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PREDICTING INFLATION INDONESIA USING NONLINEAR TIME SERIES MODEL: A COMPARATIVE STUDY

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ABSTRACT

This study aims to compare the performance of Self-Exciting Threshold Autoregressive (SETAR) and Markov Switching Autoregressive (MSAR) models in modeling and predicting inflation data in Indonesia. Inflation is one of the important economic indicators that requires accurate forecasting methods to make the right policy decisions. In this study, both models are applied to monthly inflation data in Indonesia. The SETAR model is a nonlinear autoregressive model that takes into account regime changes in the inflation rate based on a certain threshold value. Meanwhile, the MSAR model assumes that inflation data can move between regimes with a certain probability governed by a Markov process. Both models are evaluated based on the Akaike Information Criterion (AIC) and Mean Absolute Percentage Error (MAPE) values, with the aim of finding the model that provides the best forecasting results. The results show that the SETAR model has a lower AIC value of -1658 with a MAPE of 18.19% compared to the MSAR model of -832.6177 and MAPE of 25.46%, which indicates that SETAR is superior in modeling and predicting inflation data in Indonesia. This finding makes a significant contribution in choosing a more accurate forecasting method for inflation data and can help in planning better economic policies.

KEYWORDS: Inflation, Forecasting, Nonlinear, SETAR, MSAR.

1. INTRODUCTION

Macroeconomic conditions can be a benchmark in assessing the growth of a country, one of the macroeconomic conditions of a country is inflation. It needs special attention by the government because economic development and public welfare are strongly influenced by the macroeconomy of a country [1]. In the context of inflation in Indonesia, traditional linear models often fail to explain the complex and volatile characteristics of inflation data. Therefore, nonlinear models such as Self-Exciting Threshold

Autoregressive (SETAR) and Markov Switching Autoregressive (MSAR) offer a better alternative for modeling and forecasting inflation data.

The SETAR model is a time series model that can be applied to nonlinear data. The SETAR model is part of the Threshold Autoregressive (TAR) family of models. Threshold SETAR model is a lag value of the series itself or endogenous variables [2]. The formula of the SETAR model with regime j can be written as follows:

$$Y_t = \begin{cases} \phi_{0,1} + \sum_{i=1}^{p_1} \phi_{i,1} Y_{t-i} + a_t, if\ Y_{t-d} \le r_1 \\ \phi_{0,2} + \sum_{i=1}^{p_2} \phi_{i,2} Y_{t-i} + a_t, if\ r_1 < Y_{t-d} \le r_2 \\ \vdots \\ \phi_{0,j} + \sum_{i=1}^{p_j} \phi_{i,j} Y_{t-i} + a_t, if\ r_{j-1} < Y_{t-d} \end{cases}$$

The MSAR model, first introduced by [3], is a generalization of the Hidden Markov Model (HMM) that combines various AR models to describe the evolution of the process at various time periods. This model is able to model time series data that undergoes structural changes. In the Markov Switching model, structural changes or fluctuations in data are controlled by an unobserved state variable that satisfies the first order of the Markov chain [4]. The formula of the MSAR model can be written as follow:

$$(y_i - \mu_{st}) = \phi_1(y_{t-i} - \mu_{st-i}) + \cdots + \phi_p\left(y_{t-p} - \mu_{st-p}\right) + \varepsilon_t$$

Although linear models are still widely used in applied and academic research, they often fail to account for the nonlinear characteristics of financial and economic data [5]. For example, inflation rates affected by various economic policies and market changes may exhibit nonlinear patterns, which require more flexible approaches such as SETAR and MSAR. Fluctuations in inflation data often exhibit structural instability and spikes that cannot be captured by linear models. Nonlinear models such as Self-Exciting Threshold Autoregressive (SETAR) and Markov Switching Autoregressive (MSAR) are able to capture these dynamics more accurately, thus providing more reliable results in inflation forecasting. For example, the SETAR model is able to capture regime changes endogenously, while the MSAR model can control a structural change with an unobserved state that satisfies the first order of the Markov chain. Based on the description above, the author is interested in comparing the Self-Exciting Threshold Autoregressive (SETAR) and Markov Switching Autoregressive (MSAR) models in modeling inflation data in Indonesia with comparison criteria used in both methods, namely Akaike Information Criterion

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(AIC) and Mean Absolute Percentage Error (MAPE).

2. MATERIAL AND METHOD

The data used in this study is secondary data taken from https://bps.go.id. The form of data is monthly inflation data in Indonesia for the period January 1999 - December 2023 with n = 300.

This research is conducted in several stages. First of all, a plotting of Inflation data in Indonesia for the period January 1999 - December 2023 will be done to see the distribution of the data. Furthermore, the stationarity test is divided into 2 types, namely, stationary in variance and stationary in mean. Stationary test in variance is a condition where the time series data structure has a constant or fixed data pattern [6]. Stationarity test on variance can be tested using Box-Cox Transformation, the Box-Cox Transformation formula can be written as follows:

$$\mathrm{Z}_t = \frac{\mathrm{Z}_t^{\lambda}}{\lambda}$$

This transformation is done if the λ value obtained is not close to 1. The data is said to be stationary in variance if the λ value is close to 1 [7]. Stationarity test in the mean is a condition when fluctuations in the data are around a constant average value, independent of the time and variance of these fluctuations [6]. Stationarity test in the mean can be used Augmented Dickey Fuller (ADF) test [8]. Augmented Dickey Fuller (ADF) Test formula as follows:

$$\Delta Y_t = \phi Y_{t-1} \sum_{j=1}^{\rho-1} a_j^* \Delta Y_{t-j} + \varepsilon_t$$

By using the ϕ coefficient contained in the t-statistic, a statistical test can be carried out on the ADF. The criteria for decision making are if the value of the *p-value* < α then the decision taken is to reject H_0 or it can be said that the data is stationary. Meanwhile, if the *p-value* > α then the decision that can be drawn is that the data is declared non-stationary. If the results of the stationarity test on the mean find that the data is not stationary on mean, then differencing is performed. After the data is stationary, a nonlinearity test will be conducted to understand the dynamics and structure of the data. The test to be used is the Terasvirta nonlinearity test which is a development of the neural network model and one of the Lagrange Multiplier test groups with Taylor expansion [9]. The formula used is as follows:

$$F = \frac{(SSR_0 - SSR)/m}{SSR/(N - p - 1 - m)}$$

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With the decision criteria that $F_{count} < F_{(m,(N-p-1-m))}$ or p-$value < \alpha$ then reject H_0 which means $f(x)$ is a nonlinear function. After the nonlinearity test is carried out and it is known that the Inflation data in Indonesia is nonlinear, then modeling will be carried out with the SETAR model and for estimating model parameters, the Least Squares Method can be used [10]. After modeling with the SETAR model, then modeling with the MSAR model will be carried out with parameter estimation using Maximum Likelihood Estimation (MLE) combined with filtered probability and smoothed probability [11]. Furthermore, the best model parameters of the two models are estimated by looking at the Akaike Information Criterion (AIC) [12] and Mean Absolute Percentage Error (MAPE) [13] values. Based on the AIC and MAPE values, the best model is the one with the smallest AIC and MAPE values. The AIC and MAPE formulas are as follows:

$$AIC = log\left(\sum \frac{\varepsilon_t^2}{n}\right) + \frac{2k}{n}$$

$$MAPE = \frac{1}{n}\sum_{t=1}^{n}\left|\frac{y_i - \hat{y}_t}{y_t}\right| \times 100\%$$

After obtaining the best model, a model diagnosis test will be carried out to test the fulfillment of model assumptions by conducting a white noise test and a normality test [2]. Finally, forecasting is carried out using the best model between the SETAR and MSAR models on Inflation data in Indonesia for the next period.

3. RESULT AND DISCUSSION

Analysis of inflation data in Indonesia using SETAR and MSAR was first carried out by testing the fulfillment of the variance stationarity and average stationarity assumptions. To accomplish this, a scatter plot was first created. The scatter plot results can be seen in Figure 1.

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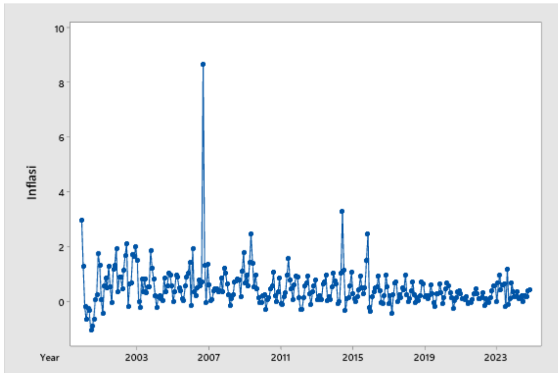

Figure 1 Scatter Plot of Inflation in Indonesia

Figure 1 shows that there were fluctuations in inflation in Indonesia from 1999 to 2023, the highest inflation occurred in 2005 caused by changes in monetary policy that led to changes in commodity prices and had an impact on political conditions in Indonesia. Whereas in the following years, inflation volatility was not as high as in 2005, although in August 2013 there was an increase compared to other years, this occurred due to changes in fuel oil subsidy policy in Indonesia which caused an increase in transportation prices. Meanwhile, from the statistical data in Figure 1, it is known that Indonesia's Inflation data has no trend and each month experiences different fluctuations, so it can be said that Inflation data in Indonesia is not stationary. Furthermore, Box-Cox transformation is carried out to see whether the data is stationary or not. Box-Cox transformation does not allow negative values. Therefore, the negative value in the data is added with a constant of 2 so as to obtain a rounding value of -0.5, then a Box-cox transformation is performed so as to obtain a rounding value of 1. The results of this transformed data are used to test the average stationarity using the Augmented Dickey Fuller (ADF) method. The ADF test results show that the data is stationary in average, because p-value = 0.01 <0.05.

After getting data that was stationary in average and variance, then a nonlinearity test was performed on the data using the Terasvirta test. The results of the Terasvirta test can be seen in Table 1.

Table 1 Terasvirta Nonlinearity Test Results

Data	Terasvirta	
	F	*P-value*
Transformation	7.6417	0.02191

From Table 1, the Terasvirta nonlinearity test has *p-value*= 0.02191 < 0.05, therefore H_0 was rejected. It can be concluded that the data is nonlinear. Because the data meets the stationary assumptions regarding

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variance, stationary regarding the average, and nonlinear assumptions, the analysis can be continued by modeling the data using the SETAR and MSAR methods.

To use the SETAR model, started by determining the embedding dimension (m) and time distance (τ) to obtain the value of the autoregressive order (p), many regimes (j), the length of the delay in the threshold variable (d), and the threshold value (r). The results of the embedding dimension value with entropy are presented in Table 2.

Table 2 Value of Embedding Dimension and Time Delay

Time delay	Embedding dimension	Entropy
1	3	0.9609702
1	4	0.9358127
1	5	0.9446189
1	6	0.9788466
1	7	0.9931155

The embedding dimension in Table 2 gives the smallest entropy, namely 4 with a delay time of 1. The entropy and delay time obtained were used to identify the SETAR model by testing the threshold to determine the number of regimes. Determining the threshold number can be seen from the p-value, nonlinear test statistics and comparing it with a significance level of 0.05. The threshold test results are presented in Table 3.

Table 3 The Results of The Nonlinearity Test vs Threshold

Model Comparison	Test Statistic	*P-value*
Linear vs SETAR (2)	31.81711	0.005
Linear vs SETAR (3)	52.40151	0.005
SETAR (2) vs SETAR (3)	18.58653	0.1375

The nonlinear vs threshold test as presented in Table 3 shows that the nonlinear vs threshold test on the data follow a 1 threshold SETAR model because testing between the linear models AR vs 1 threshold SETAR and AR vs 2 threshold SETAR gives *p-value*= 0.005 < 0.05, therefore H_0 is rejected. In addition, test the 1 threshold vs 2 threshold SETAR model resulting in *p-value*= 0.1375 > 0.05, it means that H_0 is accepted. These results indicate that the data has 1 threshold in the SETAR model, meaning that the data can be modeled in the form of a 2 regime SETAR model.

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After finding that the SETAR 2 regime model fits the data, then an autoregressive order, delay and threshold search is carried out in the SETAR model based on the smallest AIC value. The results can be seen in Table 4.

Tabel 4 AIC Value of 2-regime SETAR (d, p_1, p_2) model

d	p_1	p_2	r	AIC
1	2	1	0.6311944	-808.8241
1	2	1	0.6324555	-807.9284
1	2	1	0.6350006	-807.6838
1	2	1	0.6262243	-807.0639
1	2	1	0.6286946	-806.9202
1	2	1	0.6362848	-806.8286
1	2	2	0.6311944	-806.8258
1	2	1	0.6375767	-806.6082
1	4	1	0.6311944	-805.9771
1	2	2	0.6324555	-805.9295

In Table 4, the SETAR model that has the smallest AIC value is model 2 SETAR (1,2,1) regime with a threshold of 0.6311944 and an AIC of -808.8241. Next, the SETAR (1,2,1) model parameters were estimated using the least squares method. The results of parameter estimation can be seen in Table 5.

Tabel 5 Estimation Parameter of 2-regime SETAR (1,2,1) Model

Parameter	Estimated	*P-value*	AIC	MAPE
$\phi_{0,1}$	0.619420	1.380e-12	-1658	18.19%
$\phi_{1,1}$	0.340660	4.124e-05		
$\phi_{2,1}$	-0.321342	0.01041		
$\phi_{0,2}$	0.229186	1.228e-06		
$\phi_{1,2}$	0.632124	< 2.2e-16		

The results of the parameter significance test in the SETAR (1,2,1) model are presented in Table 5. It can be seen that all parameter values of the SETAR(1,2,1) with 2 regime model and threshold= 0.6311944 are significant because *p-value* < 0.05 with an AIC value of -1658 and a MAPE of 18.19%. Therefore,

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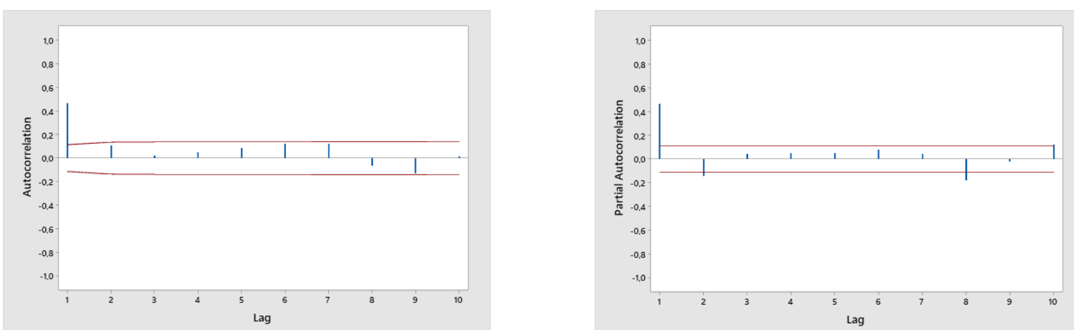
SETAR (1,2,1) 2-regime model can be written as:

$$y_t^* = \begin{cases} 0.619420 + 0.340660_{t-1}{}^* - 0.321342_{t-2}{}^* + a_t & , y_{t-2}{}^* \leq 0.6311944 \\ 0.229186 + 0.632124_{t-1}^* + a_t & , y_{t-2}{}^* > 0.6311944 \end{cases}$$

It can be interpreted from the model that the 2-regime SETAR (1,2,1) model describes the behavior of the time series y_t influenced by conditions at two previous times (y_{t-1}, y_{t-2}). If the value of y_{t-2} is smaller or equal to the threshold 0.6311944 then it is in the first regime with lower autoregressive characteristics. Conversely, if the value of y_{t-2} is greater than the threshold 0.6311944, it is in the second regime with higher autoregressive characteristics.

The next stage is modeling with MSAR. In this study, a model with 2 states was used because this model adequately describes changes in inflation data. Thus the MSAR model used is MS(2)-AR(p). To apply the MS(2)-AR(p) model to the data, a value is first determined the AR order, it can be done by looking at the ACF and PACF plots.



(a) (b)

Figure 2 ACF Plot (a) and PACF Plot (b)

Plots of ACF and PACF in Figure 2 show that there is a cut off at the first lag so that the possible models used are AR(1), MA(1), and ARIMA(1). In the Markov Switching analysis the model used is only the AR(1) model, therefore it is called the Markov Switching Autoregressive model analysis. Then for the MSAR Model with 2 states can be written as follows MS(2)-AR(1).

On the basis of the initial identification, the model that can be used to model the transformed data is the MS(2)-AR(1) model. Parameter estimates of the MSAR model for transformed data using the Maximum Likelihood Estimation (MLE) method combined with filtering and smoothing are presented in Table 6.

Table 6 Parameter Estimation of MS(2)-AR(1) Model

Parameter	Estimated	*P-value*	AIC	MAPE
$\hat{\mu}_1$	0.3725	6.661e-16 ***	-832.6177	25.46%
$\hat{\mu}_2$	0.3728	0.0001234 ***		
$\hat{\phi}_1$	0.3825	7.778e-08 ***		
$\hat{\phi}_2$	0.4640	0.0002615 ***		
$\hat{p}_{11}$	0.94587323			
$\hat{p}_{21}$	0.05412677			

The parameter estimation results in Table 6 show that the MS(2)-AR(1) model parameters are significant because the coefficients of the model have a *p-value* < 0.05 so that the MS(2)AR(1) model can be written as follows.

State 1

$$(y_t - \mu_1) = 0.3825(y_{t-1} - \mu_1) + \varepsilon_t$$

State 2

$$(y_t - \mu_2) = 0.4640(y_{t-1} - \mu_2) + \varepsilon_t$$

with state value is:

$$\hat{\mu}_{s_t} = \begin{cases} \hat{\mu}_1 = 0.3725 \text{ for } s_t = 1 \text{ (increse)} \\ \hat{\mu}_2 = 0.3728 \text{ for } s_t = 2 \text{ (decrease)} \end{cases}$$

Parameter $\hat{\mu}_1 = 0.3725$ states the average inflation data in state 1, when inflation has increased. Parameter $\hat{\mu}_2 = 0.3728$ states the average inflation data in state 2, namely when inflation has decreased. Then $\hat{\phi}_1 = 0.3825$ is the autoregressive parameter in state 1 and $\hat{\phi}_2 = 0.4640$ is the autoregressive parameter in state 2.

Based on the parameter estimation of the MSAR model with the transition opportunity value $p_{11} = 0.94587323$ and $p_{21} = 0.05412677$, the value can be formed into the transition opportunity matrix of the MS(2)-AR(1) model as follows.

$$p = \begin{bmatrix} p_{11} & p_{12} \\ p_{21} & p_{22} \end{bmatrix} = \begin{bmatrix} 0.94587323 & 0.2096148 \\ 0.05412677 & 0.7903852 \end{bmatrix}$$

Looking at the transition probability matrix above, it is known that the transition probability of inflation from state 1 to state 1 or inflation remaining in state 1 is 0.94587323. In other words, once the condition is in state 1, then the tendency is that inflation will remain in this state. However, there is a chance of 0.2096148, where inflation will move to state 2. Likewise for the case of state 2, where the probability of inflation transitioning from state 2 to state 2 or inflation remaining in state 2 is 0.7903852. There is a chance of 0.05412677 where inflation will move from state 2 to state 1.

After analyzing the results of the Self-Exciting Threshold Autoregressive (SETAR) and Markov Switching Autoregressive (MSAR) models, the best model among the two models will be selected based on the criteria of the smallest AIC and MAPE values. The following is a comparison between the SETAR and MSAR models based on the smallest AIC and MAPE values presented in Table 7.

Table 7 Comparison Based on the Smallest AIC and MAPE Values

Model	AIC	MAPE
SETAR (1,2,1)	-1658	18.19%
MS(2)-AR(1)	-832.6177	25.46%

Comparison of the two models in Table 7 shows that the smallest AIC and MAPE values are found in the SETAR(1,2,1) model. This means that of the two models used, the SETAR model is the best model for modeling Indonesian Inflation data for the period January 1999 to December 2023 because it has the smallest AIC value of -1658 and MAPE of 18.19%. Next, a normality test will be performed on the model with the Kolmogorov-Smirnov test to determine whether the residuals of the SETAR(1,2,1) model are normally distributed or not. Normality test to test whether the data is distributed normally or not using the Kolmogorov-Smirnov test is presented in Table 8.

Table 8 Kolmogorov-Smirnov Test Result

Model	D_{count}	*P-value*
SETAR (1,2,1)	0.059059	0.2567

Kolmogorov-Smirnov results in Table 8, obtained a *p-value* > α, 0.2567 > 0.05, then accept H_0, so it can be concluded that the residuals of the SETAR(1,2,1) model are normally distributed. Furthermore, testing the white noise assumption is done using the Ljung-Box test to see the independence of the residuals in the SETAR(1,2,1) model. The Ljung-Box test results are presented in Table 9.

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Table 9 Ljung-Box Test Result

Model	χ^2	Df	*P-value*
SETAR (1,2,1)	0.093336	1	0.76

Ljung-Box results in Table 9, obtained a *p-value* > α, 0.76 > 0.05 means not rejecting H_0, it can be concluded that the residuals in the SETAR(1,2,1) model are white noise. Using the SETAR(1,2,1) model, Inflation data in Indonesia will be forecast for the next 12 months ahead, from January to December 2024. The results are presented in Table 10 and Figure 3.

Table 10 SETAR Model forecasting for inflation in Indonesia for the next 12 months

Month	Forecasting	Month	Forecasting
January	0.4693122	July	0.5008589
February	0.5079416	August	0.5282822
March	0.5328296	September	0.5458504
April	0.5487535	October	0.5129059
May	0.5124290	November	0.4963099
June	0.4952443	December	0.5010709

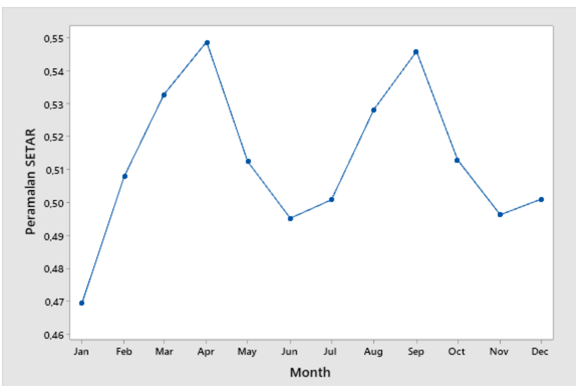

Figure 3 SETAR (1,2,1) Model forecasting for inflation in Indonesia for the next 12 months

Prediction results in Table 10 and Figure 3, it can be said that overall, this forecasting data shows an upward trend at the beginning of the year until April, then followed by a decline in the middle of the year. Then, the data again shows an upward trend from July to September, and finally shows slight fluctuations without a clear trend at the end of the year.

4. CONCLUSION

From the analysis of Inflation data in Indonesia from 1999 to 2023, it can be concluded that the SETAR model is superior to the MSAR model in terms of the balance between model fit with data and model complexity based on the smallest AIC value and MAPE. The SETAR(1,2,1) model with an AIC value of -1658 and MAPE of 18.19% is:

$$y_t^* = \begin{cases} 0.619420 + 0.340660_{t-1}{}^* - 0.321342_{t-2}{}^* + a_t & , y_{t-2}{}^* \leq 0.6311944 \\ 0.229186 + 0.632124_{t-1}^* + a_t & , y_{t-2}{}^* > 0.6311944 \end{cases}$$

The best SETAR (1,2,1) model states that inflation in Indonesia will decrease if the inflation rate is below the threshold of 0.6311944 and increase if it is above this threshold.

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