Review of Applied Economics, Vol. 3, No. 1-2, (2007) : 61-78

AN EMPIRICAL STUDY OF THE CHINESE SHORT-TERM INTEREST RATE: A COMPARISON OF THE PREDICTIVE POWER OF RIVAL ONE-FACTOR MODELS

***Hai Yan Xu*[*]*, Bert D. Ward*[**] *& Gilbert Nartea*[***]

This paper uses the one-factor models proposed by Chan, Karolyi, Longstaff and Sanders (CKLS, 1992) to study the short-term interest rate in China. Nine stochastic models of the short-term interest rate were estimated with GMM. For the Chinese one-month inter bank loan rate, the research finds strong evidence for a mean-reverting feature in the short-term interest yield curve, but no evidence was found to indicate that the volatility is highly positively correlated with the level of interest rates. What is more, evidence was found that the CKLS model, the CIR SR model, and the Brennan-Schwartz model are correctly specified to model the Chinese short-term interest rate, so that these three models are able to adequately capture the dynamics of this interest rate. Finally, Theil's U2 statistics and the Diebold and Mariano test were applied to explicitly evaluate the predictive power of the single factor models.

JEL Classification: *C52; E43*

Keywords: *single-factor models, mean reversion, GMM estimation*

INTRODUCTION

The short-term interest rate plays a vital role in many financial areas and it has strong implications for the pricing of fixed income securities and interest rate derivatives, such as bond pricing models, derivative security pricing models etc. What is more, it also has been used in general asset pricing (Cochrane, 2001) and as an input in macroeconomic models, e.g. in the analysis of the business cycle. It is also an important target instrument for monetary authorities in implementing monetary policy and a key indicator monitored by financial institutions in pricing floating rate loans. In addition, valuation of more exotic interest rate derivatives such as American style swap options, callable bonds and structured notes rely on term structure models, some of which can be constructed by specifying the behaviour of short-term interest rates. Therefore, modelling of interest rate dynamics has become a very hot topic for many researchers to work on in this field. As a result, many term structure models have developed to estimate the short-

* Economic Statistician, Statistics, New Zealand

** Economics and Finance Group, Commerce Division, PO Box 84, Lincoln University, New Zealand, *E-mail: wardb@lincoln.ac.nz*

*** Economics and Finance Group, Commerce Division, PO Box 84, Lincoln University, New Zealand, *E-mail: narteag@lincoln.ac.nz*

term interest rate dynamics in recent years. The spot rate term structure modelling approach assumes that spot interest rates are sufficient statistics for the stochastic movement of current term structure, so that the price of bonds and interest rate derivatives securities can be derived in terms of the spot rate. In general, the term structure models can be broadly categorized into three groups (Litterman and Scheinkman, 1991).

The first group contains the single factor models proposed by Chan, Karolyi, Longstaff and Sanders (CKLS 1992). The model provides a simple description of the stochastic nature of interest rates that is consistent with the empirical observation that interest rates tend to be mean-reverting. The one factor models have been widely used in practice due to their tractability and their ability to fit the dynamics of the short-term interest rates reasonably well. Group 2 is made up of the two-factor models which aim to better capture the rich yield curve structure by invoking another source of randomness. Longstaff and Schwartz (1992) and Chen and Scott (1992) developed continuous-time two-factor models along the line of CIR (Cox, Ingersoll and Ross, 1985) that can incorporate random volatility in the evolution for the short-term interest rate and offer an analytical solution for bonds and other interest rate derivatives. What is more, Brenner et al (1996) showed that interest rate models that include both a level effect (where the interest rate volatility is a function of its level) and a Generalized Autoregressive Conditional Heteroscedasticity (GARCH) specification outperform those models that exclude these features. Models in group 3 consist of the three-factor models developed recently by researchers to study the behaviour of short-term interest rates. For instance, Litterman and Scheinkman (1991) argued that at least three factors are needed to fully capture the variability of interest rates. In another important study, Chen (1996) developed a three-factor model and showed that the three-factor model can be merged into the Heath, Jarrow and Morton (HJM, 1992) framework. However, although the three-factor models can be made to better fit the term-structure of interest rates, they are generally more difficult to apply. This is principally due to the fact that the underlying state variables of the HJM models are un-observable quantities, and the dynamics are usually non-Markovian and non-linear in their (latent) state variables (HJM, 1992).

Obviously, the more advanced models such as multifactor models and HJM models have the advantage of modelling the reality more precisely, but they may suffer from complications, even impossibility, in implementation. In contrast, single-factor models constitute a relatively simple class of models where the whole term structure is driven by a single state variable, the short-term interest rate. Thus, in current literature it contains many papers using one factor models to study short-term interest rates. For example, Chan *et al.* (1992) studied U.S short-term rates, Treepongkaruna and Gray (2002) applied one factor models to estimate short-term rates for eight major countries, Tse (1995) and Dahlquist (1996) extended the analysis of CKLS to international short-term interest rates, Murphy (1995) studied UK short-term interest rates, and the New Zealand short-term interest rate was studied by Treerongkaruna (2003). However, a literature search revealed that there are few papers studying China short-term interest rates. For example, Xie and Wu (2002) empirically tested the Vasicek model and the CIR model by the one-month inter-bank interest rate, while Fan and Fang (2002) empirically analyzed the pricing of convertible bonds in China. In another study, Zheng and Lin (2003) estimated the term structure, liquidity premium and credit risk premium in China's bond market, but the models were all static approximations and did not test the dynamic behaviour of the short-term interest rate in China.

Since accurate interest rate forecasts are crucial for savings and investment decisions as well as for macroeconomic and monetary policy decisions, another aim of this paper is to explicitly show the predictive power among the one factor models. In the current literature it shows that many researchers use the Nelson-Siegel (1987) exponential components framework to distil the entire yield curve, period by period. A number of authors have explored the model's performance in out-of-sample yield curve forecasting by re-interpreting the Nelson–Siegel yield curve as a modern three-factor dynamic model of level, slope and curvature. Other researchers have proposed extensions to Nelson-Siegel to enhance flexibility, including Bliss (1997b), Soderlind and Svensson (1997), Bjork and Christensen (1999), Filipovic (1999, 2000), Bjork (2000), and Bjork and Landen (2000). In particular, they showed that forecasts appear much more accurate at long horizons than various standard benchmark forecasts. However, China was using a centrally planned economic policy and China's interest rate was thus controlled by the government. Thus, in the past literature it is hard to find a paper that compares the predictive power of single factor models for Chinese short-term interest rates.

This paper is designed to empirically study China's short-term yield curve and test if the one factor models have the ability to capture the dynamic nature of the short-term interest rate for China. Moreover, this study focuses on the comparison of the predictive power of the rival one-factor term structure models for the Chinese short-term interest rates. If the single factor models analysed in CKLS (1992) are able to characterize the behaviour of China's short-term interest rate, we would compare the predictive power of the single factor models. We carried out an empirical study based on one-month Chinese inter bank loan rates over the past two years. In order to achieve this objective, this paper has applied the generalized method of moments (GMM) for estimation of the one factor models and for the forecasting test, Theil's U2 statistics and the Diebold and Mariano forecasting test (DM) are also used.

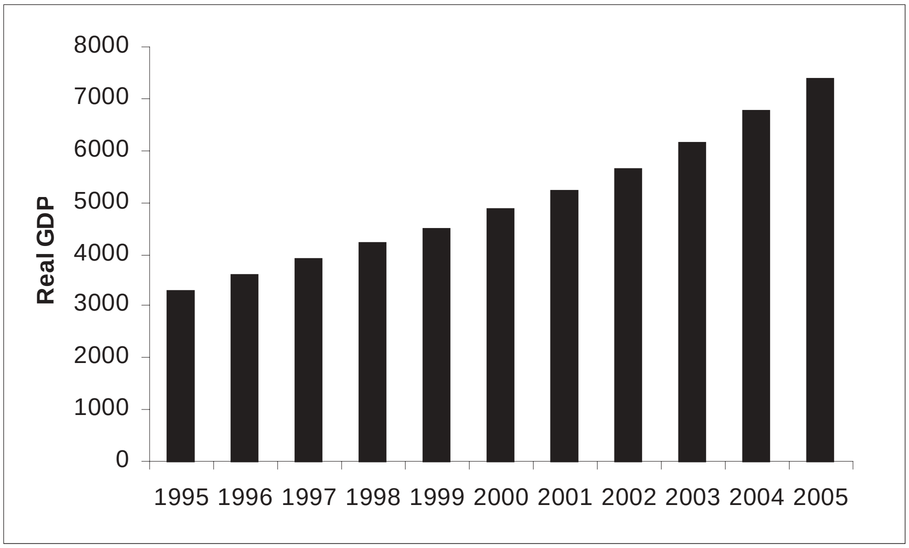
The remainder of this paper is structured as follows. Section 2 presents an overview of China's economy. Following that, Section 3 discusses methodological approach and describes the data set used for the empirical analysis. The fourth section presents the results of the study, and Section 5 concludes with a discussion of these results.

OVERVIEW OF THE CHINESE ECONOMY

In late 1978 the Chinese leadership began moving the economy from a sluggish, inefficient, Soviet-style centrally planned economy to a more market-oriented system. Since shifting to an open-door and reform policy in the late 1970s, China has entered a period of high economic growth. Because of the rapid economic growth, China has emerged as a potential economic powerhouse in the Asia-Pacific region. Figure 1 shows the Chinese real gross domestic product (GDP) in the last 10 years.

From Figure 1 it can be seen that real GDP grew continuously at a fast pace. The real GDP in 2005 is more than twice its size in 1995. However, we can hardly lose sight of the fact that the growth in net exports is the main force driving the Chinese economy's growth. Undoubtedly, China's comparative advantage lies in its abundant cheap labour supply. Therefore, China's industrialization increases the supply of labour-intensive goods to international markets while raising the demand for capital and technology-intensive goods, leading to a decline in the prices.

Figure 1
China's Read GDP



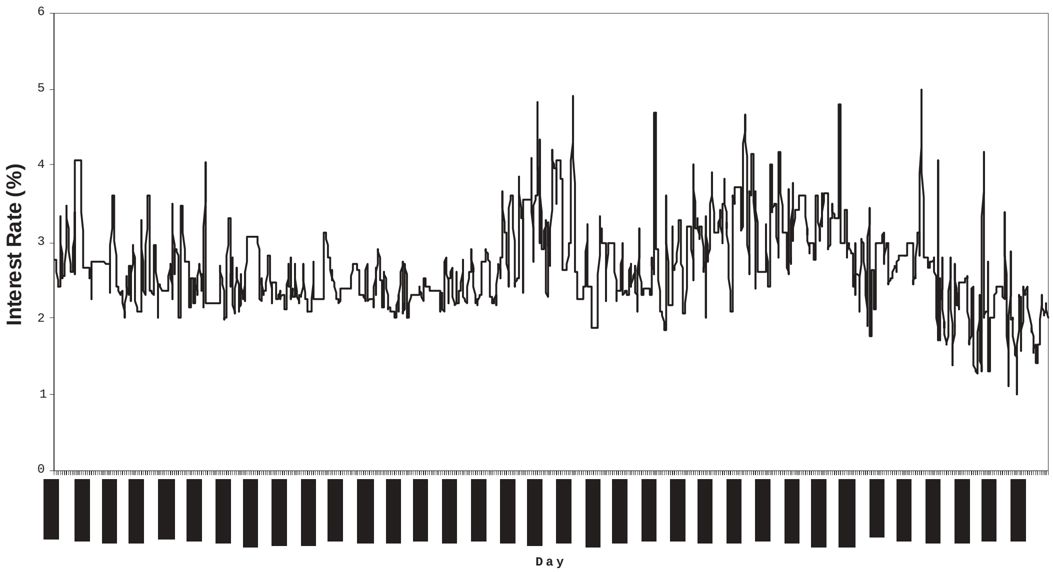
Source: Datastream. Units of measurement are billion yuans.

In some ways the pegged exchange rate can lead to growth in net exports, but a pegged exchange rate policy is not appropriate for a major economy in the global system such as China (Laurenceson and Qin 2005). Therefore, recently China started switching from the pegged exchange rate to a more flexible exchange rate regime. However, under interest rate parity conditions (CIP and UIP), it can be seen that the exchange rate is closely related to the interest rate (Copeland, 2005). For example if the interest rate in China is high, making the earning in interest rate differential much larger in absolute value than the loss in foreign exchange, arbitrage will appear. Then large amount of funds would flow from foreign countries into China, putting pressure on China to lower its interest rate. Therefore, the dynamic behaviour of China's short-term interest rate is very critical in terms of real GDP growth and the exchange rate. Even though exchange rate policy for China is still an open question, this study will leave this problem and focus on studying the short-term interest rate in China.

By the nature of the Chinese market, we have to employ China's inter-bank loan rate as an approximation of a risk free rate. In recent years the overall trend for the Chinese one month inter-bank loan rate is not very volatile, ranging from a minimum of about 1% to a maximum of approximately 5% as shown in Figure 2.

Figure 2 shows that during 2002 the interest rate was relatively low, being just above 2%. Since then, however, the interest rate has started climbing and eventually in 2005 the interest rate reached its highest point, which is approximately 5%. Thereafter, the interest rate started falling in later 2005. Moreover, the material in Figure 2 suggests that increases in the Chinese one month interbank loan rate tend to be followed by decreases in the rate. Conversely, when they drop, they tend to be followed by rate increases. In other words, from the figure it can be seen that there is neither a down sloping trend nor an up sloping trend. Instead, the interest rate

Figure 2
China's One-month Interbank Short-term Interest Rate



seems to wander around a value of about 2.5%. Therefore, the long run tendency of the one month interbank loan rate is to revert to a 'normal rate'.

From the above discussion we have strong reasons to believe that mean reversion is an important feature for the Chinese short-term interest rate. In the later stage of our analysis the statistical description of the data will not only be discussed in detail, but the mean reverting feature of the data will also be explicitly shown by using the econometric approach.

DATA AND METHODOLOGY

In China, the interest rate is regulated and decided by the central bank (People's Bank of China) without any daily change. Since there have been absolute changes in the policies before and after 1980, we neglect the short-term interest rate before 1980 and utilize the data after 2001 to estimate the short-term interest rate (since it is the best data set we can obtain). In the research, the 1-month China inter-bank loan rate is used as a proxy for the short-term rate for the Chinese market. Since the best choice for modelling the short-term interest rate is to use a risk free rate, many researchers use a T-bill rate as a proxy for the short-term interest. However, owing to the nature of China's financial market, the one-month interbank loan rate is the best data we can obtain for the Chinese market. The data are obtained from the DataStream and are retrieved daily from 10 January 2002 to 29 July 2005. In total there are 927 observations, the main features of which are shown in Table 1. (When this research was initiated, October 2005 data were the most current available. Observations for the last 3 months were reserved in order to have 1 quarter's data for forecast evaluation.)

Table 1
China's One-month Interbank Loan Rate (2002-2005)

Statistics	*Short Rate (%)*	*First Difference (%)*
Mean	2.695771	-0.000551
Median	2.580000	0.000000
Maximum	4.980000	2.310000
Minimum	1.040000	-2.280000
Std. Dev.	0.607236	0.476428
Skewness	0.944751	0.136084
Kurtosis	4.457534	8.722520
Jarque-Bera	219.9549	1266.356
Probability	0.000000	0.000000

Table 1 presents descriptive statistics for the actual level of the interest rate and its first difference. From the table it can be seen that China's short-term interest rate has not been very volatile in last two years, and the both statistics suggest that there is strong mean reverting feature for Chinese short-term interest rates. Moreover, the Jarque-Bera test suggests non-normality due to excess kurtosis in the distributions.

In this paper we focus on modelling China's short-term interest rates by applying one factor models. The single factor models for modelling short-term interest rates assume that the only factor driving the term structure of interest rate is the short-term interest rate itself. In the models the short-term interest rate is assumed to follow a diffusion (a continuous time stochastic) process. CKLS (1992) proposed the following generalized diffusion model for short-term interest rates that allows for mean-reversion:

$$dr = (\alpha + \beta r)dt + \sigma r^{\gamma} dz \tag{1}$$

In this model r is the short-term interest rate and z is a geometric Brownian motion process. What is more, the parameters α, σ and γ are assumed to be non-negative. Therefore, both drift, $\alpha + \beta r$, and the conditional variance of the interest rate process, $\sigma^2 r^{2\gamma}$, depend upon the level of the interest rate. The parameter of β captures the speed of the adjustment while α is the product of the speed of adjustment and the long-run mean.

In order to estimate the parameters of the continuous-time model in equation (1), it is convenient to use a discrete-time econometric specification, which is shown below.

$$r_{t+1} - r_t = \alpha + \beta r_t + \varepsilon_{t+1} \tag{2a}$$

$$E[\varepsilon_{t+1}] = 0, \quad E[\varepsilon_{t+1}^2] = \sigma^2 r_t^{2\gamma} \tag{2b}$$

This discrete-time model has the advantage of allowing the variance of interest rate changes to depend directly on the level of the interest rate in a way consistent with the continuous-time model. From equation (2a) we can also see the mean-reverting feature such as the β has been negative. In other words, the more negative the value of β, the faster r responds to the deviations.

As we know the stochastic differential equation given in (1) defines a broad class of interest rate processes, which includes many well-known interest rate models. These models can be obtained from equation (1) by simply placing the appropriate restrictions on the four parameters α, β, σ and γ. In this section we concentrate on the eight different specifications of the dynamics of the short-term riskless rate that have appeared in the literature, which are given below:

Table 2
The Single Factor Models

Model	*Specification*	*Restrictions*
Merton (1973)	$dr = \alpha dt + \sigma dz$	$\beta = 0, \gamma = 0$
Vasicek (1977)	$dr = (\alpha + \beta r)dt + \sigma dz$	$\gamma = 0$
Cox, Ingersoll, and Ross (1985)	$dr = (\alpha + \beta r)dt + \sigma r^{1/2}\, dz$	$\gamma = 1/2$
Dothan (1978)	$dr = \sigma r dz$	$\alpha = \beta = 0, \gamma = 1$
Geometric Brownian Motion (1973)	$dr = \beta r dt + \sigma r\, dz$	$\alpha = 0, \gamma = 1$
Brennan and Schwartz (1980)	$dr = (\alpha + \beta r)dt + \sigma r\, dz$	$\gamma = 1$
Cox, Ingersoll, and Ross (1980)	$dr = \sigma r^{3/2} dz$	$\alpha = \beta = 0, \gamma = 3/2$
Cox (1975)	$dr = \beta r dt + \sigma r^{\gamma} dz$	$\alpha = 0$

In Table 2, these eight specifications and the corresponding parameter restrictions are summarized.

From the table it can be seen that Merton's (1973) model is just simple Brownian motion with drift for short-term interest rate, and Vasicek's (1977) model is the Ornstein-Uhlenbeck process which reflects an elastic random walk. This Gaussian process has been used widely by researchers and practitioners in valuing bond options, futures, future options and other types of contingent claims, such as Jamshidain (1989) and Gibson and Schwartz (1990). Both of these models assume that the conditional volatility of changes in the riskless rate is constant. The model of Cox, Ingersoll and Ross (1985) is frequently referred to as the square-root process, which restricts γ to 0.5 thereby imposing a linear relationship between the instantaneous variance and the level of the interest rate.

The fourth specification of the single-factor model is used by Dothan (1978) in valuing discount bonds and has also been used by Brennan and Schwartz (1980) in developing numerical models of savings, retractable and callable bonds. The Geometric Brownian Motion (GBM) was used by Black and Scholes (1973) to derive the prices of options, which was referred to as the implied volatility of the option. All three of these models imply that the conditional volatility of changes in the riskless rate is proportional to γ^2.

The CIR VR model was introduced by CIR (1980) in their study of variable-rate (VR) securities, and allows a non-linear relationship between the instantaneous variance and the level of the interest rate but has no mean reversion features. The last model shown in Table 2 is the constant elasticity of variance (CEV) process introduced by Cox (1975), which does not impose restrictions on the variance but restricts the mean reversion term.

This research uses the Generalised Methods of Moments (GMM) estimator, a Likelihood ratio type test and misspecification tests to empirically analyse the one-factor models. The GMM procedure of Hansen (1982) is used to estimate the parameters of all the models under consideration. As the technical details of the GMM method can be found in Hansen (1988) and any advanced econometrics textbook, we merely provide an intuitive summary of its main features here.

GMM is closely related to the classical method of moments and instrumental variables estimation. The classical method of moments uses moment restrictions to estimate model parameters, where these restrictions can be written as population moments whose expectation is zero when evaluated at the true parameter values. One of the key concepts behind GMM is that there is a set of moment conditions involving the parameter vector in such a way that the expected value of conditions involving the parameter vector is zero. In instrumental variable estimation, the key idea is to find a set of instruments that is correlated with the regressors but uncorrelated with the error terms. In other words, the instrument vector must be orthogonal to the errors. Instrumental variable estimation can be cast in a GMM framework where the momentum conditions are given by the requirement that the instrument vector be orthogonal to the errors. This technique has a number of important advantages that make it an ideal choice for the estimation of the continuous-time interest rate process. For example, the GMM approach does not require that the distribution of interest rate changes be normal and the asymptotic justification for the GMM procedure requires only that the distribution of interest rate changes both be stationary and ergodic and that the relevant expectations exist. Because of this, the GMM approach has been used by a number of researchers for studying interest rate models, for example Chan *et al.* (1992), Vetzal (1997) and so on.

To consider the unrestricted case of the interest rate process (1), we need to estimate the parameter vector $\theta = (\alpha, \beta, \sigma, \gamma)$.

Firstly we set $\varepsilon_{t+1} = r_{t+1} - \alpha - (1+\beta) r_t$

Thus, let the vector $f_t(\theta)$ be

$$f_t(\theta) = \begin{bmatrix} \varepsilon_{t+1} \\ \varepsilon_{t+1} r_t \\ \varepsilon_{t+1}^2 - \sigma^2 r_t^{2\gamma} \\ (\varepsilon_{t+1}^2 - \sigma^2 r_t^{2\gamma}) r_t \end{bmatrix} \qquad (3)$$

If the restrictions implied by (2a) and (2b) are true, then $E(f(\theta)) = 0$. The GMM procedure consists of replacing $E(f(\theta))$ with its sample counterpart

$$g_T(\theta) = \frac{1}{T} \sum_{t=1}^{t=T} f_t(\theta)$$

and then choosing parameter estimates to minimize the quadratic form

$$J(\theta) = g'(\theta)W(\theta)g(\theta)$$

where $$W(\theta) = S^{-1}(\theta) \quad S(\theta) = E(f_t(\theta)f_t'(\theta))$$

$W(\theta)$ is a positive semi-definite weighting matrix. For the unrestricted model, the parameters are just identified and $J(\theta)$ attains zero for all choice of $W(\theta)$.

In testing restrictions for single factor models the Likelihood ratio like tests to evaluate the restrictions imposed by various models on the unrestricted models. The hypothesis-testing methods were developed by Newey and West (1987), and the test statistic is $R = n[q(\bar{\theta}) - q(\hat{\theta})]$, where $q(\bar{\theta})$ is the restricted model's objective function value and $q(\hat{\theta})$ is the unrestricted model's objective function value. The value of the LR-type test is the difference in the J statistics between the restricted model and unrestricted model. The J test is discussed in a later section. Under the null-hypothesis test the test statistic of R is asymptotically distributed χ^2_k where the degrees of freedom parameter (k) is equal to the number of restrictions under the hypothesis test.

For testing misspecification the paper applies the J-test developed in Hansen (1982). The over-identifying test statistic is shown below:

$$J_T(\theta) = Tg_T(\hat{\theta})' S_0^{-1} g_T(\hat{\theta}) .$$

If the model is correctly specified this statistic is asymptotically χ^2 distributed with degrees of freedom equal to m-k, where m is number of moments and k is number of unknown parameters.

EMPIRICAL RESULTS

GMM Estimation Results

In order to estimate the one factor interest rate models the paper applies the GMM. The estimation results displayed in Table 3 were obtained using RATS econometric software.

From Table 3 it can be seen that with exception of the Merton model, GMM estimates of α in the CKLS model, the Vasicek model, the CIR SR model, and the Brennan-Schwartz model not only satisfy the positive requirement, but they are also statistically significantly greater than zero at 5%. Table 3 also reports that in all the models GMM estimates of β not only satisfy the negativity constraint, but also they are statistically significantly different from zero at 5% significance level. Furthermore (with the exception of the GBM model) the CKLS model, the Vasicek model, the CIR SR model and the Brennan-Schwartz model all show that the estimated coefficient of β is around 0.3. Since β is the speed of adjustment to the long run mean of $-\alpha/\beta$, it indicates that China's one month inter bank loan rate has been quickly pulled back towards its long-run mean in the past two years. Finally, the negative sign of β suggests that there is a strong evidence of the mean reverting feature in China's one month inter bank loan rate. According to the estimation result, we find that the CKLS model indicates the implied long mean of the short-term interest rate is 2.6788%, the Vasicek model shows a long run mean

Table 3
GMM Estimation Results

Model	$\hat{\alpha}$ *(Std Error)*	$\hat{\beta}$ *(Std Error)*	$\hat{\sigma}^2$ *(Std Error)*	$\hat{\gamma}$ *(Std Error)*	$-\hat{\alpha}/\hat{\beta}=$ *Reversion rate*
Unrestricted CKLS	0.8358 (0.0923)	-0.312 (0.0353)	0.0394 (0.0184)	0.7834 (0.2148)	2.6788
Merton	-0.0295 (0.0209)	0.0	0.2241 (0.0204)	0.0	
Vasicek	0.9293 (0.1019)	-0.3457 (0.0392)	0.1920 (0.0157)	0.0	2.6882
CIR SR	0.8713 (0.1004)	-0.3244 (0.0387)	0.0728 (0.0059)	0.5	2.6859
Dothan	0.0	0.0	0.0313 (0.0037)	1	
GBM	0.0	-0.0186 (0.0078)	0.0294 (0.0030)	1	
Brennan-Schwartz	0.8104 (0.0979)	-0.3034 (0.0378)	0.0239 (0.0020)	1	2.6711
CIR VR	0.0	0.0	0.0095 (0.0012)	1.5	

of 2.6882%, the CIR SR model shows a long run mean of 2.6859%, and the Brennan-Schwartz model shows a long run mean of 2.6711%. Therefore, in the last two years the implied long run mean of China's inter bank loan rate is approximately 2.68%. The implied long run means, $-\hat{\alpha}/\hat{\beta}$, correspond closely to the unconditional mean reported in Table 1. Results for the CEV model are not included because they were numerically meaningless - for example, the estimated variance of the CEV model is equal to -47.2822, whereas a negative variance is uninterpretable. (The VEV model was included initially so that this research project would be consistent with the analysis conducted in the original CKLS paper. Other papers in the literature reported mixed results for this model.)

Table 3 also reports the GMM estimates of the diffusion function, which are statistically significantly different from zero at 5% significance level in all models. The diffusion function is constant for the Merton model and the Vasicek model, linear for the CIR SR model and non-linear for the rest of the models. According to Table 3 it can be seen that the estimate of volatility $(\hat{\sigma}^2)$ from the Merton model is larger than for the rest of the models. In contrast, the CIR VR model shows the smallest estimation result in volatility. Chan *et al.* (1992) used the CKLS model to estimate the 30 days U.S T-bills, and they found that models that allowed the volatility of short-term interest rates to highly depend upon the level of interest rate captured the dynamic behaviour of short-term interest rate more successfully. For the case of China's one month inter bank loan rate, we find that the value of $\hat{\gamma}=0.7834$ in the unrestricted CKLS model, which is not very high. Nevertheless, this value is statistically significantly different from zero at 5%

significance level in the model. In other words, we do not reject non-linearity in the diffusion for the CKLS model, providing strong evidence to support non-linearity in the diffusion process. The positive sign of $\hat{\gamma}$ indicates that interest rate volatility is positively correlated with the level of interest rates However, the small size of $\hat{\gamma}$ suggests that this relationship is not nearly as strong as for the USA or the UK, where the coefficient had values around 1.5.

Testing the Rival Models

The previous section discusses mean reverting features and diffusion terms in the rival one factor models. This section will not only perform the J-test to detect the goodness-of-fit of the models, but also apply Likelihood ratio type tests to the nested models.

The hypotheses for the misspecification test are as the follows:

H_0 : Moments are correctly specified vs H_a : Moments are misspecified.

Table 4
The J-test Results

Model	*J-Test*	*P-values*	*Degree of Freedom*
CKLS	8.7573	0.0125	
Merton	62.6509	0.0000	2
Vasicek	16.2960	0.0010	1
CIR SR	9.4274	0.0241	1
Dothan	67.4688	0.0000	3
GBM	67.7870	0.0000	2
Brennan-Schwartz	10.8223	0.0127	1
CIR VR	69.7047	0.0000	3

According to Table 4, it can be seen that five models (Merton, Vasicek, Dothan, GBM, and CIR VR) show evidence of misspecification at 1% significance level. However, the CKLS model, the Brennan-Schwartz model and the CIR SR model cannot be rejected at the 1% significance level, providing statistical evidence that these three models are correctly specified to capture the dynamic features of China's short-term interest rate. (But since the J test would find against the adequacy of these three specifications at 5% significance level, this evidence is not compelling.)

Next, we evaluated the restrictions imposed by various models on the unrestricted model by following the hypothesis-testing methods developed by Newey and West (1987). The likelihood like type tests results shown in Table 5.

The results show evidence that under the LR-type tests the five restricted models (Merton, Vasicek, Dothan, GBM, and CIR VR) cannot survive, since they all have such small p-values. However, we do not reject the null hypothesis of the CIR SR model and the Brennan-Schwartz model at either the 1% or the 5% significance levels. In other words, these later two models exhibit more ability to capture the distinguishing feature of the Chinese short-term interest rate.

Table 5
The LR-type test Results

Model *CKLS (UN)*	*Hull hypothesis*	*LR type statistics*	*P-values*	*Degree of freedom*
Merton	$\beta = 0, \gamma = 0$	53.8936	0.0000	2
Vasicek	$\gamma = 0$	7.5387	0.0060	1
CIR SR	$\gamma = 0.5$	0.6701	0.4130	1
Dothan	$\alpha = 0, \beta = 0, \gamma = 1$	58.7115	0.0000	3
GBM	$\alpha = 0, \gamma = 1$	59.0298	0.0000	2
Brennan- Schwartz	$\gamma = 1$	2.0651	0.1507	1
CIR VR	$\alpha = 0, \beta = 0, \gamma = 1.5$	60.9478	0.0000	3

Out of Sample Forecast

Forecast Test Strategy and the Out-of-Sample Yield Data

In order to show the forecasting ability among the one factor models, Theil's U2 statistics and Diebold and Mariano's (DM) forecasting test are carried out. Theil's U2 statistics are used as relative measures to compare forecasts for the same time series across different models. In this paper Theil's U2 statistics will be calculated and the forecasting power compared in the same out of sample period (1 August 2005 to 31 October 2005) for all nine models. According to Theil's criterion, models having smaller U2 statistics (i.e. closer to zero) are preferred. The reason for this is because the smaller the mean square error, the better the forecasting ability of that model. The equation for obtaining Theil's U2 statistics can be expressed as the following, where h depicts the number of periods for which variable y is forecasted (see Pindyck and Rubinfeld (1991, Chapter 12):

Theil's Inequality Coefficient: $$U2 = \frac{\sqrt{\sum_{t=T+1}^{T+h} (\hat{y}_t - y_t)^2 / h}}{\sqrt{\sum_{t=T+1}^{T+h} \hat{y}_t^2 / h} + \sqrt{\sum_{t=T+1}^{T+h} y_t^2 / h}}$$

Moreover, the U2 coefficient can be decomposed into three parts: bias proportion, variance proportion and covariance proportion, as follows:

Bias proportion: $$B = \frac{((\sum \hat{y}_t / h) - \overline{y})^2}{\sum (\hat{y}_t - y_t)^2 / h}$$

Variance proportion: $$V = \frac{(s_{\hat{y}} - s_y)^2}{\sum (\hat{y}_t - y_t)^2 / h}$$

Covariance proportion $$C = \frac{2(1-r) s_{\hat{y}} s_y}{\sum (\hat{y}_t - y_t)^2 / h}$$

where *r* is the coefficient of linear correlation between the values of *y* and $\hat{y}$, and $s_{\hat{y}}$ and s_y are their respective standard deviations. The bias (B) and variance (V) proportions reflect, respectively, differences between the means and variances of *y* and $\hat{y}$, and the covariance (C) proportion measures the extent to which *y* and $\hat{y}$ move together. Models having small values of B and V, but large values of C are preferred.

However, since the U2 statistic is not a formal test to detect the model's predictive power, the DM test will also be applied to test forecasting ability. In this test the quality of the forecasts is judged according to some loss function. The loss function is defined as a direct function of the forecast error $g(y_t, \hat{y}_{1t}) = g(e_{1t})$, and the loss differential is defined as $d_t = g(e_{1t}) - g(e_{2t})$. Thus, the DM test of equal predictive accuracy can be conducted as a simple t-test for:

$H_0 : E(d_t) = 0$ (equal predictive accuracy) vs $H_a : E(d_t) \neq 0$

The t-test statistic is as follows:

$$DM = \frac{\bar{d}}{\sqrt{\hat{V}(\bar{d})}}$$

where $\bar{d}$ is the mean of the loss differential, and $\hat{V}(\bar{d})$ is an estimate of its asymptotic variance.

The observed out-of-sample period yield data is provided by the Datastream and summary statistics are in Table 6. For the Chinese interbank loan the yield maturities are monthly. The data are daily and cover the period from 1 August 2005 to 31 October 2005, providing 66 observations. Table 6 presents descriptive statistics for out of sample in the one-month inter-bank loan rate, *r*. The mean value of *r* over the sample period is 1.891364 per cent, and it ranges from a low of 1.32 per cent to a high of 2.3 per cent. The interest rate has a standard deviation of 0.273304 per cent during the out of sample period. This suggests that the chosen measure of the short-term interest rate is not volatile in these three months.

Table 6
Out of Sample Data Description

Statistics	*Short Rate (%)*
Mean	1.891364
Median	1.995000
Maximum	2.300000
Minimum	1.320000
Std. Dev.	0.273304
Skewness	-0.474747
Kurtosis	2.104097
Jarque-Bera	4.686495
Probability	0.000000

Forecast Evaluation Results

As noted in the previous section Theil's U2 statistic is a relative measure to compare the forecasts with actual series. If the U2 statistic is equal to zero, it will suggest that the forecast perfectly fits the actual series. In other words, models with the smallest U2 statistics have the highest predictive power according to the criterion. Table 7 shows the U2 statistics and its decomposition results.

Table 7
Theil's U2 statistic results

	U2 statistic	*Bias*	*Variance*	*Covariance*
CKLS	0.0953	0.4218	0.0448	0.5334
MERTON	0.0896	0.0019	0.0002	0.9979
VASICEK	0.0989	0.4826	0.0494	0.4680
CIRSR	0.0966	0.4467	0.0470	0.5063
DOTHAN	0.0889	0.0012	0.0002	0.9986
GBM	0.0890	0.0038	0.0000	0.9962
B-S	0.0944	0.4027	0.0416	0.5557
CIRVR	0.0889	0.0012	0.0002	0.9986

Overall, the whole class of one-factor models is very close in terms of the U2 statistics. All models have very small U2 values, the range being 0.0889 to 0.0989. The variance proportion is also not much different among the models, where the variance proportion range is from about 0.0494 for the Vasicek model to the lowest value of virtually zero in the GBM model. However, there is a large variation for the bias proportion and the range is from the highest 0.4826 to smallest 0.0012. The large variation in bias proportion suggests that mean of the forecasts produced by some models is far from the mean of actual series.

From an observational point of view, we may say that the Vasicek model does a relatively poor job of tracking the trend of the actual series among the models, since it has the highest U2 statistic. In contrast, according to their U2 statistics, the Dothan the CIR VR models have higher predictive powers than the rest of models in terms of forecasting China's short-term interest rate. However, we can hardly deny the fact that all models have very small U2 values. Thus, from a practical point of view, we would conclude that all the one factor models do a good job of tracking the actual series. In other words, all one factor models have good ability to predict the Chinese short-term interest rate.

As discussed previously, the DM test is a formal test to detect the model's forecasting accuracy. Therefore, we will use the CKLS model as the benchmark model against which to test the other models. Table 8 contains the DM test statistics and their corresponding p-values, as produced by the RATS software programme

The DM test results indicate rejection of the Vasicek model and the CIR SR model because they both have very low p-values. In other words, the DM tests results favour the CKLS model over the Vasicek model and CIR SR model in terms of forecasting ability for China' short-term interest rate. However, since the remaining hypothesis tests have very high p-values, we can not reject the associated models. Thus, the results suggest that the DM tests can not distinguish the CKLS model from the Merton Model, the Dothan model, the GBM model, the Brennan Schwartz models, and the CIR VR model in terms of predictive power for China's short-term rates.

Table 8
DM Test Results

	DM test stats	*p-value*
CKLS vs Merton	2.32147	0.98987
CKLS vs Vasicek	-6.44158	5.91177e-11*
CKLS vs CIR SR	-5.95618	1.29098e-09*
CKLS vs Dothan	2.34751	0.99055
CKLS vs GBM	2.52680	0.99424
CKLS vs Brennan-Schwartz	3.90998	0.99995
CKLS vs CIR VR	2.34751	0.99055

* indicates rejection of the rival model.

CONCLUSION

This paper applies one-factor term structure models to capture the dynamic feature of China's short-term interest rate. In general, these models assume that the expected short-term interest rate is some function of the conditional mean and variance of the short-term interest rate itself. In other words, for a given time-series model, we should be able to forecast tomorrow's short-term interest rate from the knowledge of today's short-term interest rate and a set of parameter estimates. Therefore, our research is designed to test whether the single factor models are able to characterize the dynamic behaviour of China's short-term interest rate. What is more, from practical point of view the research tests the one factor model's forecasting power for China's short-term interest rates.

In order to estimate one factor models for China's short-term rates, GMM has been applied. The GMM estimation results provide a number of interesting insights into the dynamics of the Chinese short-term interest rates. First, there appears to be strong evidence of a mean reversion feature in the short-term interest rate, the estimated parameter $\hat{\beta}$ being statistically significant in all the one factor models. Second, in the diffusion term we find that the estimated value of $\hat{\gamma} = 0.7834$, although being statistically significant in the unrestricted model, has such a low value that we infer that the volatility of China's one month inter bank loan rate is not *strongly* positively correlated with the level of interest rates. We also find that the CEV model produces meaningless results for China's short-term interest rate, which suggests that the CEV model is not adequate to capture relevant dynamic features of this series.

Since the CKLS family provides eight additional models to model the short-term interest rate, the J test is carried out to detect whether the models are misspecified in terms of modelling China's short-term rate. From the J tests we conclude that only the CKLS model, the CIR SR model, and the Brennan-Schwarz model are correctly specified, the rest of the models being misspecified. Results from the LR type test indicate that the restrictions imposed by the CIR SR model and the Brennan-Schwartz model would be rejected at the 5% significance level. but not at 1%. Taken together, the test results broadly confirm that the CKLS , Brennan-Schwartz and CIR SR models are statistically preferable in terms of capturing the dynamics of China's short-term interest rate movements.

In order to further evaluate the relative performance of the one factor models, we tested their forecasting abilities. According to Theil's U2 statistics, we find that all the values of the U2 statistics are very small, ranging from a low of 0.0889 to a high of 0.0989, indicating that all the one factor models perform well in term of forecasting China's short-term interest rates. Consequently, we carried out a series of DM tests to empirically evaluate the forecasting ability in CKLS model competing with the eight restricted models. Under the DM tests we found that the results favour the CKLS model over the Vasicek and the CIR SR models in terms of prediction ability, however, the DM tests could not empirically distinguish the CKLS model from the Merton Model, the Dothan model, the GBM model, the Brennan Schwartz model and the CIR VR model in terms of predicting the Chinese short-term interest rate.

On the whole, according to the findings of this research, it can be seen that the CKLS model, the CIR SR model and the Brennan-Schwartz model are sufficient to capture the dynamics of Chinese short-term interest rate. In other words, these findings indicate that the CKLS model, the CIR SR model and the Brennan-Schwartz model are empirically adequate for modelling China's short-term interest rate. Moreover, the study shows that one factor models do a good job in terms of forecasting ability. Therefore, from a practical standpoint, the one factor models can be recommended in terms of the modelling dynamic movements in, and the forecasting of, Chinese short-term rates. That is, there does not seem to be much advantage in trying to develop and use the more complicated multi-factor models.

REFERENCES

Bjork, T. and Christensen, B. (1999), "Interest Rate Dynamics and Consistent Forward Rate Curves", *Mathematical Finance,* 9: 323-348.

Bjork, T. and Landen, C. (2002), "On the Construction of Finite Dimensional Realizations for Nonlinear Forward Rate Models", *Finance and Statistics,* 6: 273-302.

Bjork, T. (2000), "A Geometric View of Interest Rate Theory", in Jouini, E., Cvitanic, J. and Musiela, M. (eds), *Handbook of Mathematical Finance*, Cambridge University Press, Cambridge, pp. 241-277.

Black, F., and Scholes, M. (1973), "The Pricing of Options and Corporate Liabilities", *Journal of Political Economy,* 81: 637-654.

Bliss, R. (1997), "Testing Term Structure Estimation Methods", *Advances in Futures and Options Research,* 9: 97–231.

Brennan, M. L. and Schwartz, E. L. (1980), "Analyzing Convertible Bonds", *Journal of Financial and Quantitative Analysis*, 15: 907-929.

Brenner, R. H., Harjers, R. and Kroner, K. (1996), "Another Look at Models of Short-term Interest Rates", *Journal of Financial and Quantitative Analysis*, 31: 85-107.

Chan, K. C., Karolyi, G. A., Longstaff, F. A. and A. B. Sanders, A. B. (1992), "An Empirical Comparison of Alternative Models of the Short-term Interest Rates", *The Journal of Finance,* 1209-1227.

Chen R. and Scott, L. (1992), "Pricing Interest Rate Options in a Two-factor Cox-Ingersoll-Ross Model of the Term Structure", *Review of Financial Studies*, 5: 613-636.

Chen, L. (1996), *InterestRate Dynamics, Derivatives Pricing and Risk Management. Lecture Notes in Economics and Mathematical Systems*. Springer-Verlag, Berlin.

Cochrane, J. (2001), *Asset Pricing 1st* edition, Princeton University Press, New Jersey.

Copeland, L. (2005), *Exchange Rates and International Finance*. 4th edition, Prentice Hall, New Jersey.

Cox, J. C. (1975), *Note on Option Pricing I: Constant Elasticity of Variance Diffusion*, Working paper, Stanford University.

Cox, J. C., Ingersoll, J. E. and Ross, S. A. (1980), "An Analysis of Variable Rate Loan Contracts", *Journal of Finance,* 35: 389-403.

Cox, J. C., Ingersoll, J. E., and Ross, S. A. (1985a), "An Intertemporal General Equilibrium Model of Asset Prices", *Econometrica*, 53: 363-384.

Cox, J. C., Ingersoll, J. E., and Ross, S. A. (1985b), "A Theory of the Term Structure of Interest Rates", *Econometrica*, 53: 385-408.

Dahlquist, M. (1996), "On Alternative Interest Rate Processes", *Journal of Banking and Finance*, 20: 1093–1119.

Diebold, F. and Mariano, R. (1995), "Comparing Predictive Accuracy", *Journal of Business and Economic Statistics*, 13: 53-263.

Dothan. U. L. (1978), "On the Term Structure of Interest Rates", *Journal of Financial Economics*, 6: 59-69.

Fan, X., and Zhaoben, F. (2001), *Empirical Test on Convertible Bond Pricing Model under Stochastic Interest Rate*, University of Iowa working paper.

Filipovic, D. (1999), "A Note on the Nelson-Siegel Family", *Mathematical Finance*, 9: 349-359.

Filipovic, D. (2000), "Exponential-Polynomial Families and the Term Structure of Interest Rates", *Bernoulli*, 6: 1081-1107.

Gibson R., and Schwartz, E. S. (1990), "Stochastic Convenience Yield and the Pricing of Oil Contingent Claims", *Journal of Finance*, 45: 959-976.

Hansen, L. P. (1982), "Large Sample Properties of Generalized Method of Moments Estimators", *Econometrica ,* 22: 305-333.

Heath, D., Jarrow, R. and Morton, A. (1992), "Bond Pricing and the Term Structure of Interest Rates: A New Methodology for Contingent Claims Valuation". *Econometrica*, 60: 77-105.

Laurenceson, J. and Qin, F. (2005), *China's Exchange RatePolicy: The Case Against Abandoning the Dollar Peg,* Center for Economic Research, Tilburg University Discussion Paper No. 2005-70, Tilburg, Netherlands.

Jamshidian F. (1989), "An Exact Bond Option Formula", *Journal of Finance*, 44: 205-209.

Litterman, R., and J. Scheinkman, J. (1991), "Common Factors Affecting Bond Returns", *Journal of Fixed Income*, 3: 54-61.

Longstaff, F. A., and E. Schwartz, E. (1992), "Interest Rate Volatility and Term Structure: A Two-factor General Equilibrium Model", *Journal of Finance*, 47: 1259-1228.

Merton, R. C. (1973), "Theory of Rational Option Pricing", *Bell Journal of Economics and Management Science*, 4: 141-183.

Nelson, C. R. and Siegel, A. F. (1987), "Parsimonious Modelling of Yield Curves", *Journal of Business*, 60: 473-489.

Newey, W., and West, K. (1987), "Hypothesis Testing with Efficient Method of Moments Estimation", *International Economic Review* , 28: 777-787.

Soderlind, P. and Svensson, L. E. O. (1997), "New Techniques to Extract Market Expectations from Financial Instruments", *Journal of Monetary Economics*, 40: 383-430.

Treepongkaruna, S. (2003), "Quasi-maximum Likelihood Estimates of Kiwi Short-term Interest Rate", *Applied Economics Letters*, 10: 937-942.

Treepongkaruna, S. and Gray, S. F. (2002), "On the Robustness of Short-term Interest Rate Models", *Accounting and Finance,* 43: 87-121.

Tse, Y. K. (1995), "Some International Evidence on Stochastic Behaviour of Interest Rates", *Journal of International Money and Finance,* 14: 721–738.

Vasicek, O. (1977), "An Equilibrium Characterization of The Term Structure". *Journal of Financial Economics* 5, 177-188.

Vetzak, K. R. (1997), "Stochastic Volatility, Movements in Short-term Interest Rates, and Bond Option Values", *Journal of Banking and Finance*, 169-196.

Xie, Chi and Wu, X. (2002), "An Empirical Test of Interest Rate Behaviour in China's Monetary Market using the Vasicek Model and the CIR Model", *Chinese Journal of Management Science*, 10: 12-15.

Zheng, Z. and Lin, H. (2003a), "Static Approximation of Term Structure in China", *Wuhan Finance Monthly ,* 3: 33-37.

Zheng, Z. and Lin, H. (2003b), *Research on Liquidity Premium of Interest Rate in China*, Working Paper of Xianmen University. *http://efinance.nease.net/1966.htm.*

Zheng, Z. and Lin, H. (2003c), "Research on default risk premium in China", *Securities Market Herald*, 6: 41-45.