MAGYAR NEMZETI BANK

MNB WORKING PAPERS

2005/6

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Exchange Rate Smoothing in Hungary

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November, 2005

* I would like to thank the participants of the conference of the Applied Econometrics Association and the seminar at the Central Bank of Hungary, especially Gábor Kőrösi, Zsolt Darvas and Csilla Horváth for their useful comments. All remaining errors are mine.

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http://www.mnb.hu

ISSN 1585 5600 (online)

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Abstract

The paper proposes a structural empirical model capable of examining exchange rate smoothing in the small, open economy of Hungary. The framework assumes the existence of an unobserved and changing implicit exchange rate target. The central bank is assumed to use interest rate policy to obtain this preferred rate in the medium term, while market participants are assumed to form rational expectations about this target and influence exchange rates accordingly.
The paper applies unobserved variable method – Kalman filtering – to estimate this implicit exchange rate target, and simultaneously estimate an interest rate rule and an exchange rate equation consistent with this target. The results provide evidence for exchange rate smoothing in Hungary by providing an estimated smooth implicit exchange rate target development and by showing significant interest rate response to the deviation of the exchange rate from this target. The method also provides estimates for the ceteris paribus exchange rate effects of expected and unexpected interest rate changes.

JEL classification: E52, F31, F41
Keywords: exchange rate smoothing, interest rate rules, Kalman filter

Árfolyamsimítás Magyarországon

Az empirikus tanulmány strukturális modellkeretben vizsgálja az árfolyamsimítás hatásait Magyarországon az inflációs célkövetés rendszerének 2001-es bevezetése óta. A megközelítés egy időben változó, és közvetlenül nem megfigyelhető árfolyamcélt feltételez. A modell alapján a központi bank kamatpolitikájával az implicit árfolyamcél középtávú fenntartására törekszik, miközben a piaci szereplők racionális várakozásokat alakítanak ki a célról, és ennek megfelelően befolyásolják az árfolyam-alakulást.
A tanulmány a nem megfigyelhető változók egy módszerét – az ún. Kalman-szűrőt – alkalmazza az implicit árfolyamcél számszerű becslésére, miközben a céllal konzisztens szimultán becslést készít az árfolyamegyenletről és a központi bank által követett kamatszabályról. Az árfolyamsimítás magyarországi jelenlétét megerősíti egyrészt a becsült árfolyamcél stabil alakulása, másrészt, hogy az árfolyam eltérése a céltól szignifikáns kamatreakciót vált ki. A megközelítés számszerű becslést ad a várt és váratlan kamatváltozások árfolyamhatására.

1. Introduction

This paper is part of the transmission mechanism research of the Central Bank of Hungary, and its main motivation is to explore futher the interrelationship of short term interest rate and exchange rate development in Hungary using high frequency data. It argues that this relationship is strongly influenced by the systematic exchange rate smoothing behavior of the central bank, and applies a methodology which is capable of numerically assess some of its effects.

In open economies, like Hungary, exchange rate can play an important role in the transmission mechanism, and its volatility can cause various, potentially substantial welfare distortions. These considerations provide incentives for the central bank – even in pure inflation targeting frameworks – to pay attention to the exchange rate developments (Svensson, 2000, and Taylor, 2001). The empirical exchange rate smoothing or "fear of floating" literature presents evidence that many open economy central banks indeed use direct and indirect methods to influence exchange rate developments in practice (Calvo-Reinhart, 2000). One strand of this empirical literature examines the exchange rate smoothing behavior of central banks by estimating open economy interest rate rules with an exchange rate term (Clarida, Galí and Gertler, 1997 and Mohanty and Klau, 2004). This term is usually proxied by the *depreciation* of the exchange rate theoretically motivated by some vague "lean against the wind" interest rate policy. This paper suggests a more structural approach which assumes that, on the one hand, the central bank has a preferred exchange rate level and uses its interest rate policy to maintain this target in the medium term, and, on the other, market participants form rational expectations about the monetary policy and influence the current exchange rate accordingly.

In most cases, this preferred exchange rate level is not directly observable, because strategic considerations make the central bank silent, or sufficiently vague about it. But – given it is persistent – past interest rate decisions of the central bank provide informative signals about this unobserved target variable. Furthermore, assuming rational expectations and forward looking price determination in the foreign exchange market (e.g. uncovered interest parity), current exchange rate developments will reflect the market participants' best assessment of this target. This means that the econometrician can also use the behavior of the exchange rate to gain a better estimation of the unobserved target.

The paper applies Kalman filtering to gain the best linear estimate of the unobserved exchange rate target variable and simultaneously estimate an interest rate rule and an exchange rate equation consistent with this target. The estimated system is able to provide interest rate and exchange rate impulse responses to *known* changes in the exchange rate target, and premium shocks. Furthermore, it can also provide estimates for the ceteris paribus exchange rate effects of expected and *unexpected* interest rate changes, where the latter takes into consideration that an unexpected interest rate move changes the market participants' beliefs about the central bank's exchange rate target.

The paper uses weekly data during a fairly homogeneous period from the widening of the exchange rate band in May 2001 to the end of 2004. The frequency of the data provides a moderately large sample, but hinders the usage of more fundamental variables – like inflation or output – in the estimated rules. Not considering these variables in the interest rate rule can be partly justified by the communication of the Central Bank of Hungary (CBH) during the period. The CBH stressed its belief on the small direct influence of the interest rate on the aggregate demand, and argued that the major influence of its interest rate policy is exerted through its effect on the exchange rate. The framework does not estimate the effects of these fundamental variables on the exchange rate target either.

The paper is organized as follows. Section 2 presents some theoretical results about the welfare implications of exchange rate smoothing in the recent New Open Economy literature. The section also presents some empirical results emphasizing the widespread use of exchange rate smoothing in small and open economies. Section 3 presents some evidence for exchange rate smoothing in Hungary using the *explicit* exchange rate target announcements of the Central Bank of Hungary available up to the end of 2003. Section 4 presents the unobserved variable framework and the estimation results. Section 5 concludes.

2. Exchange rate smoothing

In small and open economies, exchange rate development can have a substantial influence on prices and output, which makes it a potentially important indirect channel of the transmission mechanism. It does not necessarily mean, however, that open economy central banks should also smooth the exchange rate, i.e. react directly to exchange rate developments by their interest rate policy. Along these lines have Clarida, Galí and Gertler (2001) and Galí and Monacelli (2002) questioned the seminal arguments of Ball (1997) and Svensson (2000) supporting exchange rate smoothing. Applying micro-founded models capable of welfare analysis CGG and GM argued that the existence of the exchange rate channel does not theoretically imply any reason for exchange rate smoothing. In their frameworks, there are only quantitative differences between closed and open economy monetary policy problems: the exchange rate channel makes the aggregate demand more responsive to interest rate policy and it increases the importance of output gap stabilization. But as the exchange rate variability causes no distortions in these models, there are no reasons for any nominal exchange rate smoothing; or for stabilization of wider inflation aggregates than domestic inflation.

Justification for exchange rate smoothing, however, reappears in the microfounded models as well, if the various potential welfare distortions caused by exchange rate volatility are also considered. Benigno and Benigno (2001), for example, argued for the positive welfare effects of exchange rate smoothing in a two country open economy model. In their model, deviations from the flexible terms of trade – resulting from excess nominal exchange rate fluctuations and sticky prices – cause distortions in production among the countries, leading to lower joint welfare. According to their centralized welfare criterion, rules with interest rate smoothing and explicit reactions to exchange rates – similarly to the one estimated in this paper – can approximate the first best optimal policies.

Microbased models considering only the welfare of an individual country have also found justifications for exchange rate smoothing. One line of recent research, for example, justified it by the welfare consequences of *imperfect exchange rate pass-through* – a general finding in empirical works (see e.g. Campa and Goldberg, 2004) –, which makes the producers' profits dependent on the exchange rate development. Corsetti and Pesenti (2001) found reasons for exchange rate smoothing in their two-country open-economy framework, and similar results were replicated in small open economy models as well. McCallum and Nelson (2001), for example, consider imports as inputs for production, which implies that exchange rate development influence the costs of production. Excess volatility of the exchange rate reduces welfare, because in the sticky price framework firms adjust their prices only gradually. Optimal monetary policy is found to smooth exchange rate also in the small open economy model of Monacelli (2003), which introduces imperfect pass-through to the model of Galí and Monacelli (2002) considering imports as consumption goods. The reason is that deviations from the law of one price due to imperfect pass-through cause welfare costs, which an optimizing monetary policy should counteract. Other justifications also exist in the current literature: in a novel example, Faia and Monacelli (2002) examine the role of external borrowing in a model with imperfect capital markets and find further justifications for exchange rate smoothing.

If one assumes that exchange rate stability is beneficial for welfare, the quantitative importance of a rule-based direct reaction to exchange rate development might increase further, as argued by Monacelli (2003). Rule-based decision-making can have important advantages in dynamic monetary policy settings, as, thereby, the central bank can have essential effects on expectations. Clarida, Galí and Gertler (1999) argued that a rule based policy can improve the short-run inflation-output tradeoff in case of persistent supply shocks. The reason is that the stronger interest rate response to shocks influences the inflation expectations by promising tough responses to further shocks. Woodford (1999), similarly, argues that the observed interest rate smoothing of central banks can be justified by assuming that they would like to meet their inflation and output targets without causing much interest rate volatility, which they can obtain by committing to a rule which helps them influence inflation expectations. Following these lines of reasoning, commitment to exchange rate smoothing might improve the efficiency of the central bank in influencing exchange rates by guiding exchange rate expectations. As an illustration, consider a generalized UIP equation with a persistent premium shock

$$s_t = E_t(s_{t+1}) + i_t + \mu_t,$$

where s_t is the nominal exchange rate, i_t is the interest rate differential and μ_t is the premium shock. Ruling out bubbles and solving the difference equation forward we can get:

$$E_t\left(s_t\right) = E_t \sum_{j=1}^{T} i_{t+j} + E_t \sum_{k=1}^{T} \mu_{t+k} + E_t s_T$$

showing that the expected exchange rate is influenced by an expected long term nominal exchange rate ($E_t s_T$) and the expected interest rate determination and premium shock development up to date T. The UIP equation implies that by following an exchange rate smoothing interest rate rule, the monetary policy can influence the exchange rate (s_t) not only through the current interest rate differential (i_t), but also through the exchange rate expectations [$E_t(s_{t+1})$]. If one assumes that besides exchange rate stability, monetary policy also prefers smooth interest rate developments, it can improve the short-run trade-off between these two variables by committing to an interest rate rule which reacts to a premium shock more strongly, than its optimal discretionary counterpart.

Turning to the empirical results, in a widely recognized article, Calvo and Reinhart (2000) found overwhelming evidence about exchange rate smoothing – or with their words "fear of floating" – in a wide range of open – mostly, but not exclusively emerging – economies. Examining volatilities and correlations of various variables, countries were shown to use direct foreign exchange market interventions and interest rate policy to avoid large exchange rate fluctuations. They present it as evidence supporting their claim that countries do not do what they actually say: despite the evidence of real life exchange rate smoothing, IMF classification shows a clear tendency towards floating exchange rate arrangements. But this evidence can be approached from a different angle: that countries tend to move towards reduced *transparency* about their exchange rate policy. A floating exchange rate regime, by itself, is a non-transparent arrangement, with no explicit information about any exchange rate target or accepted exchange rate volatility. This general tendency towards reduced transparency – with the notable exception in Europe – can be justified by the increasingly liberalized capital markets and the existence of

speculative capital, which seem to have contributed to the excess exchange rate volatility in countries with transparent arrangements (Obstfeld and Rogoff, 1995b). The reduced transparency, thereby, might be seen as a further measure to contribute to the smooth development of the exchange rate.
In a seminal paper estimating monetary policy rules in the G3 (US, Japan, Germany) and E3 (UK, Italy, France) countries, Clarida, Galí and Gertler (1997) also find evidence for exchange rate smoothing, especially in the E3 countries. In their estimated interest rate rules with reactions to anticipated inflation, and output gap, they also examined the role of exchange rate or – which also implies exchange rate smoothing – the interest rate of a partner country. They have found some, but quantitatively not important evidence for exchange rate smoothing among G3 countries, but this effect was much stronger among the E3 countries and Germany, which eventually initiated a "hard ERM" policy with fixed exchange rates. In a more recent paper, Mohanty and Klau (2004) examined robust interest rate rules in 13 emerging countries countaining also an exchange rate term. The significant estimated exchange rate depreciation terms make the authors conclude that their result support the hypothesis of exchange rate smoothing or "fear of floating" in these countries.

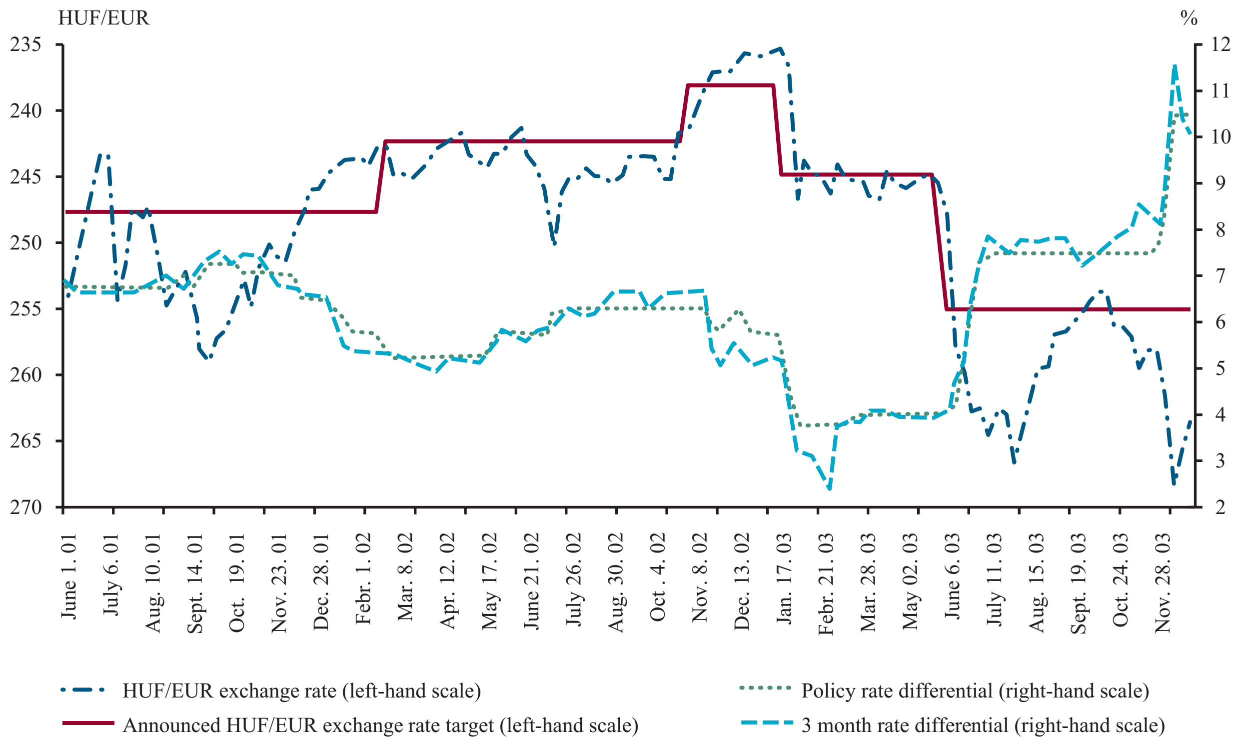
3. Estimates using announced targets

The verbal announcements of the central banks about their preferred exchange rate target, if they are specific enough, can provide a straightforward proxy for the unobserved exchange rate target variable. By announcing its exchange rate target, the central bank, on the one hand, might be able to influence expectations and thereby might gain some leverage over the exchange rate developments. On the other hand, however, announcing explicit exchange rate targets can have serious drawbacks, as they can easily be mistaken as nominal anchors potentially in conflict with other anchors (e.g. inflation target), and an explicit target – as a fixed exchange rate – could provide a focal point for speculation against the exchange rate. But if the central bank chooses to announce its exchange rate target, announcements, in most cases, might be considered truthful, as it can be assumed that reputational considerations prevent central banks from lying to financial markets with fast learning abilities. It might be noted, though, that even if the announcements are considered truthful, their influence on the rates and market expectations might be limited, as the ability and willingness of the central bank to influence exchange rates might be considered questionable by market participants.

The Central Bank of Hungary was unusually explicit about its preferred exchange rate target even after abandoning its narrow band crawling peg exchange rate regime in May 2001. Functioning in a "shadow ERM II" ±15% exchange rate band and following inflation targeting, it periodically

Figure 1

The exchange rate, the announced target and interest rates (June 2001–December 2003, weekly data)



announced an exchange rate target it considered preferable and in line with its inflation targets. It maintained this policy of exchange rate transparency up until the end of 2003, when it fully abandoned it. Using the Statements by the Monetary Council, a periodically changing exchange rate target variable can be put together from June 2001 till December 2003.[1] *Figure 1* shows the weekly announced preferred exchange rate of the Central Bank of Hungary together with the HUF/EUR exchange rate, the policy rate differential[2] and the difference between the 3 month interbank lending rates.

The graph shows the close relationship between the announced target and the exchange rate. However, there were periods – during the second half of 2001 (the financial crisis in Argentina) and in 2003 (after the devaluation of the forint exchange rate band), for example – when there were significant gaps between the exchange rate and the announced target. In these periods, we can also observe higher interest rates suggesting some exchange rate smoothing behavior of the central bank.

To examine the relationships formally, Phillips-Hansen fully modified OLS method is applied, as it is a robust methodology handling the facts that 1) the variables follow unit root processes (see appendix 6.1), 2) the shocks can be autoregressive and 3) simultaneity is expected to exist between exchange rate and interest rate developments (see Phillips and Hansen, 1990). The exchange rate equation is estimated in the following unrestricted form:

$$s_t = \alpha + \gamma i_t + \chi s_t^* + \delta s_{t-1} + \mu_t, \tag{1}$$

where s_t is the exchange rate, i_t is the interest rate differential, s_t^* is the announced exchange rate target, and μ_t is a premium shock.[3] The parameter χ measures the immediate effect of the target on the exchange rate, while the framework – by including a lagged exchange rate term, and allowing persistent shocks – allows for a gradual adjustment to this exchange rate target. The estimation results of the exchange rate equation using short term interest rates with 2 week and 3 months maturities are presented in *Table 1*.

The results show significant effects of the announced exchange rate targets on the exchange rate, even allowing for the appearance of the lagged exchange rate in the equation. The sum of estimated coefficients ($\chi+\delta$) of the exchange rate terms, furthermore, does not significantly differ from 1 according to the fully modified Wald test supporting the view that the exchange rate would fully adjust to the target level under 0 interest rate differential (though the marginally significant constant terms might cast some doubts for this result). The results show gradual, but relatively fast adjustment to the target level (approximately one third of the difference disappears weekly). The stability properties of

[1] Between the speculative attack of 17 January, occurred against the strong edge of the exchange rate band, and 26 May 2003, when the Monetary Council explicitly announced the end of it, the Central Bank of Hungary intervened in the exchange market by gradually reselling the euro it bought during the attack. Although, there were no announcements about any new preferred exchange rate, the behavior of the CB on the exchange market provided clear price signals about a preferred exchange rate around 245 HUF/EUR.

[2] The difference between the interest paid on 2 week deposits by the CBH and the 2 week refinancing rate of the ECB.

[3] The announced target (s_t^*) might exert its influence on the exchange rate through direct channels – if the central bank intervenes in the foreign exchange market – or indirectly – through its effect on expectations. As for direct interventions, the Central Bank of Hungary stressed during the period that it refrains from using direct interventions in the foreign exchange market to influence rates inside its ±15% exchange rate band, but it intervenes at the edges of the band. The unsuccessful speculative attack against the strong edge of the exchange rate band in 17-18 January forced it to buy excessive amounts of euros and in the following period up until 26 May 2003, it was present in the foreign exchange market to resell a good part of this amount. Except for this period, however, influence of the exchange rate targets on the exchange rates can be expected to be exerted through influencing expectations by the credible promise of sustained exchange rate smoothing policies.

Table 1

Estimates of the exchange rate equation using announced targets (June 2001–December 2003, weekly data)

Dependent	Explanatory variables				Stability tests
log(hufeur)	const	dif2w	log(hufeurt)	log(hufeur[-1])	LC
	-0.428**	0.010	0.34***	0.739***	0.606*
std.dev.	(0.180)	(0.062)	(0.053)	(0.043)	
log(hufeur)	const	dif3m	log(hufeurt)	log(hufeur[-1])	LC
	-0.323*	0.064	0.349***	0.709***	0.51
std.dev.	(0.179)	(0.055)	(0.052)	(0.043)	

****** significant at 1% level, ** significant at 5% level, * significant at 10% level.*

the estimated coefficients are not straightforward, but overall acceptable using the stability tests of Hansen (1992).[4]

The interest rate rule is estimated in the following unrestricted form[5]:

$$i_t = \lambda + \rho i_{t-1} + \beta s_t + \kappa s_t^* + \eta_t \quad (2)$$

The parameter ρ represents interest rate (differential) smoothing. If $\beta=-\kappa$, then the estimation does not reject the hypothesis that it is the exchange rate *gap* term that influences the interest rate determination. The process η_t follows is not determined ex ante; it can be expected to follow an autocorrelated process, as the central bank made decisions about interest rates in every two weeks up until the summer of 2004, when it switched to monthly decisions.

Table 2

Interest rate differential rules using announced targets (July 2001–December 2003, weekly data)

Dependent	Explanatory variables				Stability tests
dif2w	const	dif2w(-1)	log(hufeur)	log(hufeurt)	LC
	-0.135**	0.937***	0.09**	0.065**	1.393***
std.dev.	(0.063)	(0.020)	(0.012)	(0.026)	
log(hufeur)	const	dif3m(-1)	log(hufeur)	log(hufeurt)	LC
	-0.215***	0.901***	0.105***	0.065***	2.94***
std.dev.	(0.059)	(0.017)	(0.014)	(0.019)	

****** significant at 1% level, ** significant at 5% level, * significant at 10% level.*

[4] The presented L_c tests do not reject the null hypotheses of stability at 5% significance for any of the equations. One of the two – not shown – other tests (meanF test) can never reject the null of stability at usual significance levels, though the other test (SupF test) rejects it always at the 1% level.

[5] Using the interest rate differential, though unusual, offers an acceptable simplification. In small open economies, foreign interest rate can be considered exogenous (it does not react to the monetary policy of the observed country), and if the central bank is interested in influencing the exchange rate, it is the interest rate *differential* that matters. Furthermore, in many cases, and certainly in Hungary during the period, the foreign interest rate was substantially less volatile than the domestic one, so the volatility of the differential mainly comes from the decisions of the domestic central bank.

The results with different short term interest rates are presented in *Table 2*. The results show that the announced exchange rate target has significant effects on the short term interest rates. They also give some support that its effect is exerted through the exchange rate *gap*: the $\beta=-\kappa$ hypothesis cannot be rejected at the 5% level for the policy rate differentials, though it is rejected for the 3 month rates. The estimated effects of exchange rate gap on interest rates are also significant economically: a 5% gap would increase the interest rate by approximately 50 basis points. It should be noted, though, that the tests reject the stability of the equations, which might be the result of changes in policy or missing variables.

The results applying the exchange rate target announcements of the Central Bank of Hungary broadly support our framework and the hypothesis of exchange rate smoothing. The interest rate determination, according to the results, was significantly influenced by the exchange rate gap meaning that the monetary policy lived up to its periodically changing exchange rate announcements and systematically determined its interest rates accordingly. The announced exchange rate targets, furthermore, had important influence on the exchange rate determination. A problem with using announced preferred exchange rate targets, however, is that it is not available in many countries which use their interest rate policies to influence exchange rate determination, as it is also unavailable in Hungary after the end of 2003, when the Central Bank of Hungary stopped announcing any preferred exchange rate explicitly.

4. Unobserved variable framework

If announcements about the exchange rate target are unavailable, unobserved variable methods can be used to gain estimates about their development using information inherent in observables, like the interest rate or the exchange rate. The method can also provide simultaneous estimates of the parameters of the interest rate rule and exchange rate equation consistent with this target.

The exchange rate equation is assumed to take the following form:

$$s_t = \gamma i_{t-1} + \chi s_t^* + (1-\chi)\, s_{t-1} + \mu_t, \tag{1'}$$

where s_t^* here stands for the unobserved implicit (medium term) exchange rate target of the central bank. The market participants are assumed to form rational expectations about this target.[6] The equation allows gradual adjustment to this medium term target (but by constraining the parameter of the lagged term it requires it to be complete). The error term μ_t is considered an unobserved premium shock. The equation contains the *lagged* interest differential for primarily technical reasons[7], but can also be justified by portfolio adjustment lags. Notice that though equation 1' assumes that the direct interest rate effect is lagged, the signalling effect of an interest rate move has immediate influence on the exchange rate.

The interest rate (differential) equation is assumed to take the following form:

$$i_t = \rho i_{t-1} + \beta(s_{t-1} - s_t^*) + \eta_t, \tag{2'}$$

where the Central Bank of Hungary is assumed to modify its interest rate differential by reacting to the gap between the lagged exchange rate and its current exchange rate target. The reason of this – though it is also required by the Kalman filter – is that the regular interest rate decisions of the Central Bank of Hungary were made on Mondays during the period, so it was only a lagged exchange rate that it could have responded to.

The implicit exchange rate targets of the central bank (s_t^*) are unobserved and assumed to follow a random walk process:

$$s_t^* = s_{t-1}^* + \varepsilon_t \tag{3}$$

This assumption ensures that shocks to this target are permanent, and allows us to infer its value from past behavior of observed variables. Shocks to equations 1' (μ_t) and 2' (η_t) are also unobserved variables of the system assumed to follow first order autoregressive processes:

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[6] Rational expectations imply that market participants are assumed not to make systematic errors when forming expectations about the exchange rate target. Formally $s_t^* = s_t^{*e} + e_t$,where e_t is a white noise process. If we assume that this target-expectation influences the current exchange by affecting future exchange rate expectations according to the following equation $s_t = \gamma i_{t-1} + \chi s_t^{*e} + (1-\chi)\, s_{t-1} + \mu_t'$ then equation 1' can be regained with $\mu_t = \mu_t' - \chi e_t$.

[7] Featuring the current endogenous observable variables among the explanatory variables makes the estimation substantially more complicated.

$$\mu_t = \varsigma\mu_{t-1} + \phi_t \tag{4}$$

and

$$\eta_t = \upsilon\eta_{t-1} + \psi_t, \tag{5}$$

where $0 \le \varsigma, \upsilon \le 1$. ε_t, ϕ_t and ψ_t are assumed to follow white noise processes with variances $\lambda\ \sigma_\phi^2, \sigma_\phi^2, \sigma_\psi^2$ respectively. Specification tests of the estimated system could not reject the hypothesis that the realised error terms are indeed white noise.

So, the estimated system consists of two observable variables: the nominal exchange rate (s_t) and the nominal interest rate (i_t) determined by (observation) equations 1' and 2', and three unobservable variables: the nominal exchange rate target s_t^*, the premium shock to the exchange rate (μ_t)and the shock to the Taylor type rule (η_t) determined by (state) equations, 3, 4 and 5. The Kalman filtering method simultaneously estimates the 9 unknown parameters ($\gamma, \chi, \rho, \beta, \varsigma, \upsilon, \lambda, \sigma_\phi^2, \sigma_\psi^2$) of the model and provide the best linear estimations for the unobserved variables using the available information up to that date (filtered estimates, $s_{t|t}^*, \mu_{t|t}, \eta_{t|t}$, where *t* is a date in the past), and using all information available in the sample (smoothed estimates, $s_{t|T}^*, \mu_{t|T}, \eta_{t|T}$ where *T* refers to the last element of the sample). The mean squared error matrix of the estimated unobserved variables are $P_{t|t}$ for the filtered estimates and $P_{t|T}$ for the smoothed estimates.

The matrix representation of the state space system – following the notation of Hamilton (1994) – is going to be presented. The state equation is:

$$\xi_t = F\xi_{t-1} + v_t,$$

where

$$\xi_t' = \begin{bmatrix} s_t^* & \mu_t & \eta_t \end{bmatrix}$$

$$F = \begin{bmatrix} 1 & 0 & 0 \\ 0 & \zeta & 0 \\ 0 & 0 & \upsilon \end{bmatrix}$$

$$E\left[v_t v_t'\right] = Q = \begin{bmatrix} \lambda\sigma_\phi^2 & 0 & 0 \\ 0 & \sigma_\phi^2 & 0 \\ 0 & 0 & \sigma_\psi^2 \end{bmatrix}.$$

And the observation equation is

$$y_t = A'x_t + H'\xi_t,$$

where

$$y_t' = \begin{bmatrix} s_t & i_t \end{bmatrix}$$

$$x_t' = \begin{bmatrix} s_{t-1} & i_{t-1} \end{bmatrix}$$

$$A' = \begin{bmatrix} 1-\chi & \gamma \\ \beta & \rho \end{bmatrix}$$

$$H' = \begin{bmatrix} \chi & 1 & 0 \\ -\beta & 0 & 1 \end{bmatrix}.$$

The assumption of random walk target development introduces unit root to the state equation, which hinders the application of standard asymptotic theory developed by assuming stationarity (e.g. Hamilton, 1994). But stationarity is not a necessary condition for asymptotic convergence of the estimator: Harvey (1990, pp. 210), for example, provides regularity conditions for the state space model ensuring the asymptotic convergence of the maximum likelihood estimator. These regularity conditions are satisfied in our model as it was shown in a related work by Csiszar (2005). A further sign of convergence of our estimator is that the mean squared error of the estimates of the unobserved variables ($P_{t|t}$ and $P_{t|T}$) show clear – and relatively fast – convergence to a fixed value.

The Kalman filter and its maximum likelihood estimation assume normality of the error terms, which might be questionable in our case both by observation of the data and by more formal approaches. The assumption of normality, for example, requires frequent small changes in the shocks with rare sizeable moves. As for the exchange rate target shock (ε_t), this requirement can be acceptable if the target is thought to change constantly as new information flows in. But for the shocks to the exchange rate premium (ϕ_t) and the interest rate rule shock (ψ_t) we can observe fairly stable periods and occasional sizeable moves not characteristic of the normal distribution. A further problem is that the shadow ERM II exchange rate regime truncates the possible values of both the exchange rate target and the premium shocks. White (1982) suggested a test for distributional misspecification building on the fact that in case of correct distributional specification the estimated Hessian of the maximum likelihood function at the optimum is equal to the negative of the outer product of the gradient at the same point. In our case, the difference between these two matrices suggests distributional misspecification. But, as it was shown by White (1982), even if the normality assumption does not hold, maintaining it in the so called quasi-maximum-likelihood framework can provide consistent parameter estimates, though the estimator will not be efficient. The covariance matrix of the estimator, however, should be chosen and estimated differently from the normality case.

The results presented are obtained by using the 2 week policy rate differential, which is determined by the central banks without any expectation effects from the markets. But it should be noted that the 3 month interbank rate differentials result in very similar results both in parameter values and estimated exchange rate targets (not shown).

Obtaining valid starting values for the parameters and the state variables are important tasks of the estimation. Not surprisingly, the robustness and the convergence properties of the estimator improves significantly, if the value of λ – determining the proportion of variance of the exchange rate premium shock and that of the target – is restricted, so this restriction can be used to obtain starting parameter values. The volatility of the announced target change between July 2001 and December 2003 is one fifth of the volatility of the exchange rate change. By restricting λ to 0.2, two different (local) maximum with similar values of log likelihood can be obtained (see appendix 6.2). The estimated interest rate (differential) rules are fairly similar, the main difference between the two system is the relative weight given to the exchange rate target in the exchange rate equation. While the weight is below 0.1 in the first system, it is almost 0.9 in the second. It is only the second system of parameters, however, which stays robust after lifting the restriction on λ.

The estimated parameters and the obtained standard deviation assuming normality (stdev MLE) and using the robust standard errors suggested by White (1982) (stdev QMLE)[8] for Hungary are presented in *Table 3*.

Table 3

Unobserved variable estimation (May 2001–December 2004, weekly data)

Dependent	Explanatory variables			Error term	
dif2w	dif2w(-1)	log(hufeur[-1]/hufeurt)		ar(1)	log(stdev)
	0.994***	0.037**		0.285***	-11.93***
stdev MLE	0.013	0.018		0.072	0.106
stdev QMLE	3.4E-07	2.1E-07		2.1E-06	4.0E-07
log(hufeur)	dif2w(-1)	log(hufeurt)	log(hufeur[-1])	ar(1)	log(stdev)
	0.104	0.867***	0.133	0.933***	-9.65***
stdev MLE	0.249	0.083	-	0.047	0.162
stdev QMLE	7.2E-06	1.3E-06	-	1.1E-06	4.9E-06
log(hufeurt)		log(hufeurt(-1))			lambda
		1.000			0.192
stdev MLE		-			0.169
stdev QMLE		-			4.9E-06

****** significant at 1% level, ** significant at 5% level, * significant at 10% level.***

The results support the hypothesis that the implicit exchange rate target influences both the interest rate and the exchange rate determination. The interest rate differential rule finds a weekly interest rate smoothing parameter very close to 1 and the parameter on the exchange rate gap implies that, on average, a 5% gap results in an approximately 20 basis points change. The total interest rate response to an exchange rate gap can be obtained by cumulating the periodic interest rate moves to the gradually closing gap. The error term of the interest rate differential rule is found slightly autocorrelated, probably resulting from the fact that regular interest rate decisions were made in every two weeks up to May 2004 and monthly afterwards. The parameter of the exchange rate target term in the exchange rate equation – differently from the estimates using the announced targets – does not significantly differ from 1, suggesting very fast convergence to the estimated exchange rate target. The parameter of the interest rate, however, – contrary to the UIP hypothesis – has the wrong sign and is insignificant.

The Kalman filtering provides optimal periodic estimates for the implicit exchange rate target of the central bank using the development of the observed variables and assuming that the parameters are as estimated previously. The functioning of the filter is intuitive. In every period, using the current estimate of the unobservables, the filter formulates forecasts of the observable interest rate and exchange rate

[8] The differences between the standard errors are substantial as a sign of the already mentioned distributional misspecification. The robust covariance estimator suggested by White (1982) implies extremely significant parameters. But we cannot rule out that it underestimates the true covariance matrix (as Wooldridge, 2002, pp. 396. notes, the outer product estimator of the information matrix can be poorly behaved in even moderate samples), we presented the standard errors assuming the errors were normal.

for the next period. If the interest rate and exchange rate develop according to these forecasts, there are no reasons to update the beliefs on the exchange rate target, the exchange rate premium shock, or the interest rate rule shock. If there is a surprise caused by an unexpected interest rate or exchange rate move, however, it is optimal to change the beliefs about the unobserved variables. But as the reason for the unexpected move is unknown, it is optimal to attribute it partly to all of the unobservables depending on the uncertainties of their development. The Kalman filter solves this complicated signal-extraction exercise and provides estimates about the expected exchange rate and interest rate reaction to these unexpected shocks.

Formally, the essence of Kalman filtering is the optimal updating of a linear projection using the information obtained from the development of the observables. In our framework, this updating happens as (for details, see Hamilton, 1994):

$$\widehat{\xi}_{t|t} = \widehat{\xi}_{t|t-1} + Z_t \left(y_t - \widehat{y}_{t|t-1} \right), \tag{6}$$

where

$$Z_t = P_{t|t-1} H \left(H' P_{t|t-1} H \right)^{-1}$$

and

$$\widehat{y}_{t|t-1} = A' x_t - H' \widehat{\xi}_{t|t-1}.$$

The updating equation has the intuitive feature that the estimates of the unobserved variables $\left(\widehat{\xi}_{t|t}\right)$ change only if there is a surprise in the development of the observed variables $y_t - \widehat{y}_{t|t-1}$ and the effect of the surprise is influenced by the effect of the unobserved variables on the observables *(H)* and the potentially time-varying mean squared error of the prediction of the state variables $\left(P_{t|t-1}\right)$. It is straightforward to see that

$$\widehat{\xi}_{t|t-1} = F \widehat{\xi}_{t-1|t-1}$$

and substituting it to provides us with the following equation showing how periodic estimates $\left(\widehat{\xi}_{t|t}\right)$ are updated using the new information:

$$\widehat{\xi}_{t|t} = F \widehat{\xi}_{t-1|t-1} + Z_t \left(y_t - \widehat{y}_{t|t-1} \right). \tag{7}$$

The value of Z_t because of its already mentioned fast convergence, gets constant soon and gets equal to:

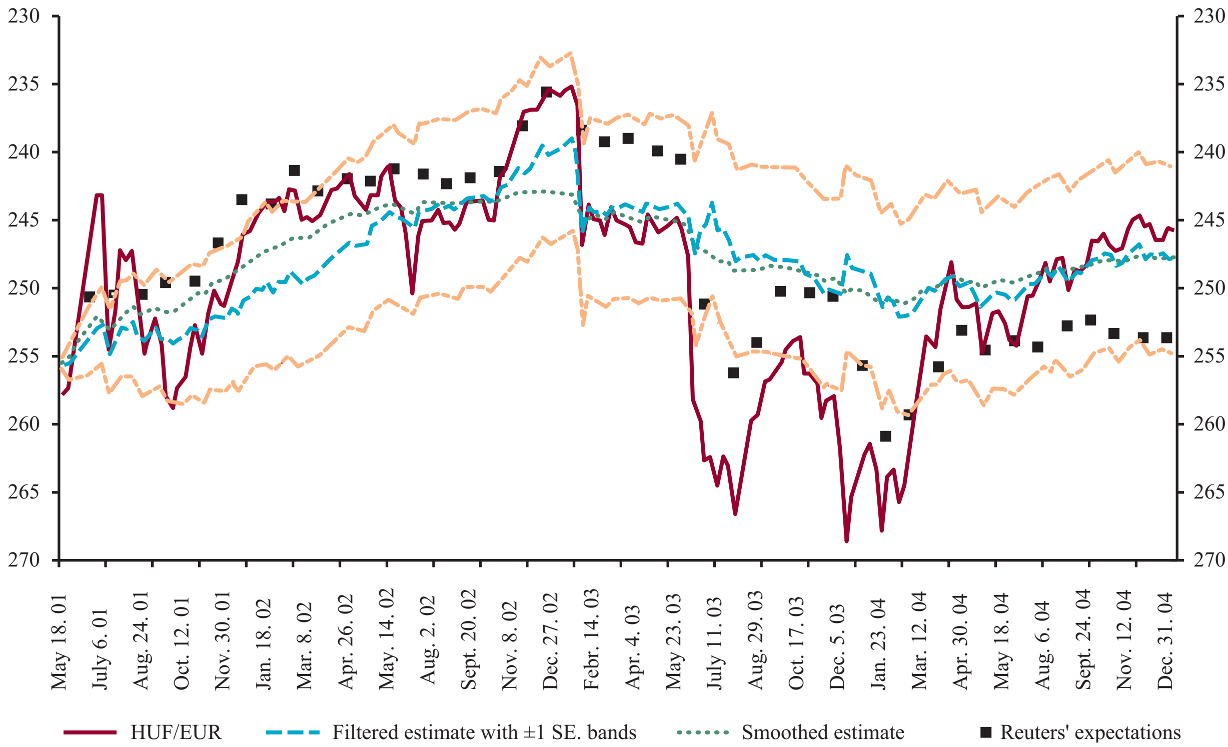
$$Z = \begin{bmatrix} 0.304 & -0.874 \\ 0.737 & 0.758 \\ 0.011 & 0.968 \end{bmatrix}.$$

The first row of the matrix implies that a 1 percentage point surprise move in the interest rate results in a 0.87 percent appreciation of the estimated exchange rate target. This effect is substantially larger than the effect of an expected interest rate move (see later). The matrix also shows that a 10 Ft (approximately 4 percent) surprise depreciation should lead to a depreciated target expectations by around 3 Ft. The second row determines the effects on the estimated values on the shocks $\mu_{t|t}$ and $\eta_{t|t}$.

The filtered (or one-sided) estimates of the exchange rate target of Hungary only use information available up to the period, and the smoothed (two-sided) estimates use all the available information. The estimates and their standard error bands together with the monthly one-year-ahead exchange rate expectations of market analysts surveyed by Reuters are shown in *Figure 2*, while *Figure 3* presents the development of the closely related surprise series $(y_t - \widehat{y}_{t|t-1})$ for the exchange rate and the interest rate.

Figure 2

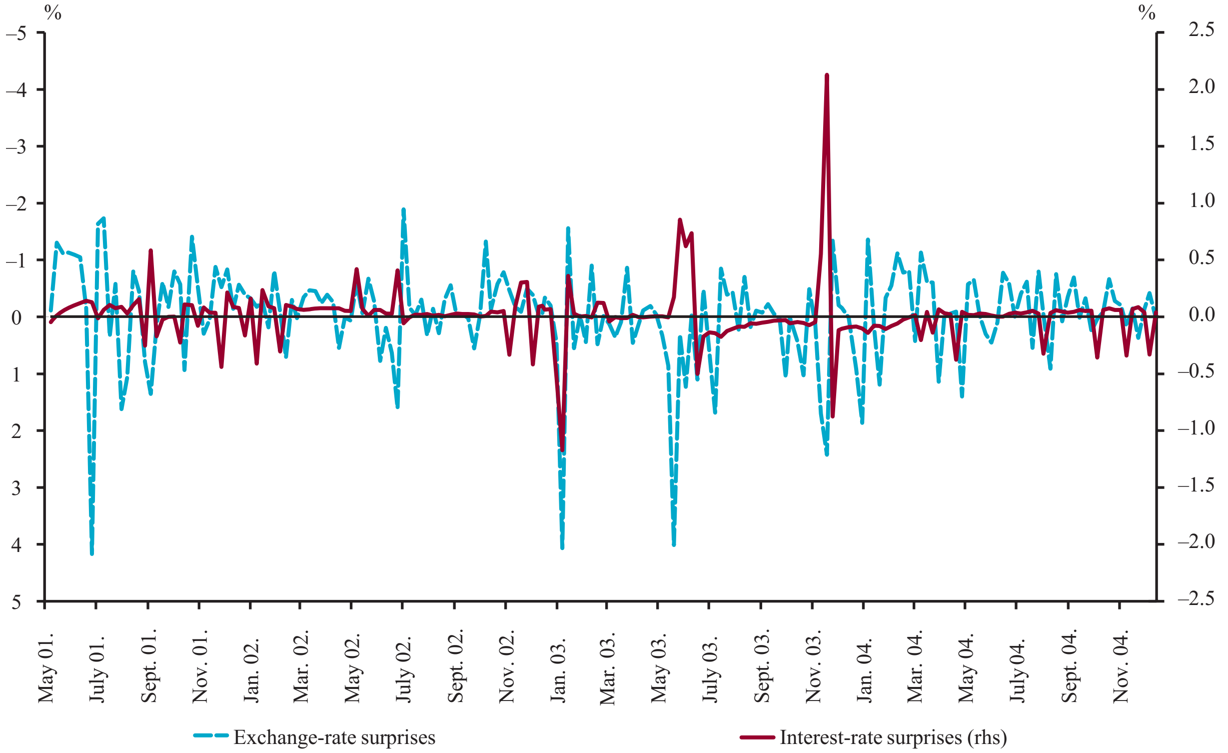
HUF/EUR exchange rate, the estimated targets and the Reuters expectations



According to the filtered estimates, the exchange rate target gradually appreciated up to the end of 2002, and was fairly in line with the exchange rate development during the second half of 2002. The significant interest rate reductions and exchange rate depreciation in January 2003, however, depreciated the estimated implicit exchange rate target, which dropped further in May and June following the devaluation of the ±15% exchange rate band. It should be noted though that the estimation considers the substantial depreciation of the forint in June mostly as a premium shock, with only limited effects on the exchange rate target. These results are in line with the structural VAR estimation of Vonnák (2005), identifying a significant risk premium shock in June 2003, but no significant monetary policy shock in that month (compare with *Figure 3*). The premium shock was counteracted by the

Figure 3

Forecast errors (surprises) in the observed exchange rate and interest rate developments (May 2001–December 2004, weekly data)



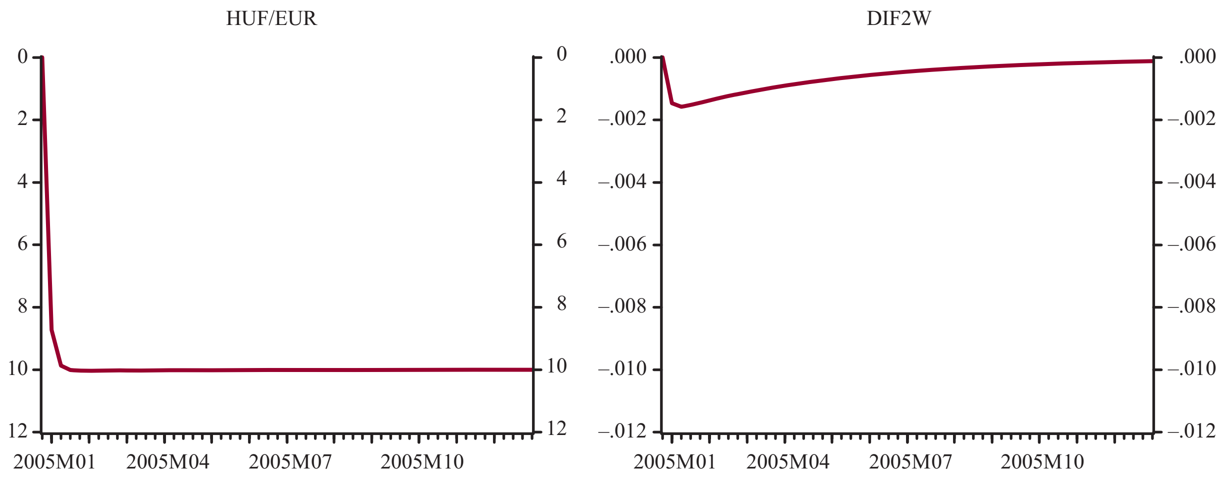
substantial interest rate moves of the Central Bank of Hungary in June and later in November with appreciating effects on the estimated targets. Around the beginning of 2004, the estimated target stabilised around 250 Ft/euro, and in the second half of 2004 it even appreciated somewhat, developing broadly in line with the exchange rate.

As the market participants are assumed to use at least as many information for developing their expectations about the exchange rate target as the applied model, the estimated exchange rate target is also an estimate for the market expectation of the exchange rate target. Reuters prepare monthly survey in Hungary among market participants about their exchange rate expectations. It might be instructive to compare their average expectations to the estimated targets. The graph contains an implied expected exchange rate 1 year after the survey, which might be considered a proxy for the expected target value. *Figure 2* shows that the Reuters expectations were more volatile than the estimated implicit target, but the development of the two series are – in most cases – broadly in line, and the framework seems to capture the most important driving forces of these expectations.

The estimated system also allows the assessment of the exchange rate and interest rate responses to *known* shocks to the exchange rate target (exchange rate target shock), to the interest rate rule (interest rate rule shock), and to the exchange rate equation (premium shock). Consider first a known 10 Ft (approximately 4%) permanent change in the implicit exchange rate target. *Figure 4* presents impulse responses about the development of the exchange rate and the interest rate.

Figure 4

Exchange rate target shock



The high parameter of the exchange rate target in the exchange rate equation ensures that a known change in the target results in a very fast adjustment of the exchange rate to the new target, and, thereby, the small exchange rate gap will have no significant influence on the interest rate determination. It has to be noted, though, that the central bank might not have direct means to make a target-change fully known, it might need to signal it by observable interest rate – or exchange rate – movements. If it is the case, substantial unexpected interest rate move is necessary to make the public update its previous target estimate. If the interest rate were the only way for the central bank to signal its knew exchange rate target, the order of the necessary move is estimated to be much higher than under a known target change: for a 1% depreciation of the exchange rate, 1.15% surprise interest rate reduction is necessary ceteris paribus.

Figure 5 shows what happens to the exchange rate and the interest rate, if there is a *known* 1 percentage-point shock to the interest rate unrelated to the exchange rate gap. The graph shows that a shock like that has a very muted estimated effect on the exchange rate (with the wrong sign). The reason is that the shock has no effect on the target-expectations, and the direct effect of the interest rate is estimated to be very small.

The third presented shock (in *Figure 6*) is a premium shock hitting the exchange rate and resulting in a 10 Ft immediate depreciation. Afterwards, the shock is allowed to disappear with its estimated average autocorrelation coefficient. The monetary policy responds to the opening of the exchange rate gap (its target is assumed to stay constant) and, as the impulse responses show, the interest rate increase is estimated to reach 50 basis points in the first month and gradually increases over 1 percentage point in the first 4-5 month before it starts decreasing. The behavior of the shock is similar to the obtained impulse responses of a risk premium shock of Vonnák (2005).

Figure 5

An interest rate rule shock

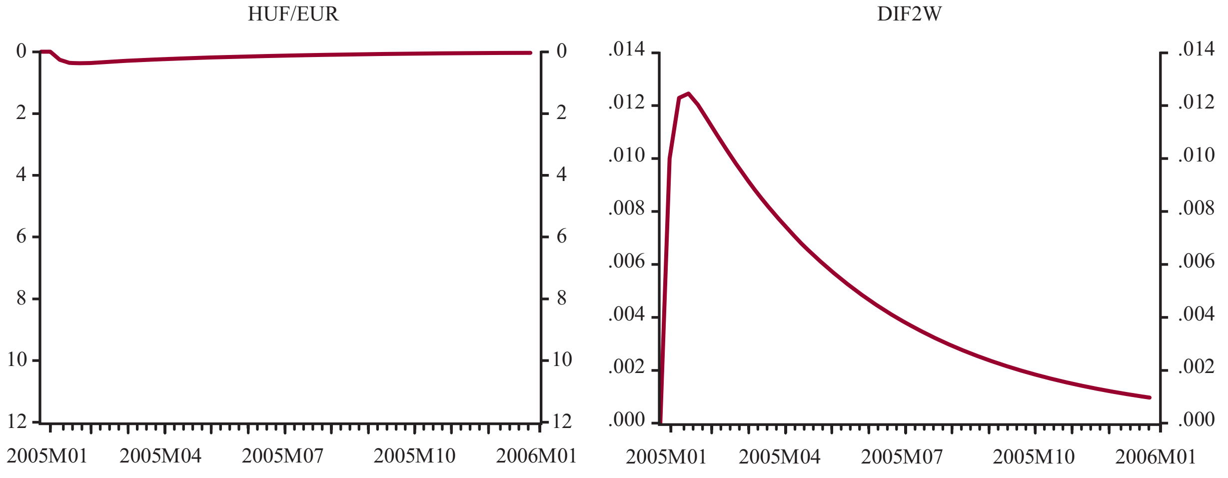
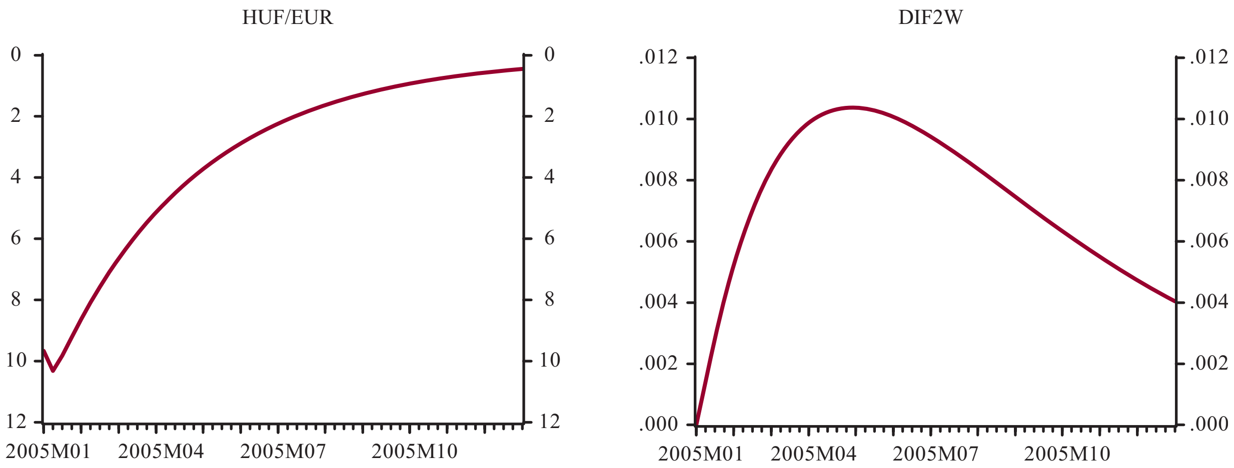


Figure 6

A premium shock



5. Conclusion

The paper proposed and successfully applied an unobserved variable framework simultaneously estimating an interest rate (differential) rule and an exchange rate equation for Hungary. The framework provided evidence for exchange rate smoothing in Hungary since the widening of the exchange rate band in May 2001 by estimating a smoothly developing unobserved implicit target and showing that the interest rate policy reacted to the deviation of the exchange rate from this target. The model was used to gain estimated interest rate and exchange rate responses to exchange rate target and exchange rate premium shocks. The framework also identified why unexpected interest rate moves have stronger exchange rate effects: they make the market participants update their previous beliefs about the central bank's exchange rate target.

The framework applying the Kalman filter assumes normality of the development of the exchange rate target and interest rate shocks. This assumption seems to be restrictive resulting in an inefficient estimation. Assuming more general – stable – distributions for the error term of the exchange rate target and applying the more general Sorenson-Alspach filter might generate more efficient estimation with estimated exchange rate targets potentially closer to the announced one: with low volatility for prolonged periods with occasional substantial changes.[9] The estimates might also be made more realistic by allowing for ARCH disturbances (see Csiszar, 2005). The framework, furthermore, is flexible enough to include the effects of more fundamental variables – like inflation and output gap – on the interest rate rule and exchange rate target developments, which was not possible for the application to Hungary because of the lack of sufficient data. A clear potential route for future research is to apply the framework to a wider set of countries with longer periods of consistent policies.

[9] The approach was successfully applied to estimate inflation targets of the US Federal Reserve, and forecast US inflation by Bidarkota and McCulloch (1998).

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7. Appendix

7.1 Unit root tests

Table 4

Unit root tests

Variables	PP q=4	ADF p=0	ADF p=10	ADF p=20	KPSS	Trend	Process
log(hufeur)	-2.47	-2.32	-2.31	-1.74	0.34	N	I(1)
SIC		-6.62	-6.56	-6.39			
dlog(hufeur)	-12.56***	-12.59***	-4.56***	-2.8*	0.11	N	
SIC		-6.6	-6.55	-6.37			
log(hufeurt)	-0.87	-0.66	-0.92	-1.6	0.49**	N	I(1)
SIC		-8.04	-7.61	-7.28			
dlog(hufeurt)	-9.92***	-9.94***	-4.09***	-1.64	0.24	N	
SIC		-8.05	-7.65	-7.24			
difpr	-1.34	-1.03	-1.64	-1.32	0.81***	N	I(1)
SIC		-8.86	-8.67	-8.35			
d(difpr)	-9.57***	-9.59***	-3.48***	-3.12**	0.11	N	
SIC		-8.97	-8.65	-8.34			
dif3m	-1.31	-1.15	-1.84	-1.5	0.79***	N	I(1)
SIC		-8.43	-8.19	-7.86			
d(dif3m)	-11.96***	-11.93***	-3.08**	-2.63*	0.13	N	
SIC		-8.44	-8.17	-7.84			

****** significant at 1% level, ** significant at 5% level, * significant at 10% level.*

PP is the Phillips-Perron, ADF is the adjusted Dickey-Fuller and KPSS is the Kwiatkowky-Phillips-Schmidt-Shin unit root tests. As the PP and the ADF tests have null-hypotheses of an existing unit root, significant test-statistics signal integration, while the null of the KPSS test is the stationarity of the time-series, so its insignificance shows integration. The q and p parameters show the lags used in the test equations.

7.2 Obtaining the starting values

The system was estimated using the Gauss code provided by Hamilton, applying the BFGS algorithm for optimization. The starting values of the parameters and of the forecasts ($\xi_{1|0}$) and mean squared errors ($P_{1|0}$) of the state variables are essential part of the estimation. To obtain the results presented in the paper the starting values were chosen as:

$$\xi'_{1|0} = \begin{bmatrix} \ln(260) & 0 & 0 \end{bmatrix}$$

and

$$P_{1|0} = \begin{bmatrix} 0.001 & 0 & 0 \\ 0 & 0.000001 & 0 \\ 0 & 0 & 0.00001 \end{bmatrix}.$$

The starting parameter values were obtained by running the algorithm in the system, where the value of λ, which determines the proportion of volatility of the exchange rate target shock and the UIP premium shock, were restricted to 0.2. The following two tables show the obtained two sets of parameter values and the values of the log likelihood. It shows that while the estimated interest rate differential rules are fairly similar, there is a substantial difference between the estimated parameter of the effect of the estimated exchange rate target on the development of the exchange rate: in the first estimation the parameter is below 0.1, while it is almost over 0.9 in the second estimation.

Table 5

Restricted unobserved variable estimation no. 1. (June 2001 – December 2004, weekly data)

Dependent	Explanatory variables		Error term	
dif2w	dif2w(-1)	log(hufeur(-1)/hufeurt)	ar(1)	log(stdev)
	0.979***	0.046**	0.281***	-11.96***
stdev	0.030	0.021	0.074	0.102
log(hufeur)	dif2w(-1)	log(hufeurt)	ar(1)	log(stdev)
	0.028	0.089**	0.146*	-9.54***
stdev	0.052	0.037	0.080	0.102
Value of log likelihood:		1505.52		

**** significant at 1% level, ** significant at 5% level, * significant at 10% level.*

Table 6

Restricted unobserved variable estimation no. 2. (June 2001 – December 2004, weekly data)

Dependent	Explanatory variables		Error term	
dif2w	dif2w(-1)	log(hufeur(-1)/hufeurt)	ar(1)	log(stdev)
	0.994***	0.037**	0.285***	-11.93***
stdev	0.010	0.015	0.072	0.105
log(hufeur)	dif2w(-1)	log(hufeurt)	ar(1)	log(stdev)
	0.102	0.867**	0.932*	-9.96***
stdev	0.184	0.082	0.044	0.105
Value of log likelihood:		1502.67		

**** significant at 1% level, ** significant at 5% level, * significant at 10% level.*

This second set of parameters were accepted as initial parameter values for the unrestricted estimates with the values:

$$\begin{pmatrix} \gamma \\ \chi \\ \rho \\ \beta \\ \varsigma \\ \upsilon \\ \lambda \\ \sigma_{\phi}^{2} \\ \sigma_{\psi}^{2} \end{pmatrix} = \begin{pmatrix} 0.102 \\ 0.867 \\ 0.994 \\ 0.037 \\ 0.932 \\ 0.285 \\ 0.200 \\ \exp(-9.66) \\ \exp(-11.93) \end{pmatrix}$$

Working Papers 2005/6
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