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*Research Article*

# Studying Term Structure of SHIBOR with the Two-Factor Vasicek Model

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With the development of the Chinese interest rate market, SHIBOR is playing an increasingly important role. Based on principal component analysing SHIBOR, a two-factor Vasicek model is established to portray the change in SHIBOR with different terms. And parameters are estimated by using the Kalman filter. The model is also used to fit and forecast SHIBOR with different terms. The results show that two-factor Vasicek model fits SHIBOR well, especially for SHIBOR in terms of three months or more.

## 1. Introduction

The benchmark interest rate is the core of the formation of market-oriented interest rate system. Without benchmark interest rate, it is difficult to determine the direction of financial derivatives is reasonable. Since Shanghai Interbank Offered Rate (SHIBOR) was launched in 2007, the currency market benchmark interest rates were gradually established, which has the guidance for pricing of stocks, bonds, and financial derivatives. With the improvement of quotation quality and the expanding of application scope of SHIBOR, the system of benchmark interest rate is developing in Chinese financial market. In 2007, based on SHIBOR interest rate swap accounts for about 13% of the total swaps. In 2008, swaps with SHIBOR as the benchmark interest rate rose by 215% over the previous year, accounting for 22% of the change of trading volume. And since 2009, all forward rate agreement was based on SHIBOR. By 2010, swap transactions in the name of the principal proportion linked to SHIBOR of RMB interest rate reached 40.3%. After 2010, the role of SHIBOR in transmission mechanism of monetary policy is more important and the circulation of SHIBOR products is gradually expanding. The reference value to price other financial products of SHIBOR has been increasing [1]. As China's "LIBOR," SHIBOR plays a more and more important role for interest rate marketization in China.

Some researchers studied the term structure of interest rates. Cajueiro and Tabak have studied the long-range dependence in LIBOR interest rates. Their empirical results show that the degree of long-range dependence of interest rates on most countries decreases with maturity. They also have found interest rates have a multifractal nature [2]. Egorov et al. have modeled the joint term structure of interest rates in the United States and the European Union and have found that a new four-factor model with two common and two local factors captures the joint term structure dynamics in the US and the EU reasonably well [3]. Jagannathan et al. have evaluated the classical CIR model using data on LIBOR, swap rates and caps, and swaptions. And they have found three-factor CIR model is able to fit the term structure of LIBOR and swap rates rather well [4]. Griffiths et al. have examined the robustness of results of Griffiths and Winters [5, 6] and Kotomin et al. [7] using pound sterling and Euro repo rates and have found a year-end preferred habitat for liquidity in the Euro repo rates [8]. Kotomin has studied incorporating year-end and quarter-end preferences for liquidity and other calendar-time effects into the test of the expectations hypothesis in the very short-term LIBOR in seven major world currencies and has found the calendar-time effects altering long-term relations between very short-term rates in these currencies [9]. Wen et al. have proposed a copula-based correlation measure to test the interdependence among stochastic variables in terms of copula function [10, 11]. Because of short SHIBOR launch time, few early launch SHIBOR product category, and small circulation, the study of SHIBOR has few results. Most of the research achievements are about its term structure, Wang has found that pure expectation hypothesis is rejected by empirical research of Shibor, and term premiums always exist. He also has found that single-factor interest rate models are appropriate in describing overnight and 1W SHIBOR. But if adding GARCH into the diffusion part, the result will be better [12]. X. N. Wang and H. T. Wang have studied the term structure of Shibor and the conclusions show that the expectation theory is valid on the short-term, medium-term, and long-term SHIBOR [13]. Zhang et al. have made an empirical analysis on the term structure of SHBOR under Vasicek and CIR models, respectively, describing the dynamics of SHIBOR. The research presents that Vasicek model does even better in capturing the dynamics of the interest rates [14]. Zhou et al. have taken Vasicek model with jumps or exponential Vasicek model with jumps as the alternative models to describe return series of SHIBOR. And parameters of two models have been estimated by particle filter approach. Comparing goodness-of-fit and forecast effect between the two models, the result shows that Vasicek model with jumps does better [15]. Su has adopted the CIR model, RSCIR model, and no-arbitrage HJM model to study the term structure of SHBOR and the dynamics of its risk premium. The result shows that three-factor HJM model does best to discribe the dynamics characteristic of term structure and volatility structure of SHBOR [16]. Through analyzing the operational mechanism of SHIBOR, Yu and Liu have proposed a practicable pricing model of SHIBOR and tested the model by empirical data [17]. Wen et al. have used the principal component analysis to find the existence of chaotic features of the Chinese finacial market [18]. Wen and Yang have studied the relationship between the skewness and the coefficient of risk premium in financial makets [19]. Huang et al. consider the dynamics of switched cellular neural networks (CNNs) with mixed delays [20]. Liu et al. introduce and investigate some new subclasses of multivalent analytic functions involving the generalized Srivastava-Attiya operator [21]. Based on the modified secant equation, Dai and Wen propose a modified Hestenes-Stiefel (HS) conjugate gradient method which has similar form as the CG-DESCENT method [22]. Under a genal affine data perturbation uncertainty set, Dai and Wen propose a computationally tractable robust optimization method for minimizing the CVaR of a portfolio [23]. Using theories and methods of behavioral finance, Wen et al. take a new look at the characteristics of investors' risk preference, building the D-GARCH-M model, DR-GARCH-M model, and GARCHC-M model to investigate their changes with states of gain and loss and values of return together with other time-varying characteristics of investors' risk preference [24]. The researchers mainly used single factor model to study the term structure of SHIBOR. Among many dynamic equilibrium models describing short-term stochastic interest rates, the most widely used is the Vasicek model [25]. Vasicek model is an equilibrium pricing model about term structure of interest rates, which reflects the risk of debt and investors' expectations of future interest rate changes. The prices of the bonds and interest rate derivatives have a simple analytical expression in Vasicek model. Interest rate derivatives market is a complicated system in real world, so it is difficult to describe the term structure of interest rates with single factor. Therefore, the single factor Vasicek model is extended to multiple-factor Vasicek model, and multiple-factor Vasicek model can also be very easy to evaluate the price of bonds and risk. Although there are many more complicated interest rate models later such as Affine model [26], the Libor model [27], and so forth, the Vasicek model is still a very important interest rate model due to the ease in pricing bond prices and the risk. This paper will describe the dynamic characteristic of SHIBOR and study its term structure by two-factor Vasicek model. In the second part, principal component analysis (PCA) will be taken to select two most important factors of SHIBOR for modeling. In the thirtd part, two-factor Vasicek model of SHIBOR will be present and parameters will be estimated by Kalman filter method. In the forth part, the two-factor Vasicek model of SHIBOR will be tested by empirical research. Finally, conclusion will be present.

Table 1: Principal component analysis results.

| Principal component | Eigenvalue | The proportion of explanation | The accumulative proportion of explanation |
|---|---|---|---|
| 1 | 6.7432 | 0.8429 | 0.8429 |
| 2 | 0.9823 | 0.1228 | 0.9657 |
| 3 | 0.1395 | 0.0174 | 0.9831 |
| 4 | 0.0736 | 0.0092 | 0.9924 |
| 5 | 0.0362 | 0.0045 | 0.9969 |
| 6 | 0.0221 | 0.0028 | 0.9997 |
| 7 | 0.0027 | 0.0003 | 1.0000 |
| 8 | 0.0003 | 0.0000 | 1 |

## 2. Principal Component Analysis of SHIBOR

Different terms of SHIBOR volatility would be influenced by economic cycle, macroeconomic policies, monetary supply, demand, and so on. And there is some correlation between these factors. It is important for modeling dynamically of SHIBOR that irrelated influence factors or components are found in the different term of SHIBOR and less new irrelated compound variables are used to replace the more interdependent variables to build the dynamic model of SHIBOR. This paper uses principal component analysis method to get the principal components affecting the SHIBOR. Then SHIBOR short-term dynamic model is set up with these main components. Although SHIBOR began trial operation from October 2006, its quoted price was a bit chaotic and trading volumes were less in that time. When Launched on January 1, 2007, SHIBOR quoted price was improved and trading volumes were also increased. This paper selects O/N, 1 week, 2 weeks, 1 month, 3 months, 6 months, 9 months, and 1 year of SHIBOR daily data to make principal component analysis from January 4, 2007, to August 21, 2013. Analysis results are shown in Table 1.

In Table 1, the first principal component interpretation for the proportion of SHIBOR volatility reaches 84.29%. The

Table 2: The coefficient of the first two principal components of different terms of SHIBOR.

| Term | The first principal component | The second principal component |
|---|---|---|
| O/N | 0.3294 | −0.4278 |
| 1 week | 0.3459 | −0.3992 |
| 2 weeks | 0.3506 | −0.3514 |
| 1 month | 0.3634 | −0.2319 |
| 3 months | 0.3702 | 0.2209 |
| 6 months | 0.3573 | 0.3730 |
| 9 months | 0.3553 | 0.3831 |
| 1 year | 0.3548 | 0.3816 |

cumulative interpretation proportion of the first two principal components reaches 96.57%. The cumulative explain proportion of the first three principal components is above 98%. The interpretation abilities of principal components behind third principal components are weakened observably. Then two irrelated variables can be used to depict the volatility of SHIBOR. By calculating the SHIBOR eigenvectors of covariance matrix, the coefficients of the first two principal components can be gotten.

We get models of the two principal components from the eigenvector as below:

$$\begin{aligned} F_1 &= 0.3294\text{shibor\_O/N} + 0.3459\text{shibor\_1W} \\ &\quad + 0.3506\text{shibor\_2W} + 0.3634\text{shibor\_1M} \\ &\quad + 0.3702\text{shibor\_3M} + 0.3573\text{shibor\_6M} \\ &\quad + 0.3553\text{shibor\_9M} + 0.3548\text{shibor\_1Y}, \\ F_2 &= -0.4278\text{shibor\_O/N} - 0.3992\text{shibor\_1W} \\ &\quad - 0.3514\text{shibor\_2W} - 0.2319\text{shibor\_1M} \\ &\quad + 0.2209\text{shibor\_3M} + 0.3730\text{shibor\_6M} \\ &\quad + 0.3831\text{shibor\_9M} + 0.3816\text{shibor\_1Y}, \end{aligned} \tag{1}$$

where $F_1$, $F_2$ denote the first principal component and the second principal component, respectively. shibor_O/N, shibor_1W, shibor_2W, shibor_1M, shibor_3M, shibor_6M, shibor_9M, and shibor_1Y denote overnight, 1-week, 2-week, 1-month, 3-month, 6-month, 9-month, and 1-year SHIBOR.

## 3. Two-Factor Vasicek Model of SHIBOR

*3.1. Two-Factor Vasicek Model.* Based on the results of principal component analysis, the term structure of SHIBOR can be described by two-factor model. In this paper, the two-factor Vasicek model is as follows [25]:

$$R_t = \delta_0 + \delta_1 F_{1t} + \delta_2 F_{2t}, \tag{2}$$

where $R_t$ is short-term interest rate, $\delta_0$, $\delta_1$, and $\delta_2$ are constants, and $F_{1t}$ and $F_{2t}$ are state variables deciding the value of SHIBOR. Under the risk neutral probability measure, the state variables are subject to the following process:

$$\begin{aligned} dF_{1t} &= -\alpha_1 F_{1t} dt + \sigma_1 dW_{1t}, \\ dF_{2t} &= -\alpha_2 F_{2t} dt + \sigma_2 dW_{2t}, \end{aligned} \tag{3}$$

where $\alpha_1$ and $\alpha_2$ are constants denoting the speed of the mean reversion of state variables, $\sigma_1$ and $\sigma_2$ are the annual volatility of two state variables, and $W_{1t}$ and $W_{2t}$ denote independent standard Brownian motion. Under real probability measure, the state variables are subject to the following process:

$$\begin{aligned} dF_{1t} &= k_1 \left[\theta_1 - F_{1t}\right] dt + \sigma_1 d\omega_{1t}, \\ dF_{2t} &= k_2 \left[\theta_2 - F_{2t}\right] dt + \sigma_2 d\omega_{2t}, \end{aligned} \tag{4}$$

where $k_1$, $k_2$, $\theta_1$, $\theta_2$, $\sigma_1$, and $\sigma_2$ are constants and $\omega_{1t}$ and $\omega_{2t}$ denote independent standard Brownian motion. Under real probability measure, the condition expectation and the condition variance of state variables are as follows:

$$\begin{aligned} E\left\{F_{it} \mid F_s\right\} &= e^{-k(t-s)} F_{is} + \theta\left(1 - e^{-k(t-s)}\right), \quad i = 1, 2, \\ \operatorname{Var}\left\{F_{it} \mid F_s\right\} &= \frac{\sigma_i^2}{2k}\left[1 - e^{-2k(t-s)}\right], \quad i = 1, 2, \end{aligned} \tag{5}$$

where $0 \le s < t$. $F_s$ is an information set at $s$ time.

*3.2. Kalman Filter to Estimate Parameters of Two-Factor Vasicek Model.* Many scholars use the generalized moment estimate method (GMM) and maximun likelihood estimate (MLE) to estimate the parameters of Vasicek. However, the parameter estimation of the GMM is not stable. Selecting different moment condition estimates will lead to different parameters. While the parameter estimation of MLE is stable and the effectiveness is better than that of GMM [28]. The Kalman filter estimation methods can build maximum likelihood estimation function of model parameters, and then through maximizing the function to obtain the estimate values of the model parameters. This method is to use state equation and recursive method to estimate, and the obtained solution is given in the form of estimate value (Table 2). Therefore, Kalman filter theory cannot only overcome the disadvantages and limitations of the classical Wiener filter theory but also implement optimal recursive filtering algorithm easily on the computer. These make the Kalman filter theory obtain a wide range of practical applications [29].

In this paper, the kalman filter will be used to estimate parameters of SHIBOR two-factor Vasicek model [30]. Firstly, the two-factor Vasicek model is written in state space system. The observation equation is as follows:

$$R_t = A' + \delta' \cdot F_t + \varepsilon_t, \tag{6}$$

where the observation vector $R_t$ is a $n \times 1$ order matrix, $A$ and $\delta$ are a $1 \times n$ order matrix and a $n \times 2$ order matrix, respectively. The disturbing part $\varepsilon_t$ is a $n \times 1$ order matrix. And

$$E\left(\varepsilon_t \varepsilon_\tau'\right) = \begin{cases} \Omega, & t = \tau \\ 0, & t \ne \tau, \end{cases} \tag{7}$$

TABLE 3: The parameter estimation results of the SHIBOR two-factor Vasicek model.

| Parameter | $\delta_0$ | $\delta_1$ | $\delta_2$ | $k_1$ | $k_2$ | $\theta_1$ | $\theta_2$ | $\sigma_1$ | $\sigma_2$ |
|---|---|---|---|---|---|---|---|---|---|
| O/N | 0.0318 | 0.5431 | −0.1387 | 1.1691 | 50.5979 | 0.0226 | 0.3002 | −0.0129 | 0.3209 |
| 1 week | 0.0247 | 0.4755 | −0.5196 | 0.6111 | 7.3607 | 0.0126 | 0.044 | −0.0252 | 0.0439 |
| 2 weeks | 0.03136 | 0.4755 | −0.5231 | 0.059 | 3.0249 | 0.014 | 0.0455 | −0.0004 | 0.0017 |
| 1 month | 0.05 | 0.6283 | −0.0164 | 0.1789 | 0.846 | 0.0077 | 0.0292 | −0.0079 | 0.0034 |
| 3 months | 0.0428 | 0.3579 | 0.0002 | 0.0174 | −0.0174 | 0.0016 | 0.0034 | 0.0271 | 0.0239 |
| 6 months | 0.0429 | 0.3282 | −0.0003 | 0.0172 | 0.2084 | 0.0022 | 0.002 | −0.0087 | 0.0069 |
| 9 months | 0.0544 | 0.3034 | −0.0001 | 0.0204 | 0.1201 | 0.001 | 0.001 | −0.0086 | 0.0051 |
| 1 year | 0.0444 | 0.3666 | −0.0002 | 0.0098 | 0.1129 | 0.0015 | 0.0012 | −0.0063 | 0.0033 |

TABLE 4: The fitting errors of the SHIBOR two-factor Vasicek model.

| Error analysis | Variance | Mean square error | Average relative error | Maximum absolute value error |
|---|---|---|---|---|
| O/N | 0.004204 | 0.012904 | 0.06176 | 1.700516 |
| 1 week | 0.004475 | 0.015309 | 0.068809 | 2.191315 |
| 2 weeks | 0.0047 | 0.015163 | 0.060387 | 3.148987 |
| 1 month | 0.0026 | 0.003363 | 0.028864 | 1.182393 |
| 3 months | $4.94E-04$ | 0.000162 | 0.003235 | 0.220396 |
| 6 months | $9.36E-04$ | 0.000883 | 0.016326 | 0.967795 |
| 9 months | $5.89E-04$ | 0.00054 | 0.014141 | 0.348812 |
| 1 year | 0.0012 | 0.00023 | 0.013917 | 0.215112 |

where $\Omega$ is a $n \times n$ order matrix. The state vector $F_t$ is a $2 \times 1$ order matrix and submits to the state equation:

$$F_{t+1} = H \cdot F_t + \mu_{t+1}, \tag{8}$$

where $H$ is a $2 \times 2$ order matrix and $\mu_t$ is a $2 \times 1$ order matrix. And

$$E\left(\mu_t \mu_\tau'\right) = \begin{cases} Q, & t = \tau \\ 0, & t \neq \tau, \end{cases} \tag{9}$$

where $Q$ is a $2 \times 2$ order matrix. The parameter estimation steps of kalman filtering are as follows.

(1) Setting the initial value, $\widehat{F}_{1|0} = E\left[\begin{smallmatrix} F_{11} \\ F_{21} \end{smallmatrix}\right]$, $\operatorname{vec}(P_{0|1}) = [I_{\gamma 2} - (H \otimes H)]^{-1} \cdot \operatorname{vec}(Q)$, where $P_{t+1|t} \equiv E[(F_{t+1} - \widehat{F}_{t+1|t})(F_{t+1} - \widehat{F}_{t+1|t})']$.

(2) Calculating $F_{t+1|t}$:

$$\widehat{F}_{t+1|t} = H\widehat{F}_{t|t-1} + E_t\left(R_t - A' - \delta' F_{t|t-1}\right), \tag{10}$$

where $E_t = HP_{t|t-1}\delta(\delta' P_{t|t-1}\delta + \Omega)^{-1}$ is a gain matrix.

(3) Calculating $P_{t+1|t}$:

$$P_{t+1|t} = H\left[P_{t|t-1} - P_{t|t-1}\delta\left(\delta' P_{t|t-1}\delta + \Omega\right)^{-1}\delta' P_{t|t-1}\right]H' + Q. \tag{11}$$

(4) We can get series of values of $\{\widehat{F}_{t|t-1}\}_{t-1}^{T}$ and $\{P_{t|t-1}\}_{t-1}^{T}$ by calculating steps (2) and (3). Based on these values, the best estimates of parameter matrices $A$, $\delta$, $H$, $\Omega$, and $Q$ can be gotten by maximizing the following maximum likelihood function:

$$\begin{aligned} \operatorname{LnL} = &-\frac{1}{2}\ln 2\pi - \frac{1}{2}\ln \delta' \left|\delta' P_{t|t-1}\delta + \Omega\right| \\ &- \frac{1}{2}\sum_{t=1}^{T}\left[\left(R_t - A' - \delta'\widehat{F}_{t|t-1}\right)'\left(\delta' P_{t|t-1}\delta + \Omega\right)^{-1}\right. \\ &\left.\times\left(R_t - A' - \delta'\widehat{F}_{t|t-1}\right)\right]. \end{aligned} \tag{12}$$

## 4. Results and Analysis of the Parameter Estimation

In this paper, overnight, SHIBOR of 1 week, 2 weeks, 1 month, 3 months, 9 months, and 1 year from January 4, 2007, to August 21, 2013 will be adopted as the observed data. The initial values of parameters $A$, $\delta$, $H$, $\Omega$, and $Q$ will be gotten by regression. Then the best values for parameters of SHIBOR two-factor Vasicek model of various terms estimated by Kalman filter are as shown in Table 3.

Accoding to the parameter estimation results in Table 3, we get eight SHIBOR two-factor Vasicek models to fit overnight SHIBOR, 1-week SHIBOR, 2-week SHIBOR, 1-month SHIBOR, 3-month SHIBOR, 9-month SHIBOR, and 1-year SHIBOR from January 4, 2007, to August 21, 2013. The goodness of fit of these models is analyzed accoding to the fitting error. We adopt variance, mean square error, the average relative error, and maximum absolute value error to measure the goodness of fit. Their computation formulas are as follows.

Table 5: Analysis results of prediction errors of SHIBOR two-factor Vasicek model.

| Error analysis | Variance | Mean square error | Average relative error | Maximum absolute value error |
|---|---|---|---|---|
| O/N | 0.004308 | 0.019736 | 0.127703 | 0.232284 |
| 1-week | 0.003746 | 0.008812 | 0.080438 | 0.118666 |
| 2-week | 0.009814 | 0.036827 | 0.14746 | 0.080697 |
| 1-month | 0.008153 | 0.028611 | 0.13772 | 0.301889 |
| 3-month | 0.001746 | 0.001335 | 0.032295 | 0.043602 |
| 6-month | 0.004104 | 0.008984 | 0.088007 | 0.054531 |
| 9-month | 0.004801 | 0.01201 | 0.104805 | 0.074383 |
| 1-year | 0.004243 | 0.008834 | 0.086004 | 0.049985 |

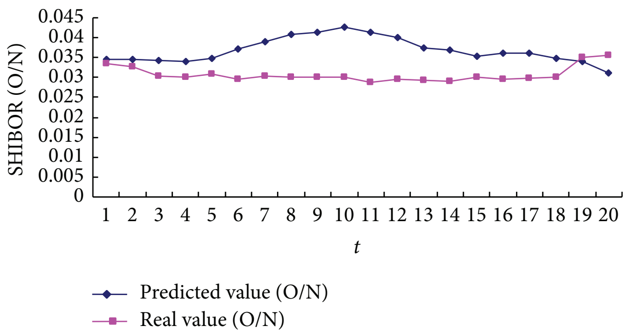


Figure 1: Overnight SHIBOR forecast figure.

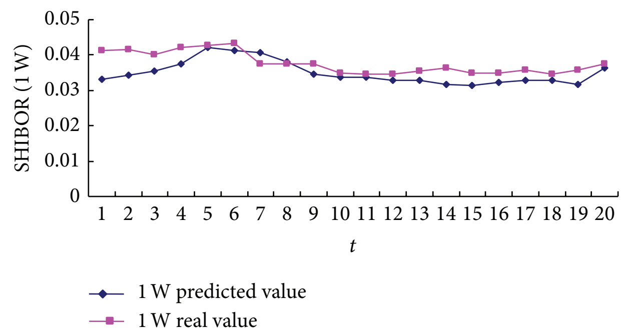


Figure 2: One-week SHIBOR forecast figure.

Variance:

$$\text{MSE} = \frac{\sum_{t=1}^{n} \left(y_t' - y_t\right)^2}{n}. \quad (13)$$

Mean square error:

$$\text{RMSE} = \frac{1}{n}\sum_{t=1}^{n}\left(\frac{y-y'}{y}\right)^2. \quad (14)$$

Average relative error:

$$\text{AVGE} = \frac{1}{n}\sum_{t=1}^{n}\left|\frac{y-y'}{y}\right|. \quad (15)$$

Maximum absolute value error:

$$\text{MAXE} = \max_{t}\left|\frac{y-y'}{y}\right|. \quad (16)$$

Results of fitting error analysis of SHIBOR two-factor Vasicek model are shown in Table 4.

Accoding to results of Table 4, the two-factor Vasicek model fitting error is small for SHIBOR of 8 different terms, especially for SHIBOR of more than 3 months. The fitting variance and mean square error of 3-month SHIBOR, 6-month SHIBOR, and 9-month SHIBOR are less than 0.001. And their average relative error and maximum absolute error are much lower than those of overnight SHIBOR, 1-week

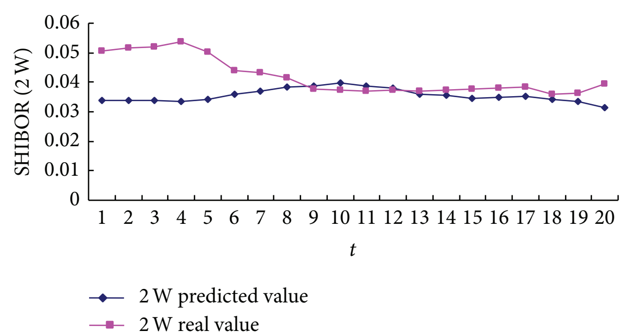


Figure 3: Two-week SHIBOR forecast figure.

SHIBOR, and 2-week SHIBOR. The fitting variance, the mean square error, and the average relative error of 1-year SHIBOR are less than these of SHIBOR of the former four varieties. Particularly its maximum absolute value error is the smallest. It means that the result of fitting the one-year SHIBOR by using two-factor Vasicek model is robust. Next, in this paper, these SHIBOR two-factor Vasicek models will be used to forecast 8 varieties of SHIBOR from August 22, 2013, to September 18, 2013. The results are shown in Figures 1, 2, 3, 4, 5, 6, 7, and 8.

The forecasting precision of SHIBOR two-factor Vasicek model is analyzed. We calculate the variance, difference quotient, the average relative error, and maximum absolute error to compare predicted SHIBOR and real SHIBOR from August 22, 2013, to September 18, 2013. The results are shown in Table 5.

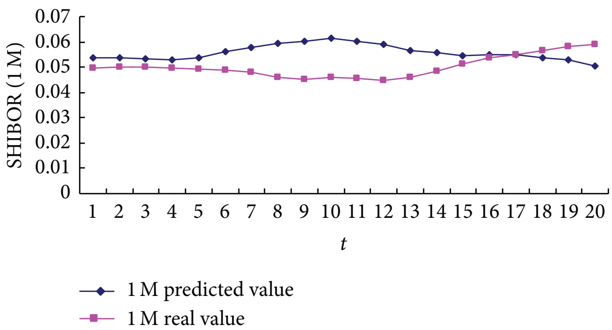


Figure 4: One-month SHIBOR forecast figure.

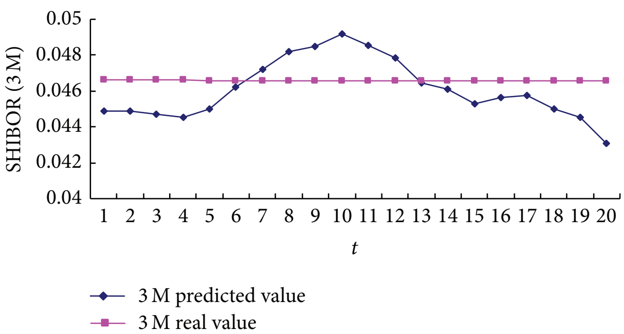


Figure 5: Three-month SHIBOR forecast figure.

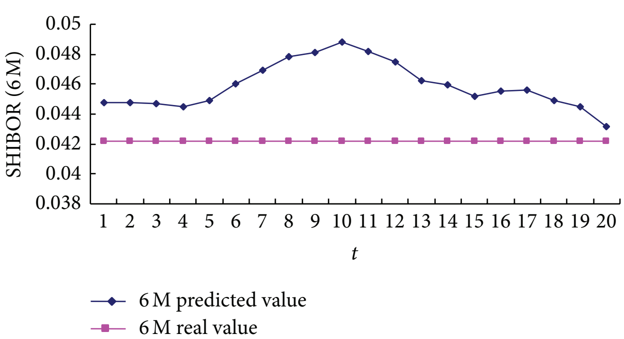


Figure 6: Six-month SHIBOR forecast figure.

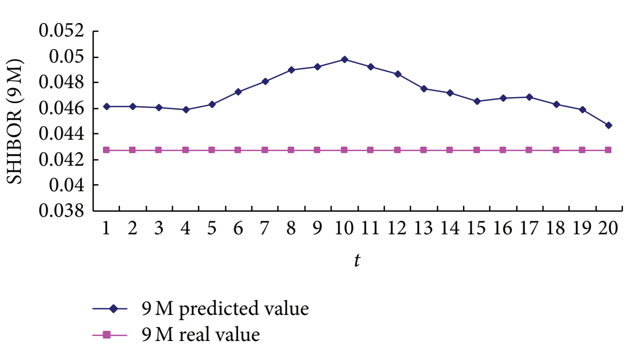


Figure 7: Nine-month SHIBOR forecast figure.

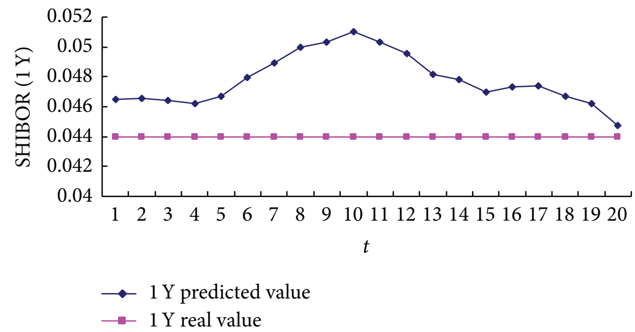


Figure 8: One-year SHIBOR forecast figure.

The results in Table 5 show that the prediction accuracy of our SHIBOR two-factor Vasicek model is quite high. Accoding to both variance, mean square error, mean relative error, and the maximum absolute error of prediction, prediction accuracy of the 3-month SHIBOR two-factor Vasicek model is superior to other two-factor Vasicek models. The prediction accuracy of SHIBOR two-factor Vasicek model of 1 week, 6 months, and 1 year is slightly higher than it of overnight, 2 weeks, 1 month, and 9 months.

## 5. Conclusion

Through principal component analysis to 8 varieties of SHIBOR, this paper found that two principal components can explain more than 96% volatility of SHIBOR. Therefore the two-factor Vasicek model can be established to describe the term structure of SHIBOR. Then we use kalman filter to estimate parameters of various terms of SHIBOR, the two-factor Vasicek model, and fit various terms of SHIBOR with this model. The results show that goodness of fit of the two-factor Vasicek model is high, especially for more than 3-month SHIBOR. Finally, we test the prediction ability of this model and find that prediction accuracy of 3-month SHIBOR is higher than it of SHIBOR with other terms.

## Conflict of Interests

The authors declare that there is no conflict of interests regarding the publication of this paper.

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