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Catching the Dynamic Behavior of Stock Market: Numerical Approach to Estimate the Catalytic Chemical Model Parameters

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This research proposes a numerical approach in estimating the trend of behavior of this market. This approach is applied to a model that is inspired by catalytic chemical model, in terms of differential equations, on four composite indices, New York Stock Exchange, Hong Kong Hang Seng, Straits Times Index, and Jakarta Stock Exchange, as suggested by Caetano and Yoneyama (2011). The approach is used to minimize the difference of estimated indices based on the model with respect to the actual data set. The result shows that the estimation is able to capture the trend of behavior in stock market well.

Keywords: *Systemic risk, Dynamic behavior, Stock market, Numerical approach*

Introduction

The crisis in 2008, that challenged the United States (US) banking system and global financial system as a whole, caused some governments to subsidize their domestic champions by injecting additional equity to avoid of massive losses from careless high risk investment (Katsimi and Moutos, 2010). Not only in banking system, this crisis also led to liquidity and credit risk in some mutual funds, companies, and pension funds. The risk that shows the domino effect of financial crisis simultaneously is known as systemic risk. Kotkatvuori-Örnberg et al. (2013) concluded that the fall of Lehman Brothers has a significant impact on stock price in many areas i.e., *Developed Europe*, G7, Asia Pacific, Middle East, Latin America, and *Emerging Europe*.

Systemic risk is characterized as a situation where the distress of one institution endangers the rest of financial system. Systemic risk involves financial system, a group of interconnected firms in business relations where the risk of illiquidity, insolvency, and bankruptcy spread merely in the period of crisis (Billio et al, 2012). Caetano and Yoneyama (2011) stated that systemic risk is the collapsed probability in a financial system or financial market. This risk is usually associated with the loss of confidence in a financial system. As the consequence of recent financial crisis, the extensive research on

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systemic risk—either its definition, measurement, and/or regulation— has been fostered by politicians, regulators, and academics.

Some studies explain the measurement of systemic risk i.e. Billio et al. (2012), Brämer (2013), Caetano and Yoneyama (2011), Girardi and Ergün (2013), Hong et al. (2009), Huang et al. (2009), Rodríguez-Moreno and Peña (2013), and Suh (2012). Billio et al. (2012) suggested some econometrics measurement of connectedness based on principal component and Granger Causality in financial sector and insurance. In the previous years, Huang et al. (2009) proposed a framework in measuring and conducting stress testing of systemic risk for some financial institution. Then, Huang et al. (2009) assessed the systemic risk of heterogent portfolio of banks in period of crisis. Suh (2012) showed a model in measuring systemic risk which including main indicators in conditional heteroscedasticity. Brämer (2013) applied a simulation technique to describe the contagion of default risk in banking market simultaneously. Girardi and Ergün (2013) estimated the CoVAR using Multivariate GARCH. Rodríguez-Moreno and Peña (2013) compared two measurement of systemic risk in *high-frequency market-based systemic risk measures* based on: (i) Granger causality test, (ii) Gonzalo and Granger metric, and (iii) correlation of a certain index from a systemic event.

Researches regarding the linkage of international stock market also rose after financial crisis (year 1987, 1997, and 2008). The possibility of movement in certain market is a critical point in anticipating the systemic risk. This movement is an implication of uncertainty in the market, the change in government regulation, and/or the influence from another market. An extreme movement can lead to investors' capital movement (Araujo and Garcia, 2013). Some empirical studies show the increasing correlation of international stock market within volatile period (Aang and Bekaert, 2002) especially when the market is in the fall period. They used a sample data from US, UK, and Germany. Bekaert et al. (2005) also found the similar result using sample of Europe, Asia, and South American data.

The investigation of risk and casualty in stock market as the effect of risk from another country has been conducted in some area which mostly based on the Granger Causality concept. Hong, Cheng, Liu, and Wang (2003) studied the existence and effect of systemic risk transmitted from or to the market in China. The Granger-Causality based kernel approach found that the existence of spillover risk from or to China to South Korea, Japan, US, and Singapore. Also using the Granger-causality concept, Araujo and Garcia (2013) found the spillover effect in North and Western Europe. Iwatsubo and Inagaki (2007) tested the contagion effect in US and Asia stock market. They claimed that the effect from US to Asia is much stronger than Asia to US. On the other hand, Morales and Andreosso-O'Callaghan (2012) did not find the significant effect of US stock market to Asia but these two markets shows a strong short term linkage in period of crisis.

This paper emphasizes the use of numerical approach to estimate the trend and random uncertainties of behavior in stock market. This objective is a part of the goal of study in evaluating the systemic risk in stock market based on research that conducted by Caetano and Yoneyama (2011). Caetano and Yoneyama proposed a model to capture the phenomena related to systemic risk by assessing the effect of many parameters on the market. The stock market dynamics can be described as a chemical reaction where financial indices of stock markets resemble the concentrations of reagents. The main idea is that the influence of stronger markets to dominated market can have reactions that influence the stronger markets. The dynamic behavior is explained by interaction of the stronger market and the weaker one. Caetano and Yoneyama used actual data of three indices from China, USA, and Brazil. The systemic risk evaluation is conducted based on VaR, the data for which is generated using Monte Carlo simulation

Differing from Caetano and Yoneyama, (2011), we used four indices as case study. These are the New York Stock Exchange (NYSE), Hong Kong Hang Seng (HSI), Straits Times Index (STI), and Jakarta Stock Exchange (JKSE). These indices are chosen since the fall of Lehman Brothers Holdings, Inc. in 2008 pushed the Indonesian Stock Exchange where the index at September 2008 are corrected at

4.7% as the lowest for the last 17 months. HSI and STI are also considered as sample since these two indices are known as strong indices in Asia.

The Catalytic Chemical Model in Stock Market

As suggested by Caetano and Yoneyama (2011), the model in this study initially used to explain the reversible polymerization, in which two reagents condense (y1 and y2) to form a single longer polymer (y3) according to Bagley and Farmer (1991). The change of concentration of y3 is described by the differential equation. The dynamic of stock market resembles the evolution in chemical reaction where the stock describes the reagent or product concentration. The influence of reagents concentration to product concentration is portrayed by the effect of stronger market to dominated market. There are three reagents concentration in this study which are index of New York Stock Exchange (NYSE), Hong Kong Hang Seng (HSI), and Straits Times Index (STI), then index of Jakarta Stock Exchange (JKSE) is considered as product concentration

As extended form of the model of Caetano and Yoneyama with three reagent concentrations, NYSE, HSI, and STI as y_1, y_2, y_3, respectively, and JKSE as product concentration y_4. If a_1 is a catalisator that will increase speed of reaction then the differential equation becomes:

$$\begin{cases} \dfrac{dy_1}{dt} = a_1\left(-a_2 y_1 + a_3 y_4\right) \\ \dfrac{dy_2}{dt} = a_1\left(-a_4 y_2 + a_5 y_4\right) \\ \dfrac{dy_3}{dt} = a_1\left(-a_6 y_3 + a_7 y_4\right) \\ \dfrac{dy_4}{dt} = a_8 y_1 y_2 y_3 - a_3 y_1 + a_1 a_2 y_1 \\ \qquad + a_1 a_4 y_2 + a_1 a_6 y_3 \end{cases} \qquad 1)$$

with a_2, a_3, a_4, a_5, a_6, a_7, and a_8 are constant as model parameter

Three reagents as stronger market concentration (index of NYSE, HSI, and STI) will affect the JKSE simultaneously with term $a_8 y_1 y_2 y_3$ with rate a_8 if those three indices rise. On the other hand, the decreasing NYSE will affect JKSE with term $a_3 y_1$. This investment that flow out from Indonesia will affect the three stronger market with terms $a_3 y_4$, $a_5 y_4$ and $a_7 y_4$, respectively. The investments that flow out from three stronger markets and flow in to Indonesian market are explain by term $a_1 a_2 y_1 + a_1 a_4 y_2 + a_1 a_6 y_3$.

In order to catch the random fluctuation in the financial model, the perturbation around the estimated parameter is generated by simulation. The effects of random fluctuations are similar to the panic behavior in the market.

Parameter Estimation with Numerical Approach

Estimation Methodology

Parameter estimation of deterministic model (1) is a process to fit the trend of dynamic behavior and capture the fluctuation around estimate parameter. There are some steps in this process that proposed by Caetano and Yoneyama (2011) which are:

1. Data set normalization in order to cope the difference in the size of economies in four market. For this work, the normalization process, for j=1,2,3,4, and *i=1,…, n, n* is a sample size, is:

$$\breve{y}_j(i) = \frac{Y_{j(i)} - Y_j(\min)}{Y_j(\max) - Y_j(\min)} \qquad 2)$$

   whey $\breve{y}_j(i), Y_{j(i)}, Y_j(\max)$, and $Y_j(\min)$, respectively, are normalized index, actual data of index, maximum index value in the sample, and min index value in the sample.
2. Estimating the parameter in model (1) by minimizing the difference of actual data of four indices. The criterion is to minimize the sum of squares of the point-wise mismatch. The search method is multidimensional unconstrained nonlinear minimization (Nelder-Mead) algorithm, using file *fminsearch.m* that includes in Matlab version 7.1. The steps in fitting the model parameters is:

i. Choose the initial value of parameters a_1, a_2, a_3, a_4, a_5, a_6, a_7, and a_8.

Table 1. Descriptive Statistics of Four Composite Indices within Period 3 January 2000 – 20 September 2013

Index	Mean	Maximum	Minimum	Std. Dev
NYSE	7,295.15	10,311.61	4,226.31	1,331.43
HSI	2,202.91	4,082.28	1,078.12	620.858
STI	1,662.78	3,341.28	586.672	802.337
JKSE	0.202	0.534	0.029	0.149

The NYSE, HIS, and STI are represent in USD and JKSE in cent USD

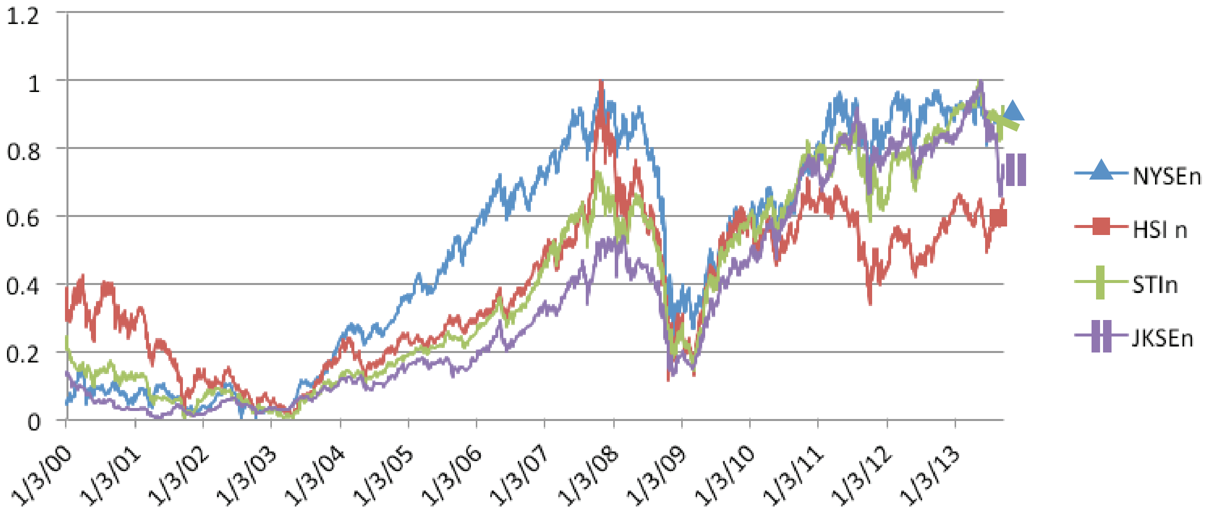

Figure 1. The normalized indices of Four Composite Indices within Period 3 January 2000 –20 September 2013

ii. Use the value of initial parameters in the differential equation system in model (1) and simulate the numerical integration method using the scripts *ode45.m* in Matlab.

iii. Implement the simulated data in to *fminsearch.m* file to minimize the function of sum squares of errors, SSE:

$$SSE = \sum_{i=1}^{tf} (y_1(i) - \breve{y}_1(i))^2 + (y_1(i) - \breve{y}_2(i))^2 + (y_1(i) - \breve{y}_3(i))^2 (y_1(i) - \breve{y}_4(i))^2 \qquad 3)$$

where the $\breve{y}_1, \breve{y}_2, \breve{y}_3, \breve{y}_4$, respectively, are the normalized of actual indices data, and tf= the finanl value of numerical integration in step (ii).

iv. If the sum of squares error SSE < Ɛ, then the algorithm is complete; else return to step (iii) using the new initial values of $a_1, a_2, \ldots, a_8$.

3. Simulating the estimate parameters from step (2) in order to catch the random fluctuation since the financial data is time varying. The process of this simulation is generated by random term *ωi, i=1,2,..,8*. as written as:

$$a_i^{new} = a_1 + \omega_i \qquad 4)$$

The parameter from this simulation will be used as revised parameter.

Data

The data that used in this study is a composite index of four stock markets, New York Stock Exchange (NYSE), Hong Kong Hang Seng (HSI), Straits Times Index (STI), and Jakarta Stock Exchange (JKSE). The indices represent the daily closing price within period 3 January 2000 to 20 September 2013. This data is obtained from Datastream and Thomson Reuter, Data Center of Economics and Business (PDEB) Resource Learning Center (RLC), faculty Economics Universitas Indonesia.

Table 2. Estimate Parameter of Deterministic Model

Parameter	a1	a2	a3	a4	a5	a6	a7	a8
Estimate	0.0048	0.0921	0.2358	0.0448	0.0035	-0.0379	0.0077	0.0359

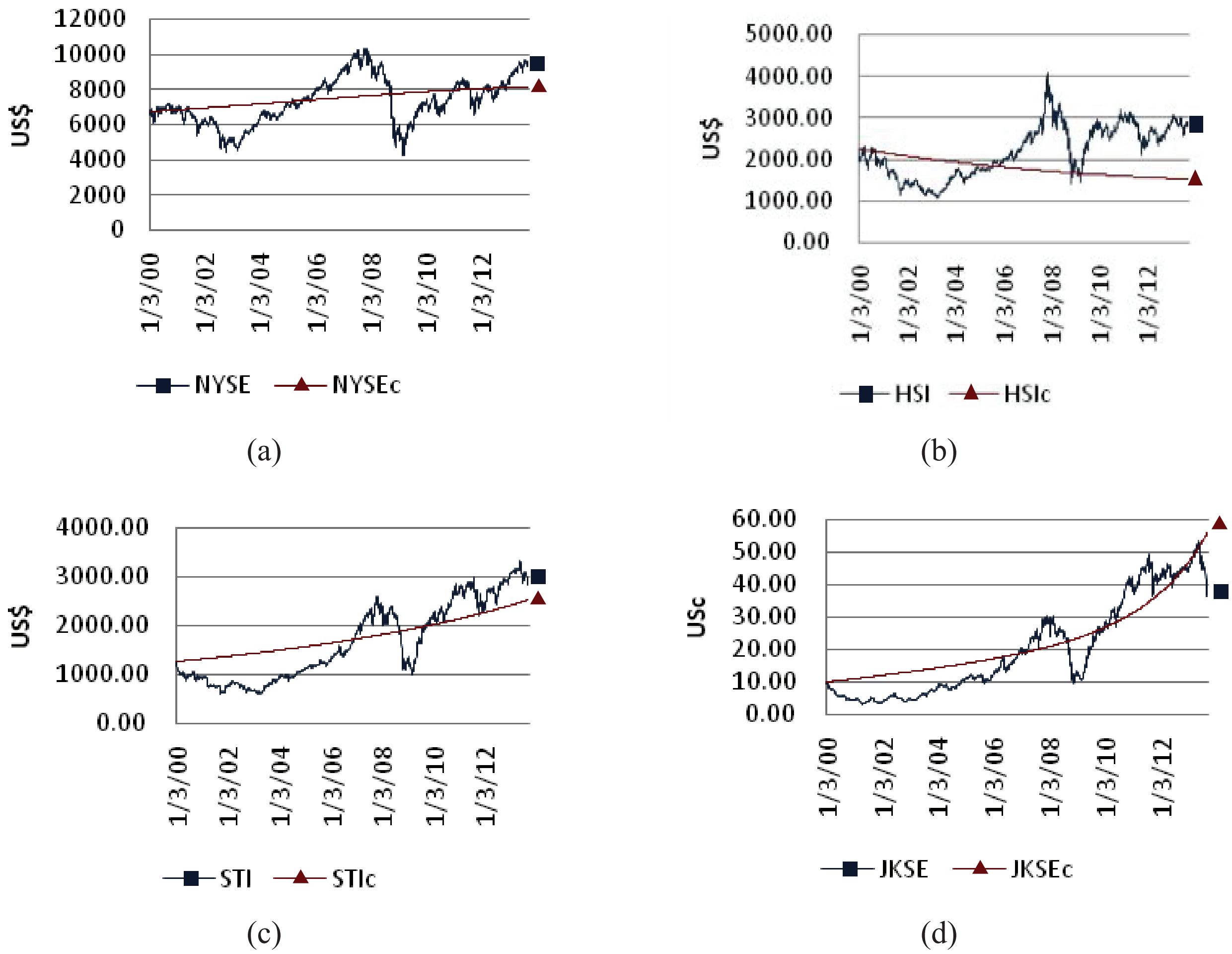

Figure 2. The Estimate Trend comparing to Actual Data of Four Indices

NYSE, HSI, STI, and JKSE represent the actual index value. It valued in USD for NYSE, HIS, and STI, and in USCent for JKSE. NYSEc, HSIc, STIc, and JKSEc is the estimate value based on deterministic catalytic chemical model

The Dynamic Behavior of Stock Market

Descriptive Statistics

Based on sample period of 3 January 2000 to 20 September 2013, the descriptive statistics of four indices are displayed in Table 1. During the period of observation, the index of New York Stock Exchange (NYSE) has the highest average price index compared to the other three indices. In addition, the NYSE price variability is also the highest among other indices. By comparing the index of HSI and STI, HSI index had an average price higher than Singapore, but the standard deviation or variability of the stock price is also higher than STI. While the price movements in the index of Jakarta Stock Exchange (JKSE) seems to be more stable than the three other indices because the index is far below the price of three other indices studied.

The pattern of normalized indices is shown in figure. 1. The figure represents that four indices has a similar pattern over the period of observation where since early 2000, the four indices continued to strengthen until it began to fall dramatically in early 2008's. The collapse of this stock index is initially caused by the financial crisis that hit the United States (US) due to bad credit in housing sector. The crisis eventu-

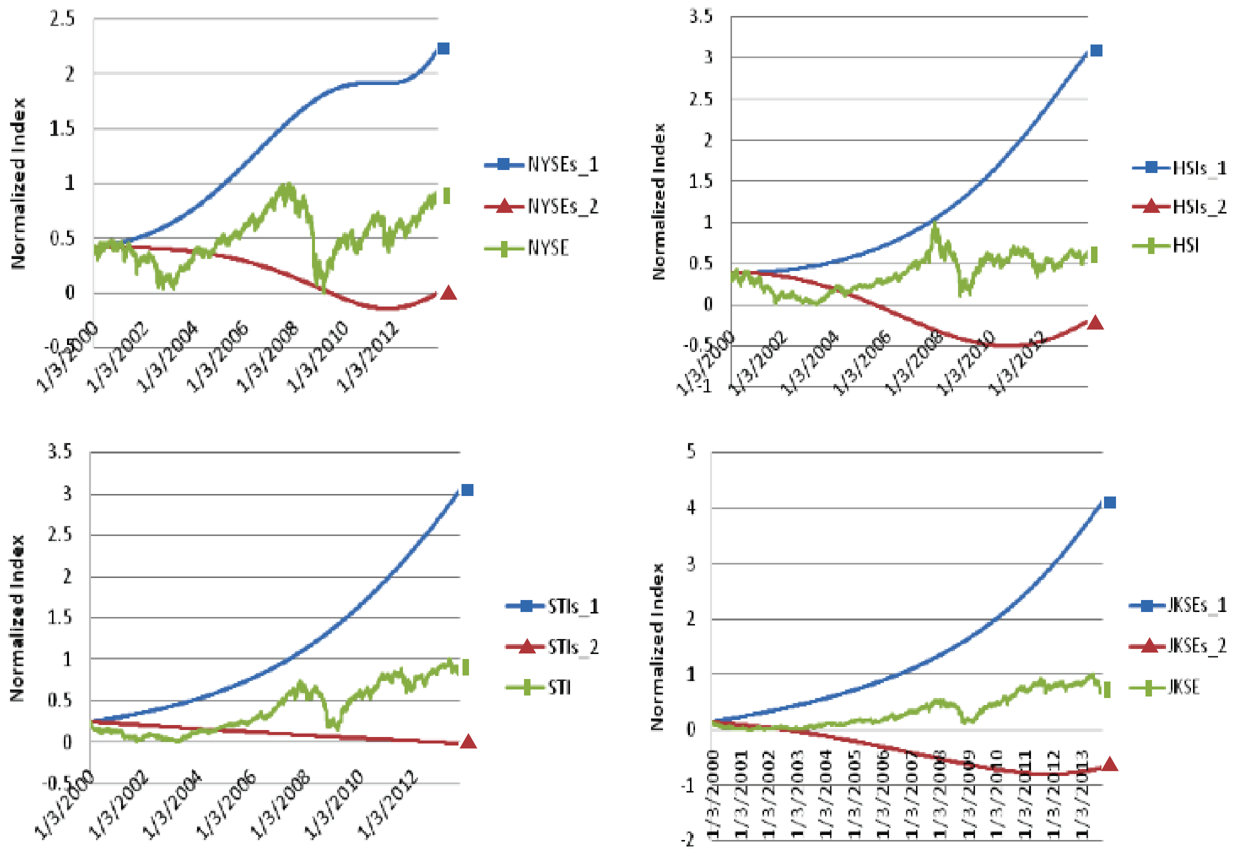

Figure 3. Envelope of 50 realizations of proposed model with random fluctuation

ally impact to the countries that depend on US. However, the movement of NYSE is moving ahead comparing to other three indices. In the period of global crisis, the NYSE index began to fall at the end of 2007, and other indices fall after that date. The decreasing pattern happened almost a year until early of January 2009.

Parameter Estimation

By implementing the numerical approach in estimating the parameters of model, we find the estimate of parameter as shown in table 2.

The estimate of influence rate of NYSE, HSI, and STI indices to JKSE is described with the estimate of a_8, which the increase of three indices will tend to increase the JKSE index. However, the decreasing pattern of NYSE will influence JKSE more than its increasing pattern by comparing the value of a_3 and a_1a_2. HSI index has a better contribution in JKSE than STI since the rate of a_4 is higher than a_6.

Figure 2 shows the trend of four stock indices movement based on catalytic chemical model. The trend of New York Stock Exchange (NYSE) index, as shown in panel (a), can be captured by estimate model. Even though within period of observation, the actual index value of NYSE showed volatile movement, but the trend is slightly increasing. This pattern is coped by the estimate model. As well as NYSE index trend, the trend of STI and JKSE are also can be captured by catalytic chemical model as shown by panel (c) and (d). The increasing pattern of actual index data can be represented by this model quite well. Figure 2 panel (b) shows that the catalytic chemical model estimate the decreasing pattern of HSI index. These trend patterns are estimated by considering the effect of other index, especially for JKSE index, where the trend is including the information of NYSE, HSI, and STI effect to local index. Moreover, the possibility of the JKSE index affecting other indices is also included.

The special feature of financial market is time varying property in which random uncertainties always appear. The effect of random uncertainties is similar to panic behavior in the market. In order to catch the random fluctuation in financial model, the perturbation around estimate parameter is generated by simulation based on equation (4). The random term, ω_i, is assumed normally distributed with mean 0 and a certain value of variance. In this paper, we use variance value at 0.1 based on estimated variance in 10 time parameter estimation in model (1).

The envelope of realizations of proposed catalytic chemical model using random fluctuations based on simulation result for 50 sample size of random term is displayed by figure 3. The normalized actual index data is displayed in central value. For four indices, it is shown that estimate index based on simulation can envelope most of the normalized actual data. The fittest simulation is shown for JKSE which almost all normalized actual data lies within the envelope.

Conclusion

As mentioned before, this paper emphasizes the numerical approach in estimating parameters of catalytic chemical model to capture the trend and random fluctuation. This research is part of a series of researches evaluating systemic risk in stock market. By applying the proposed model of Caetano and Yoneyama (2011) to four indices of stock exchange, New York Stock Exchange (NYSE), Hong Kong Hang Seng (HSI), Straits Times Index (STI), and Jakarta Stock Exchange (JKSE), the results show that this model can catch the trend and random fluctuation quite well. The advantage of this result is that estimation process considering the influence of other indices.

Further Research

For extensive research, as also suggested by Caetano and Yoneyama (2011), we can modify differential equation to model the contagion effect in global financial system. The estimate parameter of this model is more suitable in explaining the complex behavior of stock markets and may be useful in the study of systemic risk. The Monte Carlo simulation is used to find the Value at Risk for each country as a part of systemic risk evaluation.

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