Indonesian Financial Crisis Prediction Using Combined Volatility and Markov Regime Switching Model Based on Indicators of Real Interest Rate on Deposits and Lending Interest Rate/Deposit Interest Rate

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Abstract. The financial crisis that occurred in mid-1997 made it aware of the importance of building an early detection system because the crisis had a severe impact on the Indonesian economy. The crisis occurred due to several macroeconomic indicators experiencing very high fluctuations and the existence of changes in the structure (regime). The combined volatility and Markov regime switching models are very suitable to explain the crisis. Indicators of real interest rates on deposits and lending interest rate/deposit interest rates from 1990 to 2018 were used to build the combined model. The result showed that the MRS-ARCH (2,1) model for real interest rate on deposits indicator and the MRS-GARCH (3,1,1) model for lending interest rate/deposit interest rate indicator could explain the crisis. Markov regime switching predictions indicate that in 2019 there are no signs of a financial crisis in Indonesia.

1. Introduction
The financial crisis that occurred in mid-1997 began when the value of the Thai currency fell sharply. Disruptions to the financial system in economic rules can cause a currency crisis. Currency crises can be detected through banking performance. Seeing the effects of the financial crisis on the decline in economic activity made it aware of the importance of building an early detection system because the crisis had a severe impact on the Indonesian economy. Indicators of real deposit interest rates and the ratio of interest rates on loans and deposits represent performance in the banking sector that has fluctuations and can change conditions. Changes in fluctuations can be explained using the volatility model. While changing conditions can be explained using the Markov switching regime model.

The autoregressive conditional heteroskedasticity (ARCH) model was introduced by Engle\textsuperscript{[1]}, to model the variance of inflation data in the UK from 1958 to 1977 and obtained a more realistic prediction of variance. Bollerslev\textsuperscript{[2]} introduced generalized autoregressive conditional heteroskedasticity (GARCH) to model US GNP data from 1948 to 1983.Hamilton\textsuperscript{[3]} introduced the Markov switching (MS) model as a time series data model that contained changes in conditions.
Hamilton and Susmel [4] combined the MS and ARCH models to produce the Markov switching autoregressive conditional heteroscedasticity (SWARCH) model. They applied the SWARCH model on U.S gross national product (GNP) data from 1952 to 1984; the model can explain the state changes that occur in the U.S GNP data economic variables. Chang [5] used the SWARCH model to identify stock market and exchange rate volatility in Korea and the global financial crisis. Sugiyanto [6] through output real, domestic credit per gross domestic product (GDP), and ICI indicators detect the financial crisis using a combination of volatility and Markov switching models. Sugiyanto [7] also explained the financial crisis using the MS-GARCH model through banking indicators. This research discusses currency crises that might occur in Indonesia through real interest rate on deposits and lending interest rate/deposit interest rate indicators using a combination of Markov switching and volatility models.

2. Material and methods

2.1. Material

The model used for stationary time series data is the autoregressive AR (p) model which is written as follows

\[ r_t = \phi_0 + \phi_1 r_{t-1} + \cdots + \phi_p r_{t-p} + \epsilon_t, \]  (1)

where \( r_t \) is the log return at time \( t \), \( \epsilon_t \) is the residual model AR(p), and \( \phi_0, \phi_1, \ldots, \phi_p \) is the parameter model AR(p). The autoregressive conditional heteroscedasticity ARCH(m) model is an alternative to modeling non-constant variance that can be written as [1]

\[ \sigma_t^2 = \sigma_t \epsilon_t, \]  (2)

where \( \epsilon_t \sim N(0,1) \) and \( \sigma_t^2 \sim N(0, \sigma_t^2) \).

\[ \sigma_t^2 = \alpha_0 + \alpha_1 \sigma_{t-1}^2 + \cdots + \alpha_m \sigma_{t-m}^2 = \alpha_0 + \sum_{i=0}^{m} \alpha_i \sigma_{t-i}^2, \]  (3)

\( \alpha_0 > 0, \alpha_i \geq 0, \) for \( i > 0, \) \( \sigma_t^2 = E(\sigma_t^2 | \psi_{t-1}) \) is a conditional variance residual at time \( t \), and \( \psi_t \) is all information sets up to time \( t \). The GARCH(m,s) model is a generalization of the ARCH model by involving past variances that can be written as [8]

\[ \sigma_t^2 = \alpha_0 + \alpha_1 \sigma_{t-1}^2 + \cdots + \alpha_s \sigma_{t-s}^2 + \beta_1 \sigma_{t-1}^2 + \cdots + \beta_m \sigma_{t-m}^2 = \alpha_0 + \sum_{i=0}^{s} \alpha_i \sigma_{t-i}^2 + \sum_{j=0}^{m} \beta_j \sigma_{t-j}^2. \]  (4)

Changing conditions can be seen using the Markov regime switching. The MRS-ARCH model can be written as [4]

\[ r_t = \mu_{s_t} + \alpha_t, \quad \sigma_t^2 = \sigma_{s_t}, \]  (5)

\[ \sigma_{s_t}^2 = \alpha_{0,s_t} + \sum_{i=1}^{m} \alpha_{i,s_t} \sigma_{t-i}^2, \]  (6)

Equation (5) and (6) are MRS-ARCH with the \( k \) regime and order \( m \). Furthermore, the MRS-GARCH can be written as [9]

\[ \sigma_{s_t}^2 = \alpha_{0,s_t} + \sum_{i=1}^{m} \alpha_{i,s_t} \sigma_{t-i}^2 + \sum_{j=1}^{s} \beta_j \sigma_{t-j}^2. \]  (7)

For \( r_t \) is a vector of observed variable and \( s_t \) denote an unobserved random variable satisfy the first-order Markov chain that can take on the value 1,2,\ldots, \( T \). The variable \( s_t \) is regarded as the state or regime that the process is in date \( t \) and \( s_t \) governs that a first-order Markov chain governs parameters of the conditional distribution of the unobserved random variable with constant transition probability given by

\[ P[s_t = j | s_{t-1} = i] = p_{ij}, \sum_{j=1}^{T} p_{ij} = 1, \] for \( i, j = 1,2,\ldots, T. \]  (8)

In matrix notation, \( P \) can be defined by
Based on Kim and Nelson [10], smoothed probability value (Pr(S_t = i|\psi_T)) for T = 1, 2, ..., T, t = 1, 2, ..., T can be written as follows,

$$\Pr(S_t = i|\psi_T) = \sum_{j=1}^{T} \Pr(S_{t+1} = j|\psi_T) \Pr(S_t = i|S_{t+1} = T, \psi_T).$$

(10)

Based on Sopipan et al [11], smoothed probability value at time T + 1 can be predicted with

$$\Pr(S_{t+1} = i|\psi_T) = p_{1i} P(S_t = 1|\psi_T) + p_{2i} P(S_t = 2|\psi_T) + \cdots + p_{ji} P(S_t = j|\psi_T).$$

(11)

Where p_{ji} shows the elements of the P_{ji} transition matrix. Short-term crisis signals can be indicated by the number of predictive of smoothed probability values.

2.2. Method

Monthly data on real interest rate on deposits and lending interest rate/deposit interest rate from January 1990 to October 2018 were taken from International Financial Statistics (IFS). With data January 1990 to December 2017 as training data and data from January 2018 to October 2018 as testing data. The steps in this study are as follows.

1. Stationary test using ADF (augmented Dickey Fuller) test. If the data is not stationary then transformation data using log return.
2. Create an ARMA model and perform diagnostic tests on the best ARMA models.
3. Check volatility clustering using DTW (Dynamic Time Warping) distance and test heteroscedasticity ARMA residual uses the Lagrange multiplier test.
4. If there is heteroscedasticity on the residual ARMA model, then identify the volatility model. Next is a diagnostic test (autocorrelation test, heteroscedasticity and normality).
5. Perform a combination of volatility models and the Markov regime switching model.
6. Calculate the smoothed probability value from data real interest rate on deposits and lending interest rate/deposit interest rate.
7. If the smoothed probability value of of the real interest rate on deposits more than 0.89 then a financial crisis is predicted and more than 0.921 for lending interest rate/deposit interest rate.
8. Predict the financial crisis for the next year.

3. Results and discussions

Stationary data can be seen from the ADF test. Based on the ADF test, the probability value is more than 0.05, which means that the data is not stationary so the log return transformation is needed. Based on the ADF test the probability value is less than 0.05 which means that the data is stationary. After the data is stationary, ACF and PACF tests are carried out to determine the ARMA model used. Based on the AIC value, the best ARMA(2,0) model for real interest rate on deposits and ARMA(1,0) model for lending interest rate/deposit interest rate. ARMA(2,0) model and ARMA(1,0) model can be written as follows

$$r_t = -0.42556r_{t-1} - 0.20071r_{t-2}$$

$$r_t = 0.49647r_{t-1}$$

where \(r_t\) is the log return of real interest rate on deposits and lending interest rate/deposit interest rate at time \(t\), and \(\epsilon_t\) is the residue at time \(t\).

The residual ARMA model is leptokurtic, the leptokurtic curve indicates the existence of different range values, so clustering is necessary. The best clustering analysis for time series data is cluster analysis using DTW (Dynamic Time Warping) distance. Based on the result of clustering, the number of clusters that are suitable for real interest rate on deposits and lending interest rate/deposit interest rate are respectively 2 and 3.
Furthermore, heteroscedasticity test of the residual ARMA(2,0) model and ARMA(1,0) model. Based on Lagrange multiplier test, obtained a probability value less than 0.05. this means that the residual ARMA model contains heteroscedasticity. Volatility models are used to handle heteroscedasticity. The volatility model for real interest rate on deposits is ARCH(1), which can be written as follows

\[ \sigma_t^2 = 0.003404 + 2.812066\sigma_{t-1}^2 \]

and volatility model for lending interest rate/deposit interest rate is GARCH(1,1), which can be written as follows

\[ \sigma_t^2 = 0.00009936 + 0.2307a_{t-1}^2 + 0.6676\sigma_{t-1}^2. \]

where \( \sigma_t^2 \) is the variance at time \( t \), and \( a_t \) is the residue at time \( t-1 \).

Next, a diagnostic test of the ARCH(1) model and GARCH(1,1) model. Based on Ljung-Box test, the probability value is more than 0.05, which means that the residual volatility model does not contain autocorrelation. From the Lagrange multiplier test, the probability value is more than 0.05, which means that the residual volatility model is homogeneous. The probability value of the Kolmogorov-Smirnov test is more than 0.05, which means that the residual volatility model is normally distributed.

Regime is a change in conditions that occur in the Markov regime switching. Regime Regime is assumed to follow the first order markov chain with the transition probability \( p_{ij} \) with \( i, j = 1, 2 \) for indicator real interest rate on deposits and \( i, j = 1, 2, 3 \) for indicator lending interest rate/deposit interest rate. Thus, the Markov regime switching autoregressive conditional heteroscedasticity MRS-ARCH(2,1) for indicator real interest rate on deposits is an ARCH(1) model which has 2 regimes, with regime 1 having low volatility configuration and regime 2 having high volatility configuration. The MRS-GARCH(3,1,1) model for indicator lending interest rate/deposit interest rate is a GARCH(1,1) model that has 3 regimes, with 1,2,3 consecutive regimes describing low, similar and high volatility. A regime has the possibility to survive in the same regime or move to another regime the next time. The probability of a regime change can be seen in the form of a transition probability matrix. Transition probability matrix 2 regime for real interest rate on deposits is as follows.

\[
P = \begin{pmatrix} 0.98252298 & 0.01747702 \\ 0.16218110 & 0.83781890 \end{pmatrix}.
\]

Based on the transition probability matrix, it can be seen the probability value for holding on to low volatility is 0.98252298 and the probability of surviving at high volatility is 0.83781890. Transition probability matrix 3 regime for lending interest rate/deposit interest rate as follows.

\[
P = \begin{pmatrix} 0.92741666 & 0.05977186 & 0.01281148 \\ 0.06156000 & 0.91671889 & 0.02172111 \\ 0.05040072 & 0.06298390 & 0.88661539 \end{pmatrix}.
\]

To detect a crisis, it can be seen from the lowest smoothed probability value when the crisis occurred in Indonesia (1997-1998). So that the crisis results are obtained when smoothed probability values are more than 0.89 for real interest rates on deposits and more than 0.921 for lending interest rate/deposit interest rates. The plot of the smoothed probability form real interest rates on deposits and lending interest rate/deposit interest rate can be seen in Figure 1(a) and Figure 1(b) respectively.

![Figure 1](image-url)
Figure 1(a) shows that there are 25 smoothed probability values more than 0.89 and Figure 1(b) there are 34 smoothed probability values more than 0.921. Real interest rate on deposits indicator detects crises in August 1997 - October 1998, August 1999 - October 1999, October 2005 - January 2006, July 2013 - September 2013. Whereas, for indicator lending interest rate/deposit interest rate can detect crises on June 1991 - August 1991, September 1997 - November 1999, August 2003 - September 2003, June 2014 - July 2014. Thus, it can be concluded that the MRS-ARCH(2,1) model for real interest rates on deposits and MRS-GARCH(3,1,1) model for lending interest rate/deposit interest rates can detect crises.

Based on smoothed probability values from the two indicators, the indicator of real interest rates on deposits can show signals faster than the lending interest rate/deposit interest rate indicator. This is because the actual crisis began in July 1997, as the real interest rate on deposits indicator signals a crisis starting August 1997 and the lending interest rate/deposit interest rate indicator signals a crisis starting in September 1997. Both indicators cannot capture the crisis that occurred in the month October 2008.

Furthermore, the predicted value of the smoothed probability is calculated. The calculation results predict the smoothed probability value of the next period for the real interest rate on deposits and the lending interest rate/deposit interest rate respectively shown in Table 1 and Table 2.

### Table 1. Comparison of smoothed probability predictions and actual for real interest rate on deposits.

| Period      | Prediction of smoothed probability | Prediction crisis condition | Actual of smoothed probability | Actual crisis condition |
|-------------|-----------------------------------|-----------------------------|--------------------------------|-------------------------|
| January 2018 | 0.023078                          | stable                      | 0.000701                       | stable                  |
| February 2018| 0.036409                          | stable                      | 0.000701                       | stable                  |
| March 2018   | 0.047345                          | stable                      | 0.000553                       | stable                  |
| April 218    | 0.056316                          | stable                      | 0.000554                       | stable                  |
| May 2018     | 0.063675                          | stable                      | 0.000547                       | stable                  |
| June 2018    | 0.069712                          | stable                      | 0.000720                       | stable                  |
| July 2018    | 0.074665                          | stable                      | 0.000904                       | stable                  |
| August 2018  | 0.078728                          | stable                      | 0.001699                       | stable                  |
| September 2018| 0.082061                        | stable                      | 0.002011                       | stable                  |
| October 2018 | 0.084795                          | stable                      | 0.003247                       | stable                  |

### Table 2. Comparison of smoothed probability predictions and actual for lending interest rate/deposit interest rate.

| Period       | Prediction of smoothed probability | Prediction crisis condition | Actual of smoothed probability | Actual crisis condition |
|--------------|-----------------------------------|-----------------------------|--------------------------------|-------------------------|
| January 2018 | 0.034088                          | stable                      | 0.001878                       | stable                  |
| February 2018| 0.048773                          | stable                      | 0.001040                       | stable                  |
| March 2018   | 0.061255                          | stable                      | 0.000888                       | stable                  |
| April 218    | 0.071790                          | stable                      | 0.001205                       | stable                  |
| May 2018     | 0.080669                          | stable                      | 0.002025                       | stable                  |
| June 2018    | 0.088110                          | stable                      | 0.004041                       | stable                  |
| July 2018    | 0.094321                          | stable                      | 0.003915                       | stable                  |
| August 2018  | 0.099477                          | stable                      | 0.003899                       | stable                  |
| September 2018| 0.103729                        | stable                      | 0.005469                       | stable                  |
| October 2018 | 0.107206                          | stable                      | 0.015909                       | stable                  |
Based on Table 1 and Table 2, it can be concluded that the conditions of the crisis actual and predictions are the same. This means that the model is very well used to predict the financial crisis for the next year.

Using monthly data from 1990 to 2018 can be calculated predictions of smoothed probability values for real interest rates on deposits and the lending interest rate/deposit interest rate shown in Table 3.

### Table 3. Smoothed probability predictions for real interest rate on deposits and lending interest rate/deposit interest rate.

| Period         | Real interest rate on deposits | Prediction crisis condition | Lending interest rate/deposit interest rate | Prediction crisis condition |
|----------------|--------------------------------|-----------------------------|---------------------------------------------|-----------------------------|
| November 2018  | 0.019831                       | stable                      | 0.026513                                    | stable                      |
| December 2018  | 0.033450                       | stable                      | 0.036354                                    | stable                      |
| January 2019   | 0.044634                       | stable                      | 0.045441                                    | stable                      |
| February 2019  | 0.053817                       | stable                      | 0.053797                                    | stable                      |
| March 2019     | 0.061359                       | stable                      | 0.061452                                    | stable                      |
| April 2019     | 0.067551                       | stable                      | 0.068441                                    | stable                      |
| May 2019       | 0.072637                       | stable                      | 0.074805                                    | stable                      |
| June 2019      | 0.076812                       | stable                      | 0.080582                                    | stable                      |
| July 2019      | 0.080242                       | stable                      | 0.085816                                    | stable                      |
| August 2019    | 0.083056                       | stable                      | 0.090547                                    | stable                      |
| September 2019 | 0.085370                       | stable                      | 0.094814                                    | stable                      |
| October 2019   | 0.087269                       | stable                      | 0.098657                                    | stable                      |
| November 2019  | 0.088828                       | stable                      | 0.102111                                    | stable                      |
| December 2019  | 0.090108                       | stable                      | 0.105212                                    | stable                      |

4. Conclusion
The best model for indicators of real interest rates on deposits and lending interest rate/deposit interest rates are MRS-ARCH (2,1) and MRS-GARCH (3,1,1), respectively. Based on these models the results of predictions for 2019 Indonesia have no financial crisis.

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