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Inflation Targeting and Inflation Expectations: Evidence for Brazil and Turkey

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Abstract

In this paper, we study the evolution of inflation expectations for two key emerging economies, Brazil and Turkey, using a reduced form model in a state-space framework, where the level of inflation is modeled explicitly. We match the survey-based inflation expectations and inflation targets set by the central banks of Brazil and Turkey with the predictions implied by the model in a statistically coherent way. Confronting these expectations with inflation targets leads to a statistical measure of the discrepancy between inflation expectations and the target inflation. The results indicate that inflation expectations are anchored more closely the inflation target set by the Central Bank for Brazil. By contrast, there is more evidence that inflation expectations deviate significantly from the target inflation set by the Central Bank for Turkey.

Keywords: *Inflation targeting, term structure, survey-based expectations, inflation forecasting, state space models*

JEL Classification: *E31 , E37, C32, C51*

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1 Introduction

Understanding the stance of monetary policy is a key requirement for policy-makers in both developed and emerging economies. In this regard, understanding the evolution of longer term inflation expectations for controlling inflation is also key. Adrian and Wu (2009) use the term structure of breakeven inflation - the difference between nominal and real yields at different maturities - to estimate the term structure of inflation expectations. In their approach, the difference between expected inflation and breakeven inflation is given by the inflation risk premium, which they uncover using both the term structure of the yield curve and the term structure of their variances and covariance. Chernov and Mueller (2012) augment the information in the nominal yield curve with survey data on inflation expectations to derive the determinants of the model-based inflation expectations in terms of observable macroeconomic indicators and a latent factor. However, Kozicki and Tinsley (2006) argue that inflation expectations in survey data provide a more direct measure than breakeven inflation due to the presence of risk premia and other distortions in the latter. Moreover, survey-based expectations often capture information about structural changes regarding the future state of the economy, shifts in the perceptions of the goals of monetary policy, or political turmoil more rapidly than the historical data, thus incorporating valuable information about future inflation changes as well.[1]

For many emerging economies, understanding the evolution of inflation expectations is especially important given their relatively recent transition to inflation targeting regimes. As Fraga *et al.* (2004) document, emerging economies face challenges in their implementation of inflation targeting regimes in terms of higher and more volatile inflation rates. They also face challenges in terms of "(1) building credibility; (2) reducing the level of inflation levels; and (3) dealing with fiscal, financial, and external dominance" (see Fraga

[1]There are other applications of the use of survey data on inflation expectations in macroeconomic and monetary models to proxy for inflation expectations, see, e.g., Klaus and Padula (2011), or to test versions of models with informational rigidities, see Mankiw *et al.* (2004). Ormeno (2011) uses survey data to estimate a dynamic stochastic general equilibrium (DSGE) model with learning, and Del Negro and Schorfheide (2013) examine the additional predictive gains of including survey data in DSGE models.

et al. (2004), p. 375.) These authors employ a small open economy model as in Batini *et al.* (2003) and McCallum and Nelson (2000), which treats imports as intermediate goods, to assess the inflation targeting performance of emerging economies relative to developed ones. They examine the time path of inflation and the output gap under imperfect credibility and a Taylor rule determining the optimal interest rate. Çiçek and Akar (2014) examine the rate of convergence of inflation expectations in Turkey to inflation targets versus actual inflation over the period 2002-2013. They control for the size of shocks affecting the inflation gap by using a quantile autoregression approach. They find evidence for imperfect credibility of monetary policy in that inflation expectations have been anchored to both inflation targets and actual inflation, but no convergence of inflation expectations has occurred at larger quantiles. Kabundi *et al.* (2014) examine the relation between inflation and inflation expectations of different agents for the South African economy during the inflating targeting period beginning in 2000. They find that agents' expectations are heterogeneous and that the South African Reserve Bank (SARB) has successfully anchored the expectations of financial analysts but not those of price setters comprised of business and labor groups.

In this paper, we examine the evolution of inflation expectations for two key emerging economies, Brazil and Turkey, using a reduced form model in a state-space framework which incorporates the use of survey expectations of inflation and data on actual inflation targets set by the monetary authority. Many emerging economies have witnessed a transition from a high inflationary period to a more stable low inflationary period during the last decade, which suggests that it is important to control for changes in their trend inflation. Second, seasonal variation in the inflation data appears important for many emerging economies. Since macroeconomic data for emerging economies are often available without any seasonal adjustment, implementing a seasonal adjustment based on an arbitrary moving average filter may obscure the inference. In the model considered in this paper, the level, slope and seasonal components of inflation are modeled explicitly. By treating seasonality together with the other components, the model exploits further the seasonal information which is potentially correlated with the inflation level, see for example Koopman and Lee (2009). The flexibility of this model ensures that specific patterns of inflation for emerging economies such as Brazil and Turkey during the last decade are captured adequately.

An important feature of the analysis is that data on survey expectations are used to obtain additional information on inflation dynamics. By matching the survey-based inflation expectations and inflation targets set by the central banks of Brazil and Turkey with the predictions implied by the model in a statistically coherent way, we are able to construct the evolution of the term structure of inflation expectations implied by the structural and reduced form models blended with survey expectations. Moreover, confronting these expectations with inflation targets leads to a statistical measure of the discrepancy between inflation expectations and the target inflation. As a way of examining the efficacy of the model, we also compare its predictions with the predictions from (i) a moving average model, (ii) a flexible autoregressive model and variants of (iii) a backward looking Philips curve and (iv) a hybrid Philips curve which incorporates information on survey inflation expectations and measures of the output gap. Such a comparison also allows us to measure the value of expert's opinion, i.e. survey expectations, on inflation predictions.

The model is used to derive both in-sample and out-of-sample forecasting results. The in-sample results yield smoothed estimates of the level, slope, and seasonality in the inflation process together with the term structure of monthly inflation expectations that are consistent with survey expectations. The model integrates seasonal characteristics observed in the data without making assumptions that the seasonal component is independent of the remaining components such as the level of inflation. Indeed, the in-sample results indicate a non-zero covariance between the seasonal component and both the level and slope components of inflation for Turkey as well as a negative covariance between the level and the slope. By contrast, for Brazil, the model that approximates the inflation process is best represented by a local level model, with negligible effects of the slope.

The out-of-sample forecasting results indicate that for Turkey, our model clearly outperforms all the benchmark models at all horizons. The model that incorporates information from survey expectations also outperforms the standard model without survey expectations, indicating the importance of anchoring the longer term forecasts using such information. However, unless survey expectations are incorporated in a statistically coherent way, they do not help to increase the predictive power of the model, as indicated by the superior performance of our model relative to the hybrid Phillips curve. For Brazil, the performance of the model is more mediocre compared to the findings for Turkey. We attribute this result to the use of only one-year ahead survey expectations, which tends to reduce the efficiency of the estimation, together with the smoother inflation process for Brazil. We also find that inflation expectations are more in line with target inflation in Brazil than in Turkey, which is reflected in the slightly better performance of the random walk model (MA) in out-of-sample results for Brazil.

The remainder of this paper is organized as follows. Section 2 presents the state space model. It also provides some preliminary observations on the inflation and inflation targeting experiences for Brazil and Turkey. Section 3 describes how to incorporate inflation targeting into the standard state space model. Section 4 presents the in-sample estimation results while Section 5 presents the out-of-sample forecasting results. Section 6 concludes.

2 A State Space Model of Inflation for Emerging Economies

In this section, we describe a flexible model structure to approximate the inflation processes observed in emerging economies. We then integrate the survey data on inflation expectations into the model to estimate the term structure of inflation expectations. We begin with some preliminary observations on inflation for two key emerging economies, Brazil and Turkey.

2.1 Some preliminary observations

During the period of the 1990's, many emerging economies implemented stabilization policies based on an exchange rate anchor under trade and financial liberalization. However, the failure of these policies due to fiscal deficits, banking and financial sector fragility, and the ensuing crises led to the search for an alternative nominal anchor and to a new monetary policy framework in the form of inflation targeting (see Arestis *et al.*, 2008). Brazil moved to an inflation targeting regime after the currency crisis of 1999 when the Brazilian economy experienced macroeconomic instability and significant capital outflows. Turkey began practicing a form of implicit inflation targeting after the severe banking and financial crisis of 2000-2001, which erupted in the midst of an IMF-sponsored stabilization plan, and transited to a formal inflation targeting regime in 2006.[2]

We use data on the seasonally unadjusted consumer price index (CPI), survey expectations of inflation, and inflation targets for Brazil and Turkey. The sample period for Brazil is from November 2001 to January 2014 while for Turkey it is from August 2001 to January 2014. Figure 1 shows the data on annualized inflation, survey inflation expectations, and the inflation targets for the two countries.[3] The raw data display the seasonal component of the actual inflation processes, which is less pronounced for the survey data on short-run inflation expectations. These data provide some justification for our approach in terms of separately modeling the level, the slope and the seasonal component of inflation.

The episode of high inflation in 2002 stands out for the Brazilian economy, as contagion from the Argentinian debt crisis of 2002 as well as political uncertainty arising from the nature of presidential elections and global risk factors led to financial distress in the

[2]See Kara (2008) for a discussion of this process.

[3]The raw inflation data for Brazil and Turkey are obtained from OECD main economic indicators. Survey-based measures of inflation expectations are available at different forecast horizons and sample periods for the different countries. For Brazil, we use the twelve-month ahead survey expectations compiled by the Banco Central do Brazil (BCB). Likewise, for Turkey, we use two-month and one-year ahead survey expectations compiled by the Central Bank of the Republic of Turkey (CBRT). The one-month ahead survey expectation only starts from 2006 onwards, thus we exclude these expectations from our data set. We use the monthly averages of the median daily forecasts for these countries.

Brazilian economy (see Goretti, 2005). However, inflation falls rapidly after 2003 (for an account of the disinflation process during this period, see Bevilaqua *et al.* (2007)). Average annual inflation over the entire sample period from November 2001 to January 2014 for Brazil is 5.19%, and it falls to 4.48% for the period from January 2004 to January 2014. Consistent with the behavior of actual inflation, twelve-month ahead survey-based inflation expectations begin falling by mid-2003, and actual inflation and twelve-month ahead survey expectations become aligned by mid-2005. Average survey-based inflation expectations for twelve months ahead are 5.36% over the entire sample period, and 5.01% for the period from January 2004 to January 2014.

Figure 1 also provides information on the behavior of actual inflation, two-month and twelve-month ahead survey inflation expectations and the inflation target for Turkey. Reflecting the changing trend in inflation, the high inflation period at the beginning of the sample is replaced by rapidly declining inflation, as average annual inflation falls from 26.01% in 2002 to 11.97% by 2003.[4] Considering the period from January 2004 to January 2014, the average annual inflation rate is measured as 8%. The survey-based expectations of inflation two-months and twelve-months ahead also reflect the disinflation process. While they measure at 11.56% and 11.72% for the period between August 2001 and January 2014, respectively, these magnitudes fall to 7.45% and 7.18% for the period between January 2004 and January 2014. Finally, there is substantial variation in the non-seasonally adjusted inflation rate for Turkey, which appear to have increased after 2011.[5]

2.2 The econometric model: Incorporating survey expectations

In this section, we develop a local linear trend model that accommodates many observed features of inflation for emerging economies. First, we allow for changes in trend inflation

[4] This reflects the impact of the comprehensive set of reforms that Turkey undertook as part of IMF-sponsored stabilization plan initiated in May 2002.

[5] Indeed, there are instances of monthly changes in inflation from -1.5% up to 3% during this period, which correspond to seasonal fluctuations of nearly -20% to 40% on an annual basis, respectively.

by modeling the level of inflation as a random walk with a drift, where the drift itself also follows a random walk. Second, to accommodate seasonal variation in observed inflation, we explicitly model the seasonal component in the inflation process that may be correlated with the other components. Third, to capture any remaining time-dependence in inflation rates, we also allow for an AR(1) structure in the net inflation process.

Consider the following modified version of the local linear trend model for modeling inflation dynamics

$$\begin{aligned} \pi_t - \alpha_t - \gamma_t &= \phi(\pi_{t-1} - \alpha_{t-1} - \gamma_{t-1}) + \varepsilon_t \\ \alpha_t &= \alpha_{t-1} + \mu_{t-1} + \eta_{\alpha,t} \\ \mu_t &= \mu_{t-1} + \eta_{\mu,t} \\ \gamma_t &= -\sum_{j=1}^{11} \gamma_{t-j} + \eta_{\gamma,t} \end{aligned} \tag{2.1}$$

In this specification, α_t denotes the trend component of inflation, μ_t denotes the slope component of the trend inflation, γ_t denotes the time-varying seasonal component in inflation while ϕ measures the backward-looking dynamics in the net inflation process.

This local linear trend model specification is flexible enough to encompass many types of popular models used frequently for capturing unobserved components of macroeconomic time series. When $\sigma^2_{\eta_\mu} = 0$, for example, the inflation process follows a random walk with a drift, μ. When $\sigma^2_{\eta_\alpha} = 0$, a deterministic trend is obtained. Additionally, when the values of the slope become negligibly small, then the process becomes a local level model involving a random walk only for the level. On the other hand, setting only $\sigma^2_{\eta_\alpha} = 0$ but allowing $\sigma^2_{\eta_\mu}$ to be positive results in an integrated random walk process which can approximate many types of nonlinear trends including HP filter and the parameters of the HP filter can be recovered under certain re-parametrization.[6]

Given the information set that contains the observations up to and including period t,

[6]See Harvey and Jaeger (1993); Harvey and Trimbur (2008); Harvey (2011); Canova (2012). Moreover, Delle Monache and Harvey (2011) show the robustness of the (2.1) against many types of model misspecification.

the one-period ahead forecast of the inflation would be

$$E_t^M[\pi_{t+1}] = \phi\pi_t + \alpha_{t+1|t} + \gamma_{t+1|t} - \phi\alpha_{t|t} - \phi\gamma_{t|t}, \tag{2.2}$$

where the superscript M stands for the "model-based expectations". Using the evolution of the unobserved components in (2.1), $\alpha_{t+1|t}$ can be replaced by its forecast, i.e., by $\alpha_{t|t}+\mu_{t|t}$, and $\gamma_{t+1|t}$ can be written as $-\sum_{j=1}^{11}\gamma_{t+1-j|t}$. Replacing the level and seasonality predictions, the expression for one-period ahead inflation expectation from the model is given by

$$E_t^M[\pi_{t+1}] = (1-\phi)\alpha_{t|t} + \phi\pi_t + \mu_{t|t} - (1+\phi)\gamma_{t|t} - \sum_{j=1}^{10}\gamma_{t-j|t}. \tag{2.3}$$

Iterating forward, the k-period ahead inflation expectation from the model can written as

$$E_t^M[\pi_{t+k}] = (1-\phi^k)\alpha_{t|t} + \phi^k\pi_t + k\mu_{t|t} - \phi^k\gamma_{t|t} + \gamma_{t-12+k|t}. \tag{2.4}$$

Following Kozicki and Tinsley (2006), we also incorporate survey expectations of inflation into the econometric model as a way of obtaining greater information about underlying inflation forecasts. Let $E_t^S[\pi_{t+\tau}]$ denote survey expectations of inflation τ-months ahead. We assume that the survey expectations should match the prediction from the econometric model (with some random error). By matching the survey expectations together with the model-based expectations, we seek to reconcile the model-based expectations with the projections obtained through expert opinion in a statistically coherent way. Using the model, the relationship between next month's inflation prediction and survey-based expectation can be written as

$$\begin{aligned} E_t^S[\pi_{t+1}] &= E_t^M[\pi_{t+1}] + \upsilon_{1,t} \\ &= (1-\phi)\alpha_{t|t} + \phi\pi_t + \mu_{t|t} - (1+\phi)\gamma_{t|t} - \textstyle\sum_{j=1}^{10}\gamma_{t-j|t} + \upsilon_{1,t}. \end{aligned} \tag{2.5}$$

Similarly, the relationship between k-period ahead expectations and survey-based expectations for inflation can be combined as

$$
\begin{aligned}
E_t^S[\pi_{t+k}] &= \sum_{j=1}^k E_t^M[\pi_{t+j}] + \upsilon_{k,t} \\
&= \sum_{j=1}^k \phi^j \pi_t + \left(j - \sum_{j=1}^k \phi^j\right)\alpha_{t|t} + \tfrac{j(j+1)}{2}\mu_{t|t} - \sum_{j=1}^k \phi^j \gamma_{t|t} + \upsilon_{k,t}.
\end{aligned}
\tag{2.6}
$$

3 Inflation Targeting

One of the key issues for central bankers in the inflation targeting regime is the extent to which agents' expectations have become anchored to the inflation target in question. In this section, we describe how to incorporate the inflation target set by central banks into the general state space model. By doing so, we are able to assess quantitatively the systematic deviation of inflation expectations implied by the model from the inflation target.

Usually central banks set an annual inflation target for the next year at the end of each year[7], $\pi_{t,A}^T$ where the superscript T denotes the **T**arget inflation and subscript A denotes its **A**nnual frequency. Thus, target inflation implies a twelve-month ahead inflation projection in December of each year. Matching target inflation together with model based inflation projections and using our model for the month of December, we can write

$$
\begin{aligned}
\pi_{t,A}^T &= \delta_0 + \left(\sum_{j=1}^k E_t^M[\pi_{t+j}]\right) + \upsilon_t^T, \\
&= \delta_0 + \left(\sum_{j=1}^{12} \phi^j \pi_t + \left(12 - \sum_{j=1}^{12} \phi^k\right)\alpha_{t|t} + 78\mu_{t|t} - \sum_{k=1}^{12} \phi^k \gamma_{t|t}\right) + \upsilon_t^T.
\end{aligned}
\tag{3.1}
$$

We include a constant parameter δ_0 to allow for a systematic bias when the target inflation is not met by the inflation expectations. Hence, if the evolution of inflation and expectations of economic agents are in line with target inflation, then $\delta_0 = 0$. Finally, we extend the model to measure a time-varying bias by specifying a random walk process for

[7] Central banks occasionally revise their target inflation also during the course of the year for the remaining part of the year. While our exposition is for the annual targets, we also incorporate more frequent target inflation revisions in our model.

the potential bias as follows:

$$\delta_{0,t} = \delta_{0,t-1} + \eta_{\delta,t}. \tag{3.2}$$

An added issue raised by the use of data on target inflation has to do with the measurement of the target rate on an annual basis. This implies that observations on target inflation are only available for the month of December provided there are no revisions during the course of the year. This leads to missing observations for the remaining time periods. In what follows, we describe how this issue can resolved in our state space framework.

3.1 Statistical Inference

Together with (3.1) and (3.2), the extended model can be written as

$$\begin{aligned}
\pi_t &= \alpha_t + \gamma_t + \phi(\pi_{t-1} - \alpha_{t-1} - \gamma_{t-1}) + \varepsilon_t \\
E_t^S[\pi_{t+k}] &= \sum_{j=1}^{k} \phi^j \pi_t + \left(j - \sum_{j=1}^{k} \phi^j\right)\alpha_t + \tfrac{j(j+1)}{2}\mu_t - \sum_{j=1}^{k} \phi^j \gamma_t + \upsilon_{k,t} \\
\pi_{t,A}^T &= \delta_{0,t} + \left(\sum_{j=1}^{12} \phi^j \pi_t + \left(12 - \sum_{j=1}^{12} \phi^k\right)\alpha_t + 78\mu_t - \sum_{k=1}^{12} \phi^k \gamma_t\right) + \upsilon_t^T \\
\alpha_t &= \alpha_{t-1} + \mu_{t-1} + \eta_{\alpha,t} \\
\mu_t &= \mu_{t-1} + \eta_{\mu,t} \\
\gamma_t &= -\sum_{j=1}^{11} \gamma_{t-j} + \eta_{\gamma,t} \\
\delta_{0,t} &= \delta_{0,t-1} + \eta_{\delta,t}.
\end{aligned} \tag{3.3}$$

The system described in (3.3) is comprised of four unobservable states - the level α_t, slope μ_t, seasonality γ_t, and the systematic deviation of inflation expectations from target inflation $\delta_{0,t}$ - and their laws of motion together with the measurement equations for inflation π_t, k-step ahead survey-based measures of inflation expectations $E_t^S[\pi_{t+k}]$ and the inflation target $\pi_{t,A}^T$. This system can be nicely cast into a state-space framework and standard inference can be carried out using the Kalman Filter/Smoother coupled with quasi-Newton optimization methods.

The state state space framework also handles missing observations regarding the measurement of the inflation target at the annual frequency in a statistically optimal way, by using the evolution of the unobserved inflation components, and provides accurate predictions of **monthly** deviations of inflation expectations from target inflation. The estimation approach and other technical details are provided in Appendix A.

4 The Results

4.1 The estimated inflation processes

Figures 2 and 3 display the smoothed estimates of the level, slope, the seasonality of the inflation processes for Brazil and Turkey, respectively, together with 95% confidence bands for these quantities while Tables 1 and 2 provide estimates of variances and covariances of the level, slope, and seasonal components of inflation for the two countries. These tables show that the estimates indicate that the variances $\sigma^2_{\eta_\alpha}$ are not significantly different from zero for both Brazil and Turkey, implying that we cannot reject the hypothesis that the inflation process π_t is a random walk with drift for the two countries.[8] Second, we observe that the parameter ϕ measuring persistence in the net inflation process is estimated to be significantly different from zero but somewhat smaller for Turkey compared to Brazil. This result most likely reflects the disinflationary process for Turkey that occurred during the period 2002-2006.

Figure 2 for Brazil shows that both the estimated level and slope (or rate of change) of inflation, α_t and μ_t, increase rapidly during the episode of financial distress in the period between 2002 and 2003. The smoothed estimates of the level of inflation fall rapidly until the end of 2007 but show some tendency to increase during the 2008 global financial crisis as well as after 2010. Also after 2004, the smoothed estimates of the slope fall within a ± 0.001 band, indicating that the model reduces virtually to a local level model with a negligible effect of the slope. However, due to the high correlation between the level and

[8] This is consistent with the evidence for Turkey obtained by Altug and Uluceviz (2014), who cannot reject the null hypothesis that inflation is a unit root process.

slope, we observe a tendency for these two processes to move together. Table 1 further shows that neither the variance of the seasonal component nor its covariance with the level and slope of the inflation process are estimated to be significantly different from zero.[9]

From Figure 3, corresponding to the initial sharp decline in inflation in the period between 2002 and 2006 for Turkey, the smoothed estimate of the level of the monthly inflation process, α_t, is estimated to be large while the slope, μ_t, is negative but declining in absolute value. After 2006, the level of monthly inflation stabilizes around 0.5%, barring an increase in 2008, and the slope of the inflation process fluctuates around a value of zero. Table 2 shows that shocks to the level and slope of the inflation process are negatively correlated, i.e. $\sigma_{\eta_\alpha,\eta_\mu} < 0$.[10] Table 2 also indicates that the volatility of the seasonal component in the inflation process for Turkey is large and co-varies significantly with both the level and the slope.[11] The positive covariance between the processes for $\eta_{\gamma,t}$ and $\eta_{\alpha,t}$ implies that the level of inflation is positively associated the seasonal component for Turkey. This fact is also borne out from Figure 3, which displays significant fluctuations in the seasonal component that tend to occur at higher levels of inflation.

The fourth panels of Figures 2 and 3 show the smoothed estimates of the systematic deviations of the model-based inflation expectations from target inflation rate for Brazil and Turkey. This quantity is measured by the time-varying parameter $\delta_{0,t}$ in the full state space representation of the model with inflation targeting displayed in equation (3.3). Aside from the period of financial distress during 2002 and 2003 for Brazil, the systematic deviations of inflation expectations from target fluctuate around a value of zero, with some tendency for inflation expectations to fall below the target rate in 2007 and 2009. However, inflation expectations begin to rise systematically above target by 2011, despite an unchanged inflation target of 4.5% throughout this period. Turning to the experience

[9] Specifically, none of the quantities $\sigma^2_{\eta_\gamma}$, $\sigma_{\eta_\gamma,\eta_\alpha}$, and $\sigma_{\eta_\gamma,\eta_\mu}$ are estimated to be significantly different from zero.

[10] Unlike Brazil, we do not observe an inflationary spike in Turkey but rather the steady decline in inflation beginning from 2002, with a decreasing pace.

[11] Specifically, $\sigma^2_{\eta_\gamma}$, $\sigma_{\eta_\gamma,\eta_\alpha}$, and $\sigma_{\eta_\gamma,\eta_\mu}$ are estimated to be significantly different from zero, with $\sigma_{\eta_\gamma,\eta_\alpha} > 0$ and $\sigma_{\eta_\gamma,\eta_\mu} < 0$.

of Turkey, we observe that expected inflation has always been above the target rate over the entire sample period. The smoothed estimates of the systematic deviation of average inflation expectations from target inflation, $\delta_{0,t}$, are declining during the disinflationary period between 2002 and 2006. There is a tendency for inflation expectations to deviate more from the target rate during the episode of financial turbulence of 2006 and the global financial crisis of 2008.[12] After 2010, the deviations of expected inflation from target tend to increase slightly.

Tables 1 and 2 provide further information about the anchoring of expectations to the target rate for Brazil and Turkey. Table 1 shows that for Brazil, the variance of the error term in the systematic component of the deviation of average inflation expectations from target inflation, $\eta_{\delta,t}$, is large and significantly estimated, which implies that the *change* in the systematic component of the deviation is unpredictable over time. By contrast, for Turkey, the variance of $\eta_{\delta,t}$ is not estimated to be significantly different from zero, suggesting that there is little unexpected change in the systematic deviation over the relevant sample period. Second, for Brazil, we find further evidence for the anchoring of both model- and survey-based inflation expectations to the target rate in terms of the behavior of υ_t^T. Specifically, none of the quantities denoting the variance of υ_t^T, its covariance with the error in the inflation equation, ε_t, and its covariance with the error in the equation for survey expectations twelve-months ahead, $\upsilon_{12,t}$ are estimated to be significantly different from zero. For Turkey, however, there is some evidence that υ_t^T co-varies significantly and positively with the error in two-month ahead survey expectations, $\upsilon_{2,t}$, suggesting that non-systematic deviations of inflation expectations from the target and the error to short-term survey expectations tend to move together.

These observations point to the differences in the inflation targeting experience of the two countries. While Brazil displays a lower inflation level that is more closely anchored to its target, Turkey's experience reflects the strong disinflation up until 2006 but a weaker

[12] The latter finding occurs despite the fact that the target rate is increased from 4% to 7.50% for 2009.

tendency for inflation expectations to become aligned with target inflation afterwards. Some have attributed the inflationary performance in Brazil to high interest rates that were maintained by the BCB, which are also viewed as the source of relatively low growth in Brazil over this period (see Arestis *et al.*, 2008). In Turkey's case, policy interest rates also fell rapidly over the disinflationary period 2002-2006 but the CBRT has maintained the policy rate at lower levels compared to Brazil from 2010 up until 2014.[13]

4.2 The term structure of inflation expectations

The approach we follow in this paper allows us to construct the term structure of inflation expectations, as defined by equations (2.3)-(2.4). These provide information on expectations at different horizons and can be used to assess the anchoring of inflation expectations at short, medium, and longer horizons. Figures 4 and 5 show the filtered estimates of the term structure of inflation expectations with and without the seasonal component derived from (3.3).

Figure 4 shows that expectations of monthly inflation for Brazil are *negative* for very short horizons when the seasonal component of inflation is also included. Such expectations are consistent with the decline in inflation that occurred after the episode of financial distress in 2002-2003. At longer horizons, however, inflation expectations revert to positive values.[14] After 2003, inflation expectations at all horizons are positive. From the second panel of Figure 4 which displays the level of inflation expectations without the seasonal component, we observe an increase in inflation expectations at short horizons associated with the episode of financial distress during 2002-2003. However, inflation expectations at longer horizons are significantly lower, suggesting that agents expected a temporary

[13] Beginning in 2010, the CBRT also initiated a set of macro-prudential measures such as the asymmetric interest rate corridor and reserve option mechanism, see Aysan *et al.* (2014). In contrast to other countries which also implemented such measures, the macro-prudential measures undertaken by Turkey have been viewed as a "substitute rather than a complement" for macroeconomic policies, including tight fiscal policy, see Lim *et al.* (2011).

[14] When plotting the graphs for Brazil, the top panel of Figure 4 reverses the order of the years in the axes to display the negative expectations of inflation that occur in 2002 at the shortest horizons.

increase in inflation during this period. We also observe increases in inflationary expectations at short horizons during the global financial crisis of 2008. In general, however, the term structure of inflation expectations for Brazil is relatively flat over the sample period.

Figure 5 provides a slightly different picture for Turkey. At the beginning of the sample period, inflation expectations that include the seasonal component are strongly positive and very high at the shortest horizons.[15] In the early parts of the sample, the slope of the term structure is negative and steep, suggesting that private agents expected inflation to decline at longer horizons. After 2004 and beyond, we observe that inflation expectations are falling at almost all horizons. The level of inflation expectations displayed in the second panel of Figure 5 for Turkey shows that at the beginning of the sample, the level of inflation expectations is uniformly high and the slope of the term structure is occasionally hump-shaped. In this case, expectations of the level of inflation are low at the shortest horizons but increase at medium horizons, only to decline again at longer horizons. Such behavior most likely reflects agent's uncertainty and learning about the outcome of the inflation process, and an inability to form accurate estimates of inflation during the early years of the disinflation process. It is only after the beginning of 2004 that the level of inflation expectations starts falling, and the term structure acquires a negative shape.

We can obtain additional information about the anchoring of expectations by examining the relationship between model-based expectations and those from survey data. Table 1 shows that for Brazil the variance of the error term between survey- and model-based inflation expectations twelve months ahead, $\sigma_{\upsilon_{12}}$ is not estimated to be significantly different from zero, suggesting that subjective forecasts are not out of line with model-based forecasts at longer horizons. By contrast, Table 2 shows that for Turkey the variances of the errors to survey expectations two- and twelve-months ahead, σ_{υ_2} and $\sigma_{\upsilon_{12}}$, are both estimated to be significantly different from zero, suggesting a tendency for survey expectations to deviate from the model-based expectations at those horizons. Furthermore, the errors

[15] For certain months in 2002, expectations of monthly inflation at the shortest horizons register around 12%.

in forecasting average inflation expectations two- and twelve-months ahead, respectively, co-vary positively and significantly with each other, $\sigma_{\upsilon_2,\upsilon_{12}} > 0$, implying that survey-based expectations tend to vary in similar ways at both short and long horizons from their model-based counterparts.

5 Out-of-sample forecasting performance of the state space model

A good approximation for inflation dynamics should not only fit in-sample but also provide superior forecasting performance out of sample. To examine this proposition, we conduct such a forecasting exercise, where we compare the forecasting performance of the state space model against several alternatives that have been considered in the literature. We estimate and forecast recursively, using data from November 2001 for Brazil and August 2001 for Turkey to the time the forecast is made, beginning in January 2007 and extending until January 2014. Consistent with the approach in the state space model, we do not implement a de-seasonalization of the data before fitting the alternative models. Instead, we choose the best model that fits the seasonal and non-seasonal components for each forecast horizon based on the Bayesian Information Criterion (BIC).

In Tables 3 and 4, we compare the h-step ahead out-of-sample forecasting performance of the state space model with that of several natural alternatives for forecast horizons $h = 1, \ldots, 12$. Denote by $\hat{\pi}_{t+h|t}$ the forecast of inflation h periods ahead, conditional on information at date t. The alternative models that we consider in terms of their forecasting performance are

(i) A naive MA model: Next period's inflation forecast is equal to an average of inflation in the past twelve months. This specification was suggested by Atkeson and Ohanian (2001) in their analysis of inflation forecasts derived from Phillips curve forecasting models. Thus,

$$\hat{\pi}_{t+h|t} = \frac{1}{12}(\pi_t + \pi_{t-1} + \ldots + \pi_{t-12}). \tag{5.1}$$

(ii) An AR(p) model:

$$\hat{\pi}_{t+h|t} - \pi_t = \alpha_0 + \alpha(L)\Delta\pi_t + \epsilon_t^h, \tag{5.2}$$

where the order of the autoregressive lag polynomial is chosen according to model selection criteria such as BIC. The forecast of inflation now depends a distributed lag of past inflation differences.

(iii) A backward-looking Phillips curve:

$$\hat{\pi}_{t+h|t} - \pi_t = \alpha_0 + \alpha(L)\Delta\pi_t + \lambda\hat{z}_t + \delta(L)\Delta z_t, \tag{5.3}$$

where $\hat{z}_t$ denotes the output gap based on the Hodrick-Prescott filtered monthly industrial production index (IP) at time t denoted by z_t. Here Phillips curve forecasts are interpreted as models that include an economic activity variable, to forecast inflation or the change in inflation. The inclusion of the distributed lag of past inflation changes in this specification implies that these models nest the basic AR(p) model, see Stock and Watson (2007, 2008) for details.[16]

(iv) A backward-looking Philips curve without the current output gap: Following Stock and Watson (2007), we also consider a version of this model that includes a distributed lag of changes in the IP index only as

$$\hat{\pi}_{t+h|t} - \pi_t = \alpha_0 + \alpha(L)\Delta\pi_t + \delta(L)\Delta z_t, \tag{5.4}$$

[16]Typically, such variables are used to capture the real marginal cost in the Phillips curve representation. Another possibility is to measure the real marginal cost as the ratio of the labor share to nominal income but the approach followed in the text seems preferable given the poor quality of labor share data for many emerging economies.

(v) A hybrid New Keynesian Philips Curve (NKPC) with survey expectations:

$$\hat{\pi}_{t+h|t} = \gamma\pi_t + (1-\gamma)\pi_t^S + \alpha_0 + \alpha(L)\Delta\pi_t + \lambda\hat{z}_t + \delta(L)\Delta z_t, \tag{5.5}$$

More specifically, the "hybrid" NKPC (H-NKPC) model combines both backward and forward-looking dynamics by allowing the lagged inflation in the model along with forward-looking dynamics, see Galí *et al.* (2001); Galí and Gertler (1999) for details. In this equation, we have used survey data to replace the expectation of future inflation with its survey-based measure, see Basturk *et al.* (forthcoming); Del Negro and Schorfheide (2013); see also Roberts (1997), who uses survey expectations for calibrating hybrid models. Fraga *et al.* (2004) make use of the private sector's inflation expectations to assess whether the Central Bank of Brazil (BCB) reacts in a forward manner to inflation expectations during the inflation targeting era. We note that the survey data capture the actual inflation expectations with some random error which we assume to follow a normal distribution.

(vi) A hybrid New Keynesian Philips curve with survey expectations and without the current output gap, which includes a distributed lag of first differences of the IP index only as

$$\hat{\pi}_{t+h|t} = \gamma\pi_t + (1-\gamma)\pi_t^S + \alpha_0 + \alpha(L)\Delta\pi_t + \delta(L)\Delta z_t, \tag{5.6}$$

We define forecast errors at time t as $\pi_{t+h} - \hat{\pi}_{t+h|t}$, and examine the out-of-sample forecasting performance of each model according to the root mean squared error (RMSE) criterion. Mavroeidis *et al.* (2014) discuss in detail alternative estimation approaches to the New Keynesian Phillips curve, including the use of instrumental variables estimation. However, unlike the specifications that they consider, the only forward-looking variable in the models above is survey-based inflation expectations, which is likely to exhibit less endogeneity relative to the inflation process than future expectations of actual inflation that are introduced into the NKPC under the assumption of Rational Expectations. Hence, all of the alternatives discussed above are estimated using OLS. In different versions of the hybrid NKPC, we further impose the restriction that the coefficients on π_t and π_t^S sum to unity.

Table 3 for Brazil shows that the naive MA model suggested by Atkeson and Ohanian (2001) outperforms the state space model augmented with twelve-month survey expectations and the inflation target for all horizons except the one-month ahead horizon. We attribute these results to the smooth nature of the inflation process for Brazil together with the relative lack of survey expectation data for this country. As Mavroeidis (2010) or Cochrane (2011) note, effective monetary policy may paradoxically make forecasting inflation difficult through structural or reduced-form specifications typically considered in the literature. As we discussed in the previous section, the deviations of inflation expectations from target inflation for Brazil are typically small, with inflation expectations occasionally falling below the target level, and the variability of both actual and survey expectations being more minor compared to that for Turkey.

Table 4 shows that for Turkey, the state space model that includes information on two-month and twelve-month ahead inflation dominates all the other alternative specifications at all horizons. Evidently, the use of survey expectations at two different horizons for Turkey helps to improve the forecasting performance relative to the naive MA forecast, an autoregressive specification where the lag lengths are optimally chosen as well as backward and forward-looking Phillips curve models. We conclude that the use of survey expectations in frameworks that are statistically coherent, as in the full state space model described by specification (3.3), leads to efficiency gains in the estimation whereas incorporating such expectations in simple Phillips curve type frameworks does not increase the forecasting performance of these frameworks.

The comparison of results for Turkey and Brazil reveals an important feature of our model. The use of survey data to match the econometric model based forecast enables the model to accommodate changing conditions rapidly. While the standard econometric model without survey expectations learns the new conditions using Bayesian updating (Kalman filter) over time, inclusion of the expert opinion to the model accelerates this learning process yielding much superior predictions. As it is also evident from the comparison of inflation processes of Brazil and Turkey in Figure 1, inflation in Turkey is volatile and subject to rapid changes compared to inflation in Brazil. This explains the superior performance of our model in Turkey and more mediocre (though still competitive) performance in Brazil.

6 Conclusion

Understanding the evolution of inflation expectations is a key part of the implementation and success of inflation targeting regimes that have been adopted by many emerging economies during the 2000's. In this paper, we have examined the behavior of inflation expectations for two key emerging economies - Brazil and Turkey - that have commonalities and differences in their experience with inflation and the inflation targeting regime. In our analysis, we model their inflationary processes in terms of a state space model that allows for variation in the trend, slope and seasonal component of inflation and that can be combined with survey data on inflation expectations and the inflation target to derive forecasts and measures of the deviation from inflation targets in practice.

Our approach provides an efficient inflation forecasting device that incorporates expert opinion (survey based expectations) with a fully articulated statistical predictive model. This enables us to increase the information content used for prediction. Second, the model reacts to sudden changes in the inflation process that are typically observed in emerging economies such as changes in monetary policy, structural breaks or political turmoil through the use of survey expectations.

The state space framework allows us to incorporate information about annual target inflation into the model and to handle missing observations in a flexible and statistically coherent way. The inclusion of such information also enables us to obtain monthly deviations of the inflation expectations from target inflation as a way of measuring the stance of monetary policy and monetary credibility.

In this analysis, we have demonstrated the efficacy of including survey expectations of future inflation into the state space model for inflation. This arises from the superior forecasting performance of the model compared to alternatives such as variants of the backward and forward-looking Philips curve considered in the literature on inflation forecasting.

For many emerging economies, survey-based inflation expectations at different horizons are typically not available. The approach used in this paper also enables us to generate the term structure of inflation expectations during a given year. By construction, such expectations are consistent with the few available survey-based expectations. Thus, we believe that our approach provides a valuable tool for central bankers and policy-makers for assessing the impact of their actions on inflation expectations at different horizons.

Finally, as we discussed in the Introduction, for some countries such as S. Africa, survey expectations of inflation are available for different groups of agents. One extension of our framework that we believe would be worth exploring is to incorporate such heterogeneous expectations into the state-space framework. This extension would also entail alternative measures of the credibility of monetary policy.

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Tables and Figures

Table 1: Estimation results for Brazil

	ϕ	$\sigma^2_{\eta_\alpha}$	$\sigma^2_{\eta_\mu}$	$\sigma^2_{\eta_\gamma}$	$\sigma_{\eta_\alpha,\eta_\mu}$	$\sigma_{\eta_\alpha,\eta_\gamma}$	$\sigma_{\eta_\mu,\eta_\gamma}$
Estimate	0.559	0.009	0.000	0.006	0.00009	0.007	0.00007
St. dev	(0.031)	(0.003)	(0.000)	(0.024)	(0.00004)	(0.016)	(0.0001)
	$\sigma^2_{\eta_\delta}$	$\sigma_{\eta_\delta,\eta_\alpha}$	$\sigma_{\eta_\delta,\eta_\mu}$	$\sigma_{\eta_\delta,\eta_\gamma}$			
Estimate	2.349	-0.146	-0.001	-0.118			
St. dev	(0.873)	(0.054)	(0.000)	(0.249)			
	σ^2_{ε}	$\sigma^2_{\upsilon_{12}}$	$\sigma^2_{\upsilon^T}$	$\sigma_{\varepsilon,\upsilon_{12}}$	$\sigma_{\varepsilon,\upsilon^T}$	$\sigma_{\upsilon_{12},\upsilon^T}$	
Estimate	0.672	0.554	0.295	-0.608	-0.420	0.370	
St. dev.	(0.260)	(0.446)	(0.324)	(0.306)	(0.302)	(0.308)	

Note: The table presents estimation results with standard deviations (in parentheses) of parameters of the model detailed in 3.3 using the inflation obtained from consumer price index in Brazil together with the Bank of Brazil one-year ahead survey inflation expectations and the inflation target over the period from November 2001 to January 2014.

Table 2: Estimation results for Turkey

	ϕ	$\sigma^2_{\eta_\alpha}$	$\sigma^2_{\eta_\mu}$	$\sigma^2_{\eta_\gamma}$	$\sigma_{\eta_\alpha,\eta_\mu}$	$\sigma_{\eta_\alpha,\eta_\gamma}$	$\sigma_{\eta_\mu,\eta_\gamma}$
Estimate	0.371	0.002	0.000	0.023	-0.0001	0.005	-0.0007
St. dev	(0.034)	(0.001)	(0.000)	(0.006)	(0.00008)	(0.001)	(0.0002)
	$\sigma^2_{\eta_\delta}$	$\sigma_{\eta_\delta,\eta_\alpha}$	$\sigma_{\eta_\delta,\eta_\mu}$	$\sigma_{\eta_\delta,\eta_\gamma}$			
Estimate	0.021	-0.003	-0.00025	0.008			
St. dev	(0.016)	(0.004)	(0.00006)	(0.021)			
	σ^2_{ε}	$\sigma^2_{\upsilon_2}$	$\sigma^2_{\upsilon_{12}}$	$\sigma^2_{\upsilon^T}$	$\sigma_{\varepsilon,\upsilon_2}$	$\sigma_{\varepsilon,\upsilon_{12}}$	$\sigma_{\varepsilon,\upsilon^T}$
Estimate	0.388	0.063	0.140	1.106	-0.098	-0.231	-0.395
St. dev	(0.051)	(0.017)	(0.038)	(0.806)	(0.031)	(0.040)	(0.331)
	$\sigma_{\upsilon_2,\upsilon_{12}}$	$\sigma_{\upsilon_2,\upsilon^T}$	$\sigma_{\upsilon_{12},\upsilon^T}$				
Estimate	0.067	0.075	0.230				
St. dev	(0.024)	(0.029)	(0.190)				

Note: The table presents estimation results with standard deviations (in parentheses) of parameters of the model detailed in 3.3 using the inflation obtained from consumer price index in Turkey together with CBRT two-month and one-year ahead survey inflation expectations and the inflation target over the period from August 2001 to January 2014.

Table 3: Out-of-sample forecasting results for Brazil

		1	2	3	4	5	6	7	8	9	10	11	12
(i)	State space model (survey expec.)	0.225	0.263	0.283	0.284	0.278	0.270	0.270	0.275	0.284	0.296	0.304	0.305
(ii)	State space model	**0.189**	0.264	0.287	0.307	0.331	0.332	0.340	0.317	0.301	0.294	0.281	0.257
(iii)	MA (AO)	0.219	**0.228**	**0.235**	**0.240**	**0.244**	**0.244**	**0.245**	**0.245**	**0.244**	**0.236**	**0.235**	**0.236**
(iv)	AR	0.194	0.249	0.365	0.447	0.548	0.598	0.580	0.496	0.407	0.374	0.366	0.361
(v)	PC - IP gap	0.194	0.360	0.424	0.486	0.569	0.629	0.617	0.547	0.504	0.511	0.459	0.466
(vi)	PC - lagged IP gap	0.190	0.352	0.421	0.488	0.566	0.625	0.616	0.547	0.497	0.494	0.458	0.460
(vii)	Hybrid NK-PC - IP gap	0.215	0.253	0.342	0.366	0.364	0.411	0.416	0.389	0.377	0.593	0.344	0.383
(viii)	Hybrid NK-PC - lagged IP gap	0.206	0.244	0.307	0.312	0.376	0.416	0.419	0.441	0.366	1.399	0.699	0.468

Note: The table presents the out-of-sample forecasting performance of (i) the model detailed in (3.3) using information on survey expectations (ii) the model detailed in (3.3) without using information on survey expectations; (iii) a naive MA model as suggested by Atkeson and Ohanian (AO) (2001); (iv) an AR(p) model; (v) a backward-looking Phillips curve with the current IP gap; (vi) a backward-looking Phillips curve with a distributed lag of the lagged differences of the IP gap; (vii) a hybrid New Keynesian Phillips curve with twelve-month ahead survey expectations and the current IP gap; (viii) a hybrid New Keynesian Phillips curve with twelve-month ahead survey expectations and a distributed lag of the lagged differences of the IP gap. The different models are estimated and forecasted using a sample given initially by 2001:11-2007:1 and extending until 2014:1.

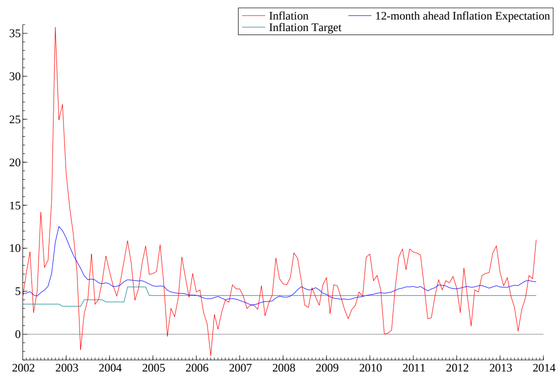
Table 4: Out-of-sample forecasting results for Turkey

		1	2	3	4	5	6	7	8	9	10	11	12
(i)	State space model (survey expec.)	**0.709**	**0.733**	**0.726**	**0.735**	**0.732**	**0.736**	**0.733**	**0.735**	**0.741**	**0.742**	**0.731**	**0.733**
(ii)	State space model	0.723	0.778	0.807	0.849	0.782	0.843	0.868	0.895	1.018	1.003	0.966	0.982
(iii)	MA (AO)	0.873	0.888	0.893	0.897	0.892	0.899	0.896	0.881	0.880	0.876	0.855	0.841
(iv)	AR	0.999	1.497	1.985	1.994	1.726	1.523	1.534	1.779	2.124	2.130	1.552	1.154
(v)	PC - IP gap	1.010	1.523	1.977	1.989	1.699	1.514	1.541	1.696	2.048	1.976	1.538	1.062
(vi)	PC - lagged IP gap	0.993	1.515	1.987	1.979	1.688	1.525	1.544	1.671	2.015	1.952	1.497	1.014
(vii)	Hybrid NK-PC - IP gap	0.827	1.020	1.062	1.183	1.081	1.056	0.994	1.098	1.284	1.308	1.146	0.975
(viii)	Hybrid NK-PC - lagged IP gap	0.857	1.078	0.989	0.937	0.923	0.871	0.899	0.959	1.112	0.999	0.903	0.823

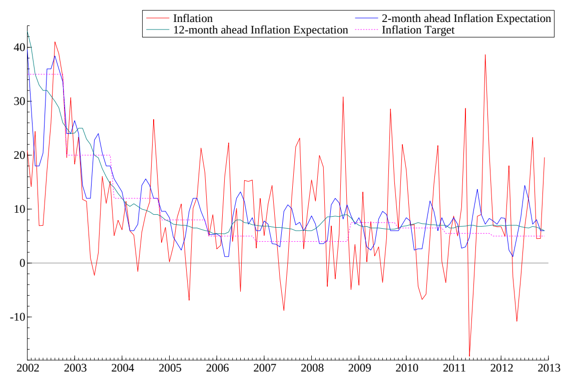
Notes: The table presents the out-of-sample forecasting performance of (i) the model detailed in (3.3) using informatioxn on survey expectations; (ii) the model detailed in (3.3) without using information on survey expectations; (iii) a naive MA model as suggested by Atkeson and Ohanian (AO) (2001); (iv) an AR(p) model; (v) a backward-looking Phillips curve with the current IP gap; (vi) a backward-looking Phillips curve with a distributed lag of the lagged differences of the IP gap; (vii) a hybrid New Keynesian Phillips curve with twelve-month ahead survey expectations and the current IP gap; (viii) a hybrid New Keynesian Phillips curve with twelve-month ahead survey expectations and a distributed lag of the lagged differences of the IP gap. The different models are estimated and forecasted using a sample given initially by 2001:8-2007:1 and extending until 2014:1.

Figure 1: Sample characteristics

(i) Brazil

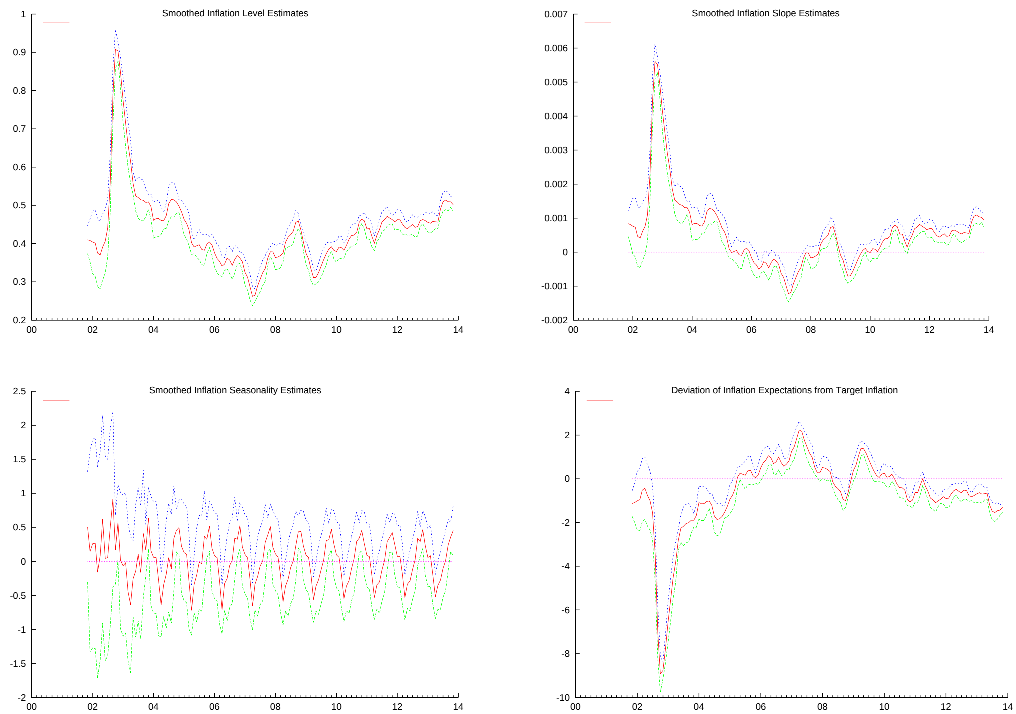


(ii) Turkey



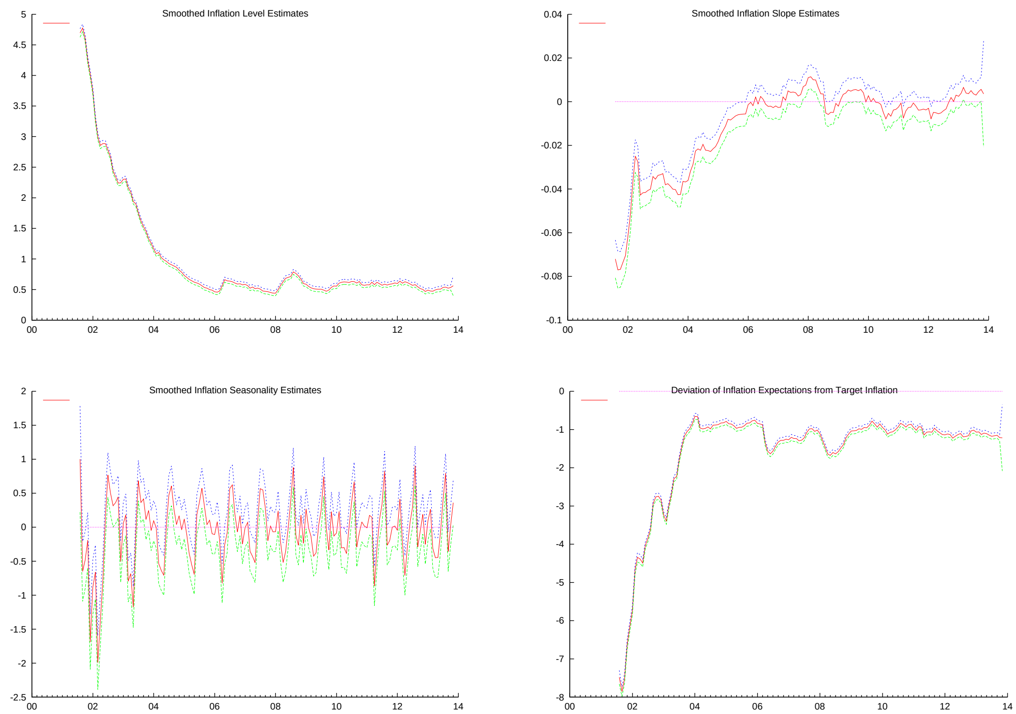
Note: For Brazil, the graph shows the inflation obtained from consumer price index in Brazil together with one-year ahead survey expectations and the inflation targets over the period November 2001-January 2014. For Turkey, the graph shows the inflation obtained from consumer price index in Turkey together with two-month and one-year ahead survey expectations and the inflation targets for the period August 2001-January 2014.

Figure 2: Estimated level, slope, seasonality, and deviations from target for Brazil



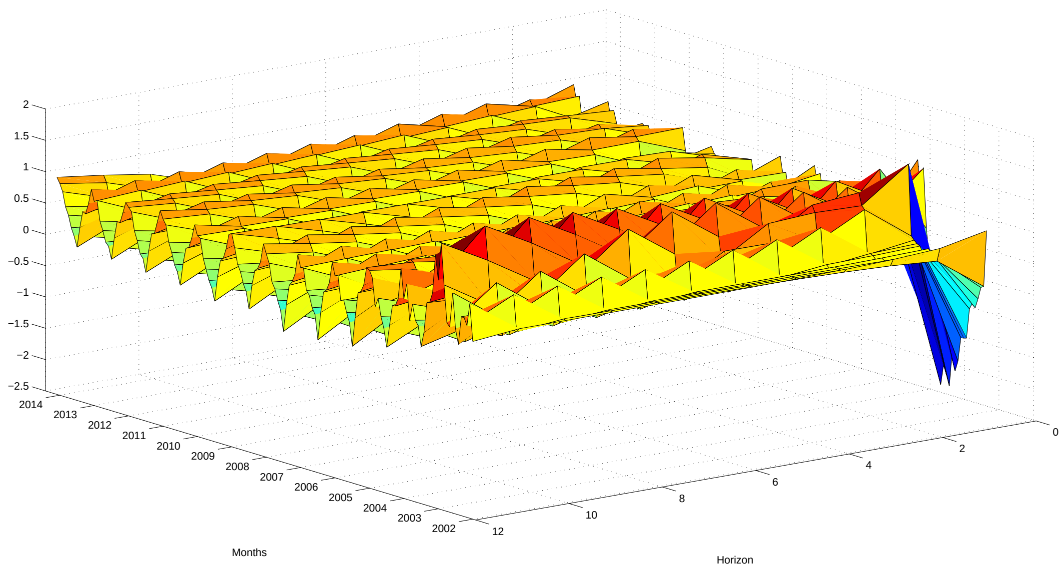
Note: The graphs show the inflation level, slope, seasonality and deviations from target inflation obtained from the model in (3.3) using consumer price index in Brazil together with survey expectations of one-year ahead inflation and the estimated deviations from target inflation over the period from November 2001 to January 2014 for Brazil.

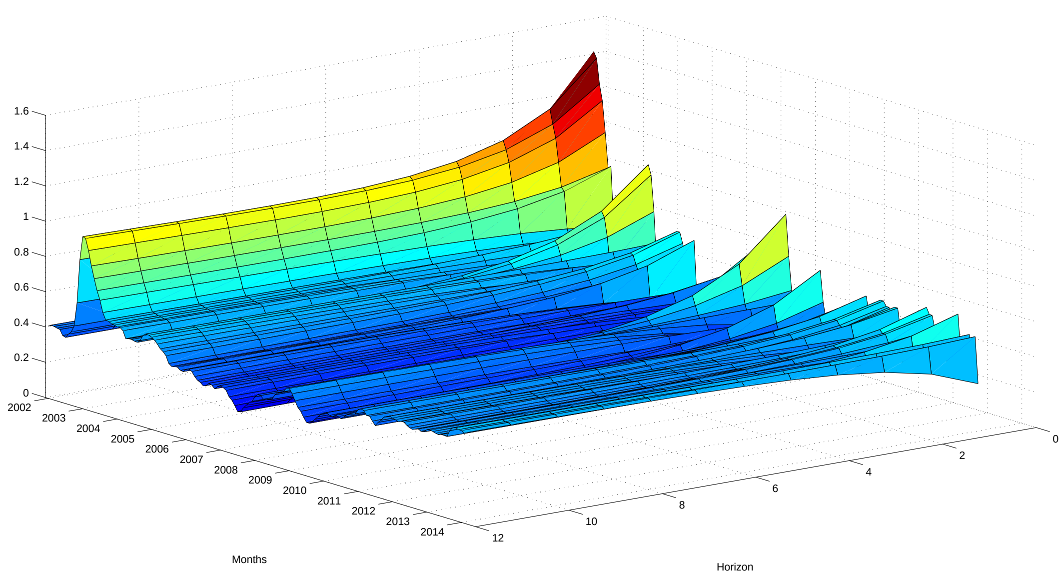
Figure 3: Estimated level, slope, seasonality, and deviations from target for Turkey



Note: The graphs show the inflation level, slope, seasonality and deviations from target inflation obtained from the full state space model in (3.3) using consumer price index in Turkey together with CBRT survey expectations of two-month and one-year ahead inflation and the estimated deviations from target inflation over the period from August 2001 to January 2014 for Turkey.

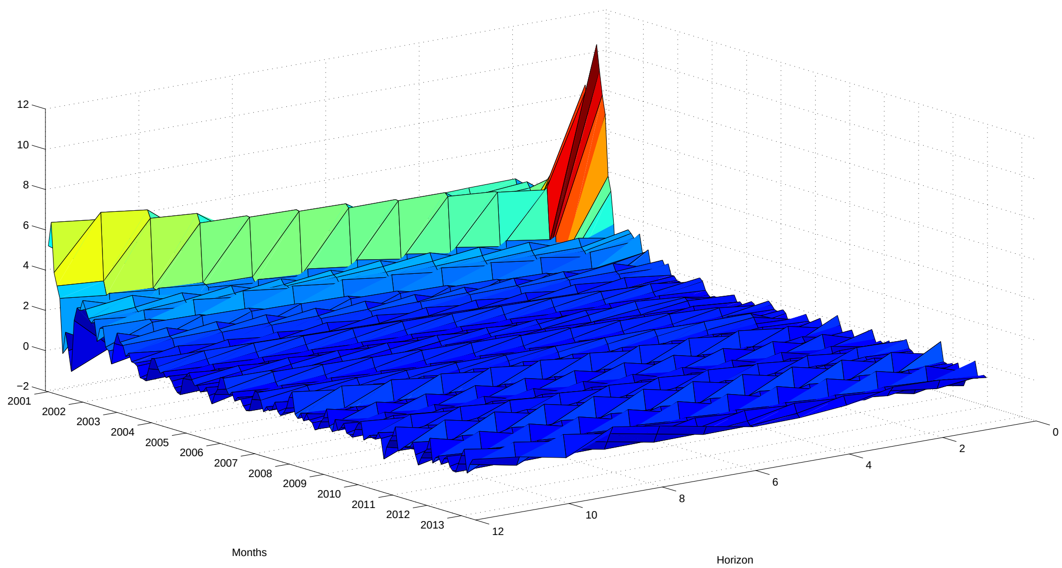
Figure 4: Term Structure of Expectations of Inflation and Its Level for Brazil

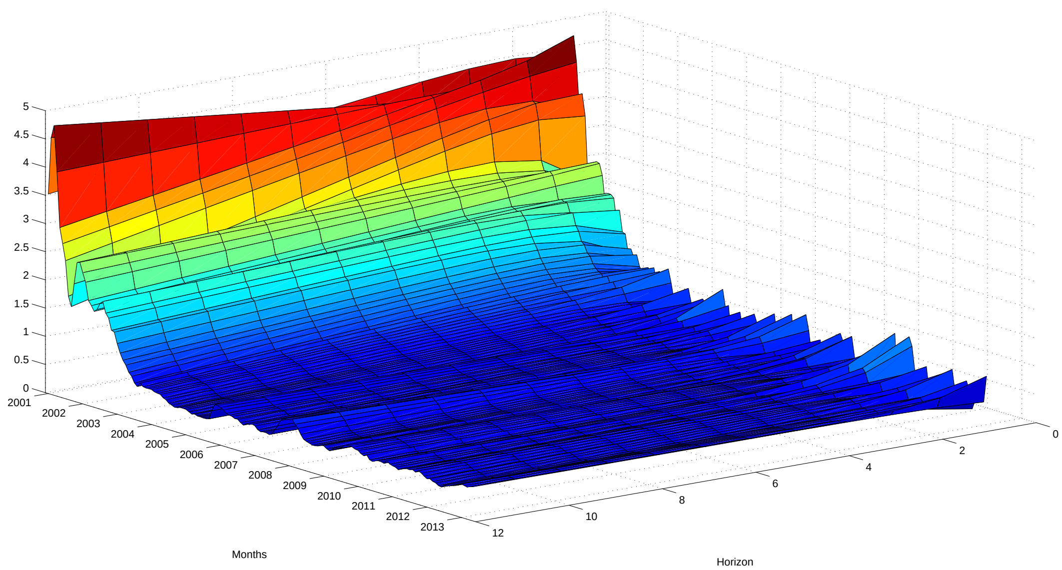




Note: The graphs show the expectations of monthly inflation and its level based on the full state space model in (3.3) for the period November 2001-January 2014

Figure 5: Term Structure of Expectations of Inflation and Its Level for Turkey





Note: The graphs show the expectations of monthly inflation and its level based on the full state space model in (3.3) for the period August 2001-January 2014

Appendix A Statistical Inference

The model can be nicely cast into a state-space framework and standard inference can be carried out using the Kalman filter/smoother coupled with quasi-Newton optimization methods. Here we provide details for the model used for Turkey. Specifically, the state space model in a more compact form is as follows

$$\begin{aligned} y_t &= BX_t + HS_t + \epsilon_t \qquad && \epsilon_t \sim N(0, R) \\ S_t &= FS_{t-1} + \eta_t && \eta_t \sim N(0, Q), \end{aligned} \tag{A.1}$$

where $y_t = \begin{pmatrix} \pi_t, & E_t^S[\pi_{t+2}], & E_t^S[\pi_{t+12}], & E_{t,A}^T[\pi_{t+12}] \end{pmatrix}'$, $X_t = \begin{pmatrix} \pi_{t-1}, & \pi_t \end{pmatrix}'$ and $S_t = (\alpha_t, \mu_t, \gamma_t, \delta_{0,t}, \alpha_{t-1}, \gamma_{t-1}, \ldots, \gamma_{t-12})'$. The system matrices are

$$H = \begin{bmatrix} 1 & 0 & 1 & 0 & -\phi & -\phi & 0 & 0 & \ldots & 0 & 0 \\ 2 - \sum_{j=1}^{2} \phi^j & 3 & 1 + \sum_{j=1}^{2} \phi^j & 0 & 0 & -1 & 0 & -1 & \ldots & -1 & 0 \\ 12 - \sum_{j=1}^{12} \phi^j & 78 & \sum_{j=1}^{12} \phi^j & 0 & 0 & 0 & 0 & 0 & \ldots & 0 & 0 \\ 12 - \sum_{j=1}^{12} \phi^j & 78 & \sum_{j=1}^{12} \phi^j & 1 & 0 & 0 & 0 & 0 & \ldots & 0 & 0 \end{bmatrix}$$

,

$$Q = \begin{bmatrix} \sigma_{\eta_\alpha}^2 & \sigma_{\eta_{\alpha,\mu}} & \sigma_{\eta_{\alpha,\gamma}} & \sigma_{\eta_{\alpha,\delta}} & 0 & \ldots & 0 \\ \sigma_{\eta_{\alpha,\mu}} & \sigma_{\eta_\mu}^2 & \sigma_{\eta_{\mu,\gamma}} & \sigma_{\eta_{\mu,\delta}} & 0 & \ldots & 0 \\ \sigma_{\eta_{\alpha,\gamma}} & \sigma_{\eta_{\mu,\gamma}} & \sigma_{\eta_\gamma}^2 & \sigma_{\eta_{\gamma,\delta}} & 0 & \ldots & 0 \\ \sigma_{\eta_{\alpha,\delta}} & \sigma_{\eta_{\mu,\delta}} & \sigma_{\eta_{\gamma,\delta}} & \sigma_{\eta_\delta}^2 & 0 & \ldots & 0 \\ 0 & 0 & 0 & 0 & 0 & \ldots & 0 \\ \vdots & \vdots & \vdots & \vdots & \vdots & \ddots & \vdots \\ 0 & 0 & 0 & 0 & 0 & \ldots & 0 \end{bmatrix}, R = \begin{bmatrix} \sigma_\varepsilon^2 & \sigma_{\varepsilon,\upsilon_2} & \sigma_{\varepsilon,\upsilon_{12}} & \sigma_{\varepsilon,\upsilon^T} \\ \sigma_{\varepsilon,\upsilon_2} & \sigma_{\upsilon_2}^2 & \sigma_{\upsilon_2,\upsilon_{12}} & \sigma_{\upsilon_2,\upsilon^T} \\ \sigma_{\varepsilon,\upsilon_{12}} & \sigma_{\upsilon_2,\upsilon_{12}} & \sigma_{\upsilon_{12}}^2 & \sigma_{\upsilon_{12},\upsilon^T} \\ \sigma_{\varepsilon,\upsilon^T} & \sigma_{\upsilon_2,\upsilon^T} & \sigma_{\upsilon_{12},\upsilon^T} & \sigma_{\upsilon^T}^2 \end{bmatrix}$$

,

$$
F = \begin{bmatrix}
1 & 1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & -1 & 0 & 0 & 0 & -1 & 0 & -1 & -1 & -1 & -1 & -1 & -1 & -1 & -1 & -1 \\
0 & 0 & 0 & 1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 1 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 1 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 1 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 1 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 1 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 1 & 0
\end{bmatrix} \text{ and}
$$

$$
B = \begin{bmatrix} \phi & 0 & 0 & 0 \\ 0 & \sum_{j=1}^{2} \phi^j & \sum_{j=1}^{12} \phi^j & \sum_{j=1}^{12} \phi^j \end{bmatrix}'
$$

For Brazil the model is identical except for the fact that we use only one-year ahead survey based inflation expectations. Using (A.1) we can employ the Kalman filter. The loglikelihood is a by-product of the Kalman filter and maximized for obtaining inference on model parameters. Once the parameters are estimated, the Kalman filter (smoother) can be employed to obtain filtered (smoothed) estimates of unobserved components.

An important feature of our modeling approach is that it can also handle missing observations due to the low frequency nature of the annual inflation target. The state space framework treats these missing observations in a statistically optimal way. Specifically, let W be the selection matrix as the identity matrix with the last diagonal element taking the value zero when the target inflation is not observed and 1 when it is observed. Then standard Kalman filter/smoother can be conducted using the modified version of the system in (A.1) using $\tilde{y_t} = W y_t$, $\tilde{H} = WH$, $\tilde{B} = WB$ and $\tilde{R} = WRW'$. The estimation procedure of the state space models become a common practice, hence for further details about the estimation of these models, we refer to the textbook expositions such as (Harvey, 1990) and (Durbin and Koopman, 2012).