EXPLORING THE SPANISH INTERBANK YIELD CURVE(*)

Autores: *Leandro Navarro*(**)
Enrique M. Quilis(***)

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(*) Any views expressed herein are those of the authors and not neccessarily those of the Instituto Nacional de Estadística (INE).

(**) Instituto Nacional de Estadística. Paseo de la Castellana, 183. 28046-Madrid (Spain) lenapa.con@ine.es.

(***) Instituto Nacional de Estadística. Paseo de la Castellana, 183. 28046-Madrid (Spain). emquilis@ine.es. [Corresponding author].

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ABSTRACT

Financial indicators play an important role in short-term monitoring due to its sensitivity to general macroeconomic conditions, their forward-looking nature, and also because of the fast availability of its data of very high frequency. In order to assess this role, we perform an econometric exploration of the interest rates of the Spanish interbank market. First, we estimate a transformation of their yield curve according to a VARMA model-based canonical and principal component analysis. The transformed indicators measure different and independent sources of variability of the observed yield curve and improve the interpretation and analysis of financial conditions. In the second step we analyze the stochastic properties of the transformed yield curve in order to asses their potential role for short-term monitoring, monetary policy, and risk management.

Keywords: yield curve, financial indicators, leading indicators, VARMA models, factor analysis, cointegration analysis.

JEL Code: C320, C430, E430, E320.

1. INTRODUCTION

Central bankers –and economic policymakers in general– are very interested in the evolution and determinants of interest rates of all maturities. Usually, the open market operations are aimed at a very short-term interest rate but many economic decisions related to investment and borrowing depend on the behavior of the long-term interest rates. As a consequence, the yield curve (a plot of interest rates as a function of maturity) is a basic element in the information framework of the monetary policy.

On one hand, from a macroeconomic point of view, interest rates at different maturities include expectations about the future stance of the monetary policy and, consequently, about future economic activity and inflation[1]. Due to this dependency on the future state of the economy, changes in the yield curve may operate as predictors of this state and therefore could be considered as leading indicators. (see Estrella and Mishkin (1996), Dombrosky and Haubrich (1996), Bernard and Gerlach (1996), Estrella et al (2000), Chauvet and Potter (2001), Wu (2001), Ang et al. (2003), among others).

On the other hand, asset managers –and their associated risk managers–, base their strategies on the evolution of interest rates at their different maturities due to their impact on the corresponding (discounted) prices. Therefore, asset allocation and risk management depend on the behaviour of the yield curve in order to set up optimal[2] portfolios and appropriate capital requirements to offset unexpected or extreme losses. Finally, if the exposure of the portfolio to movements in the yield curve has to be actively hedged[3], a proper understanding of its underlying characteristics is a basic feature.

The above mentioned reasons suggest that a better knowledge of the yield curve is relevant for many purposes. We perform an econometric exploration of the interest rates of the Spanish interbank market. We have selected this market due to its relevance in the transmission mechanism of the monetary policy, via the supply of credit of the banking system. First, we estimate a transformation of their yield curve according to a VARMA model-based canonical analysis. The transformed indicators measure different and

[1] Specially if central bankers follow monetary policy rules (e.g, Taylor rules), see Williams (2003) for an interesting analysis of these issues.

[2] Optimal in a mean-variance sense, with or without shrinkage constraints (Black and Litterman, 1992).

[3] Using financial derivatives, see Litterman (2003) for a forceful discussion.

independent sources of variability of the observed yield curve and improve the interpretation and analysis of financial conditions. In a second step we analyze the stochastic properties of the transformed yield curve in order to asses their potential role for short-term monitoring, monetary policy, and risk management.

The structure of the paper is as follows. In the second section we present some descriptive evidence on the statistical properties of the time series. In the third section we specify, estimate and validate a Vector Autoregression and Moving Average (VARMA) model for the joint system. Taking into account the fitted VARMA model, we define several linear transformations of the yield curve that shed some light on their underlying forces that drive it. These transformations and their stochastic properties are presented in the fourth section. In section five the main conclusions are presented.

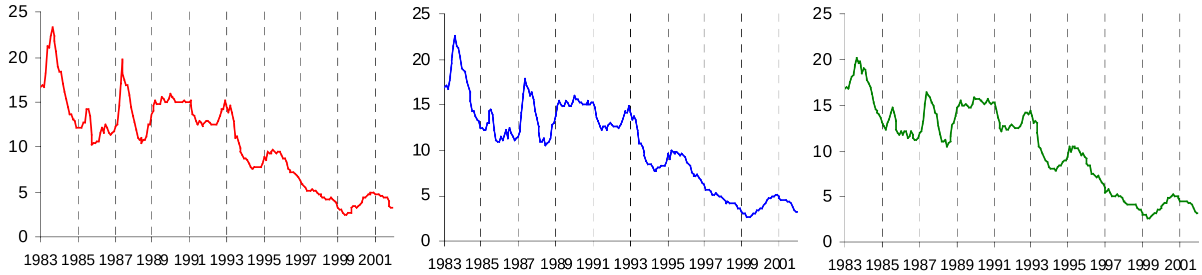
2. DESCRIPTION OF THE DATA.

Our study on the interest rates in Spain makes use of data on the monthly mean value of the three-, six- and twelve-month daily interbank deposit interest rates. Although data until May 2003 are available, the sample selected for our main analysis ranges from January 1983 till December 2001, consisting of 228 observations. The additional 29 observations are left aside for a posterior out-of-sample performance-test of the indicators resulting from our analysis. These results will be described in a separate study under elaboration.

As shown on figure 1, the three time series evolve around a downward trend, and present a high degree of synchronicity.

Figure 1

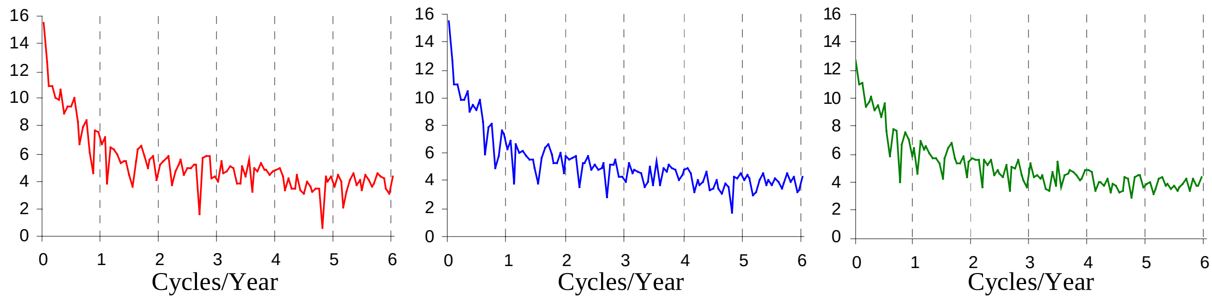
THREE-, SIX AND TWELVE-MONTH INTERBANK DEPOSIT RATES IN SPAIN. 1983-2001



The stochastic properties of the data may be explored by means of their periodograms. (See figure 2)

Figure 2

PERIODOGRAMS; THREE-, SIX AND TWELVE-MONTH INTERBANK DEPOSIT RATES IN SPAIN. 1983-2001



The periodograms suggest two basic facts; i) a dominant role of the low-frequency components of the series, which may be caused by the existence of a non-stationary trend, and ii) the complete absence of seasonal patterns, which is reflected by the non-appearance of spikes at the corresponding frequencies.

Furthermore, formal (parametric) unit-root tests confirm the presence of a non-stationary behavior. Both, the Augmented Dickey-Fuller and the Phillips-Perron tests do not fail to show that they are integrated processes of order one at the 1% level. (See table 1).

Table 1

TESTS FOR NON-STATIONARITY OF THE SERIES[a]

	Non-stationarity of the level		Non-stationarity of the 1st difference	
	ADF-Test[b]	PP-Test[c]	ADF-Test[b]	PP-Test[c]
3-Month	-3.866(*)	-2.851	-5.991(**)	-9.858(**)
6-Month	-3.401	-2.674	-5.885(**)	-9.467(**)
12-Month	-3.204	-2.471	-5.338(**)	-9.388(**)

Note: [a]The model includes a trend and an intercept. Critical values for ADF- and PP-Tests are those of MacKinnon (1991).

(*) Implies rejection of the hypothesis of an unit root at the 5%-level.

(**) at the 1% level. -- [b]Critical values for the ADF-Test: 1%: -4.0022; 5%: -3.4311; 10%: -3.1389. -- [c]Critical values for the PP-Test: 1%: -4.0015; 5%: -3.4307; 10%: -3.1387.

3. SPECIFICATION OF A MULTIVARIATE MODEL

In this section we consider a tentative specification, in which we use the class of vector autoregressive moving average model (VARMA), in order to obtain the most parsimonious representation of the dynamic relationships between the three interest rates. Then, following the methodology proposed by Tiao et al. (1993), we apply several canonical analysis to identify suitable and meaningful linear transformations of the original data.

The VARMA model is estimated on the original series, since, according to Chan and Wei (1988) and Tiao and Tsay (1990), it is not necessary to use differenced data when modeling unit-root non-stationary time series.

3.1. Model specification

Let $Z_t = (z_{1t}, \cdots, z_{kt})'$ be a k x 1 dimensional vector of observations which follows a VARMA process:

$$\Phi(B)Z_t = C + \Theta(B)a_t \qquad (1)$$

with $\Phi(B) = (I - \Phi_1 B - \cdots - \Phi_p B^p)$ and $\Theta(B) = (I - \Theta_1 B - \cdots - \Theta_q B^q)$, where B is the usual backshift operator, such that $BZ_t = Z_{t-1}$, I is a k x k identity matrix, p and q are non-negative integers, and the Φ_i's and Θ_j's are k x k matrices. Additionally, we allow the roots of the characteristic polynomials $|\Phi(B)|$ and $|\Theta(B)|$ to lie on or outside the unit circle.

Furthermore, let $a_t = (a_{1t}, \cdots, a_{kt})'$ be a sequence of random shocks that are identically distributed as a k-variate normal distribution with mean zero and positive definite k x k covariance matrix Σ. Finally, let C a k x 1 vector of constant terms. See Lütkepohl (1991) and Reinsel (1993) for a detailed analysis of VARMA models.

3.2. Model Identification

As in Tiao (2001), Liu (1986) and Liu and Hudak (1995), the identification of the underlying system dynamics is analyzed by way of cross-correlation, partial autoregression matrices and their related summary statistics[4]. Herein we employ a notation, which aims at summarizing the results obtained, assigning a plus (minus) when a coefficient is greater (less) than two times (minus two times) its estimated standard error, and a dot for intermediate values.

The cross-correlations of the three interbank data show a highly persistent pattern. From this one we can conclude that the series are not likely generated by a low order vector moving average (VMA), but by a pure vector autoregression (VAR) or a mixed VARMA model.

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[4] For a detailed description of the methodology, the reader should refer to Tiao (2001) and Liu and Hudak (1995) and the literature therein cited.

Table 2
PATTERN OF CROSS-CORRELATIONS OF THE INTERBANK DATA FOR SPAIN. 1983-2001

	Three-month	Six-month	Twelve-Month
Three-month	++++++++++++	++++++++++++	++++++++++++
Six-month	++++++++++++	++++++++++++	++++++++++++
Twelve-month	++++++++++++	++++++++++++	++++++++++++

Note: the cross-correlation pattern is shown up to lag twelve.

Taking this information into consideration, we perform stepwise autoregressions in order to determine the order of the VAR. The identification of the model is performed, in a first step, via the significance of the partial autocorrelation matrices Φ_ℓ, where ℓ is the lag of highest order of the partial autoregressions. If the vector series follow a VAR(p), then $\Phi_\ell = 0$, for $\ell > p$. As in Table 2, indicator symbols are employed for summarizing the partial significance of the coefficients. In a second step, we use the Akaike Information Criterion (AIC), and the likelihood statistic, $M(\ell)$, which is defined as

$$M(\ell) = -(N - 0.5 - \ell * k)\ln\left(\frac{|S(\ell)|}{|S(\ell-1)|}\right) \qquad (2)$$

where, N-0.5-l*k is the effective number of observations, $|S(\ell)|$ is the determinant of the residual sum of squares and cross products when a VAR of order ℓ is fitted to the series. Asymptotically, this statistic is distributed as a χ^2 with k^2 degrees of freedom.

Table 3
PARTIAL AUTOREGRESSION AND STATISTICS

Lag	Residual Variances	$M(\ell)$ Statistic $\sim\chi^2_9$ [a]	Akaike Information Criterion	Partial AR Coefficients
1	0.309	1504.15	*-9.301*	+ · ·
	0.242			· + ·
	0.189			- + +
2	0.249	59.54	*-9.503*	· · ·
	0.195			· · ·
	0.149			· · ·

(Sigue)

(Continuación)

Lag	Residual Variances	$M(\ell)$ Statistic $\sim \chi^2_9$ [a]	Akaike Information Criterion	Partial AR Coefficients
3	0.241	24.30	*-9.540*	· - +
	0.191			· · ·
	0.148			· · ·
4	0.232	19.27	*-9.554*	· · ·
	0.184			+ - ·
	0.140			+ - ·
5	0.230	12.90	*-9.539*	· · ·
	0.181			· · ·
	0.137			· · ·
6	0.225	14.08	*-9.530*	· · ·
	0.178			· · ·
	0.136			· · ·
7	0.222	5.09	*-9.477*	· · ·
	0.175			· · ·
	0.136			· · ·
8	0.219	15.21	*-9.476*	· · ·
	0.174			· · ·
	0.133			· · ·

[a]The critical values for a χ^2 with 9 degrees of freedom are: 5%-level 16.9; 1%-level 21.7.

The visual inspection of the significance of the partial AR coefficients indicates that the model should be fitted with at least VAR of order four, coinciding so, at a 5% significance level, with the results of both the AIC and the $M(\ell)$ statistic. (Table 3) If all the weight of the identification is laid upon the $M(\ell)$ statistic, we would be tempted to use a VAR of lower order, i.e. a VAR(3), at a 1% confidence level. But the visual inspection of the cross-correlation matrices of the residuals of the model after successive autoregressive fits reveals the necessity of a full VAR(4). (Table 4).

Table 4

PATTERN OF CROSS-CORRELATION MATRICES OF RESIDUALS AFTER AUTOREGRESSIVE FITS.

Lag	1	2	3	4	5	6	7	8
				AR(1) Model				
	+ + +	+ + +	+ + +	. . .	. . .	. . .	- . .	- - .
	+ + +	+ + +	+ + +	. . .	. . .	. . .	- . .	- - -
	+ + +	+ + +	+ + +	. . .	. . .	. . .	. . .	. . .
				AR(2) Model				
	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .
	. . .	. . .	+ + +	. . .	. . .	. . .	. . .	. . .
	. . .	. . .	+ + +	. . .	. . .	. . .	. . .	. . .
				AR(3) Model				
	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .
	. . .	. . .	+ + +	. . .	. . .	. . .	. . .	. . .
	. . .	. . .	+ + +	. . .	. . .	. . .	. . .	. . .
				AR(4) Model				
	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .
	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .
	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .

The results of the estimation of the VAR(4) model by means of the exact maximum likelihood method of Hillmer and Tiao (1979) are displayed in the following table.

Table 5

MODEL ESTIMATION

	Estimates			**Std. Error**		
Φ_1	1.11	0.12	0.20	0.23	0.40	0.27
	0.15	1.01	0.23	0.20	0.34	0.23
	-0.35	0.83	0.88	0.17	0.29	0.19
Φ_2	-0.30	0.26	-0.46	0.30	0.46	0.32
	-0.03	-0.16	-0.23	0.26	0.40	0.27
	0.23	-0.54	-0.08	0.22	0.33	0.23
Φ_3	0.21	-0.53	0.56	0.30	0.48	0.32
	0.08	-0.22	0.34	0.26	0.41	0.27
	-0.16	0.27	0.10	0.22	0.34	0.23
Φ_4	0.15	-0.53	0.19	0.26	0.41	0.23
	0.13	-0.46	0.15	0.22	0.35	0.19
	0.24	-0.60	0.18	0.18	0.29	0.16
Γ/Σ^a	*1.00*	*0.95*	*0.83*			
	0.27	*1.00*	*0.93*			
	0.22	**0.20**	*1.00*			
	0.16	**0.15**	**0.14**			

[a]The upper-triangular elements of the matrix are the correlations between the errors (in cursive). The lower-triangular elements the covariance matrix (in black).

A last approach used to detect other, until now undetected, relationships between the time series is the smallest canonical correlation analysis (SCAN), as proposed by Tiao and Tsay (1985). After the VAR(4) fit, the residuals fail to show further relationships between the data. (Table 6).

Table 6

RESIDUALS: SIMPLIFIED SCAN TABLE

		MA-order Q								
		0	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**
AR-order p	0	O	O	O	O	O	O	O	O	O
	1	O	O	O	O	O	O	O	O	O
	2	O	O	O	O	O	O	O	O	O
	3	O	O	O	O	O	O	O	O	O
	4	O	O	O	O	O	O	O	O	O
	5	O	O	O	O	O	O	O	O	O
	6	O	O	O	O	O	O	O	O	O
	7	O	O	O	O	O	O	O	O	O
	8	O	O	O	O	O	O	O	O	O

Scalar significance symbols as in Tsay and Tiao (1985) and the literature therein cited. "x" stands for significance at the 1% level. "o" for non-significant values.

4. LINEAR TRANSFORMATIONS OF THE DATA.

A problem encountered in time-series analysis, as well as in signal-processing, is that of finding a suitable representation of multivariate data. Often, such a representation is obtained by means of a linear transformation. Although the quantitative methods available for this purpose are numerous[5] we will focus on two, principal component analysis (henceforth, PCA) and canonical correlation analysis (further, CCA)[6].

4.1. Principal Component Analysis

The basic goal of PCA is that of reducing the dimensionality of the data set. Furthermore, the representation reached by PCA constitutes an optimal linear, noise-reducing, representation of the data in the sense of the minimum mean squared error. Nonetheless, and departing from this basic goal of the reduction of

5 See, e.g., Friedman J.H. (1987).

6 See Tiao et al. (1993) for the details on this approach.

the dimensionality of the data, we take into account all the resulting components, as they can be useful in assessing the dynamic relationships between the series.

Table 7

PRINCIPAL COMPONENTS OF THE RESIDUALS

Principal Component	Eigenvalue	Variance Proportion	Cumulative Variance Proportion	Eigenvector		
				3-Month	6-Month	12-Month
1	0.5695	0.9337	0.934	0.67	0.58	0.45
2	0.3240	0.0531	0.987	-0.58	-0.04	0.81
3	0.0081	0.0132	1.000	0.45	-0.81	0.37

According to Tiao et al. (1993), the eigenvectors of the variance-covariance matrix of the residuals may be used to simplify the underlying structure of the data. Moreover, we define two additional variables, $Y_{S\,t} = Z_{2t} - Z_{1t}$ and $Y_{L\,t} = Z_{3t} - Z_{2t}$, which respectively stand for the short- and the long-end of the yield curve, and we denote the three components obtained by means of PCA with X_{it}, for i = 1, 2, 3. As can be seen from the eigenvectors in Table 7, Y_S and Y_L are approximately embedded in the last two components in the form,

$$X_{2t} \approx 0.8Y_{L\,t} + 0.6Y_{S\,t} + 0.2Z_{2t}, \qquad (3)$$

$$X_{3t} \approx 0.4(Y_{L\,t} - Y_{S\,t}). \qquad (4)$$

The results obtained are similar to those of Litterman and Scheinkman (1988), Knez et al. (1994), Bechikh (1998) and Reimers and Zerbs (1999), among others. So, the first principal component represents the general level of the interbank interest rates, reflecting the overall incidence of common macroeconomic factors, e.g. inflation. This factor accounts for most of the observed variability of the data.

Furthermore, the second component, although less powerful in terms of explained variance, takes into account the slope of the yield curve and may be related to the short-term influences of monetary policy (see Wu 2001 and 2003). In order to simplify the structure of this second component we employ a derived linear transformation of X_{2t}, which consists in,

$$X'_{2t} \approx 0.8Y_{L\,t} + 0.6Y_{S\,t}. \qquad (3')$$

Finally, the third component may be interpreted as a curvature factor linked to the underlying volatility of the interest rates[7]. This factor is more specific to the financial conditions than the other two.

[7] See Litterman et al. (1991) for an explanation.

4.2. Canonical Correlation Analysis

A useful class of linear transformations can be derived from CCA of the original time series, as proposed by Box and Tiao (1977). In this sense, let the vector ARMA in Eq. (1) be rewritten as,

$$Z_t = \hat{Z}_{t-1}(1) + a_t, \qquad (5)$$

where $\hat{Z}_{t-1}(1)$ stands for the one-step-ahead forecast of Z_t at time $t-1$ and a_t represents the corresponding orthogonal forecast error. If Z_t is stationary, then the covariance matrix satisfies,

$$\Gamma_Z = \Gamma_Z(1) + \Sigma_a \qquad (6)$$

Further, let $y_t = \Psi' Z_t$ be a linear transformation of the data, and let

$$\lambda_y = (\Psi' \Gamma_Z \Psi)^{-1} (\Psi' \Gamma_Z(1) \Psi) \qquad (7)$$

be a measure of the dynamic dependence of y_t. As shown in Tiao (2001), λ_y represents the eigenvalues of $(\Gamma_Z)^{-1}\Gamma_Z(1)$ and Ψ the appertaining eigenvectors. The maximum (minimum) "predictability" of the series is therefore associated to the largest eigenvalue $\lambda_{y\,MAX}$ $(\lambda_{y\,MIN})$. Two extreme results are worth being mentioned. An eigenvalue close to zero will be associated to a very stationary linear combination of Z_t, while, on the contrary, an eigenvalue close to one will yield a non-stationary component[8].

4.2.1. *Empirical results*

The CCA of the three interbank series yields two linear transformations, which, according to the size of their eigenvalues, are ranked according to their decreasing predictability.

Table 8

MEASURE OF PREDICTABILITY OF THE LINEAR TRANSFORMATIONS

Linear transformations	Eigenvalue (λ)	Eigenvector (Ψ)		
		3-Month	6-Month	12-Month
C_1	0.994	0.002	-0.296	0.955
C_2	0.865	-0.418	-0.389	0.821
C_3	0.289	0.454	-0.814	0.363

[8] For a more detailed description refer to the aforementioned literature.

The second component, C_2, can be regarded as equivalent to the second component of the PCA, as it constitutes a comparison between a linear combination of the short-and medium-term rates with the long-term rates, and therefore could be regarded as a proxy for the slope.

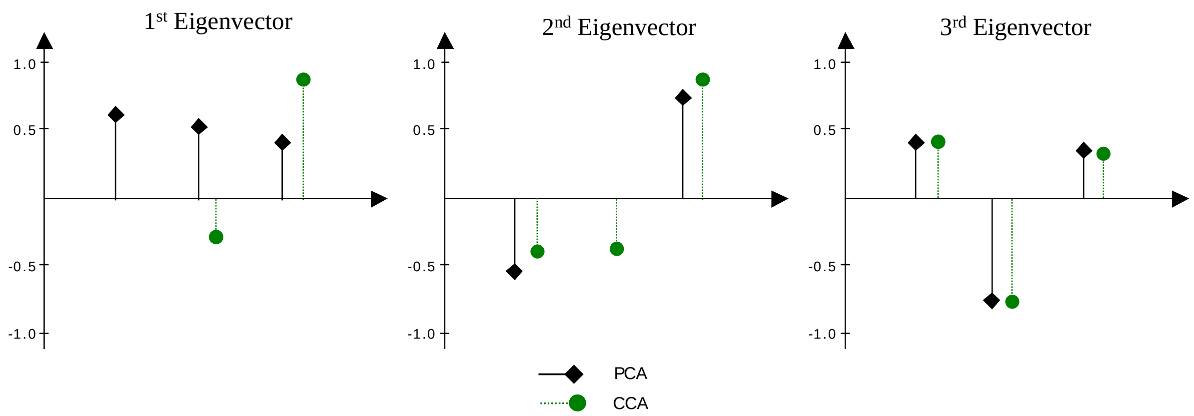
Furthermore, and identically to the third component in the PCA, the third canonical transformation of the data, C_3, establishes a comparison between the six-month interbank rate and the three-and twelve-month rates. This component stresses the importance of the medium-term and could be regarded as a proxy for the curvature of the yield curve, reflecting so its degree of convexity. Finally, the first component is highly loaded on the long-end of the yield curve.

Therefore, from the point of view of the predictability of the series, the long-term interest rate is the best summary of the trivariate series. This result is different from the one provided by PCA, which weights more evenly all the considered maturities of the yield curve.

The comparison of between the PCA and the CCA is exhibited in figure 3.

Figure 3

COMPARISON BETWEEN THE CCA AND PCA EIGENVECTORS



According to the PCA and CCA we consider four possible transformations of the yield curve for analysing its role in forecasting real activity.

$$\text{LEVEL}_t : \quad X_{1t} = 0.67Z_{1t} + 0.58Z_{2t} + 0.45Z_{3t} \qquad (8)$$

$$\text{LONG}_t : \quad C_{1t} = -0.30Z_{2t} + 0.955Z_{3t} \qquad (9)$$

$$\text{SLOPE}_t : \quad X'_{2t} = -0.58Z_{1t} - 0.20Z_{2t} + 0.81Z_{3t} \qquad (10)$$

$$\text{CURVE}_t : \quad X_{3t} = 0.45Z_{1t} - 0.81Z_{2t} + 0.37Z_{3t} \qquad (11)$$

The stochastic properties of these linear transformations are summarised in the following table.

Table 9

TESTS FOR NON-STATIONARITY OF THE SERIES

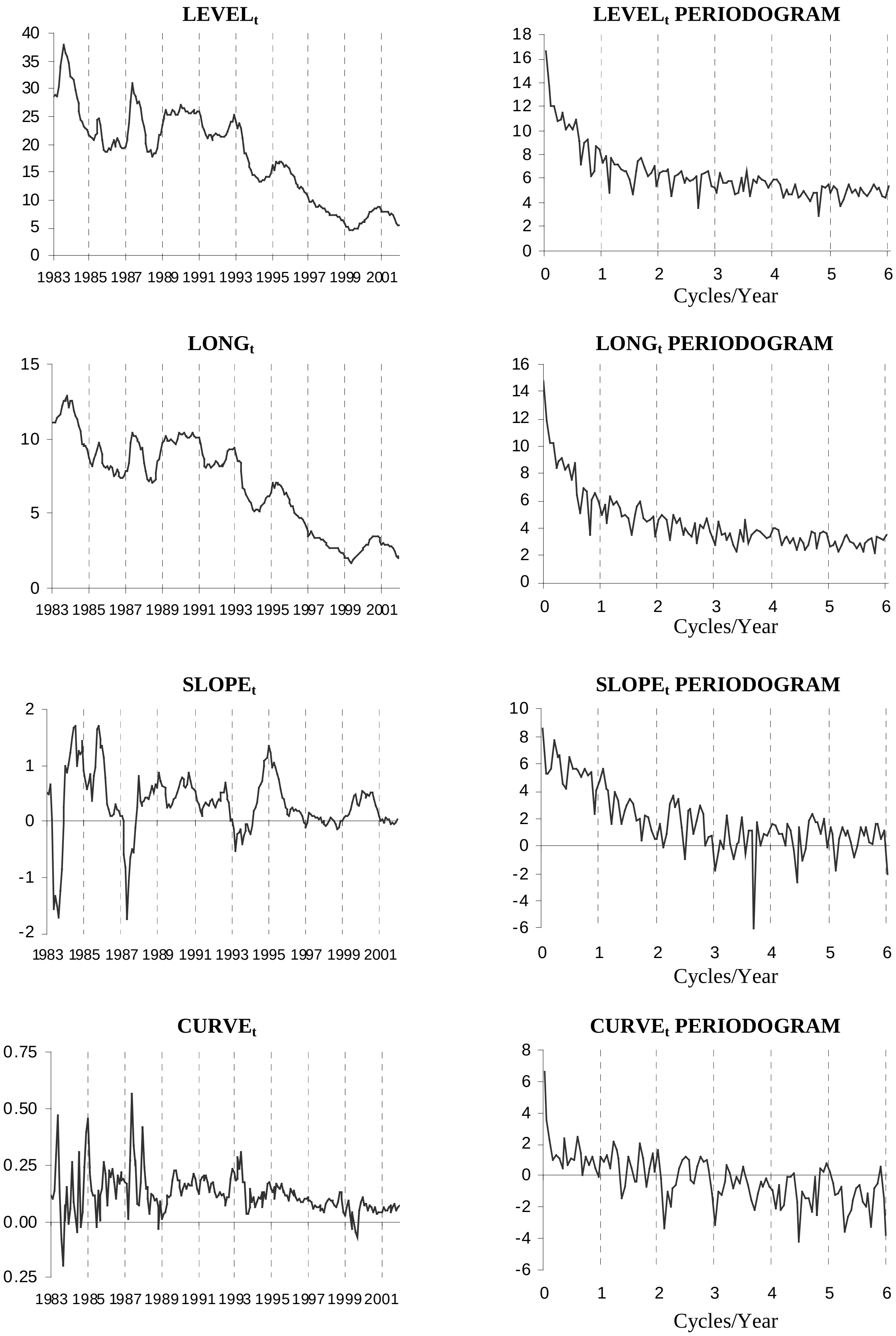
	Non-stationarity of the level		Non-stationarity of the 1st difference	
	ADF-Test	**PP-Test**	**ADF-Test**	**PP-Test**
LEVEL[a]	-3.413	-2.706	-6.084**	-9.423**
LONG[a]	-3.188	-2.409	-5.121**	-10.052**
SLOPE[b]	-3.914**	-3.452**	-7.414	-12.905
CURVE[c]	-4.392**	-12.712**	-8.994	-27.461

Note: The critical values employed are those of MacKinnon (1991). [a]Test with trend and intercept included in the model. [b]Test with no trend and no intercept. [c]Test with intercept included in the model. (*) Implies rejection of the hypothesis of an unit root at the 5%-level, (**) at the 1% level.

Combining the information provided by the formal tests (Table 9) with the periodograms (Figure 4) we may conclude that both $level_t$ and $long_t$ are alternative non-stationary common trends of the data while both $slope_t$ and $curve_t$ are both stationary and hence estimators of the cointegrating relationships of the system. It is worth noting that the stationary transformations are affected by a change in their volatility around 1989. To check this issue we should perform an ARCH (Autoregressive Conditional Heterokesdaticity) analysis that is beyond the scope of this paper.

Figure 4

LINEAR TRANSFORMATIONS OF THE DATA



5. CONCLUSIONS

The econometric analysis performed in this paper suggests the presence of three underlying factors explaining the movements of the yield curve of the Spanish interbank market. These factors are linked to linear transformations of the original curve, differing among them not only in their statistical properties, but also in their theoretical interpretation.

In the first place, a non-stationary common factor has been detected. This factor, called “level”, characterizes most of the joint variance of the series and synthetizes the essential conditions of the interbank market, reflecting the nominal (i.e., inflationary) influences which have an incidence on the level of nominal interest rates (see, McCandless and Weber, 1995 and Mannet and Weber, 2001).

Further, we have identified two cointegrating relationships. The first one, called “slope”, is a contrast between the long and the short ends of the yield curve, and reflects the different elements which exert an influence on it: monetary impulses in the short end and expectations about the future stance of monetary policy in the long end. These expectations can be interpreted as a forward-looking projection of the evolution of output, inflation and of the most likely response of the monetary authorities. Therefore, this slope or spread factor has been cited by many authors as a very useful indicator of the state of the transmission mechanism of monetary policy, as well as a leading indicator of recessions (see, i.e. Tiao, *et al*., 1993).

Furthermore, the second cointegrating relationship is embedded in a third factor, called “curvature”, which consists in a weighted difference between the medium and the extreme ends of the yield curve. This curvature component is closely related to the volatility of the interest rates and, consequently, may be associated with the idiosyncratic elements of the interbank market (see Litterman *et al*., 1991).

Finally, since the long end of the yield curve is the most predictable synthesis of the system, its role should be emphasized. This result confirms the relevance usually granted by the economic agents to the long term interest rates as one of the prevailing determinants of investment and borrowing decisions.

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