CAUCHY: Jurnal Matematika Murni dan Aplikasi
Volume 10(1) (2025), Pages 1-9
p-ISSN: 2086-0382; e-ISSN: 2477-3344

Local Polynomial Estimator in The Nonparametric Model of Inflation in Indonesia

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ABSTRACT

Inflation is a general and continuous increase in prices of goods and services over a certain period. Nonparametric regression analysis can be used to model inflation data that does not form a particular pattern. This study applies a local polynomial nonparametric method to model the rate of change rate in the inflation over a period considering two factors influencing inflation: the rate of change in the BI interest rate and the rate of change rate in the money supply from the previous period. The bivariate local polynomial method estimates the nonparametric regression function by considering the optimum Gaussian kernel bandwidth and polynomial order using the Taylor series expansion and WLS estimator. The optimal local polynomial nonparametric regression model was obtained based on a minimum GCV value of 0.015108 with two optimum Gaussian kernel bandwidth values of 0.1 and 0.03 in polynomial order of 1. The best model had a MAPE value of 3.45%, showing that all the prediction models were highly accurate. The benefits gained are additional information and consideration for determining monetary policy, especially inflation in Indonesia, by determining the BI interest rate and money supply.

Keywords: BI interest *rate*; inflation; local polynomial; money supply; nonparametric regression

INTRODUCTION

Inflation is a general and continuous increase in prices. The concepts of persistent price increases (sustained upward trend) and price increases occurring across all categories of products and services are important in this context (general price level movements). High and fluctuating inflation rates are indicators of economic instability, leading to a sustained increase in the cost of goods and services and a rise in poverty levels. High inflation rates make people unable to meet their daily needs, and high prices for goods and services increase poverty.

Some factors can influence the level of inflation. One factor influencing the inflation rate is the amount of money circulating in society. Other factors are interest rates and the dollar exchange rate. Previous research concluded that inflation can occur due to money

Submitted: June 13, 2024 Reviewed: July 12, 2024 Accepted: January 22, 2025
DOI: http://dx.doi.org/10.18860/ca.v10i1.27625

supply, BI interest rates, unemployment rates, and foreign exchange rates. Several factors, such as the foreign exchange rate, are important economic indicators as they significantly impact various aspects of the economy. The BI interest rate, known as the reference interest rate, reflects the monetary policy stance determined and announced by Bank Indonesia [1]. Lastly, the money supply is the multiplying base money by the multiplier result. The money supply benefits inflation because when it increases too much, prices will increase more than they should, ultimately hindering economic growth. Inflation factors, namely foreign exchange rate, BI interest rate, and money supply, have been put forward by several researchers: [2], [3], [4], [5], [6], [7], [8], [9], [10], [11]

Nonparametric regression is regression without using assumptions and rules like parametric regression. So, nonparametric regression is more flexible than parametric regression. Several researchers with various estimator methods have widely used nonparametric regression. One of the estimator methods used for nonparametric regression modelling is the local polynomial because the local polynomial estimator method is still rarely used in Indonesia to predict inflation levels. The local polynomial estimator depends on the fitted local polynomial order and a smoothing parameter called the optimum bandwidth. This method can increase variance and reduce bias if it is suitable for higher orders and smaller bandwidths bandwidths [12], [13], [14]. It also reduces the variance and increases the bias if the order is getting lower and the bandwidth is large. It could solve the pattern of inflation rate data with high fluctuations. The Gaussian Kernel is used as a weight because this function is considered smoother [15].

Local polynomial has several advantages, such as reducing asymptotic bias and producing good estimates. Local polynomial estimators can be utilised by minimising Weighted Least Squares (WLS). In local polynomial regression, the bandwidth determines how smooth the function is. The Generalized Cross-Validation (GCV) method can determine the optimal bandwidth, known from the minimum GCV value, as seen in the work [10].

Based on previous research described above, research has yet to be found that uses nonparametric regression on time series data, especially with local polynomial estimators and Gaussian kernel functions. Therefore, in this study, the author continues to use regression on time series data, namely the rate of change in inflation over a period as a response variable, with the predictor variables being the rate of change in the BI interest rate and the rate of change in the money supply from the previous period using a bivariate local polynomial estimator approach with a function Gaussian kernel.

METHODS

Data

Secondary data is used in this study, which is research data that researchers obtain indirectly from the media. This study uses the inflation data in Indonesia, the BI interest rate, and the amount of money in society circulation (money supply) from January 2013 to August 2024. The data used is divided into two variables: the rate of change in the inflation over a period as a response or dependent variable (Y) and the rate of change in the BI interest rate and the rate of change in the money supply from the previous period as the predictor or independent variables (X_1 and X_2).

Research Stages

1. Perform descriptive statistics on each data variable used to determine the characteristics of the data used.
2. Carry out the rescaling process using the min-max normalisation method, followed by creating a scatter plot to determine the distribution pattern of the research data.
3. Simulation of GCV combination of bandwidth and order to the training data.
4. Determine the optimum bandwidth value and polynomial order based on the minimum GCV value.
5. Carry out local polynomial nonparametric regression modelling based on optimum order and bandwidth using the Kerner Gaussian function.
6. Test the model's accuracy by calculating MAPE to the testing data.
7. Predict the inflation value in the next period using the best model.

Nonparametric Regression

Nonparametric type regression is used to estimate a model of the relationship between dependent variables or responses to predictor variables that are not tied to assumptions about certain curve shapes or function patterns. The general form of nonparametric regression is fundamental [16],

$$y_t = f\left(x_t\right) + \varepsilon_t,\ t = 1,2,\ldots,n \tag{1}$$

where:

y_t : response (dependent) variable on the t-th observation
$f(.)$: unknown smoothing function
x_t : predictor (independent) variable on the t-th observation
ε_t : regression error on the t-th observation

Weighted Least Square Estimator

In the Ordinary Least Square (OLS) method, errors are assumed to be identical or homogeneous in the residual variance. The Weighted Least Square (WLS) method can be used when the OLS assumption of constant variance in error is not met or is called heteroscedasticity. Suppose the parametric regression,

$$y = X\beta + \varepsilon \tag{2}$$

and W is the variance-covariance matrix of the regression error, which is not constant (heteroscedasticity), then the form of the WLS estimator for Eq. (2) is [17],

$$\beta = \left(X^T W X\right)^{-1} X^T W y \tag{3}$$

Bivariate Gaussian Kernel Function

The bivariate Gaussian kernel function with two different bandwidth values is defined as [18]

$$K_{h_1,h_2}\left(x_1, x_2\right) = \prod_{j=1}^{2} \frac{1}{h_j\sqrt{2\pi}} \exp\left(-\frac{1}{2}\left(\frac{x_j}{h_j}\right)^2\right), -\infty < x_j < \infty,\ h_j > 0 \tag{4}$$

Bivariate Taylor Series

The approximation of the bivariate function value x_1 around a_1 and x_2 around a_2 using the bivariate Taylor series expansion with a p-order local polynomial is [19],

$$\begin{aligned} f(x_1,x_2) \approx\ & f(a_1,a_2)+\frac{\partial f(a_1,a_2)}{\partial x_1}(x_1-a_1)+\frac{\partial f(a_1,a_2)}{\partial x_2}(x_2-a_2) \\ & +\frac{1}{2!}\frac{\partial^2 f(a_1,a_2)}{\partial x_1^{\,2}}(x_1-a_1)^2+\frac{1}{2!}\frac{\partial^2 f(a_1,a_2)}{\partial x_2^{\,2}}(x_2-a_2)^2 \\ & +\frac{1}{2!}\frac{\partial^2 f(a_1,a_2)}{\partial x_1 \partial x_2}(x_1-a_1)(x_2-a_2) \\ & +\ldots \\ & +\frac{1}{p!}\frac{\partial^p f(a_1,a_2)}{\partial x_1^{\,p}}(x_1-a_1)^p+\frac{1}{p!}\frac{\partial^p f(a_1,a_2)}{\partial x_2^{\,p}}(x_2-a_2)^p \end{aligned} \quad (5)$$

Optimum Bandwidth Selection

Bandwidth is a smoothing parameter that controls the estimated curve's smoothness [20]. Selecting an appropriate bandwidth (smoothing parameter) is an important part of nonparametric regression. It is generally known that the main problem in kernel smoothing lies not in kernel selection but in bandwidth selection. If the bandwidth chosen is too small, it will produce estimates that are not smooth (under smooth); conversely, if the bandwidth chosen is too large, it will produce very smooth estimates (over smooth) that do not match the data distribution pattern. So, the optimal bandwidth value must be chosen to produce the best estimate. The aim of curve estimation is not only to obtain a smooth curve but also to have a manageable error rate. Based on this, choos*ing* the optimal bandwidth value is necessary to obtain a smooth curve with minimum error.

The choice of bandwidth value plays an important role in determining the best model in nonparametric regression. Optimisation techniques to select the optimum bandwidth value can be used by the GCV (Generalized Cross-Validation) methods [21],

$$GCV(h_1,h_2)=\frac{1}{n}\sum_{t=1}^{n}\left[\frac{y_t-\hat{y}_t}{1-tr\left(A_{h_1,h_2}\right)}\right]^2 \quad (6)$$

with

$$\hat{y}_t = f_{h_1,h_2}(x_{1t},x_{2t}) = A_{h_1,h_2}\, y_t \quad (7)$$

Accuracy of Nonparametric Models

A model can be called a good one in regression analysis if it can produce accurate data estimates. The measure of model goodness as an evaluation of the prediction model can use the Mean Absolute Percentage Error (MAPE) [22],

$$MAPE = \frac{1}{n}\sum_{t=1}^{n}\left|\frac{\hat{y}_t - y_t}{y_t}\right| \text{ x } 100\% \quad (8)$$

The level of model accuracy according to the MAPE values is categorised in Table 1.

Table 1. MAPE Value Interpretation

MAPE Value	Interpretation
< 10 %	High Accuracy
10 % – 20 %	Good Accuracy
20 % – 50 %	Enough Accuracy
> 50 %	No Accurate

RESULTS AND DISCUSSION

Correlation Analysis

The data pattern between the response variable and the predictor variables used can be identified based on the scatter plot results. This research produces a scatter plot that does not show a particular pattern, so the data used is very suitable for application with nonparametric regression. The following is presented regarding the scatter plot results between two predictor variables and a response variable:

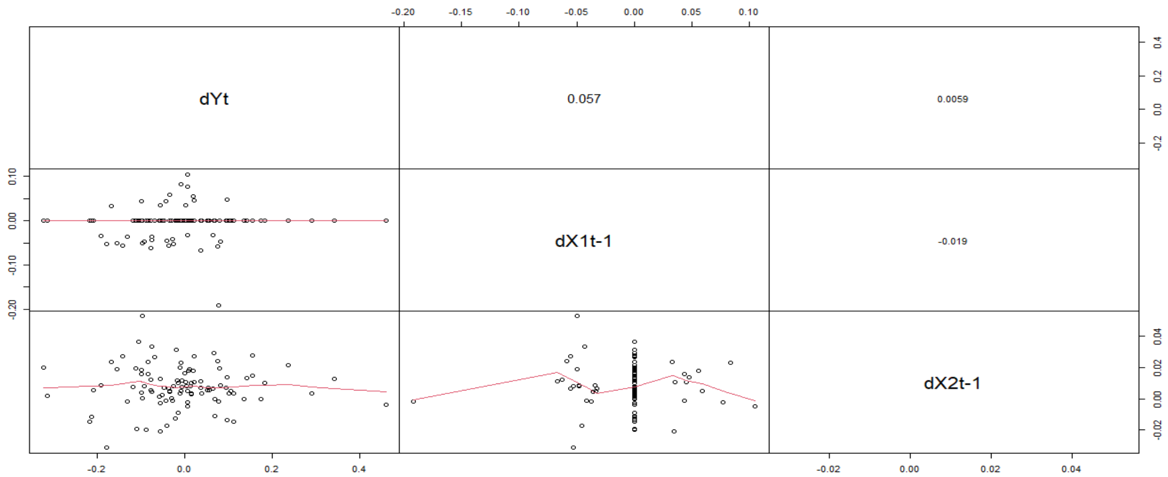

Figure 1. Data correlation scatter plot

Based on Figure 1, the distribution of the rate of change in inflation over a period (dYt) with the rate of change in the BI interest rate from the previous period ($dX1t$-1) and the rate of change in the money supply from the previous period ($dX2t$-1) on the graph does not form a trend or pattern with. It can be proven that the correlation coefficients between them are not significant. A kernel estimator must be used in the nonparametric regression function with the Gaussian Kernel approach to find the relationship between the predictor and response variables.

Estimation of Nonparametric Regression Model Using Local Polynomial

Estimation of a nonparametric regression model with two predictor variables using a local polynomial is an approximation of an unknown function value x_1 around a_1 and x_2 around a_2 using the bivariate Taylor series expansion. Substituting Eq.(5) to Eq.(1) yields,

$$\hat{y}_t = f(x_{1t}, x_{2t}) = \sum_{i=0}^{p}\sum_{j=0}^{p-i}\lambda_{ij}(x_{1t}-a_1)^i(x_{2t}-a_2)^j \tag{9}$$

The parameter value (λ_{ij}) depends on the point a_i and a_j called the local points. These parameters can be estimated using the WLS method with a kernel-weighted function that minimises the sum squared error (SSE) function,

$$S = \sum_{t=1}^{n}\left\{y_t - \sum_{i=0}^{p}\sum_{j=0}^{p-i}\lambda_{ij}(x_{1t}-a_1)^i(x_{2t}-a_2)^j\right\}^2 K_{h_1,h_2}(x_{1t}-a_1, x_{2t}-a_2) \tag{10}$$

or it can be simplified in matrix form to,

$$S = \left(Y - X\lambda\right)^T K\left(Y - X\lambda\right) \tag{11}$$

which can be solved using Eq. (3) as,

$$\lambda = \left(X^T K X\right)^{-1} X^T K Y \tag{12}$$

with K is a diagonal matrix of Eq.(4),

$$K_{h_1,h_2}\left(\left(x_{1t}-a_1\right),\left(x_{2t}-a_2\right)\right) = \frac{1}{h_1 h_2 2\pi}\exp\left(-\frac{1}{2}\left(\frac{x_{1t}-a_1}{h_1}\right)^2 - \frac{1}{2}\left(\frac{x_{2t}-a_2}{h_2}\right)^2\right) \tag{13}$$

Implementation of Nonparametric Regression Model Using Local Polynomial

Implementation of a nonparametric regression model using a local polynomial to the rate of change in the inflation over a period as response variable (Y) with the rate of change in the BI interest rate from the previous period as the first predictor variable (X_1) and the rate of change in the money supply over the previous period as the second predictor variable (X_2), with differing bandwidth value and order of local polynomial between the predictor variables. The simulation order of local polynomials 1, 2, and 3, with each simulation using bandwidth values in the interval of 0.01 to 0.1 for each predictor, yields the optimum bandwidth for each predictor variable, determined by the minimum GCV value using Eq.(6) obtained 0.015108, in the local polynomial order 1 with a bandwidth value of 0.1 for the first predictor and 0.03 for the second predictor. So, it yields the best model,

$$y_t = \lambda_0 + \lambda_1\left(x_{1t-1}-a_1\right) + \lambda_2\left(x_{2t-1}-a_2\right) + \varepsilon_t \tag{14}$$

for $\left|x_{1t-1}-a_1\right| < 0.1$ and $\left|x_{2t-1}-a_2\right| < 0.03$ with parameters estimator values using Eq.(12) for each local point as Figure 2.

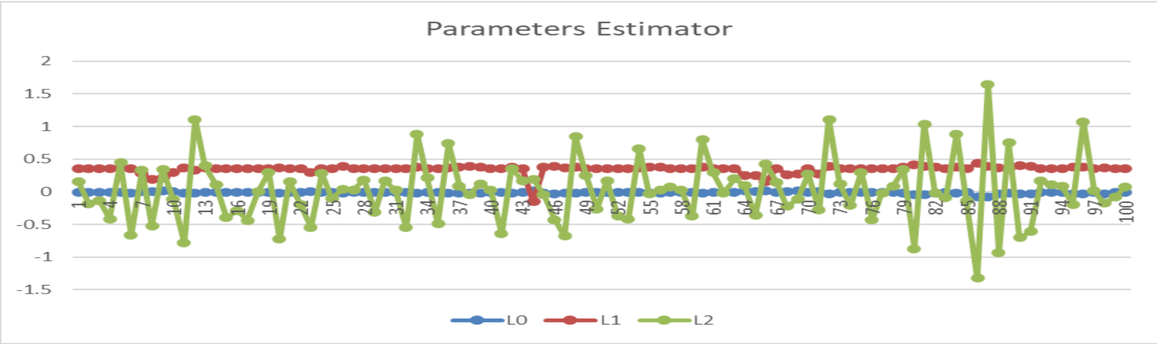

Figure 2. Parameters estimator values

The result of nonparametric regression on a local polynomial of order 1 to the training data (March 2013 to June 2021) with each data value as a local point is shown in Figure 3. The implementation result of the testing data (July 2021 to August 2024) is shown in Figure 4, with the MAPE value using Eq.(8) resulting in 3.45%, so it can be said that the model is highly accurate because it is less than 10%.

Figure 3. Nonparametric regression to training data

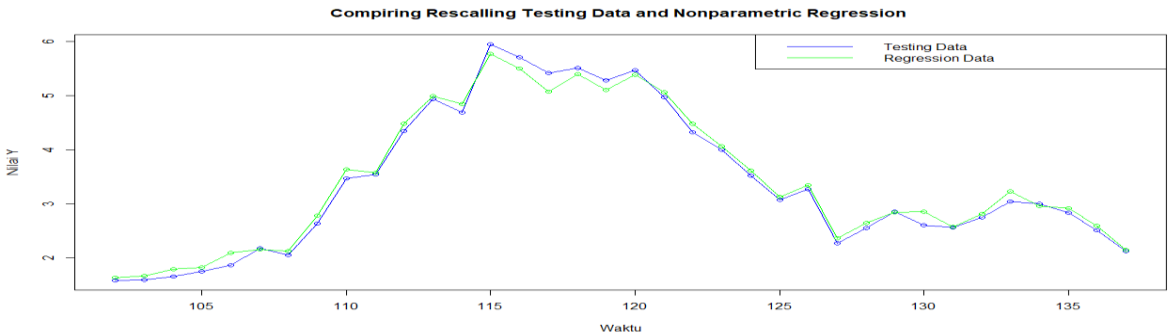

Figure 4. Nonparametric regression to testing data

CONCLUSIONS

It obtained two results based on the implementation result of the local polynomial nonparametric regression to the inflation model in Indonesia. The best model is on the local polynomial order of 1 with an optimum bandwidth value of 0.1 for the rate of change in the BI interest rate from the previous period and 0.03 for the rate of change in the money supply from the previous period with a minimum GCV value of 0.015108. The accuracy of the model is classified as high, as indicated by the MAPE value of 3.45%.

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