ESTIMATING TIME-VARYING SYSTEMATIC RISK BY USING KALMAN FILTERAPPROACH: EVIDENCES FROM THE STOCK EXCHANGE OF THAILAND

การประมาณค่าสัมประสิทธิ์ความเสี่ยงที่เป็นระบบซึ่งเปลี่ยนแปลงตามเวลา โดยตัวแบบ Kalman filter: กรณีศึกษาจากตลาดหลักทรัพย์แห่งประเทศไทย

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Abstract

The objective of this study is focusing on the time-varying systematic risk or beta estimation by using the proper model which can explain the system that varies through time appropriately like Kalman filter model. The motivation of this study comes from requirement of investors and market contributors that wish for the suitable tools to estimate beta properly. Then, this study introduced Kalman filter which is the popular state space model to improve the process of estimation. There were three model specification used in this study which were random walk model, random coefficient model and autoregressive model (AR(1)) model. The results of estimation were compared with static beta from ordinary least squares method. The data applied in this study were the daily return of Thailand Stock Exchange industries group index since January 2007 to June 2014 and there were eight industries group indexes. The results found from the plots of time-varying bet as that three models of Kalman filter can catch up volatility of risk quicker and better than Ordinary least squares. And the most volatile beta among three models of Kalman filter in most of the industries is the form of random coefficient model. Finally, the model were evaluated the performance through root mean square error and mean absolute error calculation, the study found that Kalman filter AR(1) model confirms the superiority in capturing Time-Varying Systematic risk.

Keywords: time-varying systematic risk, Dynamic beta, Kalman filter, Autoregressive model, Random walk model, Random coefficient model.

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บทคัดย่อ

วัตถุประสงค์ของการศึกษาในครั้งนี้เป็นการประมาณค่าสัมประสิทธิ์ความเสี่ยงที่เป็นระบบ ซึ่งเปลี่ยนแปลงตามเวลาโดยใช้ตัวแบบ Kalman filter ซึ่งเป็นที่ยอมรับในความสามารถในการอธิบายข้อมูลที่เปลี่ยนแปลงตามเวลาได้อย่างดี ทั้งนี้ความเข้าใจในความเสี่ยงที่เป็นระบบอย่างถูกต้องเป็นประโยชน์อย่างยิ่งกับนักลงทุน เพื่อที่จะตอบสนองกับความผันผวนของตลาดทุนได้อย่างรวดเร็ว ดังนั้นวิธีในการประมาณค่าที่เหมาะสมจึงเป็นเครื่องมือทางการเงินที่สำคัญของนักลงทุน การศึกษาในครั้งนี้จึงมุ่งเน้นที่การใช้ตัวแบบ Kalman filter ในการพัฒนาการประมาณค่าสัมประสิทธิ์ความเสี่ยงที่เป็นระบบให้ถูกต้องมากขึ้น โดยตัวแบบ Kalman filter ที่ใช้มีทั้งหมด 3 ตัวแบบ ได้แก่ ตัวแบบ Random walk ตัวแบบ Random coefficient และตัวแบบ Autoregressive (AR(1)) โดยผลการประมาณค่าโดยตัวแบบทั้ง 3 นี้จะนำมาเปรียบเทียบกับผลการประมาณค่าสัมประสิทธิ์ความเสี่ยงที่เป็นระบบโดยวิธีการวิเคราะห์การถดถอยแบบ OLS ข้อมูลที่ใช้ในการศึกษาในครั้งนี้เป็นข้อมูลผลตอบแทนรายวันจากดัชนีกลุ่มอุตสาหกรรมต่างๆ ตามตลาดหลักทรัพย์แห่งประเทศไทย ประกอบไปด้วย 8 กลุ่มอุตสาหกรรม และใช้ข้อมูลรายวันตั้งแต่มกราคม พ.ศ. 2550 ถึงมิถุนายน พ.ศ. 2557 จากผลการศึกษาโดยการสร้างแผนภาพพบว่า ตัวแบบของ Kalman filter ทั้ง 3 แบบ สามารถแสดงให้เห็นถึงความผันผวนของตลาดได้รวดเร็วและดีกว่าตัวแบบการวิเคราะห์การถดถอยแบบ OLS และตัวแบบที่ให้ค่าสัมประสิทธิ์ความเสี่ยงที่เป็นระบบผันผวนที่สุด คือ ตัวแบบ Random coefficient ซึ่งให้ผลสอดคล้องกันในกลุ่มดัชนีอุตสาหกรรมส่วนใหญ่ ในส่วนสุดท้าย การศึกษาในครั้งนี้ได้ทำการประเมินความสามารถของตัวแบบโดยคำนวณรากที่สองของความคลาดเคลื่อนกำลังสองเฉลี่ย (root mean square error; RMSE) และความคลาดเคลื่อนสัมบูรณ์เฉลี่ย (mean absolute error; MAE) ผลการศึกษาพบว่า ตัวแบบ Kalman filter AR(1) เป็นตัวแบบที่ให้ผลการประมาณค่าสัมประสิทธิ์ความเสี่ยงที่เป็นระบบ ซึ่งเปลี่ยนแปลงตามเวลาได้ดีกว่าตัวแบบอื่นในการศึกษาในครั้งนี้

คำสำคัญ: ความเสี่ยงที่เป็นระบบซึ่งเปลี่ยนแปลงตามเวลา เบต้าที่เปลี่ยนแปลงตามเวลา Kalman filter ตัวแบบ Autoregressive ตัวแบบ Random walk ตัวแบบ Random coefficient

Introduction

From modern theory of finance perception, one of the most essential risks for investor is the systematic risk. It is the risk that relates to market returns and cannot be eliminated by using diversification method. According to this characteristic, then systematic is the only one type of risk that should be rewarded. (Sharp, 1965; Lintner, 1965; Mossin, 1966; Black, 1972) Moreover, systematic risk is the general measurement for market swing sensitivity (Grundy & Malkiel, 1996). Consequently, know the market risk correctly is the benefit for all of investors to tackle with the instability of the market and be ready for the investment opportunity. Therefore, they try to find the proper model for better systematic risk estimation. The common methodology of systematic risk measurement in the market is the simple market model by using ordinary least squares which is accepted in term of straightforwardness in beta estimation for both educational research and real investment sectors for many years. Nevertheless, there are many researches that found some problems in this well-known model. Ordinary least squares regression has found the nonstationarity in parameters and error terms in estimation. Moreover, the intertemporal dependences in the number of outliers are also examined in this methodology. (Bey & Pinches, 1980) From these findings, they inferred that Ordinary least squares model is non-Gaussian model. Fortunately, there is the new hypothesis which the concept of varying through time of the systematic risk is accepted. (Fabozzi & Francis, 1978; Bos & Newbold, 1984) And time-variation betas canalso explain anomalies for example industry and size (Fama & French, 1997; Ferson & Harvey, 1999). From prior studies, there are several researches introduced the two models which align with this new hypothesis which are Kalman filter and Multivariate. Moreover, they compared the performance of these two famous models and most of the studies support Kalman filter as the superior model to estimate the time-varying beta. This brings to the motivation of this paper to use Kalman filter model which can explain the systems that change through time by using idea of state space model. However, as there are various form of Kalman filter model and most of the prior studies did not compare the evaluation performance of these forms. Therefore, this study can fill this gap by applying the technique of state space model with CAPM to estimate betas of industry index for Thailand Stock Exchange properly and evaluate the performance of Kalman filter models to find the best estimator.

Another contribution from this paper is focusing on stock market in emerging countries. According to most of the studies had focused on European stock markets which are developed stock markets. This brings to the aspiration to direct on emerging market to see whether there is the similar pattern or not. Therefore, this study focuses on Thailand Stock market as this stock exchange is the good representative of emerging market. The stock exchange also has the highest liquidity in the region and has risen considerably to become one of the top two stock exchanges in ASEAN with Singapore. Moreover, the largest proportion of Thailand stock market is retail investors which create stability to the exchange as well.

Objective of the study

According to the new hypothesis which states that beta can be changing through time, finding the suitable model to estimate the time-varying properly becomes the aspiration of this study. The objective of this study is to focus on using the Kalman filter model in three formats to estimate the systematic risk or beta of industry indexes of Thailand stock market. And the performance of each model in estimation will be compared through error calculation to see that which form of Kalman filter can benefit in explaining time-varying beta better than the others. In addition, the study will provide the explanation of the volatile beta of each industry through beta plotting. Overall, this study aim to offer the good model with precise systematic risk estimation to respond to market contributors’ constraint in time-varying systematic risk.

Literature Review

There are several studies which tried to compare time-varying betas by the two famous techniques which are Multivariate GARCH and Kalman filter. Most of them found that Kalman Filter is superior than Multivariate GARCH and simple market model. Faff et al. (2000) has examined the performance of modeling techniques that estimate time varying systematic risk between Multivariate GARCH and Kalman Filter by using data of UK portfolio. The results found that using in-sample forecasts of industry returns, only the Kalman filter random walk model, consistently performs better than the simple market model beta while surprisingly found that the simple market model compared beneficially with more complex GARCH type models.

Choudhry & Wu (2007) did the study by using GARCH model and Kalman filter model to estimate the time-varying beta of the companies in UK. This article examines the forecasting capability of three different GARCH models and also the forecasting ability the non-GARCH method, Kalman filter approach. And the results also confirm that Kalman filter approach is superior than other three models of GARCH.

Next is the paper of Mergner & Bulla (2008) which also investigated the time-varying of systematic risk for eighteen European sectors by comparing the performance of three type of models which are t-GARCH, two models of Kalman filter which are random walk model and autoregressive (AR(1)) model and two models of Markov switching by using weekly data from 1987 to 2005. The result found that two Kalman filter techniques obviously outperform other two models when comparing both error measures.

The research of Nieto, Orbe & Zarraga (2014) is another evidence to support time-varying systematic risk estimation. They used nine models from three approaches for estimation which are Ordinary least squares approach, GARCH-based approach and Kalman filter approach. The data used in their research are 42 stocks returns in Mexican Stock Exchange. The finding of this research expressed that Kalman filter in format of random coefficient model showed the lowest errors among other models. Therefore, they concluded that this model is the best estimator which produces a good fit in this research.

From the previous studies which stated that Kalman Filter normally outperforms Multivariate GARCH and simple market model. Therefore, this study will focus in using Kalman filter in estimating the time-varying beta. However, there are various forms of Kalman filter that are used in previous studies. Fabozzi & Francis (1978); Collins et al. (1987) used form of random coefficient Kalman filter model in US data. Wells (1994) has studies time-varying betas of ten individual assets on the Stockholm exchange by using form of Kalman filter random walk model and Kalman filter random coefficient model. Moonis & Shah (2003) focused on testing time-varying betas in India equity's market by using the modified Kalman filter of Harvey et al. (1992) and comparing three forms of models which are mean reverting beta, random coefficient beta and random walk beta. Choudhry & Wu (2007) also use two models of Kalman filter which are random walk model and mean reverting model. For paper of Nieto, Orbe & Zarraga (2014), they also used two general forms for Kalman filter estimation that are the random coefficient model and the random walk model. From these studies, my study concluded to cover all three formats of Kalman filter models which are random walk model, random coefficient model and auto-regressive (AR(1)) model.

Methodology

The data used in this paper were closing price of equity industry index in the Stock Exchange of Thailand. There were eight equity industries which are agriculture product and food industry (AGRO), consumer product equity sector(CONSUMP), financials equity sector (FIN), industrials equity sector (INDUS), property and construction industry (PROPCON), resource equity sector (RESOURCE), services equity sector (SERVICE) and technology equity sector (TECH). This paper used daily closing price of eight industry indexes and also the closing price of the Stock exchange of Thailand (SET Index). The period of data started since January 2007 to June 2014 which offered 1,842 observations available for estimation. The daily closing price of industry index and SET index must be transformed into returns of each industry and market returns by continuous compound return method. The following formula was applied to calculate the returns as mentioned.

$Return_i = 100*\log (Price_{i,t} / Price_{i,t-1})$

By applying the theory of Kalman filter with CAPM, the returns of individual asset in CAPM can be explained by measurement equation. And these measurement equations are the same format for all models of Kalman filter. From CAPM, the returns of the individual asset depend on the series of market returns time with beta. Therefore, when this study signifies the returns by measurement equation, the industry indexes returns will be calculated by series of SET index returns times with the time update equation which is the representative of the time-varying beta. Consequently, this study estimated the time update equation by applying 500 iterations of estimation in three models of Kalman filter.

The first model is random walk model which is the uncomplicated form of Kalman filter model in this study. The equation (1) is the measurement equation which states that the industry index returns changes from the series of market returns and the time update function. The equation (2) expressed the time update equation which shows that the current time update value depends on the time update in the previous period.

$$Y_t = F_t\theta_t + v_t \quad \text{------(1)}$$

$$\theta_t = \theta_{t-1} + \omega_t \quad \text{------(2)}$$

From the equations,

Y_t is the industry index returns at current period (t)

F_t is the stock exchange of Thailand returns at current period (t)

θ_t is the industry index time-varying beta at current period (t)

v_t and ω_t are the error terms

The second form of Kalman filter is random coefficient model which expresss in equation (3) and (4). In this model, the time-varying beta which explained by the time update equation is varied through time by the random coefficient. The previous value of time update does not effect on current value of time update.

$$Y_t = F_t\theta_t + v_t \quad \text{------(3)}$$

$$\theta_t = C_{1,t} + \omega_t \quad \text{------(4)}$$

From the equations,

Y_t is the industry index returns at current period (t)

F_t is the stock exchange of Thailand returns at current period (t)

θ_t is the industry index time-varying beta at current period (t)

v_t and ω_t are the error terms

The last set of equations is the autoregressive model which is shown by equation (5) and (6). The time update equation in this form follows autoregressive (AR(1)) model which the current value of the time update bases on the time update in previous period and the coefficient C2 as the form of AR(1).

$$Y_t = F_t\theta_t + v_t \quad \text{------(5)}$$

$$\theta_t = C_1 + C_2\theta_{t-1} + \omega_t \quad \text{------(6)}$$

From the equations,

Y_t is the industry index returns at current period (t)

F_t is the stock exchange of Thailand returns at current period (t)

θ_t is the industry index time-varying beta at current period (t)

v_t and are ω_t the error terms

The step of studies in this article was separated into four steps. Firstly, the betas that were estimated by the market model using standard regression approach. The results were expected to provide the evidence that market returns were the significant factor to industry return and the betas also follow stationary mean-reverting process. Secondly, the model has been changed to the Kalman filter in three models. Thirdly, the betas that were estimated by these various methods were plotted to compare the pattern and trend of systematic risk in each industry. Moreover, the plots were aimed to see how each model capture the change in the systematic risk of the industries. Fourthly, the performance of Kalman filter and the Ordinary least square were compared by root mean square error (RMSE) and the mean absolute error (MAE) in term of superiority of estimation.

Results

Firstly, the study tested the Ordinary least squares estimation of beta from the market model. The results of estimation were shown in table 1. The time-varying or betas of all industries were significantly different from zero at 99% confidence interval. It implied that systematic risk in the market had considerably impact on returns of each industry index. And the coefficient of each equity sector was aligned with intuitive sense. For example, consumer product equity industry had the lowest beta among the others and resource equity industry was the largest beta. Next, the study estimated random walk model Kalman filter. And the outcome was presented in table 2.

Table 1[2] Ordinary least squares estimation

Industry Group	Beta	Prob
Agro&Food	0.616509***	0.0000
Consumer	0.265784***	0.0000
Financial	1.09571***	0.0000
Industrial	0.984954***	0.0000
Property&Construc	0.945035***	0.0000
Resource	1.186272***	0.0000
Service	0.724114***	0.0000
Technology	0.823219***	0.0000

From random walk model, the time update equation of Kalman filter, which in this case were betas, were changed through time by pattern of random walk. And the beta in previous period (t-1) had also impacted on the beta that was presently estimated. In addition, the result showed that, in all of the industries, the systematic risk returns impacted on industry returns.

Next is the result from Kalman filter random coefficient approach. From the model structure, the beta in previous period (t-1) did not effect to the beta that is currently estimated. The betas in this model were varied by the random coefficient that fluctuated through time. From this reason, as the coefficient was time-varying factor, the time update or beta estimated must have been time-varying as well. The results of beta estimation by random coefficient model were illustrated in table 3. Most of the industries were found that the betas were significantly affected from market returns except the consumer product industry.

Table 2[3] Kalman filter random walk model estimation

Industry Group	θ_1 (Final State)	Prob.
Agro&Food	0.712961***	0.0000
Consumer	0.608986***	0.0000
Financial	1.127611***	0.0000
Industrial	0.677049***	0.0000
Property&Construction	1.05672***	0.0000
Resource	0.916641***	0.0000
Service	0.908421***	0.0000
Technology	1.304808***	0.0000

Next is the results from autoregressive model, the factors that impact to the time update or beta were the coefficient C2 and previous value of the beta itself (θ). The model's estimated results were shown in table 4. From the results of all of industries, it is found that the betas were time-varying and the previous value of the beta itself was found significantly impacted on the beta that was currently estimated as well. In addition, the returns of industry indexes were influenced by market

[2] *Significant at 90% confident interval
**Significant at 95% confident interval
***Significant at 99% confident interval

[3] *Significant at 90% confident interval
**Significant at 95% confident interval
***Significant at 99% confident interval

returns in most of the industries except consumer production industry. This finding was similar to the result from random coefficient model.

Table 3[4] Kalman filter random coefficient estimation

Industry Group	θ_1 (Final State)	Prob.
Agro&Food	0.621615***	0.0050
Consumer	0.240251	0.2731
Financial	1.095396***	0.0000
Industrial	0.989232***	0.0016
Property&Construction	0.939568***	0.0000
Resource	1.183937***	0.0000
Service	0.712257***	0.0010
Technology	0.832614***	0.0061

Next, the betas from three models of Kalman filter and static beta from Ordinary least square were compared in the line graphs. Consequently, the beta from ordinary least squares was the constant value which was shown by one horizontal line along the period while the patterns of beta from three models of Kalman filter have been varied through time. From the line graphs in figure 1-8, they showed that three lines of beta from Kalman filter model increased and decreased around the OLS's betas. And the most volatile betas came from Autoregressive (AR(1)) model.

Table 4 Kalman filter autoregressive model estimation

Industry Group	C1	C2	θ_1 (Final State)
Agro&Food	0.067808	0.892194***	0.553034***
	0.0004	*0.0000*	*0.0038*
Consumer	0.165254	0.301422***	0.239453
	0.0000	*0.0023*	*0.2620*
Financial	0.887006	0.190636*	1.080862***
	0.0000	*0.0581*	*0.0000*
Industrial	0.204305	0.795869***	0.909713***
	0.0000	*0.0000*	*0.0010*
Property&Construction	0.141070	0.84997***	0.97201***
	0.0000	*0.0000*	*0.0000*
Resource	0.009226	0.991959***	0.97528***
	0.0533	*0.0000*	*0.0000*
Service	0.007203	0.990282***	0.847243***
	0.0308	*0.0000*	*0.0000*
Technology	0.016028	0.981844***	1.140957***
	0.0180	*0.0000*	*0.0000*

[4] *Significant at 90% confident interval
**Significant at 95% confident interval
***Significant at 99% confident interval

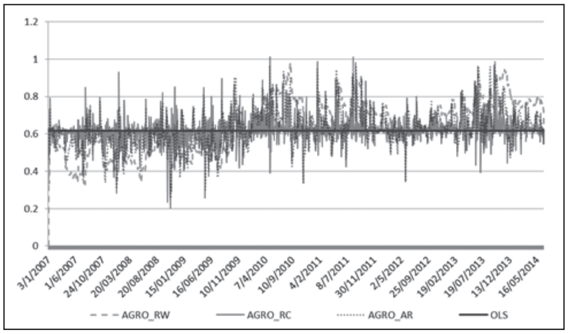

Figure 1 AGRO industry Beta Plot

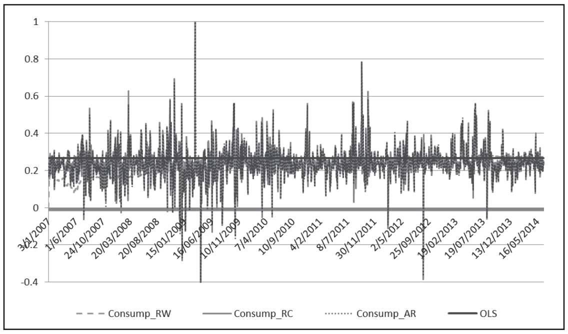

Figure 2 CONSUMP industry Beta Plot

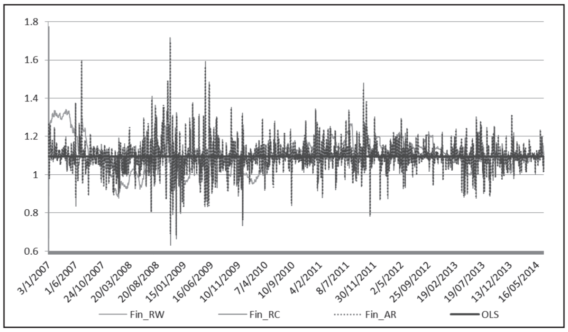

Figure 3 FIN industry Beta Plot

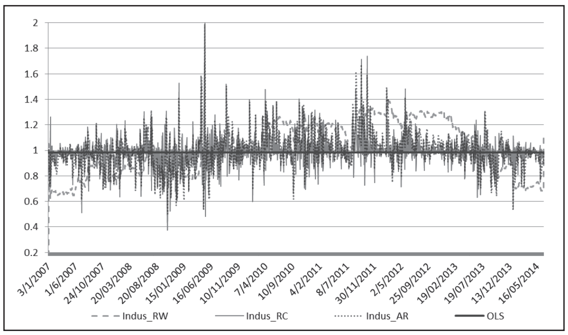

Figure 4 INDUS industry Beta Plot

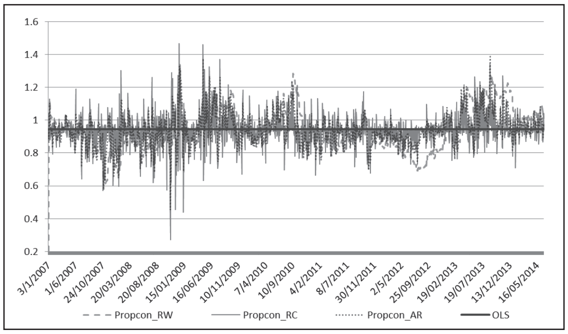

Figure 5 PROPCON industry Beta Plot

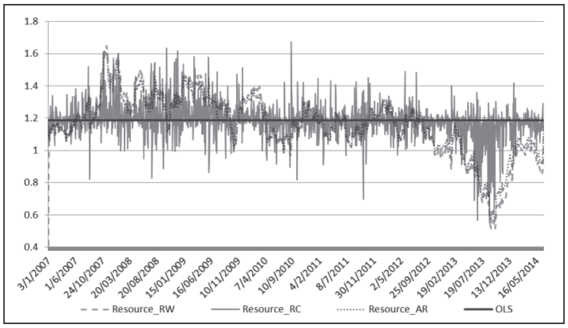

Figure 6 RESOURCE industry Beta Plot

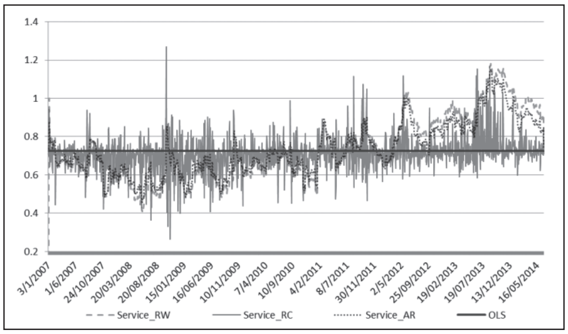

Figure 7 SERVICE industry Beta Plot

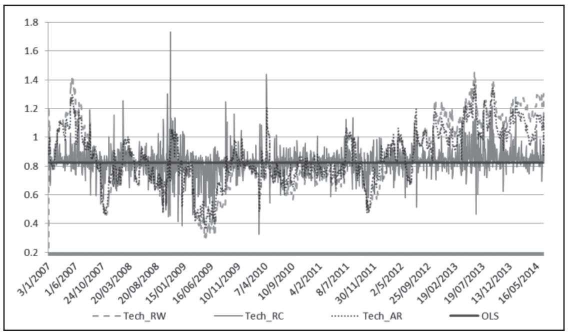

Figure 8 TECH industry Beta Plot

Table 5 Comparing RMSE and MAE of the models

	Root Mean Squre Error (RMSE)				Mean Absolute Error (MAE)			
Index	OLS	KF_AR	KF_RC	KF_RW	OLS	KF_AR	KF_RC	KF_RW
AGRO	0.00819	0.00785	0.00816	0.00757	0.00619	0.00597	0.00615	0.00574
CONSUMP	0.00548	0.00546	0.00550	0.00552	0.00390	0.00388	0.00392	0.00392
FINANC	0.00633	0.00636	0.00634	0.00637	0.00491	0.00492	0.00492	0.00493
INDUS	0.00923	0.00914	0.00928	0.00928	0.00697	0.00688	0.00699	0.00699
PROPCON	0.00542	0.00533	0.00545	0.00546	0.00413	0.00405	0.00415	0.00415
RESOURCE	0.00687	0.00647	0.00667	0.00667	0.00506	0.00488	0.00496	0.00496
SERVICE	0.00626	0.00611	0.00606	0.00606	0.00471	0.00459	0.00455	0.00455
TECH	0.01060	0.01036	0.01049	0.01049	0.00789	0.00760	0.00773	0.00773

The industry which provided the lowest time-varying systematic risk was the consumer product industry (Figure 2). Generally, the beta of this industry is around 0.2 and there was a dramatically increasing of beta in some period of time. In other word, the industry which delivered the largest time-varying beta is the resource industry (Figure 6). This was because many of individual stocks in this industry have large volumes of trading in the market. Moreover, the trend of time-varying beta of resource industry can be observed by the beta plotting of random walk model and AR(1) model. The time-varying betas estimated from these two models were aligned with the energy trend that had declining trend from the end of 2012 to the end of 2013. However, there is no obvious trend from random coefficient model.

Moreover, in some industries, we can observe the pattern of beta that match with the real situation. For example, we can observe the declining pattern in financial industry in 2008 which was the same period as financial sector crisis in US (Figure 3). And the effect from that crisis also impacted to financial sector in Thailand. Additionally, the increasing pattern of time-varying beta is also observed from the second quarter of 2010 to the end of 2010. Another example is the evidence from Technology Industry (Figure 8). The increasing pattern of time-varying beta has clearly shown since the end of 2011. Conversely, according to instability of 3G bidding in Thailand at that particular period, there were many periods which this industry confronted with declining trend as shown in the pattern of time-varying beta.

Finally, this study assessed the performing of the models by measuring mean absolute error and root mean square error of Ordinary least squares and three models of Kalman Filter. The root mean square error is the square root of total quadratic error divided by the number of observation and mean square error or MAE is sum the absolute value of error divided by the number of observation. This study calculated RMSE and MAE of OLS and Kalman filter as shown in table 5

From table 5, in most industries, Kalman filter AR(1) model provided least value of both RMSE and MAE which mean that this model is superior in Time-Varying betas among three models. Moreover, it provides lower RMSE and MAE than ordinary least squares in most industries except financial industry. Comparing to prior studies, the finding from this paper is different. The earlier papers, which mostly focused on European stock market, found that RW model is the most preferable model. This may come from unalike of characteristic of developed market and emerging market. In conclusion, Kalman filter AR(1) model is the good choice for estimating time-varying beta among Ordinary least square and other models in Thailand stock market.

Conclusion

From the volatility that observed in Thailand Stock Market and the motivation to understand the systematic risk of the market precisely, this study aim to find the methodology to estimate beta or systematic risk in a better way by introducing Kalman filter model since the model use state space model which can capture the time-varying in beta properly and better than Ordinary least squares model. The study started by estimate beta of each Thailand Industry Index by traditional least square regression. The results proved that the static beta estimated using simple Ordinary least squares exhibited heteroskedasticity problem. Next, the study introduced three forms of Kalman filter models which were random walk, random coefficient and autoregressive and most of the industry indexes showed time-varying pattern by using these three models. Then, this study showed the line graph plotting of time-varying betas which were estimated by the three forms of Kalman filter. It was found that the time-varying beta estimated by using random coefficient model presented the highest fluctuation among the others. Finally, the model performance evaluation was assessed by using root mean square error and mean absolute error calculation. And result found that Kalman filter Autoregressive model (AR(1) model) provided the lowest both root mean square error and mean absolute error among the others and OLS in most of the industries which confirmed the better model of time-varying beta estimation.

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