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Abstract

Design of policy rules for an an emerging market central bank (EMCB) operating in an inflation-targeting framework presents additional challenges beyond those for describing the behavior of a central bank in a developed economy. Even though an inflation-targeting regime entails abolishing the exchange rate target in favor of an inflation target, it is more difficult for an EMBC to ignore movements in exchange rates given the relatively shallow depth of financial markets and the the high degree of dollarization. Additionally the EMCB may be forced to change the pursued exchange rate regime following a capital account reversal so that linear Taylor rules may be inadequate for describing EMCB reactions. We develop an empirical framework that addresses these issues and propose a new methodology to estimate unobserved variables such as expected inflation and potential output within the rule. Specifically, we employ a structural, nonlinear Kalman filter algorithm to estimate time-dependent parameters and unobserved variables, and we experiment with various exchange rate mechanisms that can be employed by an EMCB. This approach allows us to track any changes in EMCB behavior - including regime shifts - following a switch to inflation targeting. Using post-2001 data from Turkey, which is a fairly dollarized small open economy, we document that the Central Bank of Turkey has given relatively more importance to the inflation gap than to the output gap or to exchange rates, but not until some time after it had switched to an inflation-targeting framework.

Keywords. Dual Extended Kalman Filter, Taylor Rule, Random Coefficients.

JEL No. E52, C32, C51

1 Introduction

After adopting floating exchange rate regimes, several emerging markets decided to switch to an inflation-targeting framework that entailed explicit medium-term quantitative targets for inflation that their central banks had publicly declared[1]. However, even after switching to inflation targeting, an emerging market's central bank (EMCB) has reasons to care about exchange rate movements and their effects on financial account balance. Firstly, due to observed high degree of asset and liability dollarization and shallow financial markets, emerging markets are more susceptible to sudden capital account reversals, and an EMCB is more likely to actively respond to sudden movements in exchange rates when compared with, for example, the Federal Reserve or the Bank of England. Secondly, central banks in countries that depend heavily on exports for their economic welfare may be more inclined to bow to political pressure to adjust exchange rates. An upcoming election, for instance, may compound that pressure.

From a policy point of view, the effect of exchange rate volatility is more than just a side concern for an EMCB adopting inflation targeting. Exchange rate movements may affect inflation expectations, since such movements generally affect the price of imported goods and are reflected in the consumer price index[2]. They may also affect the output gap by affecting employment decisions simply by changing the marginal rate of substitution between labor and capital, the latter consisting partially of imported inputs. Given the possibility that both inflation and output gap are implicitly embedded in such a policy rule as the one used by Clarida *et al.* (2000), an emerging market central bank may choose to intervene preemptively to correct for unexpected deviations in the exchange rate.

From an empirical point of view, if a central bank commits to price stability in a forward-looking

[1]Specifically Brazil, Chile, Columbia, Mexico, Peru, South Africa, Thailand, and Turkey switched to inflation-targeting framework following their adopting floating exchange rate regimes.

[2]The correlation between CPI inflation and nominal exchange rate changes is not always strong, however. See Allsopp et al. (2006) for a study on the U.K. In general, low income countries are expected to show a stronger correlation between the exchange rate and domestic prices, because the relative share of the non-tradable services sector is lower compared to the share in developed economies.

manner, then estimation of future policy inputs, such as expected inflation, becomes crucial for ensuring that the policy rule can be implemented. Since exchange rate movements are important in determining future price levels due to exchange rate pass-through to domestic prices, a model must successfully capture the link between exchange rate movements and expected inflation. While previous empirical studies report a decline in exchange rate pass-through after adopting an inflation-targeting regime, countries face, the pass-through effect will always be a force to reckon with so long as the policy emphasis remains inflation targeting[3]. This is especially true given the observation that emerging markets are generally characterized by high public debt and dollarization, which complicates the role of exchange rates in monetary policy[4]. Sargent and Wallace (1981) within a closed economy framework argue that high public debt and exogenously given public deficits will eventually cause monetary policy to be dominated by fiscal concerns. For a small highly indebted open economy, increasing the policy rate as a response to a perceived increase in inflation and currency depreciation may cause the rates on government debt to increase which in turn may increase the default risk and may lead to further currency depreciation.

We analyze the reaction function of the Central Bank of Turkey (CBT) in the post-2001, the floating exchange rate period, using a multivariate structural model with time-dependent parameters and regime shocks. Using Turkey as a case study is appealing in several respects. First, since the full capital account liberalization at the end of 1990's Turkey has experienced high inflation, lax fiscal policies and had episodes of sudden capital account reversal and high exchange rate volatility; the latest was in May 2006, almost five years after Turkey switched to inflation targeting[5]. Second, because of Turkey's concerns over the export performance as well as the high degree of asset and liability dollarization,

[3]Edwards (2006) reports declines in exchange rate pass-through for Australia, Canada, Brazil, Chile, Israel, South Korea, and Mexico. Kara et al. (2005) find the same result for Turkey in the post-2001 period.

[4]Several empirical studies report that exchange rate volatility and high inflation leads to dollarization. On the other hand, a reverse causality is also possible. Akçay *et al.* (1997) report that higher degree of dollarization leads to higher levels of exchange rate uncertainty in Turkey.

[5]For a brief review of the financial crises that Turkey faced in the aftermath of the 1989 capital account liberalization, see Alper and Öniş (2003).

sustained appreciation of the domestic currency partly due to improvements in the global liquidity conditions in the post 2001 period has put pressure on the CBT for adjustments ever since the adoption of inflation targeting in 2002, regardless of whether the adjustments have been aligned with the implied policy rule or not. Finally, although the initial phases of inflation targeting have been successful, CBT has overshot its target for the last two years by at least four percentage points, raising questions about what role exchange rates play in CBT reaction policy and about how CBT updates its inflation target following an exchange rate crisis[6].

An increase in the volatility of the exchange rates may not only induce preemptive adjustments by the EMCBs, but also lead to regime shifts or structural breaks in the policy function. In an inflation-targeting regime the monetary authority has to consider its own credibility when implementing an explicitly announced rule. Although inflation targeting as a policy increases the transparency and credibility of the monetary policy, an EMCB may initially lack institutional credibility, which could cause the monetary authority to shift regimes more frequently. Other issues associated with EMCBs also require special attention. For instance, a higher frequency of governor appointments might lead to more frequent structural breaks in the reaction function of an EMCB. Such shifts cannot be represented by the class of linear Taylor rules suggested for developed countries. Estimating a Taylor rule for the purpose of describing policymaker behavior in this case would require appropriate modeling of such policy shifts.

Another important issue is that the standard Taylor rules incorrectly assume that the policymaker has perfect information about the current actual output gap, which is not necessarily the case, a point forcefully made by Orphanides and van Norden (2005). For this reason, accurate measurement of the potential output - in other words, the productive capacity of the economy - is crucial. A serious mismeasurement of the output gap may lead to an activist stabilization policy that achieves undesired

[6]Turkey adopted implicit inflation targeting starting in 2002 and open inflation targeting in 2006. During the period of implicit inflation targeting, partly due to favorable global liquidity conditions annual inflation rate fell to single digits.

outcomes. The absence of statistical sophistication and the relatively larger informal sector in emerging economies mean that potential output is more likely to be mismeasured by an EMCB compared to a central bank in a developed country. Given the fact that potential output is at least partially determined by the available imported machinery exchange rates play a further role in determining the output gap. Such issues make it more challenging to model and predict the reaction functions of EMCBs.

In this article, we present an empirical nonlinear state-space model that addresses the concerns mentioned above. We start with a benchmark model that includes exchange rates as an input to the rule, along with inflation gap and output gap. We employ a dual extended Kalman filter (DEKF) technique to estimate simultaneously both time varying parameters (random coefficients) and unobserved variables, such as expected inflation and potential output. This technique allows us to track changes in central bank behavior over time. We estimate several augmented Taylor rules for the Turkish economy in the post-2001 period and we find positively significant coefficients for output gap and inflation gap and a negatively insignificant coefficient for exchange rate gap. We also report that the Central Bank of Turkey (CB) has given relatively more importance to the inflation gap than to either the output gap or the exchange rate gap in determining interest rates, though this did not happen immediately after the switch. We compare our model with existing models of smooth adjustment as well as with linear models that treat exchange rates as an input to the rule. While our model does not offer an accurate measurement of the potential output, it offers an empirical advantage. Specifically, it produces a larger set of information that can be utilized for the optimal estimation of the output gap as it pertains the estimation of reaction policy.

There are several articles that include exchange rates in the Taylor Rule, albeit without any consideration of the operational framework of the monetary authority in developing countries[7]. Taylor (2001) finds that rules that respond directly to exchange rates do not perform better than those that respond indirectly. Edwards (2006) examines the role of exchange rate in Taylor rules and finds that it has a

[7]See Clarida *et al.* (1998), Benigno (1999), and Edwards (2006) on developed economies.

significant coefficient for most of the inflation-targeting countries. Our analysis extends that of Edwards (2006) in that we incorporate the effect of exchange rates both in the measurement of output gap and in the estimation of expected inflation, both of which are inputs to the policy rule. We also compare this new rule to those of Edwards (2006) and previous researchers who use exchange rates as exogenous inputs. We find that incorporating the effects of exchange rates into the rule gives a better description of CBT behavior in the period after 2001.

Engle and West (2005) and Mark (2005) study open-economy Taylor rules that include exchange rates, but their aim is to evaluate the effect of such a rule on time-series properties of exchange rates. In a developing country framework, De Gregorio *et al.* (2005) study the case of Chile and argue that if the effects of the exchange rate changes are already incorporated in calculations of output gap and inflation gap, there is no need to give an independent role to the exchange rate in the policy rule. We follow this approach in the present paper, even though there is room for the EMCB to intervene preemptively and directly when the inflation and output gap are slow to respond to changes in exchange rate. On the other hand, our work differs from that of De Gregorio *et al.* (2005) in how we estimate unobservables and how we incorporate exchange rates into the model, which we explain in more detail in the next section.

One major difficulty in estimating a Taylor rule is measuring the potential output as a determinant of the output gap. Basic procedures such as Hodrick-Prescott (HP) filters and quadratic detrending methods are widely used, while the Kalman filter and its extended version have also been recently employed. While HP filters do perform well when estimating potential output in developed economies, where output is less volatile, it is poorly suited to emerging market economies, which are more prone to outside shocks and therefore show wider variation in their trend indicators. The Kalman filter algorithm, on the other hand, has several advantages over traditional filters [8]. These merits have

[8]First, unlike the HP filter or other detrending methods, the Kalman filter allows for greater volatility in the trend component and more flexibility in modeling the trend. This is especially crucial for emerging market economies and it has been one of the main criticisms of the HP filter, which produces too 'smooth' a trend for

been documented by Ozbek and Ozlale (2005), who use a univariate extended Kalman filter to provide potential output estimates for Turkey. Orphanides and van Norden (2005) calculate the potential output using a univariate Kalman filter, whereas we use a multivariate one[9]. Similarly, Bueno (2005) looks at the hidden states in the policy rule in a Markov switching model using a multivariate Kalman filter, but without including exchange rates as a determinant of the policy rule.

Another major issue is estimating potential output correctly when it is affected by movements in exchange rates. By employing a multivariate structural version of the filter one can capture such effects and utilize more of the available information to estimate the output trend. We can introduce time-varying parameters, which allows us to track the changes in the Central Bank's behavior after its switch to the inflation-targeting regime. Finally, the state-space setup allows us to evaluate the Taylor rule using a multivariate structural model that incorporates the joint estimation of all important unobserved variables - such as potential output - into one complete model. The aim of this paper is to explain the behavior of an EMCB with the available information at hand. Therefore, it does not address the issue of real-time measurement of the potential output as suggested by Orphanides (2003b). The methodology that we employ provides recursive optimal forecasts of the potential output at each point in time, which approximates the level of information available to an EMCB when it makes policy decisions.

The organization of this article is as follows. In the next section, we describe the model. In the third section we present the data and our estimation results. Section four concludes.

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such economies. Second, by including all possible variables in the estimation of the potential output, the Kalman filter utilizes more information in the estimation of the potential output, which results in lower forecast errors. Thirdly, the Kalman filter is not plagued by the problem of incorrectly estimating the trend at the end of the sample period.

[9]In the univariate version, the only information source is the actual real GDP.

2 The Empirical Model

Both theoretical and empirical studies document that the exchange rate has an indirect role in inflation targeting because it affects both the expected inflation and output gap. Therefore, such effects may already be embedded in a forward-looking Taylor rule that considers the exchange rate as an input to the rule. In this respect, one possibility is to include in the original rule the deviations of the real exchange rate from the trend instead of including the nominal or the real exchange rate as a separate term in the rule. A zero real exchange rate gap can be considered to be consistent both with a zero inflation gap and a zero output gap. Another possibility is to model the effects of nominal exchange rate changes on inflation expectations separately by treating inflation expectations as an unobserved variable. Both approaches are different from the one used in Clarida *et al.* (1998) and in subsequent papers mentioned above, all of which use exchange rates as exogenous linear inputs to the policy rule. The problem of accurately estimating future inflation is more difficult in the case of developing countries such as Turkey. Our results suggest that it is more appropriate to use the second approach because it captures the role of exchange rates in a way that more closely resembles the behavior of an EMCB in an inflation-targeting regime. In other words, exchange rate matters to the extent that it affects future inflation and output gaps. This approach is also useful in the sense that it prevents an EMCB from responding both to depreciation and a higher expected future inflation, given that the latter already includes effects of the former. However, when there is a delayed response between changes in the exchange rate and the inflation or output gaps, the EMCB may choose to respond immediately to changes in the exchange rate to control the pass-through effect on the inflation and output gaps. This preemptive intervention by the central bank is suggested by Edwards (2006), who argues that the exact reaction function will be country-specific and dependent on pass-through elasticities. For the Turkish case, Kara and Öğünç (2005) provide evidence that the pass-through effect is relatively high, which might justify looking at the effect of exchange rates on expected future inflation separately, as opposed to including exchange rates explicitly in a Taylor rule that already includes expected future inflation in its inflation gap component[10].

Ample evidence in the literature indicates that rules with lagged policy rates have better predictive power over those without interest rate smoothing (Rudebusch, 2006). While this may reflect monetary policy inertia, there may also be persistent influences on central bank behavior that cannot be explained by smooth adjustment of interest rates. In fact, the distinction between interest rate smoothing and persistent influences on EMCB is even more blurred in emerging markets pursuing inflation targeting, because the central bank may be subject to political pressures as well as to sustained periods of currency devaluation or appreciation. In order to control for such effects, we experimented with the inclusion of a lagged interest rate term in the Taylor rule as suggested by Rudebusch (2006), as well as a time-varying intercept term to capture regime shifts and other external factors.

We assume that the central bank follows a Taylor Rule in a forward-looking manner in order to control inflation[11]. We started with a baseline model in which the EMCB responds to inflation gaps, output gaps, and some external factors like foreign interest rates or real exchange rate gaps. We took the nominal over-night interbank interest rate as the policy rate, and we made several implicit assumptions. First, the response of the central bank is immediate, i.e. we assumed the EMCB does not smooth changes in the interest rate eliminating the need for a lagged term in the rule. Second, we assumed that the EMCB is concerned only with the economic environment and we do not allow systematic changes in the EMCB's behavior, whether triggered by an internal mechanism or by political influence. Hence the first baseline model can be written as:

[10] For instance, in March 2006, the Central Bank of Turkey increased the interest rate by 16.5%, or 425 basis points, from 13.25% to 17.5% in response to a sudden currency depreciation.

[11] Lawrence and Rostagno (2001) show that monetary policy characterized by the Taylor rule may inject additional volatility into the economy if it ignores the money growth rate. We ignore the money growth rate on the following grounds. Firstly, a single interest rate policy can be supported by various money growth rules. Secondly, in an inflation-targeting framework, money growth is important to the extent that it can forecast future inflation, but there is little evidence that it can forecast this.

$$i_t = \alpha + \beta(\pi^e_{t,t+1} - \pi^*_{t,t+1}) + \gamma(y_t - y^*_t) + \delta q_t + \varepsilon_t \tag{1}$$

where i_t is the policy rate, $\pi^*_{t,t+1}$ is the target level of the inflation rate as announced by the central bank, $\pi^e_{t,t+1}$ is the inflation at t+1 as expected at time t, y_t is the actual output, y^*_t is the unobserved potential output, q_t represents external factors, such as real exchange rate gap or foreign interest rate.

We then relax the assumption that the EMCB does not smooth its policy rate and estimate the following equation.

$$i_t = \alpha + \rho i_{t-1} + \beta(\pi^e_{t,t+1} - \pi^*_{t,t+1}) + \gamma(y_t - y^*_t) + \delta q_t + \varepsilon_t \tag{2}$$

We further relax the above assumptions by allowing systematic changes in the EMCB's behavior. We also allow for time-variable coefficients and regime switches. We further assume that the central bank responds to changes in exchange rates with the goal of controlling inflation. In other words, changes in the exchange rate affect the expected inflation in the reaction function. In this setup, the expected inflation is not directly observable by the central bank but can be inferred in a way that is consistent with the state of the economy as described by the model. This leads to the following specification:

$$i_t = \alpha_t + \rho_t i_{t-1} + \beta_t(\pi^e_{t,t+1} - \pi^*_t) + \gamma_t(y_t - y^*_t) + \delta q_t + \varepsilon_t \tag{3}$$

$$\alpha_t = \lambda_1 + \lambda_2 \alpha_{t-1} + \xi_t \tag{4}$$

$$\pi^e_{t,t+1} = a\pi_t + b\Delta s_t + c\Delta s_{t-1} + \zeta_t \tag{5}$$

$$y_t^* = y_{t-1}^* + \phi_{t-1} + \omega_t \tag{6}$$

$$\phi_t = (1 - \eta_t)\phi_0 + \eta_t \phi_{t-1} + \vartheta_t \tag{7}$$

$$y_t = y_t^* + x_t \tag{8}$$

$$x_t = \tau_{1,t} x_{t-1} + \tau_{2,t} r_t + \tau_{3,t} q_t + \tau_{4,t} \pi_t + \psi_t \tag{9}$$

where Δs_t is the change in nominal exchange rate from the previous period, ϕ_t is the potential output growth rate or the trend output growth rate, η_t is the persistence of the deviations from the trend output, x_t is the output gap and r_t is the real rate. Finally α_t, β_t, γ_t, η_t, $\tau_{1,t}$, $\tau_{2,t}$, $\tau_{3,t}$ and $\tau_{4,t}$ are random coefficients and ε_t, ξ_t, ζ_t, ω_t, ϑ_t and ψ_t represent shocks to the system, which are assumed to be *i.i.d.* with zero mean and constant variances.

The third equation is the augmented Taylor rule we adopted in our estimations and represents our baseline model. EMCB responds to changes in deviations of the expected inflation from its target, as described by the term $(\pi_{t,t+1}^e - \pi_t^*)$, to changes in actual output from its potential level, as described by the term $(y_t - y_t^*)$ and to an external factor, q_t, such as the deviation of the real exchange rate from its trend or foreign interest rate. The inclusion of the lagged dependent variable, i_{t-1}, reflects the inertia in monetary policy or smooth adjustments to the policy rate. The variable intercept term, α_t, represents regime shocks or noisy information faced by the central bank as emphasized by Orphanides (2003a). The policy follows an AR(1) process if output gap and inflation gap are zero and there is no noisy information about the state of the economy as it is perceived by the EMCB.

We extend the model to a state space setup by adding the following equations.The fourth equation describes the evolution of the noisy information faced by the EMCB. The fifth equation expresses the dynamics of inflationary expectations, π_t^e, both through inflation persistence and exchange rate pass-through calculated by the marginal effect of past nominal exchange exchange rates, s_{t-1} and s_{t-2}. The sixth equation describes the evolution of the potential output as in Aguiar and Gopinath (2004) and Sarıkaya *et al.*(2005). We specify a flexible random walk with a drift model where growth rate of the output trend, ϕ_t, is time-variable. We argue that in developing countries the trend of potential output is more prone to external shocks and may depend on productivity and labor force participation. Aguiar and Gopinath (2004) show that business cycles in emerging markets occur because there are the frequent changes in economic policies that cause shocks to the growth rate of the trend. Given the vulnerability of the emerging markets to such volatile shocks we adopt a stochastic model as in Sarıkaya *et al.* (2005) for the trend where shocks are permanent and the persistence of the growth rate, η_t, can be specified *a priori*. This is given in equation 7, where the potential growth rate exhibits an AR(1) process with η_t representing the persistence of the deviations from the the long-run growth rate ϕ_0. The eighth equation is the decomposition of the actual output into potential output and output gap. The above model can be expressed in state-space form in the following way:

$$\begin{aligned} W_{t+1} &= A_t W_t + B_t U_t + u_{t+1} \\ Y_t &= C_t W_t + D_t V_t + v_t \end{aligned} \tag{10}$$

where Y_t is an $n \times 1$ vector of observed variables, U_t and V_t are $k \times 1$ and $j \times 1$ vectors of predetermined or exogenous variables. A_t, B_t, C_t and D_t are time-variable coefficient matrices. W_t is a $r \times 1$ vector of unobserved state variables. We then estimate the unobserved components in a state-space setup using Kalman filtering methods. [12]

[12] The specification of these matrices can be found in the Appendix.

After switching to a new monetary policy regime, there is a period during which the agents, including the central bank, adjust to the new environment. In this respect, allowing the parameters to vary lets us explore how central banks adapt to an inflation-targeting regime. In econometric terms this extension is not straightforward. If one allows for time-variable parameters the model becomes nonlinear in state variables and it is no longer appropriate to apply SKF. Moreover, since both these parameters and the state variables are presented in multiplicative form, EKF by itself is insufficient to linearize the system due to the filter's recursive structure. Briefly summarizing, each state estimate requires the full knowledge of the coordinates where the linearization should take place. One also needs other state estimates, such as estimates of the unknown parameters to specify the coordinates. In order to address this problem, we propose a Dual Extended Kalman filter (DEKF) which applies a linear approximation algorithm to the SKF at the last step in state variables and parameters. It does so by using two separate extended Kalman filters, one for signal estimation and another for model estimation. One EKF generates state estimates by utilizing a priori state estimates and a priori parameter estimates, while the other EKF generates parameter estimates by utilizing a priori state estimates. DEKF has several advantages to the simple EKF, as described in Haykin (2000).

3 Data and Estimation

We use the simple monthly average of the daily overnight interbank borrowing rate set by the Turkish Central Bank as the policy rate for the sample period 2002:01 through 2007:07. Inflation is defined as the logarithmic difference of annual seasonally adjusted CPI value. Output is taken to be the natural logarithm of seasonally adjusted real GDP. The real exchange rate is based on CPI and taken from the CBT's web-site along with the real rates. The nominal exchange rate is a basket of Euro and Dollar with equal weights.

Our estimation consists of several steps. First we estimate the baseline model with constant parameters where we experiment with several candidates for q_t. Next we estimate the multivariate structural model with constant coefficients using SKF, again experimenting with several candidates for q_t and several initial conditions. Finally, we estimate the complete model with time-variable parameters using EKF. We experimented with several candidates for q_t. One candidate we experimented with is the real exchange rate as put forward by Taylor (2001). Another is the real exchange rate gap where the gap is measured by a deviation from its HP trend. We also included the US federal funds rate as in Adam *et al.*(2005).

We estimated the above model for the period between the first month of 2002 and seventh month of 2007. The results are selectively reported in Table 1. What we selectively report are based on the best results we were able to obtain using the above methodology, where we define "best" as having the lowest mean squared error[13]. The baseline models refer to the estimation of (1), where each gap is calculated using a HP filter and coefficients are time-invariant. The coefficient of output gap and inflation gap are positive and significant. The coefficient of inflation gap is greater than one, reflecting the aggressive monetary policy employed by the CBT during the inflation-targeting period. The coefficient of exchange rate gap is insignificant and negative. Introducing the lagged interest rate improves the fit of the model. This is expected, since the CBT smoothed the interest rate movements, except for the one-time hike in May 2006 as shown in Figure 1.

The last two columns show the results we obtained using the extended model. They are similar to the baseline model, except the extended model fits the data considerably better. The estimation exercise using the constant coefficient model with SKF results in a positive and significant coefficient for both the inflation gap, and the output gap and a negative and insignificant coefficient for the exchange rate gap. By employing the random coefficient model with EKF we obtain similar results. This is shown in the last column. We present the results we obtained by letting $q_t = 0$ in equation (3), the exchange

[13] All other estimation results are available from the authors.

rates and the foreign interest rate are not considered exogenous policy inputs. All of the coefficient estimates are the estimates at the last observation of the sample period[14]. While the coefficient of the inflation gap turns out to be positive for each step of the estimation, the coefficient of the output gap is insignificant. The coefficient of the exchange rate is negative and insignificant at the last step.

To show how the baseline model and the extended model compare in describing the CBT's response, we present the actual overnight rates and the fitted rates in Figure 1. Unlike Clarida *et al.* (2000), we tested our model's fit by comparing the actual rates with the fitted rates instead actual target rates with fitted target rates. This is because the target rates are set well in advance in the inflation-targeting framework and therefore do not show volatility. The extended model with constant coefficients performs better than the baseline one. In particular, there are sustained periods during which the implied rule overestimates or underestimates the actual rates. To recap, we found that an empirical Taylor rule with variable policy parameters and regime shocks explains the CBT behavior after 2001 better than the baseline model or the extended model with constant coefficients.

In Figure 2, we traced the CBT response over time. Reading Figure 2 requires caution: initial estimates in the sample period are produced with few observations and do not carry any statistical significance. Therefore, we choose to comment about the last half of the sample only. According to the figure, the CBT has always given more weight to the inflation gap than to the exchange rate, although the relative weights have varied. The inflation gap has become more important over the course of the inflation-targeting period, reflecting the fact that the CBT was initially more concerned with fiscal dominance and lack of credibility. The relative importance subsequently diminished, which may explain the overshooting observed in the last 1.5 years.

[14]The Bayesian recursive estimation also requires specification of the initial conditions for all state variables, including the random coefficients. For the potential output, we chose the actual value at the beginning of the sample. For the expected inflation, we used a fitted value from Equation (5). For the random coefficients, we started with the fitted values we obtain from the baseline model. We further experimented with a considerably large set of arbitrary initial conditions. These results are also available from the authors.

4 Conclusion

In this paper, we proposed a model to estimate the reaction function for an inflation-targeting emerging market central bank of a highly dollarized economy during the floating exchange rate period. It is not immediately clear from the previous literature whether the exchange rate should be considered separately within the Taylor rule for open economies. If the output gap and the inflation gap carry enough information to describe the state of the economy, then there is no need to include exchange rate because any information it contains will already be captured in these two statistics. However, since these statistics include unobservables such as potential output and inflationary expectations, the current and future values of which are at least partially determined by exchange rates, one can improve the estimates by utilizing the information provided by exchange rate movements. Our model incorporates the effects of exchange rate movements on inflationary expectations and output gap in a state-space setup. We introduce time-varying parameters and regime shifts to describe changes in EMCB behavior. We used the model to estimate the CBT reaction function in the post-2001 period. When taking into account regime shifts, the extended model predicted the CBT behavior better than the standard Taylor rule. We found that CBT has responded to inflation more aggressively over time, reflecting its initial concerns about fiscal dominance. We also found that the CBT has mostly ignored the movements in exchange rates during the inflation-targeting period, in line with the classical definition of inflation targeting.

From an econometric point of view, it is better to consider the exchange rate a tool of monetary policy for the EMCB rather than an exogenous input for the implied rule in inflation-targeting regimes. While further study is needed to understand the general role of exchange rates in describing EMCB behavior, we recognized that the use of exchange rates as a tool of monetary policy is largely an empirical and country-specific issue, as suggested by Edwards (2006). An exercise using real-time output gaps instead of forecasts provided by the algorithm in this article would provide more insight into the observed outcomes of monetary policy. The model presented in this paper can be useful in studying central bank behavior in other emerging market economies subject to similar shocks, such as Egypt, where the central bank is on the verge of adopting an inflation-targeting regime.

5 Appendix

While estimating the state space model, in addition to Equations 3-9 we use a random-walk specification for the parameters. The detailed exposition of Kalman filtering theory can be found in Haykin (2000). We present here the modifications and the specifications of state-space matrices, as well as the computational algorithm we employ.

The state-space matrices are specified as follows.

$$W_t^T = \begin{bmatrix} \alpha_t & \pi^e_{t,t+1} & y_t^* & \phi_t & x_t & \beta_t & \gamma_t & \rho_t & \eta_t & \tau_{1,t} & \tau_{2,t} & \tau_{3,t} & \tau_{4,t} \end{bmatrix}$$

$$Y_t^T = \begin{bmatrix} i_t & y_t \end{bmatrix}$$

$$U_t^T = \begin{bmatrix} \pi^*_{t,t+1} & i_{t-1} & 1 & \pi_{t-1} & \Delta s_t & \Delta s_{t-1} & 1 & -\phi_0 & \eta_t & 1 & r_t & q_t & \pi_t \end{bmatrix}$$

where T denotes the transpose of a matrix.The parameters are collected in the following matrices:

Except for the single cell $A(3,4) = 1$, A_t is a 13×13 diagonal matrix with the diagonal elements as follows: $A_t = \text{Diag}\{\lambda_2,\ 0,\ 1,\ \eta_t,\ \theta_{1,t},\ 1,\ 1\ 1,\ 1,\ 1,\ 1,\ 1,\ 1\}$

B_t is a 13×13 matrix of zeros with the following exceptions: $B(1,3) = \lambda_1$, $B(2,4) = a$, $B(2,5) = b$, $B(2,6) = c$, $B(4,7) = -\phi_0$, $B(4,7) = \eta_t$, $B(5,8) = \tau_{2,t}$, $B(5,9) = \tau_{3,t}$, $B(5,10) = \tau_{4,t}$

$$C_t = \begin{bmatrix} 1 & \beta_t & 0 & 0 & \gamma_t & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 1 & 0 & 1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \end{bmatrix}$$

$$D_t = \begin{bmatrix} -\beta_t & \rho_t & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \end{bmatrix}$$

The unobserved state variables and parameters are initialized by:

$$\widehat{i_0} = E(i) \quad \Sigma_a = E\left[(i_-\widehat{i_0})(i_-\widehat{i_0})^T\right] \text{ for } i = A, B, C, D$$

$$\widehat{W_0} = E(W) \quad \Sigma_w = E\left[(W_-\widehat{W_0})(W_-\widehat{W_0})^T\right]$$

where E denotes the expectations operator and Σ_i is the covariance matrix for random variable vector i. In the simulation, we used values obtained from the baseline model including those obtained from an HP filter. Two separate, non-linear filters provide their estimates by running concurrently for both the parameters and the state variables. The state filter takes a priori state estimates and a priori parameter estimates to produce a current state estimate. The current state estimate is then updated by using the measurement taken on observed variables to produce the a posteriori state estimate. The parameter filter, on the other hand, takes the a priori state estimates to produce a current parameter estimate, then updates it using the current state estimate and the measurement taken on observed variables. In both filters, the time update and the measurement update steps are run using extended Kalman filtering methods.

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