The prediction of financial crisis in Indonesia based on the smoothed probability value from the combination of volatility and Markov switching models

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Abstract. Indonesia is a country that applies an open economic system. The application of an open economic system can lead to the transmission of crises from other countries, for example the major financial crisis that experienced by Indonesia in 1997 and 2008. The financial crisis caused disruption to the economy stability of the country itself, so it is necessary to predict the financial crisis with the aim to protect economy stability. The indicators used in this research are the Indonesia Composite Index (ICI) and foreign exchange reserves. The method used is a combination of volatility and Markov switching models, namely the MS-ARCH(2,1) for ICI indicator and MS-GARCH(2,1,1) for foreign exchange reserves indicator. The result showed that based on the smoothed probability value of the combination of those two models, the ICI indicator could explain the crisis that occurred in 1997 and 2008, while the foreign exchange reserves indicator could only explain the crisis that occurred in 1997. In addition, the results of financial crisis prediction in Indonesia show that Indonesia will not experience a financial crisis for the next year. However, if the ICI and foreign exchange reserves indicators decrease by at least 32%, a crisis can occur.

1. Introduction

Indonesia is one of the countries implementing open economy system providing ease to interact with other countries, for instance through export and import activities. Besides providing ease of interaction, the application of an open economic system can lead to the transmission of crises from other countries, for example the financial crises of 1997 and 2008 have been experienced by Indonesia. Crisis hinders the country’s economy stability. This condition raised the various economic difficulty in Indonesia. Considering the impact of crisis being highly disadvantageous for a country, it is necessary to predict the financial crisis that aims to anticipate the crisis in the future by taking action as soon as possible in the event of a crisis so that the country’s economy remains stable. Kaminsky et. al. [1] have developed an early detection system using a number of indicators, namely 15 indicators. Two of those indicators are Indonesia Composite Index (ICI) and foreign exchange reserves. ICI is the index that measures the movement of stock price on the Indonesia Stock Exchange. Foreign exchange reserves is foreign currency that is reserved by the central bank and useful for financing imbalances in the balance of payments.
One of methods that can be used to predict crisis is a combined volatility and Markov switching models. Both indicators can be modelled into the volatility model because they are indicated to have heteroscedasticity effect on the Autoregressive Moving Average (ARMA) residual. The ARMA model was introduced by Box et. al. [2]. In overcoming the effect of heteroscedasticity, Engle [3] introduced the Autoregressive Conditional Heteroscedasticity or ARCH model. Furthermore, Bollerslev [4] generalized ARCH model to Generalized Autoregressive Conditional Heteroscedasticity or GARCH model. Hamilton [5] introduced the Markov switching (MS) model to see the change of condition on both indicators. Hamilton and Sumsel [6] combined the MS and ARCH models to obtain the MS-ARCH models which is used to analyze the stock price volatility, while Sopipan et. al. [7] combined the MS and GARCH models into MS-GARCH models to predict the gold price volatility.

The combination of volatility and Markov switching models produces smoothed probability value. Sugiyanto et. al. [8] used the smoothed probability of the MS-ARCH models with the assumption of three states to analyze the financial crisis based on indicators of bank deposits, real exchange rates, and trade terms. Sugiyanto et. al. [9] also researched about the crisis detection by applied the MS-GARCH models with the three states assumption based on banking indicators. Almonares [10] used the smoothed probability to analyze the monthly return of the Philippine Stock Exchange. According to Kim and Nelson [11], smoothed probability refer to inferences about conditional on all the information available on the sample so in this research, the smoothed probability is used to predict financial crisis in Indonesia. If the ICICI and foreign exchange reserves indicators decline, it can cause a crisis. Simulation on the two indicators were performed to find the minimum decrease that could cause a crisis on the ICICI and foreign exchange reserves.

2. Theoretical structures

2.1. ARMA model
ARMA($p,q$) model is the mean model which consists of AR orde $p$ and MA orde $q$. According to Box et. al. [2], ARMA($p,q$) model is formulated as

$$r_t = \sum_{i=1}^{p} \phi_i r_{t-i} + \alpha_t - \sum_{i=1}^{q} \theta_i a_{t-i}$$

$r_t$ denotes the value of log return transformation at $t$-time, $\phi_i, i=1,2,...,p$ are the parameters of AR model, $\alpha_t$ denotes the residual of ARMA model at $t$-time, and $\theta_i, i=1,2,...,q$ are the parameters of MA model.

2.2. Volatility models
The volatility models are used to explain fluctuations in the data. There are several of volatility models, including the ARCH and GARCH models. According to Engle [3], ARCH($m$) model is formulated as

$$\sigma_t^2 = \alpha_0 + \sum_{i=1}^{m} \alpha_i a_{t-i}^2$$

and according to Bollerslev [4], GARCH($m,s$) model is formulated as

$$\sigma_t^2 = \alpha_0 + \sum_{i=1}^{m} \alpha_i a_{t-i}^2 + \sum_{j=1}^{s} \beta_j \sigma_{t-j}^2$$

$\alpha_0$ is the model constant, $m$ is ARCH order, $\alpha_i, i=1,2,...,m$ are ARCH parameters, $s$ is GARCH order and $\beta_j, j=1,2,...,s$ are GARCH parameters.
2.3. Combination of volatility and Markov switching models

According to Hamilton and Sumsel [6], MS-ARCH\((K,m)\) model is formulated as
\[
\sigma^2_{i,t} = \alpha_{0,i} + \sum_{i=1}^{m} \alpha_{i,j} \sigma^2_{i-1}
\]
and according to Sopipan et. al. [7], MS-GARCH\((K,m,s)\) model is formulated as
\[
\sigma^2_{i,s} = \alpha_{0,s} + \sum_{i=1}^{m} \alpha_{i,s} \sigma^2_{i-1} + \sum_{j=1}^{s} \beta_{j,s} \sigma^2_{i-j}
\]
where \(K\) is state assumption and \(s\), is state at \(t\)-time, \(t=1,2,...,K\).

2.4. Smoothed probability

According to Kim and Nelson [11], the smoothed probability value is formulated as
\[
P(S_t = i | \psi_T) = \sum_{j=1}^{K} P(S_{t+1} = j | \psi_T) P(S_t = i | S_{t+1} = j, \psi_T)
\]
\(\psi_T\) is all information until \(t\)-time and \(t=1,2,...,T\).

3. Research methods

In this research, the researchers used monthly data on the ICI and foreign exchange reserves were obtained from Bank Indonesia. The data start from January 1990 to June 2019 were divided into two parts, namely training data from January 1990 until June 2018 and testing data from July 2018 until June 2019. The stages conducted in this research were:

1. Creating data plot and conducting ADF or Augmented Dickey Fuller test to check the data stationary on both indicators.
2. Conducting log return transformation if the data are not stationary.
3. Forming ARMA\((p,q)\) model and conducting heteroscedasticity effect test.
4. Creating the best volatility model and conducting diagnostic test on the residual of volatility model.
5. Forming the combination of volatility and Markov switching models.
6. Calculating the smoothed probability value for both indicators.
7. Determining the limit of smoothed probability value and conducting the model accuracy.
8. Predicting financial crisis in Indonesia.

4. Results

In this section, an analysis will be conducted to answer the research questions of predicting the financial crisis based on ICI and foreign exchange reserves indicators. The analysis begins by plotting data on the two indicators until finally a prediction of the financial crisis is obtained.

4.1. Data plot

The data are said to be stationary if it does not contain trend. The trend in data can be determined by looking at the data plot. The plots of ICI and foreign exchange reserves are presented in figure 1 and figure 2.
Based on the figure 1 and figure 2, it is seen that the ICI and foreign exchange reserves indicators are not stationary because the increase over time or contain trend. It is supported by the implementation of ADF test. The result of ADF test shows that the p-value of the ICI and foreign exchange reserves indicators are 0.6656 and 0.9617, respectively. The p-value of the two indicators are bigger than $\alpha = 0.05$ so $H_0$ is not rejected, which means that the ICI and foreign exchange reserves indicators are not stationary. Thus, a log return transformation must be conducted to make both indicators stationary.

4.2. Log return transformation

The plots of ICI and foreign exchange reserves as the result of log return transformation are presented in figure 3 and figure 4.

Based on figure 3 and figure 4, it is seen that the indicators of ICI and foreign exchange reserves have been stationary because both of them contain no trend. Based on the result of ADF test, the obtained p-value of both indicators are 0.01. Therefore, $H_0$ is rejected which means that the indicators of ICI and foreign exchange reserves are stationary.
4.3. Formation of ARMA model

The ARMA order determination was based on the plots of Partial Autocorrelation Function and Autocorrelation Function, while the selection of the best model is based on the smallest AIC value so that the best mean model for ICI indicator is ARMA(1,0) with the AIC value of -783.67 which can be written as

\[ r_t = 0.21540r_{t-1} + a_t \]

and for foreign exchange reserves indicator is ARMA(3,4) with the AIC value of -825.54 which can be written as

\[ r_t = 0.009062 + 0.568347r_{t-1} - 0.551171r_{t-2} + 0.389358r_{t-3} + a_t + 0.640243a_{t-1} - 0.536598a_{t-2} + 0.596777a_{t-3} - 0.319556a_{t-4} \]

Based on the result of Lagrange multiplier test, the p-value obtained on the ICI and foreign exchange reserves indicators are 0.01392 and 0.01573, respectively which is smaller than \( \alpha = 0.05 \) so \( H_0 \) is rejected which means that the residual of ARMA(1,0) and ARMA(3,4) models contains heteroscedasticity effect and that it must be modeled into volatility model.

4.4. Volatility model formation

Based on the plot of PACF from ARMA squared residual for each indicator indicated that the volatility model appropriate for ICI indicator is ARCH(1) with the AIC value of -792.0203 which can be written as

\[ \sigma_t^2 = 0.0047030 + 0.1995886a_{t-1}^2 \]

while for foreign exchange reserves indicator is GARCH(1,1) with the AIC value of -1098.801 which can be written as

\[ \sigma_t^2 = 0.0003154 + 0.5953a_{t-1}^2 + 0.4814\sigma_{t-1}^2 \]

The results of diagnostic test on the residual of volatility model through Kolmogorov-Smirnov, Ljung-Box, and Lagrange multiplier test for the residual of ARCH(1) model indicate that the p-values obtained are 0.8824, 0.9354, and 0.8071 respectively. While the values for the residual of GARCH(1,1) model indicate that the p-values obtained are 0.9021, 0.2379, and 0.5395 respectively. It means that the residual of ARCH(1) and GARCH(1,1) models has normal distribution, no autocorrelation, and no heteroscedasticity effect.

4.5. Combination of volatility and Markov switching models

Data fluctuations and changing conditions can be identified using combination of volatility and Markov switching models with the two states, where state 1 as low volatility and state 2 as high volatility. Thus, the combination of models obtained for ICI and foreign exchange reserves indicators are MS-ARCH(2,1) and MS-GARCH(2,1,1), respectively. The transition probability matrix for ICI indicator \((P_1)\) and foreign exchange reserves indicator \((P_2)\) are

\[
P_1 = \begin{pmatrix}
0.98541813 & 0.01458187 \\
0.03657325 & 0.96342675 
\end{pmatrix} \quad \text{and} \quad P_2 = \begin{pmatrix}
0.98895935 & 0.01104065 \\
0.05204993 & 0.94795007 
\end{pmatrix}
\]

\(P_1\) shows that the state probability to stand in low volatility of 0.98541813 and it will stand in high volatility of 0.96342675, while \(P_2\) shows that the state probability to stand in low volatility of 0.98895935 and it will stand in high volatility of 0.94795007. The mean and variance for each state in ICI indicator are

\[ \mu_1 = \begin{cases}
0.000043214, \text{for state 1} \\
-0.000053416, \text{for state 2}
\end{cases} \quad \text{and} \quad \sigma_1^2 = \begin{cases}
0.000009661, \text{for state 1} \\
0.000046471, \text{for state 2}
\end{cases} \]

The mean and variance for each state in foreign exchange reserves indicator are
\[ \mu_t = \begin{cases} 0.000034497, & \text{for state 1} \\ 0.000121673, & \text{for state 2} \end{cases} \quad \text{and} \quad \sigma^2_t = \begin{cases} 0.000003451, & \text{for state 1} \\ 0.000110367, & \text{for state 2} \end{cases} \]

### 4.6. Smoothed probability

The determination of financial crisis condition was based on the minimum value of smoothed probability when the financial crisis happened (1997-1998). The limit of smoothed probability for stable conditions based on ICI indicator is 0.98 and foreign exchange reserves indicator is 0.92. Thus, when the value of smoothed probability is bigger than 0.98 and 0.92 for each indicator, it is said to have a crisis. The plots of smoothed probability for both indicators are presented in figure 5 and figure 6.

![Figure 5. Smoothed probability plot of ICI indicator.](image1)

![Figure 6. Smoothed probability plot of foreign exchange reserves indicator.](image2)

Figure 5 shows the smoothed probability that exceeds 0.98 as many as 39 observations, while figure 6 shows the smoothed probability that exceeds 0.92 as many as 37 observations. This means that based on the ICI indicator, there were 39 crisis periods that have occurred in Indonesia, which occurred in August-October 1990, August 1997-May 2000, and September-October 2008, while based on the foreign exchange reserves indicator, there were 37 crisis periods which occurred in June-December 1990, August 1997-October 1999, and June-August 2001. The values of prediction and actual from smoothed probability for both indicators in July 2018 to June 2019 are presented in table 1 and table 2.

| Period       | ICI indicator |
|--------------|---------------|
| July '18     | 0.032117      |
| August '18   | 0.045056      |
| September '18| 0.057333      |
| October '18  | 0.068982      |
| November '18 | 0.080035      |
| December '18 | 0.090523      |
| January '19  | 0.100474      |
| February '19 | 0.109916      |
| March '19    | 0.118875      |
| April '19    | 0.127376      |
| May '19      | 0.135442      |
| June '19     | 0.143095      |

| Period       | ICI indicator |
|--------------|---------------|
| July '18     | Noncrisis     |
| August '18   | Noncrisis     |
| September '18| Noncrisis     |
| October '18  | Noncrisis     |
| November '18 | Noncrisis     |
| December '18 | Noncrisis     |
| January '19  | Noncrisis     |
| February '19 | Noncrisis     |
| March '19    | Noncrisis     |
| April '19    | Noncrisis     |
| May '19      | Noncrisis     |
| June '19     | Noncrisis     |

| Period       | ICI indicator |
|--------------|---------------|
| July '18     | 0.001016      |
| August '18   | 0.000942      |
| September '18| 0.001005      |
| October '18  | 0.001096      |
| November '18 | 0.001055      |
| December '18 | 0.001094      |
| January '19  | 0.001391      |
| February '19 | 0.001899      |
| March '19    | 0.002585      |
| April '19    | 0.004463      |
| May '19      | 0.008689      |
| June '19     | 0.014594      |

| Period       | ICI indicator |
|--------------|---------------|
| July '18     | Noncrisis     |
| August '18   | Noncrisis     |
| September '18| Noncrisis     |
| October '18  | Noncrisis     |
| November '18 | Noncrisis     |
| December '18 | Noncrisis     |
| January '19  | Noncrisis     |
| February '19 | Noncrisis     |
| March '19    | Noncrisis     |
| April '19    | Noncrisis     |
| May '19      | Noncrisis     |
| June '19     | Noncrisis     |
Table 2. The prediction and actual value of smoothed probability for foreign exchange reserves indicator.

| Period     | Foreign exchange reserves indicator | Prediction | Condition | Actual | Condition |
|------------|-------------------------------------|------------|-----------|--------|-----------|
| July '18   | 0.013686                            | Noncrisis  | 0.000186  | Noncrisis |
| August '18 | 0.023863                            | Noncrisis  | 0.000169  | Noncrisis |
| September '18 | 0.033398                | Noncrisis  | 0.000194  | Noncrisis |
| October '18 | 0.042332                             | Noncrisis  | 0.000242  | Noncrisis |
| November '18 | 0.050702                  | Noncrisis  | 0.000483  | Noncrisis |
| December '18 | 0.058543                         | Noncrisis  | 0.000312  | Noncrisis |
| January '19 | 0.065891                             | Noncrisis  | 0.000335  | Noncrisis |
| February '19 | 0.072774                        | Noncrisis  | 0.000207  | Noncrisis |
| March '19   | 0.079223                             | Noncrisis  | 0.000241  | Noncrisis |
| April '19   | 0.085266                             | Noncrisis  | 0.000321  | Noncrisis |
| May '19     | 0.090927                             | Noncrisis  | 0.000842  | Noncrisis |
| June '19    | 0.096231                             | Noncrisis  | 0.002731  | Noncrisis |

Table 1 shows that the results of prediction and actual smoothed probability for ICI indicator from the period of July 2018 to June 2019 are in a noncrisis condition. Table 2 also shows the same for foreign exchange reserves indicator. Therefore, because the results of prediction and actual smoothed probability show the same results, the prediction of the financial crisis using the value of smoothed probability has an accuracy of 100%. Therefore, MS-ARCH(2,1) model and MS-GARCH(2,1,1) model are accurate in modelling ICI and foreign exchange reserves indicators.

4.7. Financial crisis prediction
The prediction of financial crisis in Indonesia for the upcoming year can be determined by looking for the prediction value of smoothed probability. The predictions of smoothed probability for both indicators in July 2019-June 2020 are presented in table 3.

Table 3. The prediction of smoothed probability.

| Period     | Smoothed probability prediction | ICI     | Condition | Foreign exchange reserves | Condition |
|------------|---------------------------------|---------|-----------|---------------------------|-----------|
| July '19   | 0.028534                         | Noncrisis | 0.013157  | Noncrisis |
| August '19 | 0.041760                         | Noncrisis | 0.022933  | Noncrisis |
| September '19 | 0.054308                   | Noncrisis | 0.032100  | Noncrisis |
| October '19 | 0.066212                         | Noncrisis | 0.040696  | Noncrisis |
| November '19 | 0.077506                     | Noncrisis | 0.048758  | Noncrisis |
| December '19 | 0.088220                       | Noncrisis | 0.056317  | Noncrisis |
| January '20 | 0.098386                         | Noncrisis | 0.063405  | Noncrisis |
| February '20 | 0.108029                        | Noncrisis | 0.070052  | Noncrisis |
| March '20   | 0.117179                         | Noncrisis | 0.076285  | Noncrisis |
| April '20   | 0.125859                         | Noncrisis | 0.082130  | Noncrisis |
| May '20     | 0.134094                         | Noncrisis | 0.087612  | Noncrisis |
| June '20    | 0.141907                         | Noncrisis | 0.092751  | Noncrisis |

Table 3 shows that based on ICI and foreign exchange reserves indicators, in the period of July 2019 to June 2020 Indonesia was in a stable condition (noncrisis). Next, simulate a smoothed probability in the period of July 2019 by decreasing ICI and foreign exchange reserves data of 32% from the period
of June 2019. The results of the simulation of smoothed probability for both indicators are presented in figure 7 and figure 8.

![Figure 7. Smoothed probability from ICI indicator simulation.](image1)

![Figure 8. Smoothed probability from foreign exchange reserves indicator simulation.](image2)

Based on figure 7 and figure 8, it appears that in the period of July 2019 there was a crisis. This can be seen from the value of smoothed probability which is worth 1 or more than the predetermined limit of smoothed probability so that it can be conclude that the decrease in ICI and foreign exchange reserves by 32% in July 2019 can cause a crisis.

5. Conclusion
The best model for ICI and foreign exchange reserves indicators respectively are MS-ARCH(2,1) and MS-GARCH(2,1,1). The ICI indicator could explain the crisis that occurred in 1997 and 2008, while the foreign exchange reserves indicator could only explain the crisis that occurred in 1997. The financial crisis prediction in Indonesia indicates that Indonesia will not experience financial crisis in July 2019 to June 2020. Based on the results of simulation, in the future a crisis might occur if the ICI and foreign exchange reserves indicators decrease by at least 32%. In this research using the univariate time series model where the two data are not analyzed together. It is hoped that further research can use the multivariate time series model in predicting the crisis.

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