extent, monetary shocks. Trecroci and Vassalli (2006) estimated forward-looking TVP Taylor rule for the UK, Germany, France, Italy and the US, using Kalman filter. It was demonstrated that the countries analyzed have different interest rate rules and TVP Taylor rules are preferred, compared to fixed parameter rules, in capturing the variations in the policy rates. Furthermore, the coefficients of the policy rules are changing over time in a gradual fashion. Trehan and Wu (2007) employed Kalman filter to predict a Taylor rule for the backward-looking US economy focusing on time-varying equilibrium real interest rate. It was interpreted that taking into account the time-variation in the equilibrium real interest rate makes substantial difference in the assessment of monetary policy. Hatipoglu and Alper (2009) estimate an augmented Taylor policy rule that responds to an exchange rate gap in the context of emerging markets utilizing Turkish data.

To estimate time varying parameters and unobserved variables, such as exchange rate target and potential output simultaneously they employ a dual extended Kalman filter which allows them to trace any changes in central bank behavior including regime shifts. Boivin (2006), Jalil (2006), Kim and Nelson (1990) and Mandler (2007) used Kalman filter and MLE together to estimate time varying Taylor rule for the US. Jalil (2006) estimated a TVP backward-looking Taylor rule with ex-post and real-time data for the US and stated that there are gradual adjustments in the coefficients of the policy rule in the US, which cannot be captured adequately by sub-sample analysis. Boivin (2006) estimated forward-looking Taylor rule for the US employing Kalman filter to construct likelihood function. The conclusion was similar to Jalil (2006) and Trecroci and Vassalli (2006) in the sense that the parameters of Taylor rule are changing slowly. Following Boivin (2006), Kim and Nelson (1990) attempted to characterize a forward-looking Taylor rule with TVP using ex post data. Besides TVP property, this study also considered the uncertainty included in the forecasts of future inflation and output gap. Two-step MLE procedure with Kalman filter was used to estimate the model and their empirical result was in favor of division of monetary policy history of the US into three periods instead of two – contrary to Orphanides (2004). Mandler (2007) suggested Taylor rule with TVPs and unobserved components model for the output gap together to predict uncertainty in the future values of the Fed rate using MLE technique via Kalman filter. It was found that the predicted uncertainty can be divided into three namely, uncertainty due to time-dependent coefficients of the Taylor rule, uncertainty about the future economic events and residual uncertainty.

VAR representation with Kalman filter was also employed to model TVP Taylor rule as in Canova and Gambetti (2004), Cogley and Sargent (2001) and Mesonnier and Renne (2007). Cogley and Sargent (2001) showed empirically that after World War II, policy actions alter significantly with respect to the status of the economy, implying that coefficients in the policy rule are changing with time. A similar conclusion was drawn by Canova and Gambetti (2004) by examining changes in the structure of the US economy via structural VAR framework. Their work differs from Cogley and Sargent (2001) in the sense that structural shocks were also included in the analysis. For the euro area, Mesonnier and Renne (2007) examined TVP property of natural rate of interest. The study suggested a Taylor-type policy rule with time-varying natural rate of interest for the euro area using Kalman filter.

Plantier and Scrimgeour (2002) estimated Taylor rule with TVP specification employing Kalman filter with OLS to reveal that neutral real interest rate of New Zealand follows a downward trend in recent years. Horvath (2006) modeled various forms of fixed-parameter and TVP Taylor-type rules for the Czech Republic using GMM and Kalman filter. It was found that equilibrium interest rate has decreased steadily over time. In addition to previous works made for euro area, Kuzin (2006) estimated a backward-looking (opposed to forwardlooking) Taylor rule with time-dependent coefficients using Markov switching models and Kalman filter, for Germany only. The conclusion was similar to the work of Trecroci and Vassalli (2006) so that TVP Taylor rule performed well in capturing the policy shifts.

Orphanides and Williams (2005) adopted time variation in parameters of the model by allowing agents to update their expectations about the structure of the economy and monetary policy. For this, they used VAR and OLS framework and investigated changes in the view of policymakers and monetary policy implementation in the US. Likewise, Sims and Zha (2006) sdocumented inferences about monetary policy changes in the US by allowing time variation both in the coefficients of the Taylor rule and variances of shocks to the economy within a structural VAR framework. Models allowing changes in the parameters of disturbances and monetary policy function were found to be the best-fit models for the US data.

Wesche (2003) performed a TVP Taylor rule analysis for the countries considered in Trecroci and Vassalli (2006). A similar conclusion was reached using a different estimation procedure, Markov-switching model with independent switching processes for the TVPs of the Taylor rule and variances of disturbances. Later, Wesche (2006) showed changing preferences of policymakers for interest rate setting in a Markov-switching framework for the US, the UK and Germany. Markov-switching model was also employed by Owyang and Ramey (2004) to measure the shifts in the parameters of the policy rule of the US Fed. Parallel to previous works, Partouche (2007) estimated a forward-looking TVP policy rule for the US, as well. Instead of Kalman filter this study adopted a different technique, which combined GMM framework with smoothing splines. Such a technique is not restrictive on econometric terms so that it imposes no constraints on the form of heteroscedasticity of the shock terms and the correlations between the regressors and disturbances. Likewise, McCulloch (2007) estimated TVP forward-looking Taylor rule for the US using a different method, adaptive least squares (Adaptive LS), to model time-varying structural VAR framework. Recently, Gerlach and Lewis (2010) used smooth transition regression model to show the shifts in the parameters of monetary policy rule of European Central Bank during the financial crisis. The summary of the literature on TVP policy rules is presented in Table.

3 Data

In this section we describe the data. In doing so we would like to emphasize that the estimation procedure is mainly based on data provided by the MNB. On the one hand we rely on the MNB's short term (one-year-ahead) inflation forecast, which is published quarterly with the Inflation Report. The CPI based inflation forecast was first available in August 2001, so the first forward looking inflation gap stands for Q3 2002. As the inflation forecast is available until Q3 2015, the last inflation gap is for Q3 2016. To calculate inflation gaps, which will be needed to estimate our models, we also use inflation targets declared by the MNB (MNB, 2015).

In order to estimate a Taylor rule, we would need to know the MNB's contemporaneous output gap estimates as well. Sadly these estimates are available only from Q2 2007. So if we insisted on using solely MNB date then we would have insufficiont number of observations. To deal with this problem we filled out the series of the contemporaneous output gap estimates: From Q3 2001 to Q1 2007 we applied a basic recursive HP filter technique (MNB, 2015; Tóth, 2011).

In our extended nonlinear model, which assumes an implicit form of exchange rate targeting, we use the EUR/HUF nominal exchange rate (quarterly average values). The source of this data is the Eurostat.

Lastly, our measurement (signal) variable is the quarterly average of the day-to-day money market interest rates for this period. This short-term rate is considered to be one of the most well-controllable rate for monetary policy. In this case the source of the data is the Eurostat as well.

Our full sample is from Q3 2001 to Q3 2015, which includes 57 valid observations.

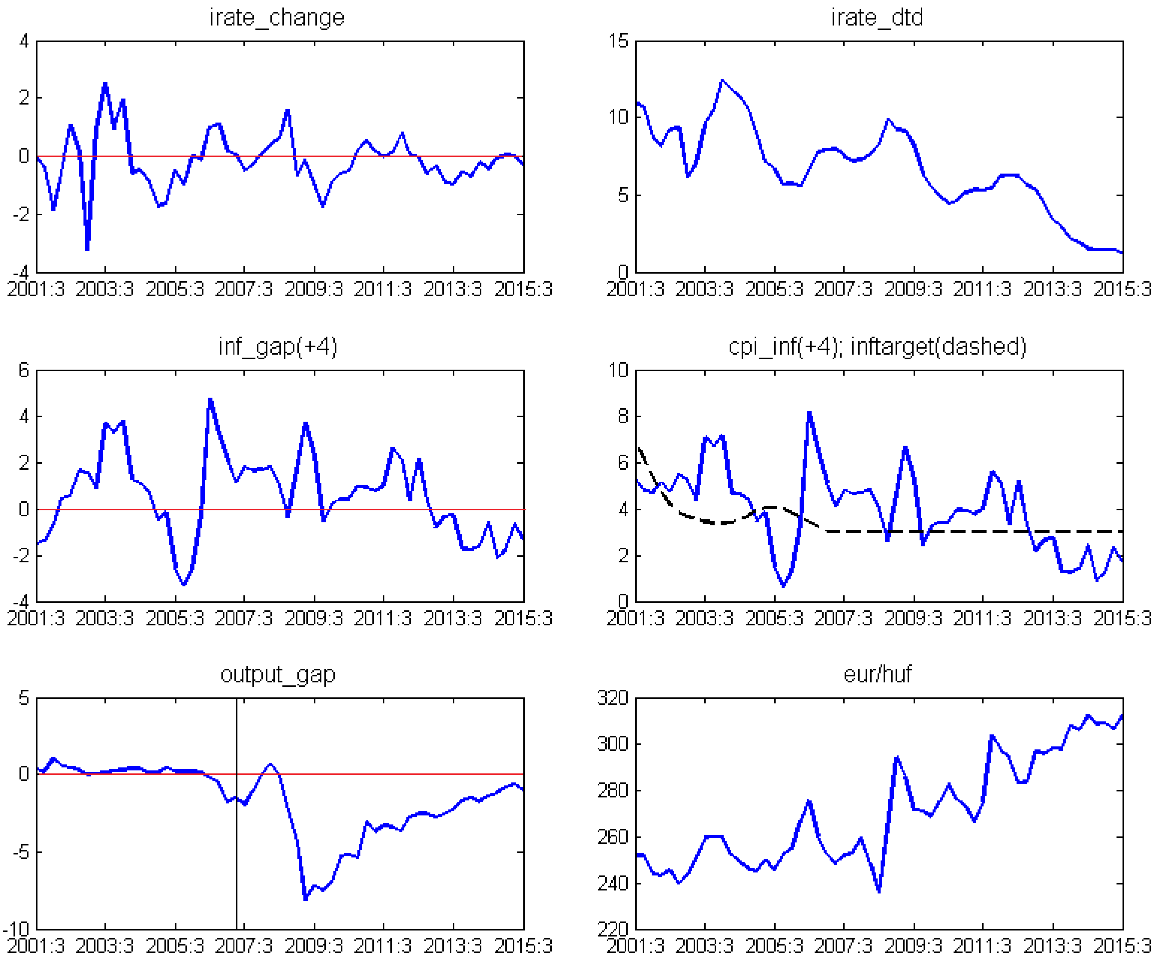

Figure 1: Model input data

4 Model specification

According to the basic idea of Taylor's rule, deviations of the central bank policy rate from its equilibrium level can be traced back to two fundamental factors, namely the deviation of inflation from its target and the output gap. Initially the impact of these factors was supposed to be the same. Based on Taylor's original study (Taylor, 1993) and using our own notations:

$$i_t = \pi_t + 0.5 \cdot \hat{y}_t + 0.5 \cdot (\pi_t - \pi^*) + 0.02 \tag{1}$$

Due to the relatively short sample and the special features of the Hungarian economy several modifications should be made on the equation above. As we can see above the original model does not assume any type of interest rate smoothing, while the majority of the recent models includes this assumption. We also use a so-called dynamic Taylor rule in our analysis because assuming interest rate smoothing seems to be quite reasonable. Partly because the policy rate's high level of volatility would otherwise cause unjustified fluctuations in real economic activity, but also because rate-setting decisions also imply the prevalence of certain aspects of financial stability.

4.1 Basic linear model

The path for the policy rate is defined by the monetary policy reaction function, a Taylor-type rule:

$$r_t = \alpha_t \cdot \hat{\pi}_t^{t+4} + \beta_t \cdot \hat{y}_t, \tag{2}$$

where the variables represent the following quantities in period t:

- r_t: change of the short-term money market interest rate, which is controlled by the central bank policy rate,
- $\hat{\pi}_t^{t+4}$: inflation gap, the difference between the one-year-ahead inflation expectations and the current target,
- $\hat{y}_t$: output gap.

In the case of a TVP model we assume that the coefficients depends on time and follow a discrete time random walk:

$$\alpha_t = \alpha_{t-1} + \varepsilon_t^{\alpha}, \quad \varepsilon_t^{\alpha} \sim \mathcal{N}(0, \sigma_{\alpha}^2), \tag{3}$$
$$\beta_t = \beta_{t-1} + \varepsilon_t^{\beta}, \quad \varepsilon_t^{\beta} \sim \mathcal{N}(0, \sigma_{\beta}^2). \tag{4}$$

It is a common practice in the econometrical literature (Hamilton, 1994). Through the estimation we calculate the realization of each random walk on the sample. Those paths express then how the focus of the monetary policy has changed over time.

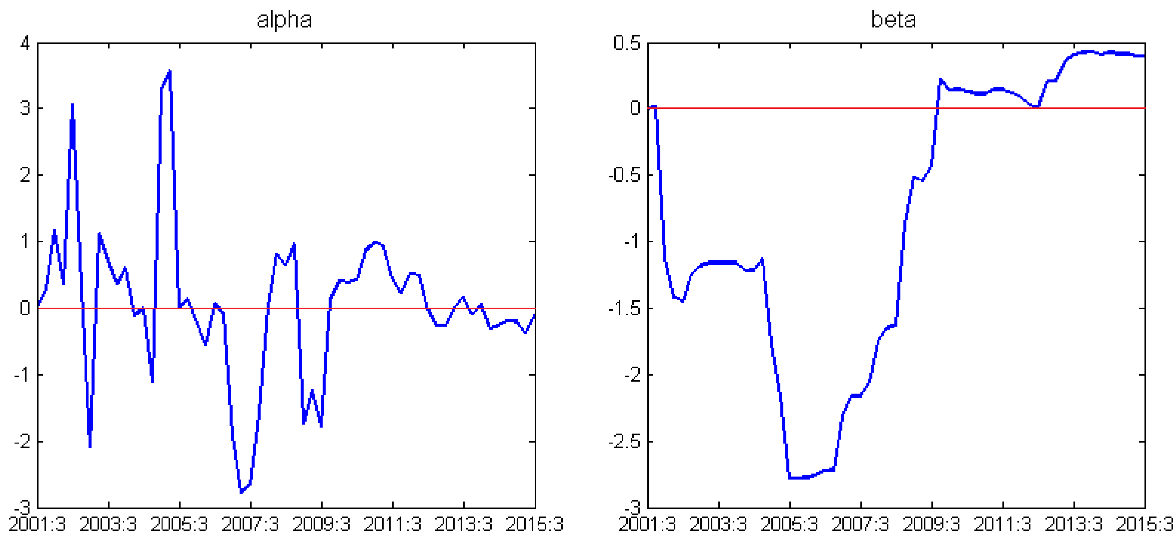

Figure 2: Results of the basic linear model

In the light of the abvoe briefly assess the results of the basic linear model. Figure 2 shows the filtered state estimates for α_t and β_t (i.e. $\hat{\alpha}_{t|t}$ and $\hat{\beta}_{t|t}$). Although the results are relatively hard to interpret, some important conclusions can be drawn. As we can see in Figure 2 the focus of the Hungarian monetary policy has changed significantly over the period. While the effect of the real term has been small (and also hard to interpret) at beginning of the period, it has become the primary factor of the policy decisions. Meanwhile the effect of the nominal term (i.e. inflation gap) has continuously decreased.

We can see in Figure 2 that the value of the state estimates become quite stable and much more acceptable after the 2008 crisis. In contrast the results are very hard to interpret at the beginning of the period. These findings gave the grounds for altering, that is expanding the model specification.

4.2 Extended model

Considering that Hungary is a small open economy the development of import prices is also relevant therefore the exchange rate plays an important rule in the monetary policy. We decided to extended the model with an additional non-linear part:

$$r_t = \alpha_t \cdot \hat{\pi}_t^{t+4} + \beta_t \cdot \hat{y}_t + \gamma_t \cdot (e_t - e_t^*). \tag{5}$$

where e_t denotes the EURHUF exchange rate in the period t. With the last part we handle that the monetary policy in an open economy reflects on a 'exchange rate gap'. It means there may be a 'psychological' target in the 'head' of the decision makers. We tried to express this idea with our modell and estimate the target exchange rate.

The additional parameters are assumed to behave like in the case of the linear model, namely

$$\gamma_t = \gamma_{t-1} + \varepsilon_t^{\gamma}, \quad \varepsilon_{\gamma}^{t} \sim \mathcal{N}(0, \sigma_{\gamma}^2) \tag{6}$$

$$e_t^* = e_{t-1}^* + \varepsilon_t^{e^*}, \quad \varepsilon_t^{e^*} \sim \mathcal{N}(0, \sigma_{e^*}^2). \tag{7}$$

Before we turn to the results we would like to draw attention on the problems we had to deal with. The short sample ($T = 57$) made the estimation of the parameters (i.e. the state variables) difficult, therefore their confidence are maybe questionable.

The second problem is the possible endogeneity of the variable $\hat{\pi}_t^{t+4}$. It can be a realistic assumption, that the change of the interest rate in the present influences the value of the forward looking interest expectations. Although the impact of the endogeneity can result a noticable bias in the estimation, we do not aspire to explain the endogen variable trough a macro model (Yüksel et al., 2012; Wesche , 2003). This paper is for the most part descriptive we do not use our model to forecast the interest rate therefore this problem is not critical.

The third and most difficult problem is how to specify the model. The literature gives a clear direction to the definition of the state variables, however in the case of the observation equation we could use only general, theoretical guidelines (Taylor, 1995, 1999a,b; Mellár , 2008).

5 Estimation method

In the previous section we introduced a model that contains a quadratic part in the observation equation, therefore we cannot use the traditional linear Kalman-Filter to estimate the coefficients of the modell. The solution of the problem is the Extended Kalman-Filter (EDF) which can deal with non-linearities. The basic idea of the EKF method is that we can use first order Taylor series as an approximation of the non-linear model (Harvey, 1990).

Now we briefly describe algorithm of the EKF method applied for the modell 5. Some notations has to be introduced to simplify the calculations

$$\mathbf{x}_{t|s} = \begin{bmatrix} \alpha_{t|s} \\ \beta_{t|s} \\ \gamma_{t|s} \\ e_{t|s}^* \end{bmatrix}, \qquad \mathbf{Q} = \begin{bmatrix} \sigma_\alpha & 0 & 0 & 0 \\ 0 & \sigma_\beta & 0 & 0 \\ 0 & 0 & \sigma_\gamma & 0 \\ 0 & 0 & 0 & \sigma_{e^*} \end{bmatrix} \tag{8}$$

where $\mathbf{x}_{t|s}$ denotes conditional mean based on information set available in period t and $\mathbf{Q}$ stands for the variance-covariance matrix of the error terms corresponding to the state system.

$$\mathbf{H}_t = [\hat{\iota}_t^{t+4} \quad \hat{y}_t \quad e_t - e_t^* \quad \gamma_t] \tag{9}$$

which is a simple row vector in our case. Now we are ready to turn to the algorithym.

For all t period in the range of $1, \ldots, T$ we have to follow the next steps:

- **Step 1**: calculate of the preditions for the state variables and the covariances

$$\mathbf{x}_{t|t-1} = \mathbf{x}_{t-1|t-1} \tag{10}$$
$$\mathbf{P}_{t|t-1} = \mathbf{P}_{t-1|t-1} + \mathbf{Q}. \tag{11}$$

- **Step 2**: calculate the innovation and the approximate Kalman-gain

$$z_t = r_t - \left(\alpha_t \cdot \hat{\iota}_t^{t+4} + \beta_t \cdot \hat{y}_t + \gamma_t \cdot (e_t - e_t^*)\right) \tag{12}$$
$$S_t = \mathbf{H}_t \mathbf{P}_{t|t-1} \mathbf{H}_t^{\intercal} \tag{13}$$
$$K_t = \mathbf{P}_{t|t-1} \mathbf{H}_t^{\intercal} S_t^{-1}. \tag{14}$$

- **Step 3**: update the covariances and the state variables

$$\mathbf{P}_{t|t} = (\mathbf{I} - K_t \mathbf{H}_t) \mathbf{P}_{t|t-1} \tag{15}$$
$$\mathbf{x}_{t|t} = \mathbf{x}_{t|t-1} + K_t z_t. \tag{16}$$

After we have the measurement errors in each period we can calculate the loglikelihood function:

$$LL(\sigma_\alpha, \sigma_\beta, \sigma_\gamma, \sigma_{e_t^*}) = -\frac{T}{2}\log(2\pi) - \frac{1}{2}\sum_{t=1}^{T}\log(S_t) - \frac{1}{2}\sum_{t=1}^{T}\frac{z_t^2}{S_t}, \tag{17}$$

what we have to maximize along the four standard deviation parameters. Actually we can think about this estimation as a NLP where the objective is the loglikehood value, the contraints was described in the step 1–3 for all $t \in \{1, \dots, T\}$ and the variables are nonnegative[1]. We used the optimization toolbox of MATLAB to find the best fitting values for the sigmas.

At last we have to spend some words about the initial values of the simulation. According the literature for the initial values of the state variables we used the zero vector, that means in the case of the exchange rate target (e^*) the first value must equals with e_0 therefore the initial value of the gap is zero i.e.

$$x_{0|0} = [0 \quad 0 \quad 0 \quad e_0]. \tag{18}$$

In the case of the covariances we used the $\mathbf{P}_{0|0} = \mathbf{I}$ as the starting point of the algorithm.

6 Model results

In the light of the above assess the results of model estimation.

[1] The nonnegativity is ensured with the $\sigma = \mathrm{e}^{\hat{\sigma}}$ transformation for all of the standard deviation parameters

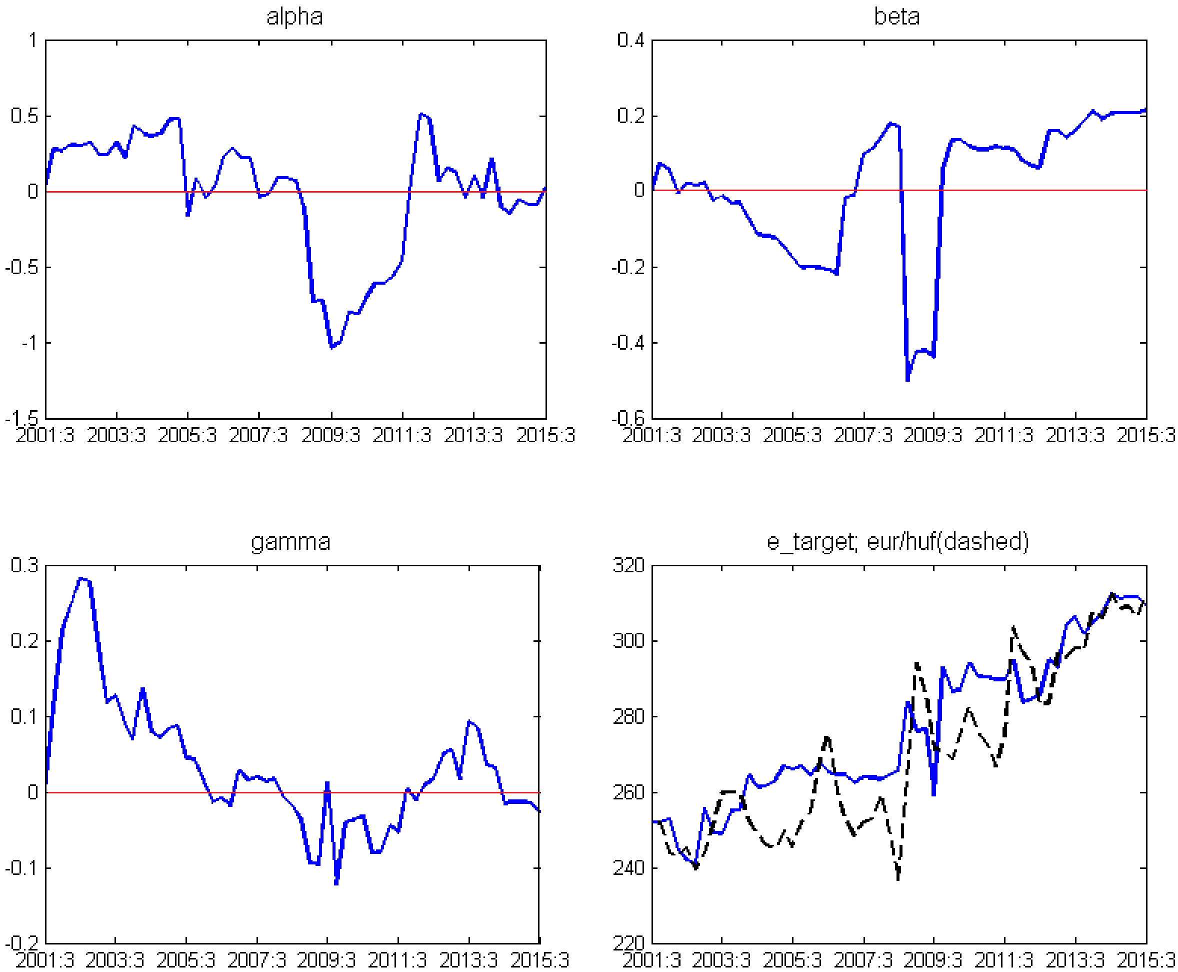

Figure 3: Results of the extended model

Figure 3 shows the filtered estimate ($\hat{\mathbf{x}}_{\mathbf{t}|\mathbf{t}}$) of the four state variables on the whole sample. As can be seen in the figure the reaction function of the Hungarian monetary policy changed significantly over time in the sample period (from Q3 2001 to Q3 2015) which is the first and most important result of our study. We could distinguish three largely distinct subperiods of monetary policy which are not marked by the mandate of the governor of the national bank but by the economic necessities. Next we characterize these three stages subperiods.

Subperiod 1 (From Q3 2001 to Q4 2007) In this subperiod both the deviation from the latent exchange rate goal (nominal EUR/HUF rate) and the forward looking inflation gap have positive and significant parameters in almost every quarter. Figure 3 indicates that the monetary policy focused on stabilizing the implicit goal on the EUR/HUF rate. Also at the end of this subperiod (from the beginning of 2007) handling real economic imbalances starts to be more important than exchange rate goals. At the beginning of 2007 the recursive HP filter estimates a negative output gap and also the related parameter is negative. It seems that the central bank itself did not believe the estimates of the output gap based on the HP filter and tried to manage real economy imbalances.

Subperiod 2 (From Q1 2008 to Q4 2011) During the financial crisis and the years of depression the primary goal of the monetary policy was clearly to protect the exchange rate. At high foreign exposure it is not surprising that strengthening the Forint had high priority. The monetary policy tried to react to the suddenly positive (HP filter endpoint problem) output gap but from autumn 2008 both the inflation goal and the real goal became secondary. Figure 3 shows that between 2008 q3 and 2009 q4 the implicit EUR/HUF exchange rate goal weakened by nearly 27 HUF. Although the $(e_t - e_t^*)$ difference stayed negative in these years, the negative value of the related parameter emphasizes the importance of the implicit exchange rate goal.

Subperiod 3 (From Q1 2012 to Q3 2015) The third stage is the end of the recession. At the beginning of 2012 the focus was on forward looking inflation gap. By that time the gap was around +2% due to the deprication of the forint. By the end of 2012 the explanatory power of the inflation gap practically disappears. From that on the monetary policy supports the closure of the negative output gap and the depriciation.

7 Conclusion

In our narrative analysis we found that the focus of the Hungarian monetary policy has changed significantly over the inflation targeting regime. These changes can be explained by the development of the economic conditions. While the relative importance of the nominal and the real term has showed high fluctuations, the importance of the implicit exchange rate targeting remained always relevant. We also found that the latent exchange rate target has constantly weakened during the period. In recent years of economic recovery we see that the relative weight of the output gap has grown significantly. Considering this fact it is questionable how reliable are the contemporaneous output gap estimates.

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