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# Direction of Interest Rate Movements and Interest Rate Trends of Mexican Treasury Securities

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## ABSTRACT

*This empirical study focuses on the short-term movements of the Mexican yield curve. Consistent with the fixed-income literature one shows that three factors (level, steepness, and curvature) explain shocks on the short-term Mexican yield curve. Furthermore, using a principal component analysis, one provides i) a three-factor model to forecast the direction (up or down) of Treasury bills interest rates movements and ii) a tool to detect, a priori, the change of trends on Treasury bills interest rates. The three-factor model succeeds 84% of the times on forecasting the direction of Treasury bills interest rates movements.*

## 1. Introduction

The yield curve (i.e., the relationship between yields on bonds with similar credit-quality but different maturities) has received much attention in research on fixed-income securities. This is not surprising as the yield curve is a benchmark for pricing of such securities. In this empirical study one analyzes short-term Mexican Treasury interest rates or yields. In particular, one provides i) a model to forecast the *direction* (up or down) of Treasury bills interest rates movements and ii) a tool to detect, a priori, *changes of trends* on Treasury bills interest rates.

The identification of common factors affecting yields has been a concern in the fixed-income securities literature. Consensus exists that shifts on the yield curve are attributable to *only* a few unobservable common factors. Litterman and Scheinkman (1991) first document that most of the variability of returns in all fixed-income securities can be explained in terms of three factors or attributes of the yield curve: *level*, *steepness*, and *curvature*. They present evidence of the level factor accounting for about 90% of the total explained variance.

Knetz, Litterman and Scheinkman (1994) suggest a three-factor model explaining 86% of the total variation in most of the US money market instruments. They study returns across sectors including Treasury and corporate debt. Knetz, Litterman and Scheinkman (1994) call their three factors *level*, *steepness*, and *Treasury*, emphasizing the importance of Treasuries over corporate securities to explain movements in the yield curve. Others have used the framework by Litterman and Scheinkman (1991) with different type of securities, methodologies, and contexts.

For instance, Blanco, Soronow and Stefiszyn (2002) have used the three factor model in the context of modeling the natural gas forward price curves. Given the extensive number of futures contracts trading at different maturities, by reducing the number of common factors while retaining most of the information contained in the original data set, Blanco, Soronow and Stefiszyn (2002) suggest a practical risk management and trading tool for derivate markets. Rodrigues (1997) and Driessen, Bertrand and Nijman (2003) extend the work by Litterman and Scheinkman (1991) by analyzing bond returns of different maturities in an international context. Instead of estimating both the unobserved factors and the factor loadings (i.e., unrestricted factor analysis) as in Litterman and Scheinkman (1991), Diebold and Li (2006) used the three factor framework, restricted by the Nelson-Siegel approach, to model the entire yield curve

With the exception of the Diebold and Li (2006) work, all cited works use principal component analysis (PCA) to estimate the unobservable common factors. In this work, one also uses PCA along with regression analysis. The main contribution of this study is the application of the three factor model to explain the short-term behavior of interest rates in Mexico. To the best of our knowledge, so far no study has done this for the Mexican yield curve. This study is important for two reasons: Mexican fixed- income securities represent an important proportion of institutional investors' portfolios, and US Treasury bond market research results (and results from other sophisticated markets) should not necessarily hold in emerging economies (Ho and Lee (2004)).

The paper is organized as follows: in the next section one describes the data set, model and methodology used to conduct the empirical study; in the third section one presents the main results of the study and the last section concludes the work.

## 2. Methodology

One analyzes short-term discounted securities issued by the Mexican government (i.e., Mexican Treasury bills). Specifically, one uses bid-ask average rates for Treasury bills' secondary market with 28-, 90-, 182-, and 360-days maturities available in Thomson Datastream database (Datastream codes: MXSCM28(IR), MXSCM90(IR), MXSCM182(IR), and MXSCM360(IR)). Other short-term maturities have been issued by the Mexican government in the past, but for the period analyzed in this study these were all maturities available. In general, one uses daily information frequency corresponding to the period 1996 to 2006, but one also uses weekly information frequency instead of daily information frequency for some empirical tests.

With respect to the methodology, one uses PCA to obtain the factor loadings needed to estimate the three principal components. Thus, the number of variables (e.g., maturities) in the data set is reduced from four to three. Let  $\mathbf{P}$  be a matrix containing the factor loadings  $PC1$ ,  $PC2$ , and  $PC3$  by maturities (subscripts in (1) below).  $PC1$  relates to the first principal component or *level* factor,  $PC2$  relates to *steepness* and  $PC3$  to *curvature*.

$$P = \begin{pmatrix} PC1_{28} & PC2_{28} & PC3_{28} \\ PC1_{90} & PC2_{90} & PC3_{90} \\ PC1_{182} & PC2_{182} & PC3_{182} \\ PC1_{360} & PC2_{360} & PC3_{360} \end{pmatrix}. \quad (1)$$

Each factor, denoted as  $F1$ ,  $F2$ , and  $F3$ , is a linear function of actual interest rates and factor loadings in  $\mathbf{P}$ . For instance,  $F1$  at time  $i$  is equal to:

$$F1_i = r_{28,i}(PC1_{28}) + r_{90,i}(PC1_{90}) + r_{182,i}(PC1_{182}) + r_{360,i}(PC1_{360}). \quad (2)$$

Where  $r_{28,i}$  represents Treasury rate for 28-days maturity at time  $i$ , and similarly for other maturities. In general, one defines  $\mathbf{R}$  as a matrix containing rates by maturities at time  $i$  (for  $i$  from  $1$  to  $K$ ) as follows:

$$R = \begin{pmatrix} r_{28,1} & r_{90,1} & r_{182,1} & r_{360,1} \\ r_{28,2} & r_{90,2} & r_{182,2} & r_{360,2} \\ \vdots & \vdots & \vdots & \vdots \\ r_{28,K} & r_{90,K} & r_{182,K} & r_{360,K} \end{pmatrix}, \quad (3)$$

a  $K \times 3$  matrix  $\mathbf{F}$  of unobserved factors is obtained by pre-multiplying  $\mathbf{P}$  by  $\mathbf{R}$ . That is,

$$\mathbf{F} = \mathbf{R} \otimes \mathbf{P}. \quad (4)$$

Concerning forecasting, one accomplishes this by using a dynamic algorithm. In brief, matrix  $\mathbf{F}$  (equation 4) is estimated using a two-year rolling window or 104-weeks. The choice of a two-year rolling window is rather arbitrary and it attempts to represent the length of time by which practitioners might use historical data to forecast interest rates<sup>1</sup>. Then,  $\mathbf{F}$  is estimated for 417 two-year rolling windows. Every time the algorithm is repeated one drops the first week data from the subsample and added the next week rates out of the subsample. For instance, the very first time  $\mathbf{F}$  is estimated the rolling window contains data from week 1 to 104; the next rolling window contains data from week 2 to week 105, and so forth. Thus, one has  $\mathbf{F}_n$  for  $n = 1, 2, \dots, 417$ , where  $n$  represents a two-year rolling window for the complete ten-year period 1996-2006 (i.e., for the total sample of 521 weeks minus 104 from the first subsample).

One obtains estimates by running OLS regressions with the Newey and West (1987) correction for heteroscedasticity and autocorrelation with

$$r_{j,t} = \alpha + \beta F1_{t-1} + \gamma F2_{t-1} + \delta F3_{t-1} + \varepsilon. \quad (5)$$

Where  $r_{j,t}$  is interest rate of security for the  $j^{\text{th}}$  maturity in week  $t$ , and  $F$  is the corresponding factor previously estimated (in  $\mathbf{F}$ ) lagged one week. One runs regressions dynamically for 417 two-year rolling windows as explained above. Thus, from the first four regressions (for matrix  $\mathbf{F}_1$  with rates for  $t = 1$  to 104 and  $j = 1$  to 4) one obtain twelve regression coefficients  $\beta, \gamma$ , and  $\delta$ .<sup>2</sup>

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<sup>1</sup> The choice of a different rolling window is immaterial because the conclusions don't change.

<sup>2</sup> One ignores hats from the estimates to simplify notation

If one defines  $\mathbf{B}$  as the matrix with regression coefficients as,

$$B = \begin{pmatrix} \beta_{28} & \gamma_{28} & \delta_{28} \\ \beta_{90} & \gamma_{90} & \delta_{90} \\ \beta_{182} & \gamma_{182} & \delta_{182} \\ \beta_{360} & \gamma_{360} & \delta_{360} \end{pmatrix}, \quad (6)$$

Then one has  $\mathbf{B}_n$ , for  $n = 1, 2 \dots 417$ , for the ten-year period of study.

In general, the model is

$$R_n = \Gamma_n + F_n \otimes B_n^T + E_n. \quad (7)$$

Where  $\Gamma$  and  $\mathbf{E}$  have as entries intercepts and errors;  $\mathbf{B}^T$  is transpose of  $\mathbf{B}$ ; and  $\mathbf{R}$  and  $\mathbf{F}$  are as defined above, where two-year rolling windows,  $n$ , go from 1 to 417. To illustrate the forecast algorithm, one starts the projection for the security with  $j$ th maturity in week 105, the next week out of the first rolling window. One uses unobserved factors  $F1$ ,  $F2$ , and  $F3$  from previous week 104 and the corresponding regression coefficients estimated from the first two-year rolling window to make the forecast, and then one repeats the algorithm 417 times.

### 3. Results

**Table 1** provides the three eigenvectors from PCA containing principal components' factor loadings  $PC1$ ,  $PC2$ , and  $PC3$  by maturities (i.e., matrix  $\mathbf{P}$ ) and their corresponding explained variation<sup>3</sup>. Results are provided for five two-year rolling windows corresponding to the time span 1996-2006<sup>4</sup>. Results in **Table 1** show that three factors explain almost all the variation in Mexican Treasuries rates (99%). This is not surprising as PCA is reducing the number of variables or maturities by only one, from four to three. Previous research has also shown that three factors explain almost all variation on interest rates (Litterman and Scheinkman (1991), 98.4%; Ho and Lee (2004), 97.5%; among others).

In contrast to previous research, however, the power of explanation of the first principal component in our results is higher than previous studies. The first principal component (related to *level* factor) explains from 97% to 98% of variation according to results in **Table 1** (eigenvector 1's explained variation). In Litterman and Scheinkman (1991), for instance, the *level* factor explains about 90% of total variation.

It is important to note that all previous research cited in the introductory section has been conducted in sophisticated bond markets. In those markets movements of the yield curve are explained by the *level*, *steepness*, and *curvature* factors.

<sup>3</sup> Explained variation is the ratio of the variance of the component to the trace of the covariance matrix of interest rates.

<sup>4</sup> Instead of reporting 417 two-year subsamples as in the forecasting section, one only presents 5 periods here with the only purpose to illustrate the usefulness of PCA for this application.

Ho and Lee (2004) state that in the U.S. the existence of a significant long-term bond segment as well as a large money market could explain the segmentation of the yield curve in three movements or three factors. In contrast, they suggest that in less sophisticated markets movements of the yield curve *might* be explained by just the *level* factor or by the *level* and *steepness* factors. Ho and Lee (2004), however, do not provide empirical evidence for their intuition. The higher explanatory power of the first principal component in our results compared to results from previous research might be explained by Ho and Lee's rationale.

<Insert Table 1 about here>

One may wonder whether the use of three factors, as opposed to only one or two, is correct when analyzing interest rates in the Mexican Treasury secondary market. In fact, this is an empirical matter because our forecast model with three factors explains better Mexican Treasury rates than a two- and a one-factor model as we will show later. For now, one shows graphically that the three factors have a systematic impact on movements on the short-term interest rates of Mexican Treasuries.

In **Figure 1** one plots factor loadings by maturities for the five 2-year rolling windows from **Table 1**. The curve of the first principal component is almost flat. This means that a shock of the first principal component (eigenvector 1) has a similar impact or produces a parallel shift on interest rates of all maturities in the short-term of the Mexican yield curve (equation (2) relates factor loadings with interest rates across maturities). In contrast, the second principal component shows different impacts or nonparallel shifts across maturities. While the shorter-term rates (i.e., 28 and 90 days maturities) fall, the 182 and 360 maturities rise from 1996 to 2000, and vice versa beyond year 2000. The third principal component illustrates the *curvature* factor of the yield curve. While the extreme maturities (e.g., 28 and 360 days) rise, the middle maturities fall consistently during the five periods. This graphical representation illustrates why in the literature the factors explaining the yield curve are called *level*, *steepness*, and *curvature* factors.

The names given to the common factors describe the way a shock changes the shape of the yield curve. The *level* factor influences the yield curve by shifting it in a parallel fashion. A shock of the *steepness* factor changes the slope of the curve either by changing in lower amounts the interest rates for short term maturities compared to long-term maturities or vice versa. Finally, the effect of the *curvature* factor is in the middle of the curve.

Empirical results from the three factors explaining the short-term of the Mexican yield curve are consistent with results graphically represented in previous studies (Golub and Tilman (2000), Litterman and Scheinkman (1991), Diebold and Li (2006), Blanco, Soronow and Stefiszyn (2002), Ho and Lee (2004), Wu (2003)). We proceed to apply the three-factor model for forecasting purposes.

<Insert Figure 1 about here>

One then forecasts interest rates according to the algorithm described in the previous section (equations (5) to (7)). Thus, one obtains 417 estimated  $\mathbf{R}$  vectors with projected interest rates by maturities as entries from weeks 105 to 521. One of the objectives of this study is to forecast whether interest rates would increase or decrease (up or down) on week  $t+1$  relative to week  $t$  using two years of historical data. Thus, to test our model one compares our forecasted interest rates with actual values. As one is concerned on forecasting the *direction* (up or down) rather than the magnitude or precision of the estimates, one does this comparison as follows:

$$(\hat{r}_{j,t} - r_{j,t-1})(r_{j,t} - r_{j,t-1}) > 0, \quad (8)$$

where  $\hat{r}_{j,t}$  represents projected interest rate,  $j$  and  $t$  represent maturity and week as before. The first term in (8) shows whether one expects an increase or a decrease in interest rates next week relative to current week rates. The second term represents the actual increase or decrease in rates according to the historical data. Thus, a positive number in (8) means that our model succeeds in forecasting the direction of interest rates<sup>5</sup>. The first line of **Table 2**, ( $\theta = 0$ ), presents the percentage of successes of the 3-factor model on forecasting the direction of interest rates. 84% (83% for 90 days maturity) of the time our model was able to forecast whether interest rates next week would increase or decrease relative to current week rates using two year of historical data.

One might use the predictions of this model for the purpose of trading (e.g., rebalancing of a portfolio). As transaction costs for trading exist, a practitioner using such a model would only trade as long as the benefits surpass transaction costs. One defines transaction costs of trading as ( $\theta$ ) the minimum magnitude (in basis points) that the practitioner needs to observe in order to trade<sup>6</sup>. Hence,  $\theta$  is the absolute value of the difference between forecasted interest rates and current week interest rates, or

$$|\hat{r}_{j,t} - r_{j,t-1}| \geq \theta. \quad (9)$$

**Table 2** provides the level of success of the model as one includes transaction costs. Results for a two factor model (level, and steepness) and a one factor model (level) are presented in Table 2 as well. Results show that forecasting interest rates with three factors (level, steepness, and curvature) as documented in the literature for developed bond markets also works for an emerging market such as Mexico, contrary to suggestions by Ho and Lee (2004).<sup>7</sup>

<Insert Table 2 about here>

Another important result is that PCA also provides signals to detect the timing when a trend in the Mexican interest rate movements is about to change. Following Rachlin (2006) one compares the explained variation of the first principal component with actual interest rates over the ten-year period of study. One finds systematic relations between principal components' explained variations and interest rates movements.

<sup>5</sup> In none of the cases equation (8) was equal to zero.

<sup>6</sup> In fact transactions costs include commission, fees and market impact costs as stated by Mongrut (2007).

<sup>7</sup> Results broken down by years, not reported, also show similar levels of success for the three-factor model.

In **Figure 2** one plots first principal components' explained variations (i.e., explained variation thereafter) and actual interest rates for 28-days securities. One presents the results with the first principal component and for 28-days Treasuries only since the patterns for other maturities and for the second and third principal component are similar. 28-days Mexican Treasuries have been the benchmark for the domestic market for many years as well (Estevez-Breton et. al, 2008). For this section explained variations for two-year rolling windows is estimated from the changes in interest rates, rather than from interest rates by itself as it was done previously.

In **Figure 2** it could be noticed that the fraction of explained variation captured by the first principal component changes. Often these changes are gradual, but sometimes the changes are drastically marked, as indicated by the vertical lines in the Figure. This means that between periods marked by abrupt changes a distinct interest rates trend might be experienced and a larger or lower portion of market variability is captured by the first eigenvector or principal component.

The series starts on 12/11/1998 with an explained variation value around 0.71% (market with the vertical line 0 in **Figure 2**). On mid January, specifically on 1/13/1999, the explained variation rises to 74%. This number remains stable around 75% until mid August, 2000 when it suddenly falls to levels below 70%. During that one year and a half period of stability on explained variations, interest rates present a decreasing trend (market with *a* in **Figure 2**), which precisely ends about mid August, when the abrupt change in explained variation happens.

The vertical line 1 shows the abrupt change in explained variation, which monotonically decreases (with the exception of two days) from 0.75 to 0.67 from 8/16/2000 to 9/06/2000. After this, explained variation gradually increases to levels around 71% until the beginning of January 2001, when it suddenly falls (vertical line 2). In between lines 1 and 2 interest rates also present a trend, market with *b* in the Figure. The end of this trend precisely coincides with vertical line 2 (i.e. the sudden change in explained variation). Thus, so far, an abrupt change in explained variation, which is interpreted as a first component shock on the yield curve, ends a trend and marks the beginning of a new one (from decreasing to increasing in our results).

This result is encouraging as it systematically occurs seven times (*a* to *h* in **Figure 2** excluding *f* since a change in the trend is not observed) during 8 years. An exception is the end of the period marked between lines 3 and 4 in the Figure, when a change in the trend occurs without a change in explained variation.

Although one does not provide what specific magnitude of change in explained variation of the first principal component would signal a change in interest rates trend, one finds that any abrupt change in the explained variation represents a signal for a change in the trend (to increasing, decreasing or parallel). Also, the results for the Mexican Treasury market in **Figure 2** show that in periods when interest rates volatilities are higher (for instance, periods delimited by vertical lines 0 to 1, 1 to 2, and 3 to 4) the explained variation of the first principal component is also relatively high. This suggests that in periods of low volatilities on interest rates, the level and curvature factors become more important. As volatilities of interest rates are higher in emerging economies compared to developed economies, one finds this model suitable for emerging economies.



<Insert Figure 2 about here>

#### **4. Conclusions**

Consistent with previous research on developed bond markets, one shows that three factors (i.e., *level*, *steepness*, and *curvature*) explain shocks on the short-term movements of interest rates in the Mexican yield curve. This is important since it has been suggested that results for developed bond markets should not necessarily hold in emerging economies. Ho and Lee (2004), for instance, state that in the U.S. the existence of a significant long-term bond segment as well as a large money market could explain the segmentation of the yield curve in three movements or three factors. In contrast, they suggest that in less sophisticated markets movements of the yield curve *might* be explained by just the *level* factor or by the *level* and *steepness* factors.

Using principal component analysis (PCA) and regression analysis, one provides i) a three-factor model to forecast the direction (up or down) of Treasury bills interest rates movements and ii) a tool to detect, *ex-ante* changes in the trend of Treasury bills interest rates. The three-factor model succeeds 84% of the times on forecasting the direction of Treasury bills interest rates movements during the ten-year period analyzed.

If one uses this forecasting model as a trading tool, one finds that PCA gives signals to detect the timing when a trend changes in the Mexican Treasury market. One finds systematic relations between principal components' explained variations and interest rates trends. In particular, one documents that abrupt changes in explained variation end an interest rates trend and mark the beginning of a new one. Although one does not provide what specific magnitude of change in explained variation of the first principal component would signal a change in interest rates trend, one finds that any abrupt change in the explained variation represents a signal for a change in the trend (to increasing, decreasing or parallel).

Future studies might explore modeling of the complete yield curve also in other emerging markets, including different maturities and alternative security sectors, especially the corporate debt sector. Also, it might be possible to statistically determine magnitudes at which changes on explained variation would signal changes, if any, in trends of interest rates.

Table 1- Three Principal Components' Factor Loadings from Mexican Treasury Bills

**1996-1998**

	Eigenvector 1	Eigenvector 2	Eigenvector 3
28 days	0.4987	-0.6035	0.4813
90 days	0.5028	-0.2716	-0.212
182 days	0.5019	0.1436	-0.7176
360 days	0.4966	0.7358	0.4565
Explained Variation	0.9817	0.0129	0.0044

**1998-2000**

	Eigenvector 1	Eigenvector 2	Eigenvector 3
28 days	0.497	-0.6381	0.5632
90 days	0.503	-0.2883	-0.6074
182 days	0.5035	0.2636	-0.3667
360 days	0.4965	0.6635	0.4235
Explained Variation	0.9774	0.0194	0.0022

**2000-2002**

	Eigenvector 1	Eigenvector 2	Eigenvector 3
28 days	0.4972	0.676	0.5432
90 days	0.5026	0.2196	-0.7511
182 days	0.5028	-0.2304	-0.1332
360 days	0.4975	-0.6646	0.3506
Explained Variation	0.9848	0.0138	0.0009

**2002-2004**

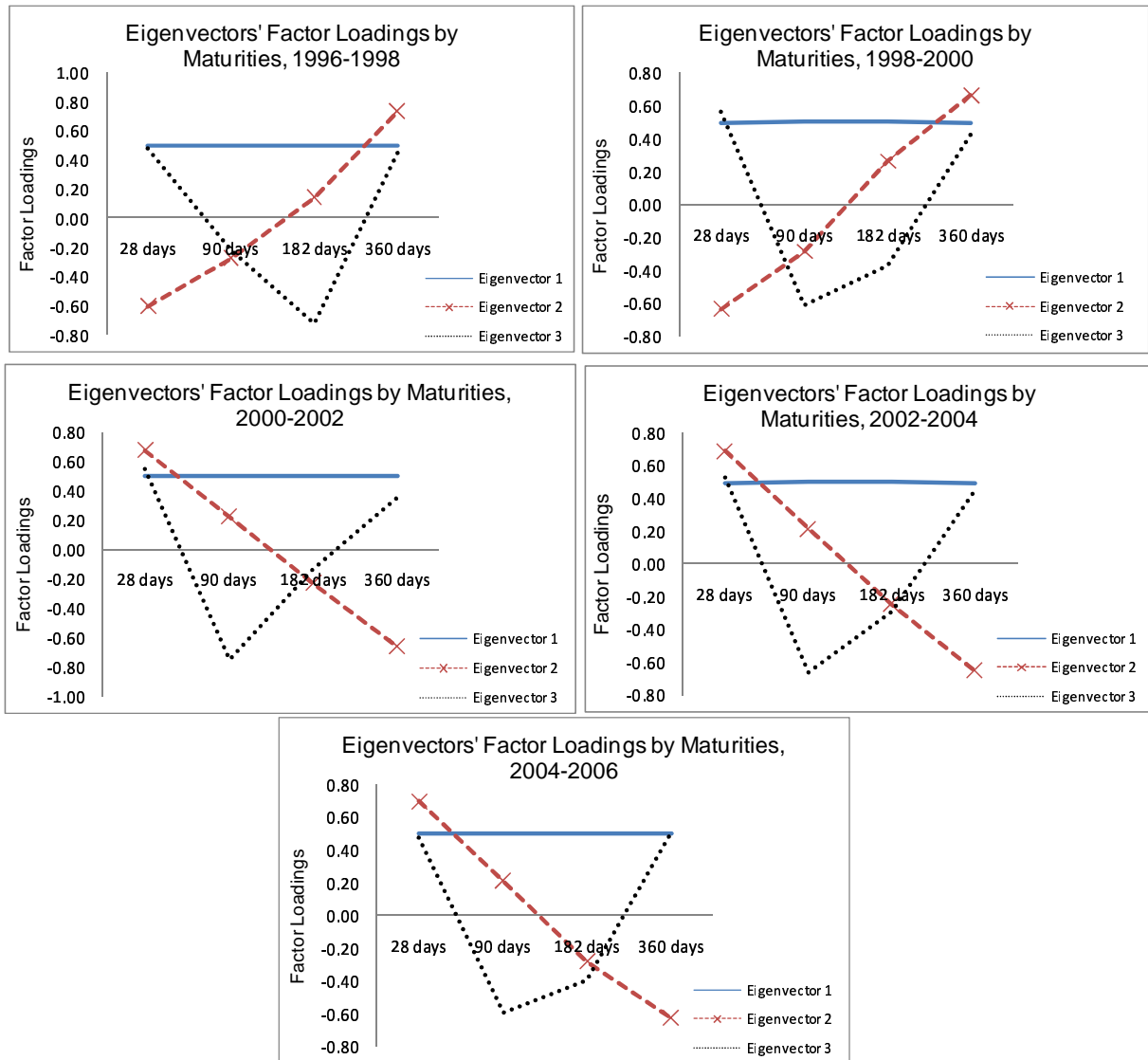
	Eigenvector 1	Eigenvector 2	Eigenvector 3
28 days	0.4953	0.6864	0.5239
90 days	0.5041	0.2124	-0.6611
182 days	0.5041	-0.2463	-0.2953
360 days	0.4964	-0.6505	0.4487
Explained Variation	0.9750	0.0218	0.0021

**2004-2006**

	Eigenvector 1	Eigenvector 2	Eigenvector 3
28 days	0.4978	0.697	0.4801
90 days	0.5019	0.2105	-0.5914
182 days	0.5016	-0.2807	-0.3952
360 days	0.4987	-0.6253	0.5134
Explained Variation	0.9896	0.0095	0.0005

**1996-1998:** 12/31/1996 – 12/23/1998; **1998-2000:** 12/31/1998 – 12/22/2000; **2000-2002:** 12/29/2000 – 12/23/2002; **2002-2004:** 12/31/2002 – 12/22/2004; **2004-2006:** 12/31/2004 – 12/21/2006

Figure 1- Shapes of the Three Principal Components' Factor Loadings for Mexican Treasury Bills



EXPLANATION ///Weekly Data

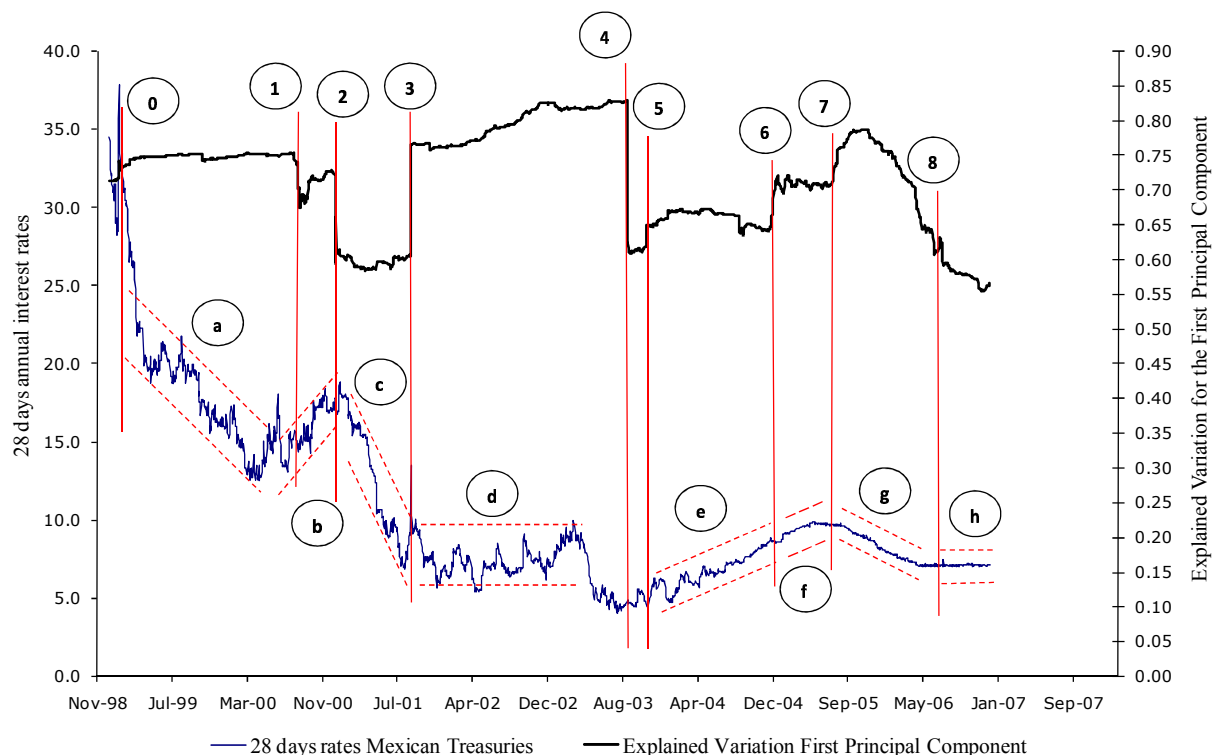
1996-1998: 12/31/1996 – 12/23/1998; 1998-2000: 12/31/1998 – 12/22/2000; 2000-2002: 12/29/2000 – 12/23/2002; 2002-2004: 12/31/2002 – 12/22/2004; 2004-2006: 12/31/2004 – 12/21/2006

Table 2 - Percentage of Successes of One-, Two-, and Three-Factors Models on Forecasting the Direction of Interest Rates Movements on Mexican Treasury Rates

$\theta$	28 days	90 days	182 days	360 days
Three- Factor Model				
0.00	84%	83%	84%	84%
0.05	88%	89%	90%	91%
0.10	89%	90%	92%	92%
0.15	89%	91%	92%	93%
Two-Factor Model				
0.00	83%	79%	81%	84%
One-Factor Model				
0.00	68%	73%	77%	61%

Table 2 shows the percentage of successes of our model (equation 7) in predicting the *direction* of interest rates by maturities in week  $t$  (i.e.,  $t$  from 105 to 521). To predict rates in week  $t$  one uses two-years of historical rates to extract common factors, and actual interest rates in  $t-1$ . The predictions were done 417 times with a dynamic algorithm as explained in section 2.  $\Theta$  represents transaction costs, defined as ----

Figure 2 - Actual Daily Interest Rates and First Principal Component, Mexico 1998-2006



**Explained variation of principal components** is estimated from the changes in interest rates rather than the actual values of interest rates.

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