Currency Risk in an Affine Term Structure Model for Brazil

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Abstract

This paper estimates a term structure model of interest rates with two forward looking currency variables for Brazil. We use both expected currency devaluation and currency risk premium as macro factors to model the short rate dynamics and the market price of risk that determinates the entire term structure. We follow Ang and Piazzesi (2003) and impose no-arbitrage restrictions in a Vector Autoregression to study the joint dynamics of yields and essentially forward looking currency factors. The forecasting power of the model improves with the macro factors when compared with a pure latent model. An impulse response analysis shows that the composition of the forward premium impacts the yield curve. Currency devaluations that are of compensated by equivalent increase in the currency risk premium term such that the forward premium remains constant contribute to higher yields in the entire curve. Variance decompositions reveal that currency factors can explain up to 51% of the variation in medium term yields.

Keywords: Forward Premium; Currency Risk Premium; Affine Term Stucture Models; Estimation

1 Introduction

This paper estimates a term structure model of interest rates with two forward looking currency variables for Brazil. We use both expected currency devaluation and currency risk premium instead of the usual inflation and output as macro factors to model the short rate dynamics and the market price of risk that determinates the entire term structure. The variables considered are essentially forward looking and can be easily inverted from widely traded non-deliverable forward contracts and currency expectation surveys collected among

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market participants. The currency risk premium will be defined as the excess return between the forward premium and the expected currency devaluation. A positive risk premium confirms the forward premium puzzle documented in several studies, as in Frankel and Engel (1984), Bekaert and Hodrick (1993) and Backus, Gregory and Telmer (1993), just to new a few.

The forward rates and market expectations reveal most of the information available in the economy, as well as the relevant expectations used to determinate the interest rate path. We view the short rate equation as a simplified uncovered interest parity (UIP), where the one month nominal rate reacts to one year ahead expected currency devaluation and currency risk premium. Results show that those forward looking factors can explain much of the short rate trajectory and improve a lot the forecasts both in-sample and out-of-sample for every maturity in the curve when compared with a model with only unobserved factors.

There are many advantages in using the proposed simplified UIP instead of a Taylor rule. First, we handle daily data obtained in widely traded financial instruments. Avoiding the use of output variables we drop a major estimation limitation of traditional models related to the frequency of the data. Such limitation may not be critical if there is no intention to use and evaluate the model regularly, but is certainly a serious issue if you want to price and follow movements in the curve frequently. Second, the UIP here is essentially forward-looking, such as the nature of the term structure that we want to evaluate. Modeling the short term rate as simple function of expected exchange rate movements and currency risk premium allows us to study the impact of those in the entire curve.

This work is related to the no-arbitrage macro literature beginning with Ang and Piazzesi (2003). We follow the literature and impose no-arbitrage restrictions in a Vector Autoregression to describe the joint dynamics of swap Pre x DI yields in Brazil and the currency variables. The option for a traditional macro-finance framework when we use financial data brings concerns about the consistency of the model. As in Ang e Piazzesi (2003), we prefer to see the currency variables as macro factors and for simplification assume that interest rates have no impact on our currency factors. The limitation to consider the contemporaneous correlations between macro and latent factors is a common issue in most studies in this literature. Complete macro models including Taylor rules, Phillips and IS curves in a no-arbitrage setup have been formulated to capture the cross effects among all the variabels included. The estimation of many parameters in a highly non-linear system is a serious issue in structural models. Rudebusch and Wu (2004), Bekaert, Cho and Moreno (2005), Hordahl, Tristani and Vestin (2006) and Hordahl and Tristani (2007) are example of studies that use structural macro frameworks in arbitrage free models. We discuss later in this article an alternative specification to account for the joint dynamics of interest rates and currency expectations in a consistent framework, as proposed by Chernov and Mueller (2008), but prefer to leave this extensions for a future research.

The model we propose here shows that shocks to expected devaluation and currency risk premium impact the entire term structure. Currency spot movements that do not change the forward premium, such that all the variation is assumed to be compensated by an equivalent movement in the currency risk term, have a positive impact on the curve. We view this result as an increase in currency risk perception affecting the curve term premium.In the Brazilian case, Shousha (2006) demonstrates that output and inflation do not appear to explain much of the variance of yields in the curve. He shows, on the other side, that nominal spot currency capture as much as 41% of this variance.

This paper is divided as follows. Section 2 describes the data. Section 3 proposes an affine representation for the UIP used to model the short rate. Section 4 presents the general affine term structure model. Section 5 estimates the model using Chen and Scott (1993) while Section 6 presents the results and evaluate the dynamics of the model. Section 7 concludes.

2 Data

2.1 Yields

We use one month swap PrexDI as the short rate and 3, 4, 6, 12, 18, 24 and 30 months equivalent swaps for the entire term structure. Swap PrexDI is an interest rate swap contract where one party borrows in a fixed rate and pays a cash flow of overnight interbank deposit rates. The rate is quoted like zero coupon bound and the curve is liquid for several different maturities. Contracts are traded over the counter in local markets and usually registered at CETIP (Central de Custodia e de Liquidação Financeira de Títulos). Yields are continuously compounded in 252 business days basis. All data compiled in this paper is from Bloomberg. Figure 1 plots the yields from 24-apr-2004 to 01-feb-2008 and tables 1 and 2 show the central moments and autocorrelation.

$$Figure 1$$

$$Table 1$$

$$Table 2$$

Yields of different maturities have a similar pattern, but in periods of higher uncertainty longer maturities stress more, as expected. Longer maturities yields present more pronounced skewness and kurtosis, the opposite of what is documented for United States. Another interesting aspect is related to the first two moments of brazilian yields. Mean and standard deviation decreases as maturities rises, also contrary to what is usually observed in developed countries.

2.2 Forward Premium, Expected Devaluation and Currency Risk Premium

We will use currency variables to model the short rate dynamics and the market price of risk that will determinate the term structure of interest rates. We take one year Non-deliverable Forward (NDF) Brazilian Reais contracts traded in US markets. NDFs are over the counter forward contracts in which counterparties settle the difference in a specific future date between the spot price and the contracted price. There is no physical delivery. By absence of arbitrage, the forward currency rate should equal the interest rate differential between deposits in two currencies, plus a premium for credit and currency risks between issuers and currencies. Furthermore, that interest rate differential should reflect the expected currency devaluation of the higher yield deposit, otherwise one betting against that currency movement would be willing to buy the currency. We assume that this parity holds and use currency expectations to decompose the forward premium into expected devaluation and currency risk. In logs we can write:

$$fp_t^{t+k} = E_t\left(\Delta e\right) + crp_t^{t+k} \tag{1}$$

The Central Bank of Brazil (BCB) evaluates weekly currency expectation surveys collected among market participants. We use those to construct a daily series of expected currency rate exactly one year ahead for each day in our sample. Figure 2 plots the series in the forward premium equation above.

$Figure 2$

From Figure 2, we see that currency risk premium and expected currency devaluation from Central Bank surveys have opposite behavior, risk premium rises when there is appreciation expectation.

3 Short Rate Dynamics

We assume that movements in short rate r_t can be explained by a modified interest rate parity condition where the 1 month nominal rate reacts to one year ahead expected currency devaluation and currency risk premium. Both variables keep a significant correlation with the broad macroeconomic environment and reflect the attractivity of capital flows that move the entire term structure:

$$r_t = a_0 + a_1 E_t\left(\Delta e\right) + a_2 crp_t^{t+k} + e_t \tag{2}$$

This setup provides, in our view, two main advantages when compared to usual Taylor rules for the short rate equations. First, markets provide daily liquid instruments that trade all the variables evolved. This allows us to estimate our model in a daily basis, while inflation indices and output measures are at best available monthly. Second, our variables capture a great deal of future expectation and so we can drop lagged arguments in the right hand side, the way forward looking versions of Taylor rule usually handle the problem. Such simplification eliminates a considerable number of variables that need to be estimated in an already highly non-linear model.

The failure of traditional uncovered parity conditions is usually explained by a risk premium term that capture differences mainly between issuers' credit risk. For the purpose of this article we let the residual e_t in (2) be treated as a latent factor X_t^u:

$$e_t = a_5 X_t^u \tag{3}$$

We can combine equations (2) and (3) to write an extended short rate equation:

$$r_t = \delta_0 + \delta_1 E_t(\Delta e) + \delta_2 crp_t^{t+k} + \delta_3 X_t^u \tag{4}$$

3.1 OLS Estimation of the Short Rate Equation

Independence assumption of the macro factor and the latent factor in (4) allows us to estimate parity equation coefficients as in (2). Finally, in Table 3 we report the results. Expected currency devaluation and currency risk premium are highly significant to explain one-month Brazilian yield. Residuals correlation suggest that usual "level" factor should reappear in our setup.

$Table3$

The estimates for all coefficients are highly significant and have an intuitive interpretation. The higher is the expected currency devaluation, the higher will be the Brazilian 1-month yield. The same intuition can be used to explain the positive sign of the coefficient of currency risk.

4 Term Structure Model

4.1 State Dynamics

We assume that both macro and latent factor $X_t = (macro; latent)$ follow a first order Gaussian VAR:

$$X_t = \mu + \Phi X_{t-1} + \Sigma\varepsilon_t \tag{5}$$

To impose independence between macro and latent factor we write Φ and as diagonal $5x5$ matrices. As noted by And and Piazzesi (2003), this independence assumption will be a drawback of the model. In our formulation this simplification means that interest rates have no impact on the currency variables we use. One way to consider contemporaneous correlations between macro and latent factors could be done by freeing up the companion matrix Φ. Another way would be considering a complete model to accomodate the joint dynamics of both interest rates and the currency factors. Chernov and Mueller (2008) use survey forecasts of inflation and construct private sector expectations of inflation that enter a modified no-arbitrage term structure model. A variation of their model using currency expectation instead of inflation could be proposed. For the sake of tractability we let those extensions for a future research.

4.2 No-Arbitrage Restrictions

To impose no-arbitrage restriction we assume the existence of an equivalent martingale measure Q under which a zero-coupon bond S_t can be written as $S_t = E_t^Q(\exp(-r_t)S_{t+1})$.Under Q the current price of a zero-coupon will be discounted present value using a risk-free rate. To recover from the equivalent measure Q to real data generating measure we take the Radon-Nikodym derivate ξ_{t+1} such that:

$$E_t^Q\left(S_{t+1}\right)=E_t\left(\xi_{t+1}S_{t+1}\right)/\xi_t$$

Assuming that ξ_{t+1} follows a log-normal process we model as in Ang and Piazessi (2003) the nominal pricing kernel that prices all nominal assets in the economy as a function of the macro variables:

$$m_{t+1}=\exp\left(-r_t\right)\exp\left(-\frac{1}{2}\lambda_t'\lambda_t-\lambda_t'\varepsilon_{t+1}\right) \tag{6}$$

where r_t follows the short rate equation $r_t=\delta_0+\delta' X_t$ and the market price of risk λ_t can be parameterized as an affine process:

$$\lambda_t=\lambda_0+\lambda_1 X_t \tag{7}$$

Shocks to the macro variables in X_t affect the term structure through both the short term rate r_t and market price of risk λ_t. The return R_{t+1} of any nominal bond will be:

$$E_t\left(m_{t+1}R_{t+1}\right)=1$$

Particularly, bond prices will be recursively determined by:

$$p_t^{n+1}=E_t\left(m_{t+1}p_{t+1}^n\right)$$

Duffie and Kahn (1996) show that bond prices are exponential affine function of the state variable X_t and can be written in the form:

$$p_t^n=\exp\left(A_n+B_n'X_t\right)$$

where $\overline{A}_n$ and $\overline{B}_n$ follow the difference equations:

$$\begin{aligned}A_{n+1} &= A_n+B_n'\left(\mu-\Sigma\lambda_0\right)+\frac{1}{2}B_n'\Sigma\Sigma' B_n-\delta_0\\ B_{n+1}' &= B_n\left(\Phi-\Sigma\lambda_1\right)-\delta'\end{aligned}$$

5 Estimations

We follow Chen and Scott (1993) and assume that as many yields as unobservable factors are measured without error. In particular, we let 2, 6 and 24 months be considered without error. To handle the non-linearity of the system and help achieve convergence we also follow the literature and adopt a two-step procedure. In the first step we estimate the macro coefficients in both the short rate dynamics (4) and the state dynamics VAR. In the second step we estimate all other parameters holding the ones collected in the first step fixed. We assume independence between the macro variables and the non-observed factors such that Φ, Σ and λ_1 will be block diagonal.

For a given parameter $\theta = (\mu, \phi, \Omega, \delta_0, \delta_1, \lambda_0, \lambda_1)$ we invert from the yields observed without error to solve for X_t^u, and then from the yields measured with error to collect e_t. Finally, to proceed with the maximum likelihood estimation of the remaining parameters in θ we define f_x and f_e as the normal density functions of the state variables X_t^u and e_t respectively. The joint likelihood $L(\theta)$ of the observed data on zero coupon yields and the macroeconomics variables observed is given by:

$$L(\theta) = \prod_{t=2}^{T} f\left(y_t, X_t^o | y_{t-1}, X_{t-1}^o\right)$$

Applying logs in both sides:

$$\begin{aligned}
\log\{L(\theta)\} &= \sum_{t=2}^{T} f\left(y_t, X_t^o | y_{t-1}, X_{t-1}^o\right) \\
&= \sum_{t=2}^{T} -\log|\det(J)| + \log f_x\left(X_t^o, X_t^u | X_{t-1}^o, X_{t-1}^u\right) + \log\left(f_e(e)\right) \\
&= -(T-1)\log|\det(J)| - \frac{(T-1)}{2}\log\left(\det\left(\Sigma\Sigma'\right)\right) \\
&\quad -\frac{1}{2}\sum_{t=2}^{T}\left(X_t - \mu - \phi X_{t-1}\right)'\left(\Sigma\Sigma'\right)\left(X_t - \mu - \phi X_{t-1}\right) \\
&\quad -\frac{(T-1)}{2}\log\sum_{i=1}^{4}\sigma_i^2 - \frac{1}{2}\sum_{t=2}^{T}\sum_{i=1}^{4}\frac{e_i^2}{\sigma_i^2}
\end{aligned}$$

where σ_i^2 is the variance of the ith measurement error and the Jacobian term is given by $J = \begin{pmatrix} I & 0 & 0 \\ B^o & B^u & B^e \end{pmatrix}$

6 Results

Table 4 presents the results of the macro model. The coefficients of latent factors in (4) can be seen at the top of the table. We investigate the correlation between the three unobserved factors and yield transformations identified with usual level, slope and curvature of the yield curve as proposed by Litterman and Scheinkman (1991). The first unobserved does not seems to be linked to a level factor. The correlation is below 10%, contrary to usual values for the US curve of above 90%. The first factor, however, seems to be more correlated to a slope factor (71%). The second latent factor, on the other side, has a 63% correlation with the level transformation. The third unobserved series has a negative 92% correlation with the curvature transformation.

$Table4$

Figure 3 shows the normalized weights B_n estimated for different maturities n. These weights B_n represent the contribution of the various factors to yield curve. As can be seen, the currency factors contribute with a great extent of the short end of the curve. Those factors decay as we move across the curve, increasing the contribution of the second latent factor.

$Figure 3$

6.1 Impulse Response

To investigate the effects of each factor in the curve we perform impulse responses in each variable in the complete model Vector Autoregression. The magnitude of the currency coefficients in the short end of the curve suggests that shocks to those variables should affect shorter yields greater than longer yields. Figures 4 and 5 show the impulse responses of one standard deviation on expected currency devaluation and currency risk premium. The standard deviation of expected currency devaluation is 4.31%, slightly higher than the 3.84% observed for the currency risk series. Shocks of those magnitudes induce significant effects on the curve. Shorter 1 month yields increase by 3% after shocks in the first macro variable that decay slowly trough time. After 90 days the curve is still over 2% above its level before the shock. Six month and one year yields do also react quite strong to shocks on the expected currency devaluation, but less than what is observed for the shorter yield. The dynamic after one standard deviation shock on the currency risk premium reveals a similar pattern.

$figure 4$

$figure 5$

An interesting way to investigate the effects of shocks on the currency variables is to simulate a simultaneous but oppossite shock on both. We can simulate a change in the composition of the forward premium that takes place when a currency spot devaluation, for example, occurs while the expected currency 1 year ahead remains steady. If that happens by definition the currency risk premium would have to increase by the same extent to compensate the lower expected currency devaluation. Figure 2 shows tha this is something quite common in the sample considered, as agents takes longer to change their forecasts and keep on trading currency NDFs on the same levels. Figure 6 shows the impulse response of 100 basis point decrease on the expected currency devaluation that is followed by and equivalent increase in the currency risk premium. Results suggest that this would have a positive impact on the curve. Yields would increase due to this increase in risk perception, up to 7 bps in the shorter yield after 120 days.

$figure 6$

6.2 Variance Decomposition

Table 5 reports the proportion of the forecast variance attributable to each factor. As documented by Shousha (2006), the currency is able to explain a considerable extent of the variance of several maturities. We confirm those findings here, but do also offer a deeper understanding of what can be explained by two currency factors. The proportion that can be credited to expected devaluation is greater for the 3 month yield (33,6%) and looses significance as we move to the end of the curve. The contribution of the currency risk premium is similar, reaching 18% of the variance of the 4 month yield. Together those variables explain up to 51% of the variance of the 3 and 4 month yields. The results do not change much as we compare 1 and 60 days forecast out-of-sample.

$table5$

6.3 Forecast

We compare the predictive power of the macro model here proposed and a pure latent model. The macro model reveals better results both in and out-of-sample. We considered as in-sample the model estimated for the entire 972 days in our data. As out-of-sample we consider the 60 days after the end of our sample, for which we do also have the realized data.

Figure 7 shows the fit of estimated curves for two selected dates. Figures 8 and 9 compare the forecasted one year yield for approximately 1 year at the end of our sample and for 60 days out-of-sample. It can be easily seen that the latent model fails to capture the upward sloping at the end of the sample and across the out-of-sample interval. The macro model presents a better fit and successfully capture the upward trajectory of the one year yield after the end of the sample. We test different sub-samples in our data and perform several forecasts. The ability of the model to outperform the latent model is confirmed, although the macro model fails to capture some others downward and upward trends in the sample. Therefore, we still rely on the macro model here as a better predictor when compared with the canonical model, but would be careful when considering its ability to capture shifts in rates trajectory.

$Figure7$

$Figure8$

$Figure9$

To compare the forecasts of each model we calculate the Mean Squared Error (MSE). The mean squared error of each model is constructed as the average of the mean squared error of each yield[1]. Table 6 presents the results. The macro model by far reveals much better results.

$Table6$

[1] Three maturities have zero in-sample mean squared error by construction (Chen-Scott)

7 Conclusion

This paper proposes an affine term structure model with observable currency factors for Brazil. The option for currency variables instead of traditional output and inflation is due to the incapacity of those to explain a significant proportion of the variance of yields in the curve. The currency appears as a natural candidate because it is widely traded and reveals much of the mood with the general macro environment. We focus on two currency factors: the expected currency devaluation and the currency risk premium inverted from the first and the NDF contracts traded in US over the counter markets. We follow Ang and Piazzesi (2003) and use these currency variables to estimate a daily model with additional 3 unobserved latent factors.

Results show that shocks to both currency factors contribute to significant changes in the curve. The composition of the forward premium is also relevant to the shape of the curve. Yields appear to be higher as currency risk premium increase after an equivalent reduction in the expected currency devaluation followed by a spot devaluation. A significant proportion of the variance of the yields in the curve can be attributed to the currency factors. The expected devaluation can explain as much as 33,6% of the 3 month yield variance, while the currency risk explain 18% of the 4 month yield. Together both factors account for up to 51% of the variance of 3 and 4 months yields.

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Table1: Central Moments

	Mean	Standard-Deviation	Skewness	Kurtosis
BRZ 1-month yield	15.44	2.89	-0.05	-1.29
BRZ 2-month yield	15.40	2.91	-0.04	-1.31
BRZ 3-month yield	15.37	2.93	-0.04	-1.34
BRZ 4-month yield	15.34	2.93	-0.06	-1.38
BRZ 6-month yield	15.30	2.93	-0.08	-1.43
BRZ 1-year yield	15.18	2.84	-0.18	-1.52
BRZ 1.5-year yield	15.13	2.75	-0.23	-1.47
BRZ 2-year yield	15.08	2.69	-0.22	-1.37
BRZ 2.5-year yield	15.05	2.68	-0.17	-1.21
Expec. Currency Devaluation 12m	0.00	4.31	0.23	-0.15
Currency Risk 12m	0.00	3.84	1.34	2.12
Lat1	9.16	25.99	-0.32	-0.45
Lat2	39.04	9.33	0.65	0.05
Lat3	-109.13	57.39	-0.10	-0.24

Table2: Autocorrelation

	Autocorrelation (lag1)	Autocorrelation (lag5)	Autocorrelation (lag10)	Autocorrelation (lag50)	Autocorrelation (lag100)
BRZ 1-month yield	1.00	1.00	1.00	0.97	0.87
BRZ 2-month yield	1.00	1.00	1.00	0.97	0.88
BRZ 3-month yield	1.00	1.00	1.00	0.97	0.88
BRZ 4-month yield	1.00	1.00	1.00	0.97	0.89
BRZ 6-month yield	1.00	1.00	1.00	0.97	0.90
BRZ 1-year yield	1.00	1.00	0.99	0.97	0.92
BRZ 1.5-year yield	1.00	0.99	0.99	0.96	0.91
BRZ 2-year yield	1.00	0.99	0.98	0.95	0.89
BRZ 2.5-year yield	1.00	0.99	0.98	0.94	0.88
Expec. Currency Devaluation 12m	0.98	0.89	0.83	0.61	0.43
Currency Risk 12m	0.97	0.86	0.76	0.42	0.22
Lat1	0.98	0.93	0.89	0.76	0.48
Lat2	1.00	0.98	0.95	0.84	0.62
Lat3	0.99	0.98	0.96	0.75	0.40

Table3: Short Rate Dynamics - OLS

Dependent variable: BRZ 1-month yield Sample: 04/24/2004 - -2/29/2008 (972 observations)	
Constant	15.44 (402.74)
Expec. Currency Devaluation 12m	0.72 (68.53)
Currency Risk 12m	0.44 (36.89)
Adjusted R-squared	0.83
F-statistic	2348.05

in parenthesis, t-statistic

Table4: Complete Model Estimates

Short Rate Equation: Three Latent Factor

δ_3= 0,0807 $\delta 4$= 0,0063 $\delta 5$= -0,0001

State Dynamics

	Φ				
	Exp.Curr	Curr.Risk	Lat1	Lat2	Lat3
Exp.Curr	1,0000	-0,0096	0,0000	0,0000	0,0000
Curr.Risk	0,0013	0,9858	0,0000	0,0000	0,0000
Lat1	0,0000	0,0000	0,9634	0,0180	0,0125
Lat2	0,0000	0,0000	0,0057	0,9988	-0,0022
Lat3	0,0000	0,0000	0,0100	0,0099	0,9973

Price of Risk

	λ_0	λ_1				
		Exp.Curr	Curr.Risk	Lat1	Lat2	Lat3
Exp.Curr	-0,0006	0,1808	0,0001	0,0000	0,0000	0,0000
Curr.Risk	-0,0016	0,5934	0,0002	0,0000	0,0000	0,0000
Lat1	0,0045	0,0000	0,0000	0,0055	-0,0034	-0,0002
Lat2	0,0029	0,0000	0,0000	-0,0098	0,0009	-0,0010
Lat3	-0,0011	0,0000	0,0000	-0,0025	0,0000	0,0001

Table 5: Variance Decomposition (h-steps ahead forecasts)

		Yields (months to maturity)								
	h	**1**	**2**	**3**	**4**	**6**	**12**	**18**	**24**	**30**
Expec. Currency Dev. 12m	1	27,73%	32,79%	33,64%	32,70%	29,22%	18,07%	10,29%	5,91%	3,61%
	60	28,49%	33,35%	33,99%	32,91%	29,30%	18,07%	10,29%	5,91%	3,61%
Currency Risk 12m	1	9,40%	14,38%	16,99%	17,98%	17,63%	11,97%	7,02%	4,09%	2,52%
	60	9,58%	14,50%	17,03%	17,96%	17,53%	11,88%	6,97%	4,06%	2,50%
Lat1	1	58,97%	41,45%	31,17%	25,61%	20,85%	18,83%	18,76%	18,09%	16,98%
	60	57,78%	40,21%	30,03%	24,58%	19,94%	17,96%	17,90%	17,25%	16,18%
Lat2	1	1,37%	4,02%	7,11%	10,36%	17,29%	39,74%	58,37%	70,23%	76,80%
	60	1,43%	4,14%	7,27%	10,55%	17,54%	40,21%	59,05%	71,03%	77,62%
Lat3	1	2,54%	7,36%	11,09%	13,34%	15,01%	11,40%	5,56%	1,68%	0,10%
	60	2,71%	7,80%	11,68%	13,99%	15,68%	11,88%	5,79%	1,75%	0,10%

Table 6: Forecast Comparison

RMSE Criteria		
	In-Sample	60-step ahead
Macro Model	0,0560	0,2174
Latent Model	1,149	4,920
MAD Criteria		
	In-Sample	60-step ahead
Macro Model	0,1782	0,3414
Latent Model	0,453	1,118

Figure 1: Brazilian PrexDI Swap Rates

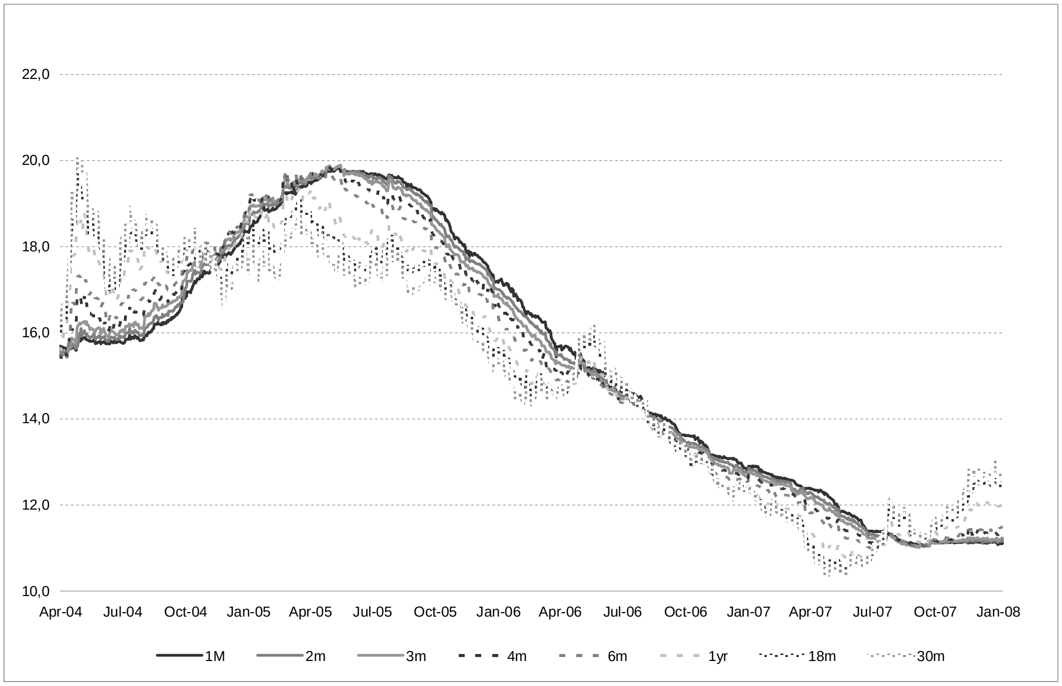

Figure2: Forward Premium
Expected Currency Movements + Currency Risk Premium

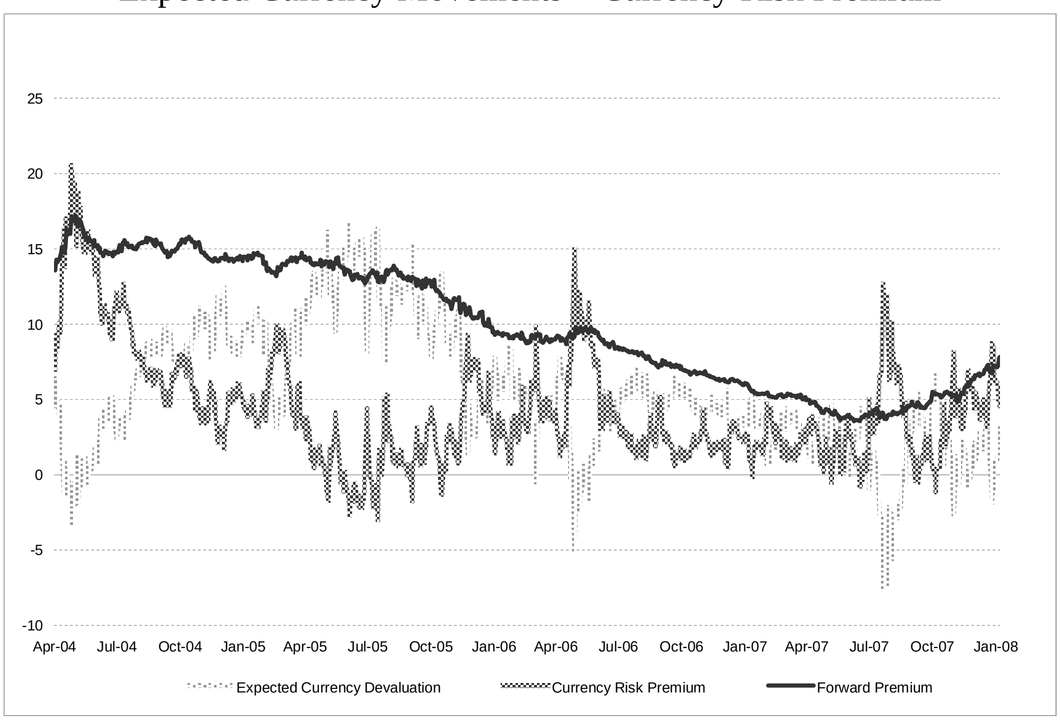

Figure3: State Dynamics Equation Normalized Coefficients
(from 30 to 900 days)

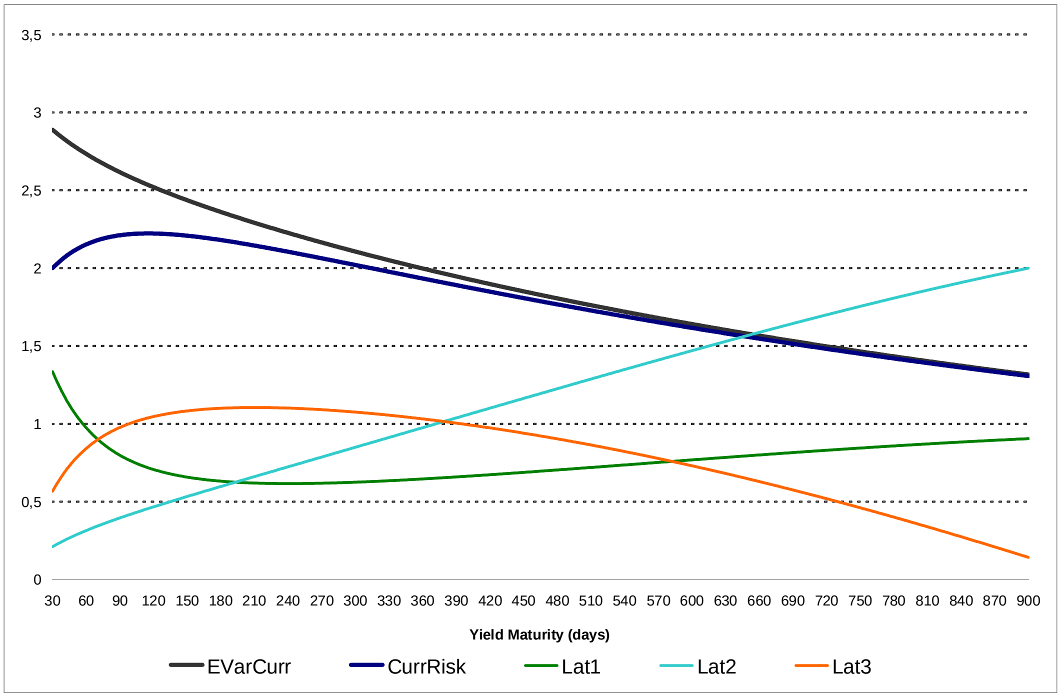

Figure 4: Impulse Response
+1dp E(e)

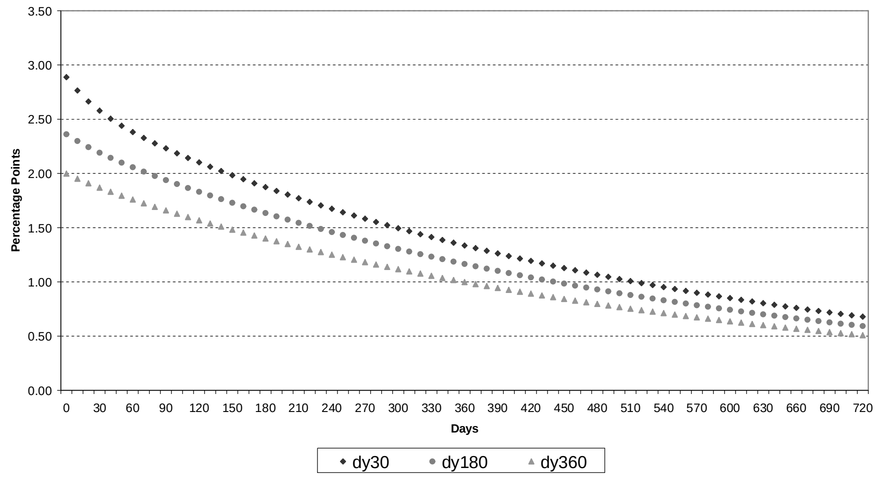

Figure 5: Impulse Response
+1dp CRP

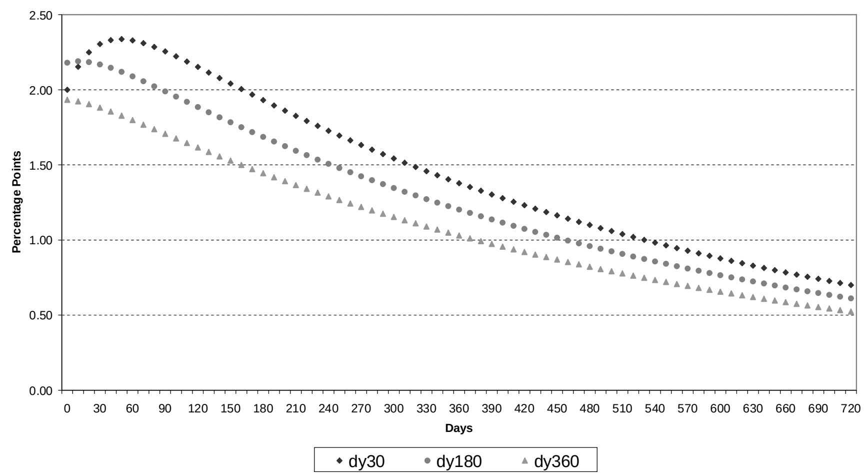

Figure 6: Impulse Response
-100bps E(e) + 100bps CRP

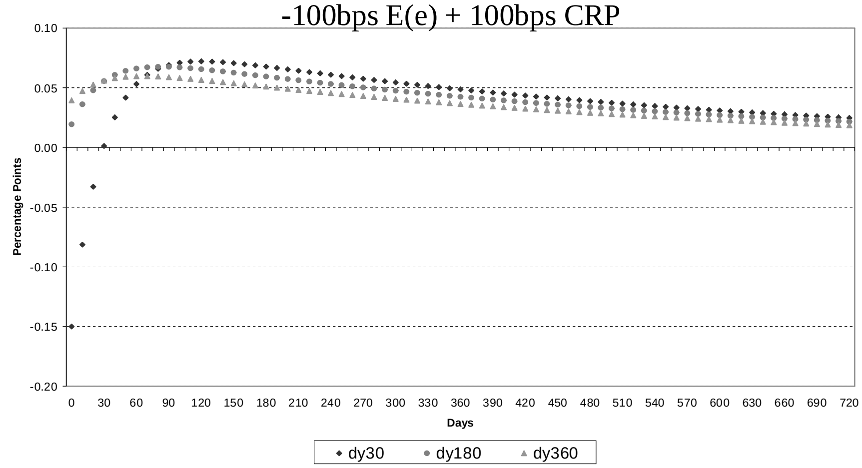

Figure 7: In-Sample Curve Estimation

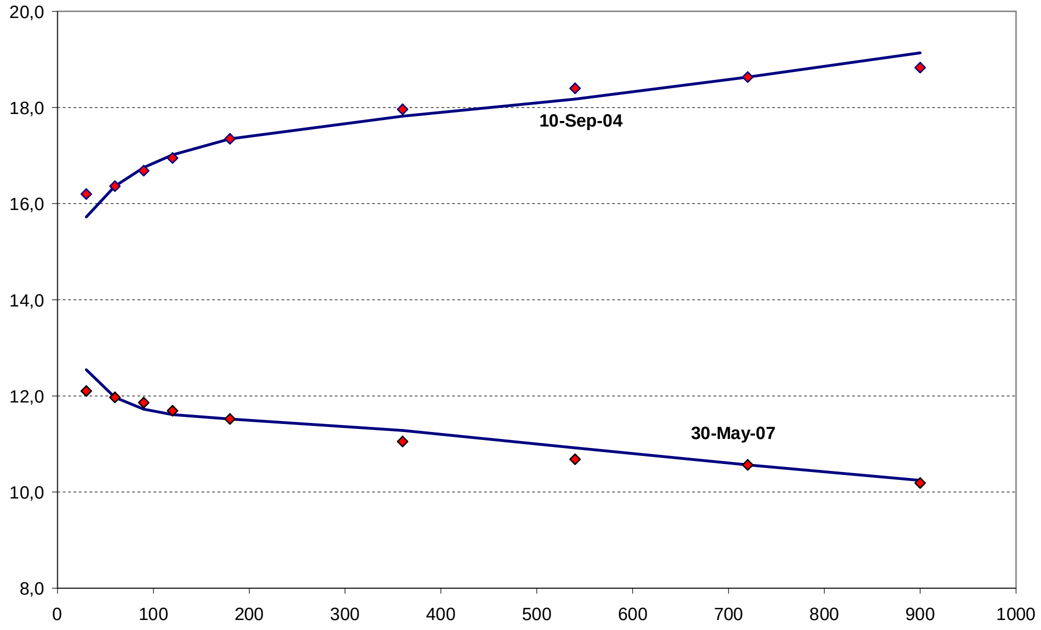

Figure 8: Latent Model - Forecast Out-of-Sample (60 days)
360 days yield

Figure 9: Macro Model - Forecast Out-of-Sample (60 days)
360 days yield