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FORECASTING PERFORMANCE OF THOR FORWARD RATES FOR THOR AVERAGES

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Abstract

Since July 1, 2021, Thai financial institutions have stopped issuing financial products linked to the Thai baht interest rate fixing (THBFIX). The Thai overnight repurchase rate (THOR) now serves as a substitute. However, the settlement of THOR-linked products refers to the average daily THOR (THOR average) computed in arrears. THOR averages are backward-looking, random, and unknown to the present market. By adopting THOR, interest rate swaps become overnight index swaps (OIS). THOR forward rates are fixed for the expected THOR averages, to calculate cash flows in the floating rate leg, in the modified model for the valuation of THOR OIS contracts. The success of the modified model depends critically on the equality of the THOR forward rates and expected THOR averages. This study tests the implications of the equality condition—informativeness, unbiasedness, and forecast accuracy. The data were captured daily over a sample period from June 22, 2020, to September 23, 2021. THOR forward rates are not informative or unbiased. However, the competing government has implied that forward rates and lagged THOR averages perform equally poorly. In terms of forecast accuracy, the THOR forward rates perform significantly better. Therefore, THOR forward rates are recommended over competing rates for the valuation of THOR OIS contracts.

Keywords: IRS, LIBOR, term rates

INTRODUCTION

Thailand's Thai baht interest rate swap (IRS) market is very large and growing. In June 2021, the outstanding notional value of its contracts was 3,015 billion baht. In the past ten years, it has grown 14.10% from 2,618 billion baht in July 2011 (Bank of Thailand, 2021a). Among these contracts, the Thai baht interest rate fixing (THBFIX) had the largest share of 99.17% (Laksanasut, 2018). The THBFIX is constructed based on the USD London interbank offered rate (LIBOR), spot USD-baht exchange rate, and USD-baht forward point. Due to the cessation and earlier planned cessation of USD LIBOR, the THBFIX was phased out. The Bank of Thailand (2021b) imposed the seizure of the issuance of new THBFIX-linked financial products by financial institutions, including THBFIX IRS contracts, from July 1, 2021. The Thai overnight repurchase rate (THOR) is the new reference rate.

THOR is the secured interbank overnight repurchase rate; thus, it is nearly risk-free (Bank of Thailand, 2021c). THOR was introduced as an alternative reference rate by the Bank of Thailand in the first half of 2020, while it was promoted in the cash and derivatives markets in the second half of 2020 (Bank of Thailand, 2021d). In the third quarter of 2020, THOR overnight index swap (OIS) transactions totaled 14.8 billion baht. Even before July 1, 2021, in the second

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quarter of 2021, transactions had increased to 26.0 billion baht (Bank of Thailand, 2021e).

When THORs are referenced in swap contracts, they become overnight index swap (OIS) contracts. The compound average (THOR average) of daily THORs during the settlement period is the settlement rate for the floating-rate leg. The Bank of Thailand (2021f) explained that THOR averages were compounded in arrears. Unlike THBFIXs, which were forward-looking rates known on the first day of the settlement period, THOR averages are backward-looking rates known on future settlement dates.

The transition from THBFIXs in IRS to THOR averages in OIS calls for new valuation models for THOR OIS contracts. Rigopoulos (2020) showed that the OIS valuation model is similar to textbook models (e.g., Hull, 2021). The expected cash flow computed from the THOR average for the floating-rate leg is fixed by the THOR forward rate for the same settlement period. Thus, the value of the THOR OIS contract is the present value of expected future cash flows of the floating-rate leg, net of those of the fixed-rate leg. The discount rates are risk-free THOR term rates, bootstrapped from the THOR OIS curve.

The fair prices of THOR OIS contracts are important for trading and financial reporting. Model prices can serve as fair prices only when the model is correct. The condition that the forward interest rates equal the expected THOR averages is necessary for the correct model. The forward interest rates originate from the THOR OIS rates. In theory, they embed the market's expectation of THOR averages (Joyce & Meldrum, 2008). It is important to note that the THOR OIS market is young, and its trading volume is very thin. A thin OIS market cannot provide robust THOR terms or forward interest rates (Federal Reserve Bank of New York, 2021).

This study examines the forecasting performance of THOR forward rates for THOR averages vis-à-vis the equality condition of the two rates. Notably, the THOR forward rates are nearly risk-free. However, it is likely that the rates are not robust due to the young and thin THOR OIS market. The study constructs implied forward rates from government spot rates to compete in the performance comparison.

THE MODEL

The Equality Condition

Let r_i be the THOR in percent per annum on day i in the settlement period from years $t+\tau$ to $t+\tau+\frac{M}{12}$. The M-month compound average of THOR $\left(A\left(t+\tau, t+\tau+\frac{M}{12}\right)\right)$ is found by:

$$A\left(t+\tau, t+\tau+\frac{M}{12}\right) = \left[\prod_{i=1}^{d_b}\left(1+\frac{r_i \times n_i}{365}\right)-1\right] \times \frac{365}{d_c}, \qquad (1)$$

where d_b and d_c are the numbers of business and calendar days in the settlement period, respectively, and n_i is the number of days for which r_i is applied. As $A\left(t+\tau, t+\tau+\frac{M}{12}\right)$ is computed in arrears, it is a random interest rate at or before year $t+\tau$. In practice, a payment delay for $A\left(t+\tau, t+\tau+\frac{M}{12}\right)$ is agreed upon to provide floating-rate payers with sufficient time to prepare money. The present date is considered as year 0.

Using forward measure martingales under a no-payment-delay assumption, Rigopoulos (2020) showed that the forward rate $F\left(t, t+\tau, t+\tau+\frac{M}{12}\right)$, known at year t, to be applied for the settlement period from years $t+\tau$ to $t+\tau+\frac{M}{12}$, is:

$$F\left(t, t+\tau, t+\tau+\frac{M}{12}\right) = E_t\left\{\tilde{A}\left(t+\tau, t+\tau+\frac{M}{12}\right)\right\}, \qquad (2)$$

where, E_t is the expectation operator formed at year t, while the symbol $\sim$ over A indicates the random nature of the THOR average. Even at year t, the M-month THOR average $\tilde{A}\left(t, t+\frac{M}{12}\right)$ is unknown to the market. Thus, it is a random interest rate.

THOR Forward Rates

The forward rate $F\left(t, t+\tau, t+\tau+\frac{M}{12}\right)$ is computed from the term rates $Y\left(t, t+\tau+\frac{M}{12}\right)$ and $Y(t, t+\tau)$ observed at year t for the loan periods of $\tau+\frac{M}{12}$ and τ years, respectively, as in equation (3).

$$F\left(t, t+\tau, t+\tau+\frac{M}{12}\right) = \frac{12}{M}\left[\frac{1+\left(\tau+\frac{M}{12}\right)\times Y\left(t, t+\tau+\frac{M}{12}\right)}{1+\tau\times Y(t, t+\tau)} - 1\right]. \quad (3)$$

THOR Term Rates

The forward-looking term rates $Y\left(t, t+\tau+\frac{M}{12}\right)$ and $Y(t, t+\tau)$ for THOR are unobserved. Here, the term rates from the THOR OIS rates are bootstrapped. Let $K(t, t+T)$ be the market's T-year OIS rate at year t. For $T < 12$ months, the payment frequency is at maturity. This study sets $Y(t, t+T) = K(t, t+T)$. The rate follows the Federal Reserve Bank of New York (2021), stating that any forward-looking term rates are expected to be equal or close to the underlying OIS curve. For $T \geq 12$ months, the Bank of Thailand (2020) imposed a quarterly payment frequency. Hence, the term rates using the fair swap rate formula are bootstrapped (Cairns, 2004).

$$K(t, t+T) = 4\frac{1-\frac{1}{1+T\times Y(t,t+T)}}{\sum_{k=1}^{4T}\frac{1}{1+0.25k\times Y(t,t+0.25k)}}. \quad (4)$$

If $Y(t, t+j)$ for $j < T$ is not available from the previous step, $Y(t, t+j)$ is linearly interpolated from $Y(t, t+T)$ and the immediately available shorter-term rate $Y\big(t, t+(j^{-} < j)\big)$. Linear interpolation in bootstrapping is common in the marketplace (Ron, 2000).

Government Spot Rates

This study constructs government-implied forward rates from government spot rates for performance comparison with THOR forward rates. The government spot and THOR term rates are equivalent because they are risk-free and nearly risk-free, respectively. If certain spot rates are not available to construct the forward rates, the rates are set to the rates linearly interpolated from adjacent available rates.

Forecasting Forward Rates

The study forecasts THOR averages for $M < 12$ months using the THOR M-month term rates. The rates are forward-looking. Moreover, $F\left(t, t, t+\frac{M}{12}\right) = Y\left(t, t+\frac{M}{12}\right)$. For $(M \geq 12)$-month contracts, the THOR averages are $A(t+0.25(m-1), t+0.25m)$, where $m = 1,2,..,m^{*}$ and $0.25m^{*} = \frac{M}{12}$ years—the term of the contract. The settlement dates are 0.25 years apart due to the Bank of Thailand's (2020) recommended convention. The forecasting forward rate for $A(t+0.25(m-1), t+0.25m)$ is $F(t, t+0.25(m-1), t+0.25m)$, while $Y(t, t+0.25)$ forecasts $A(t, t+0.25)$.

Forecast Date

The M-month THOR average $\tilde{A}\left(t+\tau, t+\tau+\frac{M}{12}\right)$ is settled $\tau+\frac{M}{12}$ years in the future from year t. The forecast date t is the same calendar date as the settlement date $t+\tau+\frac{M}{12}$. If t is not a business day, the forecast date is the business day immediately before t. The identification of the forecast date is inferred from the calculation formula for THOR averages (Bank of Thailand, 2021f).

Forecasting Performance

The forecasting performance is assessed based on the equality condition (2) in three dimensions: informativeness, unbiasedness, and forecast accuracy.

Informativeness

Consider the linear regression equation (5) of $A\left(t+\tau, t+\tau+\frac{M}{12}\right)$ on $F\left(t, t+\tau, t+\tau+\frac{M}{12}\right)$.

$$A\left(t+\tau, t+\tau+\frac{M}{12}\right) = \alpha + \beta F\left(t, t+\tau, t+\tau+\frac{M}{12}\right) + \varepsilon(t), \quad (5)$$

where α and β are the intercept and slope coefficients, respectively. The term $\varepsilon(t)$ denotes the regression error. In general, equation (5) can be estimated using the ordinary least squares (OLS) method. However, Cole and Reichenstein (1994) noted that most interest rates are non-stationary; thus, the OLS regression for (5) leads to incorrect statistical inference. However, the researchers proposed estimating a regression of the differences in interest rates. This can be done using:

$$\Delta A\left(t+\tau, t+\tau+\frac{M}{12}\right) = \alpha + \beta \Delta F\left(t, t+\tau, t+\tau+\frac{M}{12}\right) + u(t). \quad (6)$$

The term $\Delta A\left(t+\tau, t+\tau+\frac{M}{12}\right)$ is equal to $A\left(t+\tau, t+\tau+\frac{M}{12}\right) - A\left((t-d)+\tau, (t-d)+\tau+\frac{M}{12}\right)$, while the term $\Delta F\left(t, t+\tau, t+\tau+\frac{M}{12}\right)$ is equal to $F\left(t, t+\tau, t+\tau+\frac{M}{12}\right) - F\left((t-d), (t-d)+\tau, (t-d)+\tau+\frac{M}{12}\right)$. The notation d is a one-business-day time interval. Finally, $u(t) = \varepsilon(t) - \varepsilon(t-d)$.

If forward rates can forecast future THOR averages, as equation (2) indicates, they possess information about the averages. From equation (6), the slope coefficient β must be significant. The informativeness hypothesis for $F\left(t, t+\tau, t+\tau+\frac{M}{12}\right)$ is the condition where $\beta = 0$. Moreover, the movement $\Delta F\left(t, t+\tau, t+\tau+\frac{M}{12}\right)$ should explain the movement $\Delta A\left(t+\tau, t+\tau+\frac{M}{12}\right)$ in most cases. The coefficient of determination (R^2) should be high and close to 1.00.

Unbiasedness

The equality condition (2) suggests that $F\left(t, t+\tau, t+\tau+\frac{M}{12}\right)$ is an unbiased predictor for $A\left(t+\tau, t+\tau+\frac{M}{12}\right)$. Unbiasedness implies two sets of testable hypotheses (Cole & Reichenstein, 1994).

(i) The hypothesis of zero forecast errors, where $e(t) = A\left(t+\tau, t+\tau+\frac{M}{12}\right) - F\left(t, t+\tau, t+\tau+\frac{M}{12}\right)$ is the forecast error, and $\bar{e}$ is the average forecast error, under the unbiasedness hypothesis, $\bar{e} = 0$.

(ii) The hypotheses of $\alpha = 0$ and $1 - \beta = 0$, and the joint hypothesis of $\alpha = 0$ and $1 - \beta = 0$. Here, 0 is substituted for α, and 1 is substituted for β, in equations (5) and (6), while considering the expectation of the equations presents the equality condition (2).

Forecast Accuracy

If the forecast is accurate, the forecast error $e(t) = A\left(t+\tau, t+\tau+\frac{M}{12}\right) - F\left(t, t+\tau, t+\tau+\frac{M}{12}\right)$ must be small and close to 0.00. In this study, the forecast accuracy was measured using the mean absolute error (MAE), and root mean squared error ($RMSE$). $RMSE$ penalizes large errors more severely than small errors, whereas MAE addresses large and small errors on the same scale. The average error $\bar{e}$ was not considered because a small $\bar{e}$ does not necessarily indicate a small $e(t)$. The error $e(t)$ can be negative or positive. Large positive and negative $e(t)$ cancel each other out, resulting in a small $\bar{e}$. Thus, MAE and $RMSE$ were used, defined by equations (7) and (8), respectively.

$$MAE = \frac{1}{N}\sum_{n=1}^{N}|e_n(t)|, \quad (7)$$

$$RMSE = \sqrt{\frac{1}{N}\sum_{n=1}^{N}\{e_n(t)\}^2}. \quad (8)$$

The term $e_n(t)$ is the forecast error for observation n in the sample, while N is the total number of observations.

Here, the forecasting performance of the THOR forward rates is compared against the government-implied forward rates. The terms $\Delta MAE = MAE_T - MAE_G$ and $\Delta RMSE = RMSE_T - RMSE_G$ are defined, where the subscripts T and G denote the THOR and government-implied forward rates, respectively. Negative and significant ΔMAE and $\Delta RMSE$ would suggest the superior forecast accuracy of the THOR forward rates.

Hypothesis Tests

The hypothesis tests were performed using Newey and West's (1987) heteroscedasticity and autocorrelation-consistent standard errors and covariance matrices. The Wald test was used for the joint hypothesis of $\alpha = 0$ and $1 - \beta = 0$. Under the null hypothesis, the Wald statistic is a chi-square variable with two degrees of freedom.

THE DATA

Daily data were used, with sample interest rates scaled by 100. The THOR OIS rates were retrieved from the Reuters database, while the THOR averages and government spot rates were taken from the Thai Bond Market Association's database. The sample collected runs from June 22, 2020, to September 23, 2021, a total of 303 observations. On June 22, 2020, the THOR OIS rates were available on Reuters. Reuters reports bid and ask rates; the average bid and ask rates in the analysis were considered. On certain business days, bid or ask OIS rates were missing for some tenors. If the rates were missing on a particular day, the rates for the same tenors available on the previous business day of the missing tenors were attributed.

Forecasts for 1-, 3-, and 6-month THOR averages for the next settlement dates were considered. Owing to the short sample, the forecasts of the 3-month THOR average included only those to be settled in the next 6 9, and 12 months. Table 1 reports the descriptive statistics for the differences in, THOR averages, term rates, and forward

Table 1 Descriptive Statistics

Panel 1.1 THOR Averages

Statistic	M-Month THOR Average		
	M=1	M=3	M=6
Average	4.64E-06	-5.62E-04	-1.31E-03
Standard Deviation	1.59E-04	0.0019	0.0027
Skewness	-0.6606	-4.4969	-3.1873
Excess Kurtosis	11.0008	22.7956	13.7187
AR(1) Coefficient	0.0310	0.4984***	0.5198***
Jarque-Bera Statistic	1.54E+03***	7.56E+03***	2.88E+03***
Augmented Dickey-Fuller Statistic	-16.7634***	-2.9386**	-3.5688***
Number of Observations	302	302	302
Augmented Dickey-Fuller Statistic for Level	-1.2431	-4.9117***	-3.3888**

NOTE: ** and *** indicate significance at the 95% and 99% confidence levels, respectively.

Table 1 Descriptive Statistics (Continued)

Panel 1.2 THOR Term and Government Spot Rates

Statistic	M-Month THOR Term Rate			M-Month Government Spot Rate		
	M=1	M=3	M=6	M=1	M=3	M=6
Average	3.31E-05	4.97E-05	1.82E-04	1.32E-05	1.00E-04	-1.81E-05
Standard Deviation	5.75E-04	0.0034	0.0037	0.0055	0.0057	0.0047
Skewness	17.3781	1.7405	3.2914	-1.1367	-0.8957	-0.5838
Excess Kurtosis	302.0000	62.4575	55.6857	13.0439	11.2007	7.1406
AR(1) Coefficient	-0.0033	-0.0002	-0.0024	0.6193***	0.6128***	0.5565***
Jarque-Bera Statistic	1.16E+06***	4.92E+04***	3.96E+04***	2.21E+03***	1.62E+03***	6.59E+02***
Augmented Dickey-Fuller Statistic	-17.3494***	-17.2953***	-17.3329***	-4.4957***	-4.4160***	-5.1545***
Number of Observations	302	302	302	302	302	302
Augmented Dickey-Fuller Statistic for Level	-0.4660	-1.9948	-0.9430	-2.3340	-2.5273	-2.2624

Note: *** indicates significance at the 99% confidence level.

Panel 1.3 THOR and Government Implied τ-Month Forward Rates for 3-Month Average THOR

Statistic	THOR Forward Rate			Government Implied Forward Rate		
	τ=1	τ=3	τ=6	τ=1	τ=3	τ=6
Average	3.14E-04	1.81E-04	1.84E-04	-1.36E-04	3.74E-05	7.42E-05
Standard Deviation	0.0055	0.0087	0.0268	0.0051	0.0047	0.0060
Skewness	8.3966	6.8684	0.6170	0.2818	1.2560	1.9380
Excess Kurtosis	118.3212	134.4421	26.6334	6.0005	10.2894	13.1674
AR(1) Coefficient	-0.0033	-0.0136	-0.1129*	0.4147***	0.3774***	0.2463***
Jarque-Bera Statistic	1.80E+05***	2.30E+05***	8.95E+03***	4.57E+02***	1.41E+03***	2.37E+03***
Augmented Dickey-Fuller Statistic	-17.3481***	-12.5775***	-19.3679***	-11.2383***	-8.2001***	-13.4580***
Number of Observations	302	302	302	302	302	302
Augmented Dickey-Fuller Statistic of Level	-0.4085	-1.8505	-2.5003	-1.6546	-2.0975	-2.4311

Note**:** * and *** indicate significance at the 90% and 99% confidence levels, respectively.

rates. Rate differences rather than rate levels were used because of the possible non-stationarity property of interest levels (Cole & Reichenstein, 1994). The Augmented Dickey-Fuller (ADF) tests for the interest levels could not reject the non-stationarity hypothesis for all the rates, except for the 3- and 6-month THOR averages. Meanwhile, the ADF tests did reject the non-stationarity hypothesis for all the rate differences.

The rate differences were not distributed normally, while most also showed significant autocorrelation. Non-normality should not adversely affect the statistical inferences. For the analyses based on $\bar{e}$, MAE, and $RMSE$, the number of observations in the tests was much larger than 32. Significant auto-correlation is accounted for by Newey and West's (1987) heteroscedasticity and autocorrelation-consistent standard errors and covariance matrices.

EMPIRICAL RESULTS

Table 2 reports the forecasting performance of the THOR term and government spot rates for the next 1-, 3-, and 6-month THOR averages. For informativeness, the slope coefficient β is significant for the 1-month THOR term rate and 6-month government spot rate. However, the R^2 values were very small. These results suggest that THOR term and government spot rates are not informative predictors for the next THOR averages. The unbiasedness hypotheses implied by the equality condition (2) were rejected at high confidence levels, for the two rates in most cases. The MAEs and $RMSE$s suggest that THOR term rates forecast the next THOR averages more accurately than government spot rates. The superior performance equates to 4 to 10 basis points for ΔMAEs and 7 to 12 basis points for $\Delta RMSE$s. These statistics were significant at the 99% confidence level.

Table 3 reports the 6-, 9-, and 12-month forecasts of the 3-month THOR averages by the THOR and government implied forward rates. The 3-month forecast was not included in this table. However, it is considered from the next 3-month THOR average in Table 2. The results are very similar to those in Table 2. The THOR and government implied forward rates were found to be non-informative and not unbiased predictors of the future THOR averages. The THOR forward rates forecast the 3-month THOR average more accurately than the government implied forward rates for the 6- and 9-month forecasting horizons. For the 12-month horizon, the government implied forward rate was more accurate.

The results in Tables 2 and 3 conclude that the THOR term, government spot, THOR forward, and government implied forward rates contain little information about THOR averages. Moreover, forward rates, regardless of whether they are constructed from THOR term rates or government spot rates, are not unbiased predictors of THOR averages. The equality condition (2) proposed by Rigopoulos (2020) is not supported by the interest rate data in the Thai market. Despite the poor performance of the competing rates in terms of informativeness and unbiasedness, the THOR term and THOR forward rates should be preferred to government spot and implied-forward rates from a forecast accuracy perspective.

DISCUSSION

Poor Performance of Government Spot and Implied Forward Rates

The THOR OIS market is young, and its trading is thin. Thus, the THOR OIS rates do not satisfy the conditions under which THOR term rates are robust risk-free rates. However, the government securities market is more mature and much deeper than the THOR OIS market. Therefore, government spot rates should be more robust, with the forecasting performance of the government spot and implied forward rates being superior to that of the THOR term and forward rates. It is therefore interesting that the government spot and implied forward rates show poor performance for the sample in this study. There are three possible explanations.

Table 2 Forecasting Performance of THOR Term and Government Spot Rates for Next THOR Averages

Statistic		1-Month THOR Average		3-Month THOR Average		6-Month THOR Average	
		THOR Term	Government Spot	THOR Term	Government Spot	THOR Term	Government Spot
Informativeness	$b = 0$	0.0063***	-7.46E-04	3.90E-04	1.77E-04	5.54E-05	4.08E-04**
	R^2	5.48E-04	8.84E-04	9.46E-04	8.10E-04	5.00E-05	0.0117
Unbiasedness	$\bar{e} = 0$	0.0014***	0.1058***	-0.0062**	0.0807***	-0.0047	0.0603***
	$a = 0$	6.79E-06	6.86E-06	9.56E-06***	9.62E-06***	9.05E-06***	9.20E-06***
	$1 - b = 0$	0.9937***	1.0007***	0.9996***	0.9998***	0.9999***	0.9996***
	$a = 0$ and $1 - b = 0$[a]	4.22E+25***	9.55E+09***	1.01E+11***	1.02E+11***	2.19E+11***	2.33E+11***
Forecast Accuracy	Mean Absolute Error	0.0028***	0.1058***	0.0147***	0.0814***	0.0163***	0.0610***
	Difference	-0.1030***		-0.0667***		-0.0446***	
	Root Mean Square Error	0.0031***	0.1269***	0.0189***	0.1076***	0.0204***	0.0915***
	Difference	-0.1238***		-0.0887***		-0.0710***	
Test Sample (Number of Observations)		7/22/2020 – 9/23/2021 (282)		9/22/2020 – 9/23/2021 (243)		12/22/2020 – 9/23/2021 (183)	
Engle-Granger Co-integration Test Statistic		-2.2481	-1.6567	-0.3399	-1.5190	-2.4353	-1.4334

Note: [a] = chi-square variable with two degrees of freedom. ** and *** indicate significance at the 95% and 99% confidence levels, respectively.

Table 3 Six-, Nine-, and Twelve-Month Forecasting Performance of THOR and Government Implied Forward Rates for 3-Month THOR Average

Statistic		6-Month Forward		9-Month Forward		12-Month Forward	
		THOR	Government Implied	THOR	Government Implied	THOR	Government Implied
Informativeness	$b = 0$	-0.0011	3.53E-04	2.72E-04	-0.0034***	-1.89E-04	0.0010
	R^2	0.0061	0.0028	5.34E-04	0.0693	0.0243	0.0087
Unbiasedness	$\bar{e} = 0$	-0.0101***	0.0043	-0.0015	-0.0089*	0.0161	-0.0147***
	$a = 0$	1.12E-05***	1.11E-05***	9.08E-06**	6.33E-06	1.64E-05***	1.58E-05***
	$1 - b = 0$	1.0011***	0.9996***	0.9997***	1.0034***	1.0002***	0.9990***
	$a = 0$ and $1 - b = 0$[a]	8.33E+10***	8.47E+10***	5.49E+10***	6.76E+10***	3.67E+10***	3.61E+10***
Forecast Accuracy	Mean Absolute Error	0.0162***	0.0405***	0.0124***	0.0220***	0.0450***	0.0158***
	Difference	-0.0243***		-0.0096**		0.0292***	
	Root Mean Square Error	0.0184***	0.0540***	0.0144***	0.0284***	0.0638***	0.0184***
	Difference	-0.0356***		-0.0140***		0.0454***	
Test Sample (Number of Observations)		12/22/2020 – 9/23/2021 (183)		3/22/2021 – 9/23/2021 (123)		6/22/2021 – 9/23/2021 (65)	
Engle-Granger Co-integration Test Statistic		-3.1996**	-0.5319	-0.0444	-1.0799	-0.1753	-1.8198

Note: [a] = chi-square variable with two degrees of freedom. *, **, and *** indicate significance at the 90%, 95%, and 99% confidence levels, respectively.

First, the government spot rates represent the rate in the government market, while the THOR terms and averages represent the interbank market. Additionally, the two markets are segmented. In the sample, arbitrage trades cannot eliminate market segmentation (Hammond, 1987).

Second, government spot rates are truly risk-free, while the THOR term rates are nearly risk-free (Bank of Thailand, 2021c). Although the risk levels of the two rates are close, the market may perceive the difference as significant.

Third, government spot rates are interpolated from the yields of a limited number of qualified government securities. Interpolation is inherently noisy (Duffee, 2013). Thus, government spot rates have large interpolation errors.

Poor Performance of THOR Term and Forward Rates

As the THOR OIS market is young and thin, it is unlikely that robust THOR term rates can be bootstrapped from the THOR OIS rates (Federal Reserve Bank of New York, 2021). This may help explain the poor performance of the THOR term and forward rates with respect to the informativeness hypothesis.

Cole and Reichenstein (1994) argued that risk premiums, described by Hicks (1939), Keynes (1930), and Meulbroek (1992), could explain the rejection of the unbiasedness hypothesis. In this study, the significant average forecasting error $\bar{e}$ can be interpreted as a risk premium. However, a risk-premium explanation is unlikely. The size of $\bar{e}$ does not change monotonically within the forecasting horizons.

It is important to note that the THOR terms were bootstrapped from the THOR OIS rates. Therefore, the performance is conditioned on the chosen bootstrapping technique. This study used a textbook formula to relate the term rates to OIS rates. Missing term rates were produced by linear interpolation. In the literature (Hagan & West, 2006), other interpolation techniques, such as log-linear and cubic spline, are possible and can yield term and forward rates of superior performance.

Recently, Heitfield and Park (2019) proposed a model for the U.S. market to recover term rates from future rates and swap overnight interest rates. In the model, the overnight rate jumps up or down on the scheduled Federal Open Market Committee (FOMC) policy rate announcement dates. The rate remains unchanged during the periods between FOMC meetings. The researchers reported that the resulting term rates could accurately forecast the realized compound average overnight rates. The CME Group (2021) adopted the Heitfield-Park method to calculate U.S. term overnight reference rates. Thus, the Heitfield-Park method can be adapted to infer THOR term rates. It is possible that the Heitfield-Park THOR term rates could be used to improve forecasting performance over the THOR term rates in this study.

Random-Walk THOR Averages

Interest rates may follow a random walk process. The current rate is an unbiased predictor of the future rate, and its forecasting performance is superior to competing models (den Butter & Jansen, 2013). If THOR averages follow a random walk, $A\left(t-\frac{M}{12},t\right)=E_t\left\{\tilde{A}\left(t+\tau,t+\tau+\frac{M}{12}\right)\right\}$. The ADF statistics in the last row of Panel 1.1, Table 1 support the random walk hypothesis for THOR averages. As the forecasting performance of THOR forward rates is not satisfactory, it is interesting to determine whether the forecasting performance of lagged THOR averages is better.

Based on the current observed rates, the next 1-, 3-, and 6-month THOR averages were forecasted. Additionally, the current 3-month THOR average was used to forecast the 3-month THOR average to be settled in the next 6, 9, and 12 months. The associated forecasting performance is presented in Table 4. The observed THOR averages were not informative and were not unbiased predictors

Table 4 Forecasting Performance for THOR Averages by their Lags

Statistic		M-Month THOR Average					
		M=1 by 1-Month Lag	M=6 by 6-Month Lag	M=3 by 3-Month Lag	M=3 by 6-Month Lag	M=3 by 9-Month Lag	M=3 by 12-Month Lag
Informative-ness	$b = 0$	-0.2373**	0.0033	-4.50E-04	-0.0036**	0.0013	2.85E-04
	R^2	0.0577	0.0217	0.0024	0.0360	0.0071	8.86E-04
Unbiased-ness	$\bar{e} = 0$	1.56E-04	-0.0132**	-0.0828***	-0.0171**	-0.0255	-0.0492
	$a = 0$	9.08E-06	1.19E-05***	8.08E-06***	7.67E-06**	1.10E-05**	1.70E-05***
	$1 - b = 0$	1.2373***	0.9967***	1.0005***	1.0036***	0.9987***	0.9997***
	$a = 0$ and $1 - b = 0$[a]	1.10E+10***	1.06E+11***	2.32E+11***	9.01E+10***	6.06E+10***	4.05E+10***
Forecast Accuracy	Mean Absolute Error	7.09E-04***	0.0141***	0.0837***	0.0187***	0.0276***	0.0509***
	Difference[b]	0.0020***	6.75E-04	-0.0674***	-0.0025	-0.0152*	-0.0059
	Root Mean Square Error	9.16E-04***	0.0392***	0.1418***	0.0449***	0.0545***	0.0749***
	Difference[b]	0.0021***	-0.0203***	-0.1214***	-0.0265***	-0.0402***	-0.0111**
Test Sample (Number of Observations)		7/22/2020 – 9/23/2021 (282)	12/22/2020 – 9/23/2021 (183)	9/22/2020 – 9/23/2021 (243)	12/22/2020 – 9/23/2021 (183)	3/22/2021 – 9/23/2021 (123)	6/22/2021 – 9/23/2021 (65)
Engle-Granger Co-integration Test Statistic		-2.1706	0.5961	0.1122	1.0710	0.8124	-1.2902

Note: [a] = chi-square variable with two degrees of freedom; [b] = comparison with the performance of overnight-indexed-swap and implied forward rates. *, **, and *** indicate significance at the 90%, 95%, and 99% confidence levels, respectively.

of the future THOR averages. In most cases, the accuracy of their forecasts was poorer than that of the THOR terms and forward rates.

Co-integration Regressions

The ADF statistics in Table 1 suggest that the interest rates are non-stationary. Therefore, the regression model (6) was used to assess the information levels and test for the unbiasedness hypothesis for the forward rates. However, if the THOR averages and forecasting THOR terms and forward rates are co-integrated, differencing the interest rates eliminates valuable information about the relationship between the forecast and forecasting interest rates (Ruxanda & Botezatu, 2008). Therefore, poor performance may be caused by the loss of information due to differencing. Thus, the co-integrated regression model (5) should be preferred (Stock, 1987).

The Engle and Granger's (1987) test for no co-integration was conducted between the forecast and forecasting interest rates to ensure the appropriate choice for the regression model (6). The associated test statistics are reported in the last rows of Tables 2, 3, and 4. These tests cannot be used to reject the hypothesis for all cases except for the 6-month forecast of the 3-month THOR average. The results indicate that the regression model (6) is appropriate.

CONCLUSION

The THOR serves as a new reference rate substituting the THBFIX from July 1, 2021. THOR-linked financial products are now settled based on THOR averages. THOR averages are backward-looking, while the THBFIX is forward-looking. The valuation models for THBFIX-linked products must be modified or replaced due to the different nature of the THOR averages and THBFIX.

The valuation model for THOR OIS contracts is similar to the textbook model for THBFIX swap contracts. The expected THOR averages to compute cash flows on the floating rate leg were estimated using the corresponding THOR forward rates. The study then proceeded to test the hypotheses as implied by the equality of expected THOR averages and THOR forward rates.

The study found that THOR forward rates were not informative or unbiased predictors of THOR averages. However, the forecast accuracy of the THOR forward rates was significantly higher than that of the competing rates—government spot rates and lagged THOR averages. This result leads to recommendation of the use of THOR forward rates in the valuation model.

In this study, THOR forward rates were constructed from THOR term rates, which were bootstrapped from the THOR OIS curves. Linear interpolation was used in some steps, when the term rates were not possible. Therefore, the empirical results are dependent on the way the THOR term and forward rates were constructed. Alternative interpolation techniques are available, and new methods for bootstrapping or calibrating THOR term rates have been proposed. Applying alternative interpolation techniques or new methods may yield THOR forward rates that better satisfy the equality condition or enhance the forecasting accuracy. The performance improvement of THOR forward rates should be considered for future research.

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