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Physica A 350 (2005) 418–426
PHYSICA A
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The long-range dependence behavior of the term structure of interest rates in Japan

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Received 7 October 2004; received in revised form 12 November 2004
Available online 18 December 2004

Abstract

This paper presents an empirical evidence suggesting that Japanese interest rates for different maturities possess long-range dependence in both mean and volatility. For long-term bonds, predictability in the term structure of interest rates increases with maturity, suggesting that there exists a term premium. Furthermore, the dynamics of short-term interest rates (6 months) is very different from longer term bonds, as the former are anti-persistent, which implies that the zero-interest rate policy is perceived to be temporary.

PACS: 05.45. Df; 05.45. Tp

Keywords: Emerging markets; Hurst exponent; GARCH; Long-range dependence

1. Introduction

This study investigates the presence of long-range dependence in a variety of Japanese interest rates (6 months to 20-year maturity interest rates) from the beginning of 1992 to July, 2004. In general, the analysis of persistence in interest

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0378-4371/$ - see front matter
doi:10.1016/j.physa.2004.11.048

rates is a fundamental question in macroeconomics and finance. For example, in macroeconomics, since monetary policy is implemented through the setting of short-term interest, interest rates are crucial to the conduction of monetary policy in most countries. On the other hand, in finance, since most portfolio models include interest rate as a fundamental parameter, interest rate movements are essential to make investment decisions.

This research is particularly interesting for the Japanese economy since during the time span of this research, interest rates have been the main instruments to stimulate the economy recovery. To be more precise, it is interesting to review briefly some important facts that happened in this period in the Japanese Economy.[1] In the beginning of 1990, the Japanese economy went to a recession after the bubble burst that occurred in January, 1990.[2] Since then, the Japanese Central Bank has put into operation several efforts to recover the economy. In 1991, the official discount rate was dropped from 6.0 to 5.5% and continued falling until reaching the value of 0.5% on September 8, 1995. Weak recovery of the economy made the Japanese Central Bank to implement a zero interest policy from February 12, 1999. This policy was abandoned on August 11, 2002. Actually, this kind of policy is very restrictive, since the central bank is not able anymore to stimulate the economy via the nominal interest rate setting (this phenomena is called *liquidity trap*).

In this context, this paper studies the long-range dependence behavior of the term structure of interest rates in Japan. Using the local Whittle method due to [6] as our measure of long-range dependence, we have found a very interesting pattern regarding the long-range dependence behavior of the term structure of interest rates in Japan which was not presented in the literature yet.

Actually, while the presence of long-range dependence in equity asset returns seems to be a stylized fact,[3] only few papers have provided empirical evidence of long-range dependence in interest rates. The first to consider the existence of long memory in interest rates seems to be Backus and Zin (1993) [1] who found evidence of long memory in the 3-month zero-coupon rate for the US, and that allowing for long memory in the short interest rate improves the fitted mean and volatility yield curves. Since then, others have supported Backus and Zin's results, see for example Refs. [2,3,8].

This paper proceeds as follows. In Section 2, the local Whittle method which is our measure of long range is reviewed. In Section 3, the data are described. In Section 4, the results of this paper are presented. Finally, in Section 5, this paper is concluded.

2. The local Whittle estimator

In this paper, the local Whittle estimator due to Ref. [6] is used to provide Hurst's exponent H.

[1] A more detailed description of the Japanese economy in this period may be found in Ref. [5].

[2] The Nikkei average recorded its highest-ever value (38,916 yen) in December, 1989.

[3] For details, see Ref. [4].

The local Whittle estimator is a semi-parametric estimator, which only requires specifying the parametric form of the spectral density when the frequency λ is close to zero,

$$f(\lambda) \sim G(H)|\lambda|^{1-2H} \quad \text{as } \lambda \to 0\,, \tag{1}$$

where $G(H)$ is a constant. The computation involves an additional parameter m, an integer less than $N/2$, where N is the size of the time series, and such that, as $N \to \infty$,

$$\frac{1}{m} + \frac{m}{N} \to 0\,. \tag{2}$$

This means that as N gets large, m gets large as well, although slower. For a spectral density of form (1), the Whittle approximation of the Gaussian likelihood function is obtained by minimizing

$$Q(G,H) = \frac{1}{m}\sum_{j=1}^{m}\left(\frac{I(\lambda_j)}{G\lambda_j^{1-2H}} + \log(G\lambda_j^{1-2H})\right), \tag{3}$$

where $\lambda_j = 2\pi j/N$ and $I(\lambda_j)$ is periodogram. So this estimator sums the frequencies only up to $2\pi m/N$.

Replacing above G by its estimate $\hat{G}$,

$$\hat{G} = \frac{1}{m}\sum_{j=1}^{m}\frac{I(\lambda_j)}{\lambda_j^{1-2H}}\,. \tag{4}$$

One may define

$$R(H) = Q(\hat{G},H) - 1 = \log\left(\frac{1}{m}\sum_{j=1}^{m}\frac{I(\lambda)}{\lambda_j^{1-2H}} - \frac{2H-1}{m}\sum_{j=1}^{m}\log(\lambda_j)\right). \tag{5}$$

It is shown [6] that under certain technical assumptions,

$$\hat{H} = \arg\min R(H) \tag{6}$$

converges in probability to actual value H, i.e.,

$$m^{1/2}(\hat{H} - H) \to_{\mathrm{d}} \mathrm{Normal}(0, \tfrac{1}{4})\,. \tag{7}$$

Therefore, the choice of m is quite important. The larger the value of m, the faster $\hat{H}$ converges to H. On the other hand, if the series also presents short-range behavior, then m should be small. In this paper, in order to ensure faster convergence of $\hat{H}$ to H, the limiting value of $m = N/2 - 1$ is used.[4]

[4] One should note that using this limiting value of m, larger frequencies are not considered. Therefore, the short-range dependence phenomena is not affecting our conclusions.

Table 1
Bloomberg codes for the Japanese interest rates used in this paper

Bloomberg code	Maturity (in months)
GJTB6MO	6
GJGB2	24
GJGB3	36
GJGB4	48
GJGB5	60
GJGB7	84
GJGB10	120
GJGB15	180
GJGB20	240

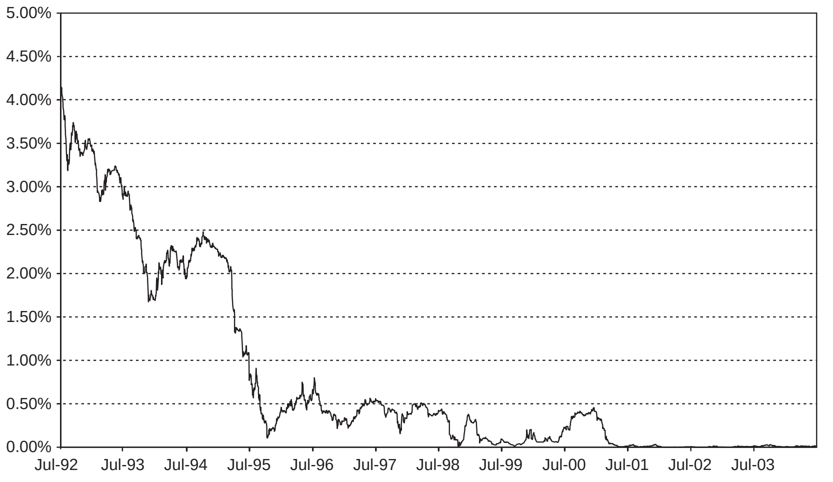

Fig. 1. Daily yields to maturity for the 6-months interest rate.

3. Data

The data consist of daily observations on Japanese interest rates over the period from July 10, 1992 to July 7, 2004 (an average of 2960 observations).

The data were extracted from the Bloomberg database system. In Table 1 we present the Bloomberg codes for each one of these interest rates with the time to maturity (Fig. 1). Each one of these series was constructed by pasting together "rolling" on-the-run bonds for each maturity.[5]

[5]On-the-run securities are those which are the most recently issued government debt securities.

4. Results

The main results of this paper may be found in Fig. 4. In this figure, one may see that interest rates with maturities between 6 and 24 months present increasing Hurst's exponents from 0.425 to above 0.575. These results suggest that the dynamics of short-term interest rates is very different from long-term interest rates in Japan, which confirms that studying the entire yield curve is of crucial importance, rather than focusing on a single maturity.

Short-term interest rates are anti-persistent ($H < 0.5$) while longer term bonds are mainly persistent ($H > 0.5$). These results suggest that the zero-interest rate policy is perceived to be temporary by economic agents. Moreover, the antipersistent behavior of interest rates with short maturities in Japan may reflect the abrupt change of their value on September 8, 1995 and again on August 11, 2002 (Fig. 2).

If we focus on the end of the yield curve it is striking that interest rates with maturities between 7 and 20 years present monotonically increasing Hurst's exponents from 0.525 to above 0.60 (Fig. 3). These results indicate that interest rates with low maturities present a different statistical behavior from interest rates with long maturities. On the other hand, the pattern of rising of Hurst's exponents for interest rates with long maturities may argue that these interest rates increase in predictability, i.e., longer maturity interest rates are more predictable than shorter maturity interest rates.

The intriguing behavior of interest rates in Japan, as described above, is probably explained by the nonnegativity constraint in the interest rate. In Ref. [7], it is pointed out that this constraint implies (1) a nonlinear and convex relation between the long-term interest rate and the level and standard deviation of the short-term interest rate; (2) the response of long-term interest rates to changes in the short-term rate is

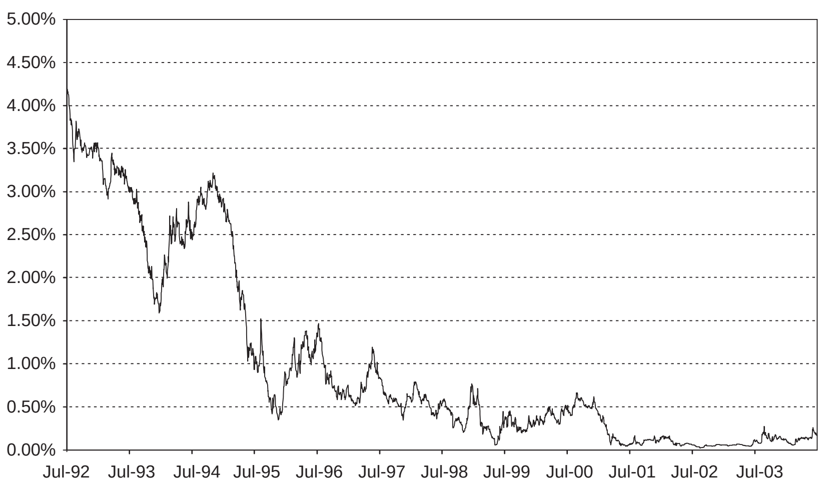

Fig. 2. Daily yields to maturity for the 2-years interest rate.

Fig. 3. Daily yields to maturity for the 20-year interest rate.

asymmetric;[6] (3) the response of long-term rates to changes in the short-term rate (whether an increase or a decrease) is smaller in the neighborhood of the zero lower bound, specially for longer maturities; (4) the yield curve becomes steeper as the short-term interest rate approaches zero.[7] Hence, their forecasts of future short-term interest rates are above the current rate and the spread between current long- and short-term rates increases.

Another interpretation for the positive slope in the Hurst exponents curve is that there is a positive risk premium for longer maturity bonds, which is reflected in a higher predictability. Therefore, this increase in predictability could be fully rational. Furthermore, an active debt management strategy pursued by the Japanese Ministry of Finance or the Central Bank, focusing on a particular range of maturities could influence the dynamics of these interest rates as well, and is certainly an interesting route to explore in further research. An in-depth analysis of the Japanese government debt market microstructure is beyond the scope of this paper, but would certainly substantially increase our understanding of this phenomena.

In Figs. 4 and 5 we present the Hurst exponents estimated on absolute changes of interest rates for each maturity, which is used as a proxy for volatility. As we can see the dynamics of the short-term interest rate is different from the rest of the curve, while there seems to be a small positive trend in the predictability of interest rates depending on the maturity. These results have important implications for option pricing and risk management.

[6] A decrease in the short-term rate produces a smaller response (in absolute value) in the long-term rate than an increase of the same magnitude.

[7] The reason is that when the short-term interest rate is close to zero, agents understand that the range of its possible future realization is larger above than below the current rate.

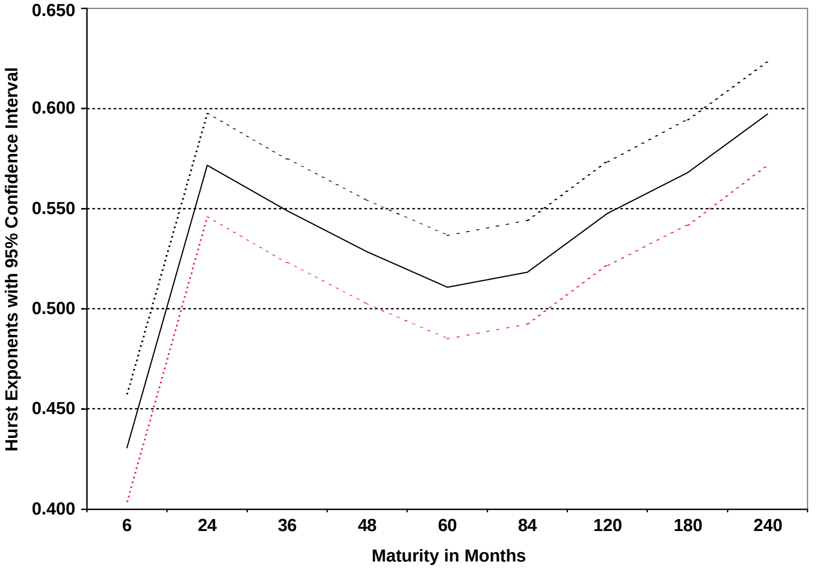

Fig. 4. Hurst's exponent evaluated for the Japanese term structure of interest rates. The mid-line stands for the estimated Hurst exponent with upper and lower limits at the 95% confidence level.

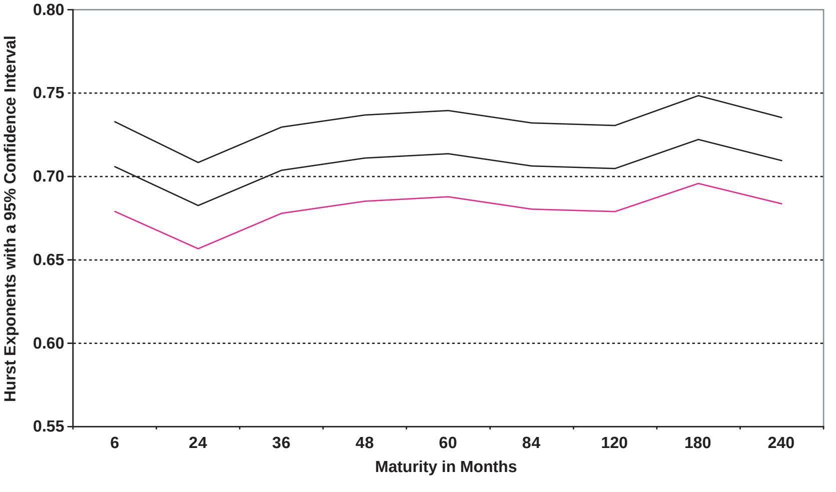

Fig. 5. Hurst's exponent evaluated for the volatility of the Japanese term structure of interest rates. The mid-line stands for the estimated Hurst exponent with upper and lower limits at the 95% confidence level.

In Tables 2 and 3 we present Hurst exponents and standard errors for each maturity for changes in interest rates and the absolute value of changes in interest rates (proxy for volatility of interest rates). A Wald statistic was employed to test the hypothesis that $H = 0.5$ (no predictability in interest rates). As we can see only in

Table 2
Hurst exponents for changes in interest rates

Maturity (in months)	Hurst	Std. error	Wald	*P*-value
6	0.431	0.013	26.56	0.00
24	0.572	0.013	30.76	0.00
36	0.549	0.013	14.38	0.00
48	0.529	0.013	4.89	0.03
60	0.511	0.013	0.71	0.40
84	0.518	0.013	2.02	0.15
120	0.548	0.013	13.61	0.00
180	0.568	0.013	26.72	0.00
240	0.597	0.013	56.77	0.00

Table 3
Hurst exponents for volatility of interest rates

Maturity (in months)	Hurst	Std. error	Wald	*P*-value
6	0.706	0.013	234.53	0.00
24	0.683	0.013	199.59	0.00
36	0.704	0.013	248.87	0.00
48	0.711	0.013	266.80	0.00
60	0.714	0.013	273.49	0.00
84	0.706	0.013	254.91	0.00
120	0.705	0.013	251.38	0.00
180	0.722	0.013	284.63	0.00
240	0.709	0.013	263.14	0.00

two cases this hypothesis is rejected, which coincide in Fig. 4 with the middle of the term structure, which has the Hurst exponent $H = 0.5$ inside the 95% confidence interval. On the other hand, the rejection of absence of long-range dependence is striking for interest rates' volatility.

5. Conclusion

In this paper, we have found a very interesting pattern regarding the long-range dependence behavior of the term structure of interest rates in Japan. Short-term interest rates were found to be anti-persistent, which can be interpreted as a perception that the zero-interest rate policy is temporary. On the other hand, for longer maturity bonds Hurst exponents (and therefore predictability) increase monotonically with maturity, and this result is in line with a higher risk premium for longer maturity bonds. Therefore, risk premium for interest rates in Japan seem to be increasing with maturity.

The results presented in this paper suggest a highly significant role for long-range dependence studies. It is possible to uncover the dynamics of interest rates and improve our understanding of the term structure of interest rates, which is crucial to the understanding of the economy. Two lines of future research are suggested. The first is related to deepen our understanding of the government debt market microstructure and its relation with long-range dependence and predictability. The other line of research relates to the role of the dynamics of the debt management strategy and its impact on the dynamics of interest rates.

The results presented in this paper have important implications in many areas. If interest rates possess long-range dependence in mean then one could improve forecasting on the term structure. Furthermore, macroeconomics models should take this feature into account. Additionally, the strong long-range dependence found in volatility of interest rates implies that this feature should be taken into account in best risk management practices and portfolio management and on option pricing.

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