

# Application of Truncated Spline Nonparametric Regression to Modeling the Factors Affecting Economic Growth in South Sulawesi Province

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## Abstract:

Nonparametric regression is a statistical method that does not require a predetermined regression function and is therefore appropriate when the relationship between the response and predictor variables does not follow a specific pattern. One of the most widely used approaches is truncated spline regression, which models the relationship using segmented polynomials connected by knot points, allowing it to flexibly accommodate changes in data patterns. This study aims to model the factors affecting economic growth across regencies and municipalities in South Sulawesi Province in 2024 using truncated spline nonparametric regression. The predictor variables include the percentage of the poor population, the Open Unemployment Rate (OUR), the Labor Force Participation Rate (LFPR), and the Human Development Index (HDI). The best model was selected based on the Generalized Cross Validation (GCV) criterion. The results indicate that the optimal model was obtained with three knot points, yielding a minimum GCV value of 0.85 and a coefficient of determination ( $R^2$ ) of 94.32%. All four predictor variables were found to have a statistically significant effect on economic growth in South Sulawesi Province.

## 1. Introduction

Regression analysis is a statistical approach used to establish the mathematical relationship between predictor variables and a response variable, as well as to make predictions (Dani & Adrianingsih, 2021). There are three main approaches to regression analysis, namely parametric, semiparametric, and nonparametric regression (Widyastuti et al., 2021). Parametric regression es several assumptions, including normally distributed residuals and constant variance (Astiti et al., 2016). As an alternative, nonparametric regression offers greater flexibility because it does not require a specific functional form to model the relationship between variables (Rahayu & Wachidah, 2022).

In nonparametric regression, the regression function is assumed to be smooth and flexible, allowing it to adapt to and capture the underlying pattern of the data (Rositawati & Budiantara, 2019). One of the most effective methods when the functional relationship between variables is unknown is truncated spline regression (Matdoan et al., 2019). A truncated spline model represents the regression function as a segmented polynomial constructed using a set of knot points (Tanaty et al., 2023).

Truncated spline nonparametric regression can be applied to a wide range of real-world problems. One of the major issues faced by South Sulawesi Province is economic growth, which serves as a key indicator of development success and is closely associated with the welfare of the population (Erdkhadifa, 2022).

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South Sulawesi Province has recorded generally positive economic growth in recent years, reaching 5.02% in 2024. During the 2014–2019 period, economic growth remained relatively stable at a high level, reflecting the region's strong economic performance prior to the COVID-19 pandemic. However, in 2020, the economy experienced a sharp contraction of 0.71% due to the impact of the COVID-19 pandemic. Since 2021, the regional economy has gradually recovered, although the pace of recovery has remained vulnerable to both external and internal factors, including global market conditions and the adaptive capacity of key economic sectors during the post-pandemic period.

The recovery has not been evenly distributed across all regions. While several regions and municipalities have experienced stronger economic recovery, others continue to lag behind, indicating regional disparities that may hinder the equitable distribution of welfare. This condition highlights the need for an approach capable of identifying the dominant factors affecting each region, thereby enabling development policies to be formulated in a more targeted and sustainable manner.

Previous studies have shown that the open unemployment rate and the poverty rate are closely related and tend to reduce social welfare, both of which have a significant influence on economic growth (Erdkhadifa, 2022). The Human Development Index (HDI) serves as an indicator of human resource quality and also affects economic growth (Habriyanto et al., 2022). In addition, the Labor Force Participation Rate (LFPR) reflects labor force mobilization and contributes to economic growth (Yuniarti et al., 2020). Furthermore, (Matdoan et al., 2019) applied truncated spline nonparametric regression to analyze the factors influencing economic growth in Maluku Province and obtained a coefficient of determination ( $R^2$ ) of 0.94, indicating an excellent model fit.

These findings provide further evidence that truncated spline nonparametric regression is an effective approach for analyzing the factors influencing economic growth across different regions. However, studies employing truncated spline nonparametric regression to analyze the factors affecting economic growth in South Sulawesi Province remain limited. Therefore, this study was conducted to model the factors influencing economic growth in South Sulawesi Province using truncated spline nonparametric regression.

## 2. Literature Review

### 2.1. Truncated Spline Nonparametric Regression

Nonparametric regression is a regression method that is highly flexible and does not require a predetermined regression function. It also assumes that the underlying regression function is smooth. (Rositawati & Budiantara, 2019). In general, the nonparametric regression model can be expressed as shown in Equation (2.1) (Ramadhan et al., 2024).

$$y_i = f(x_i) + \varepsilon_i, \quad i = 1, 2, \dots, n \quad (2.1)$$

In general,  $f(x_i)$  represents a spline function of order  $p$  with knot points  $k_1, k_2, \dots, k_m$  and can be expressed as shown in Equation (2.2) (Muhgni et al., 2020).

$$f(x_i) = \sum_{j=0}^p \beta_j x_i^j + \sum_{k=1}^r \beta_{p+r}(x_i - K_r)_+^p \quad (2.2)$$

By substituting Equation (2.2) into Equation (2.1), the nonparametric spline regression model is obtained, as presented in Equation (2.3).

$$y_i = \sum_{j=0}^p \beta_j x_i^j + \sum_{k=1}^r \beta_{p+r}(x_i - K_r)_+^p + \varepsilon_i, \quad i = 1, 2, \dots, n \quad (2.3)$$

The function  $(x_i - K_r)_+^p$  is a truncated function that yields Equation (2.4).

$$(x_i - K_r)_+^p = \begin{cases} (x_i - K_r)^p, & x_i \geq K_r \\ 0, & x_i < K_r \end{cases} \quad (2.4)$$

## 2.2. Selection of the Optimal Knot Points

Knot points play an important role in spline functions, as they divide the regression curve into several segments (Astuti et al., 2016). One of the most commonly used methods for selecting the optimal knot points is Generalized Cross Validation (GCV), which possesses asymptotic optimality. The GCV criterion can be expressed as shown in Equation (2.5) (Sholika et al., 2018).

$$GCV = \frac{MSE(K)}{[n^{-1}trace(\mathbf{I} - \mathbf{A})]^2} \quad (2.5)$$

## 2.3. Significance Testing Parameter Model

The overall parameter significance test is conducted to determine whether all predictor variables collectively have a significant effect on the response variable (Wardani & Ratna, 2022). The hypotheses used in this test are as follows.

$$H_0 : \beta_1 = \beta_2 = \dots = \beta_{p+r} = 0$$

$$H_1 : \text{there is at least one } \beta_j \neq 0; j = 1, 2, \dots, p + r$$

The test statistic used is presented in Equation (2.6).

$$F = \frac{MSR}{MSE} = \frac{SSR/df \text{ regression}}{SSE/df \text{ error}} \quad (2.6)$$

Reject  $H_0$  if  $F \geq F_{\alpha; (p+r, n-(p+r)-1)}$  or  $p\text{-value} < \alpha$ .

Furthermore, the partial significance test is conducted to evaluate the significance of each predictor variable individually. This test is performed using the t-test (Wardani & Ratna, 2022). The hypotheses are stated as follows:

$$H_0 : \beta_1 = \beta_2 = \dots = \beta_{p+r} = 0$$

$$H_1 : \text{there is at least one } \beta_j \neq 0, j = 1, 2, \dots, p + r$$

The test statistics used in the t-test are presented as follows.

$$t = \frac{\hat{\beta}_j}{se(\hat{\beta}_j)} \quad (2.7)$$

Reject  $H_0$  if  $t > t_{\frac{\alpha}{2}, (n-(p+r)-1)}$  or  $p\text{-value} < \alpha$ .

## 2.4. Residual Assumption Testing

The assumption test is conducted to verify that the residual variance is homogeneous. The homoscedasticity assumption is assessed using the Glejser test based on residual analysis (Pramesti et al., 2019). The hypotheses used in this test are as follows.

$$H_0 : \sigma_1^2 = \sigma_2^2 = \dots = \sigma_n^2 = \sigma^2$$

$$H_1 : \text{there is at least one } \sigma_i^2 \neq \sigma^2, i = 1, 2, \dots, n$$

The test statistic is given as follows (Alwi et al., 2021).

$$F = \frac{\sum_{i=1}^n (|\hat{e}_i| - |\bar{e}|)^2 / (k-1)}{\sum_{i=1}^n (|e_i| - \hat{e}_i)^2 / (n-k)} \quad (2.8)$$

Reject  $H_0$  if  $F > F_{\alpha; (k-1, n-k)}$  or  $p\text{-value} < \alpha$ .

Furthermore, the independence test, also known as the autocorrelation test, is performed to verify the regression model assumption that the residuals are uncorrelated. Autocorrelation can be detected using the Durbin–Watson test. The hypotheses used in this test are as follows.

$H_0 : \rho = \dots = 0$  (independent residuals)

$H_1 : \rho \neq 0$  (dependent residuals)

The test statistic is given as follows (Ramadhan et al., 2024).

$$d = \frac{\sum_{t=2}^n (\varepsilon_t - \varepsilon_{t-1})^2}{\sum_{t=2}^n \varepsilon_t^2} \quad (2.9)$$

Reject  $H_0$  if  $d \leq d_{L, \alpha, n}$ .

Furthermore, the normality assumption test is conducted to determine whether the residuals are normally distributed (Fajriyyah & Budiantara, 2015). The Shapiro–Wilk test can be used to assess the normality of the residuals, as it is considered more reliable than other normality testing methods. The hypotheses used in this test are as follows.

$H_0$  : normally distributed residuals

$H_1$  : residuals are not normally distributed

The test statistic is given as follows (Sintia et al., 2022).

$$T_3 \frac{1}{D} \left[ \sum_i^k a_i (X_{n-i+1} - X_i) \right]^2 \quad i = 1, 2, 3, \dots, n \quad (2.10)$$

Where,

$$D = \sum_{i=1}^n (X_i - \bar{X})^2; i = 1, 2, 3, \dots, n \quad (2.11)$$

Reject  $H_0$  if  $p\text{-value} < \alpha$ .

### 2.5. Economic growth

Economic growth is defined as a continuous process of increasing output or production within an economy, as reflected by the growth in national income over a given period (Indayani & Hartono, 2020). One of the key indicators of the success of national or regional development is the economic growth rate, which is measured at the national level by changes in Gross Domestic Product (GDP) from year to year (Yuniarti et al., 2020)

## 3. Research methods

The data used in this study are secondary data obtained from the 2024 publication of Statistics Indonesia (BPS) of South Sulawesi Province. The study sample consists of 24 regencies and municipalities in South Sulawesi Province. The dataset comprises one response variable and four predictor variables. The response variable ( $Y$ ) is the economic growth

rate of each regency and municipality, while the predictor variables include the percentage of the poor population ( $X_1$ ), the Open Unemployment Rate (OUR) ( $X_2$ ), the Labor Force Participation Rate (LFPR) ( $X_3$ ), and the Human Development Index (HDI) ( $X_4$ ).

The data analysis process began with data preparation, descriptive statistical analysis, and the construction of scatter plots. Subsequently, truncated spline nonparametric regression models with one, two, and three knot points were fitted. The best model was selected based on the minimum Generalized Cross Validation (GCV) criterion. Parameter significance tests and residual assumption tests, including homoscedasticity, independence, and normality (HIN), were then conducted. The final stage of the study involved interpreting the selected model and drawing conclusions.

## 4. Results and Discussion

### 4.1. Descriptive Analysis

Table 4.1 presents the descriptive statistics of economic growth and the factors hypothesized to influence it.

**Table 1** Descriptive Statistics

| Variable | Standard Deviation | Minimum | Maximum | Mean  |
|----------|--------------------|---------|---------|-------|
| $y$      | 0.72               | 3.27    | 6.03    | 4.67  |
| $x_1$    | 2.31               | 4.97    | 12.41   | 8.66  |
| $x_2$    | 1.97               | 1.51    | 9.71    | 3.71  |
| $x_3$    | 5.16               | 59.32   | 78.39   | 6,22  |
| $x_4$    | 3.55               | 69.45   | 85.23   | 74.49 |

Based on Table 1, the standard deviation of each study variable is smaller than its corresponding mean, indicating that the data are concentrated around their respective mean values and that the variation among regencies and municipalities in South Sulawesi Province is relatively low.

### 4.2. Relationship Between Economic Growth and the Predictor Variables

The scatter plots showing the relationships between economic growth and each of the predictor variables are presented below.

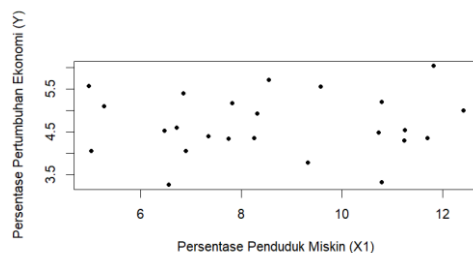


**Figure 1** Scatter Plot of the Response Variable  $y$  and  $x_1$

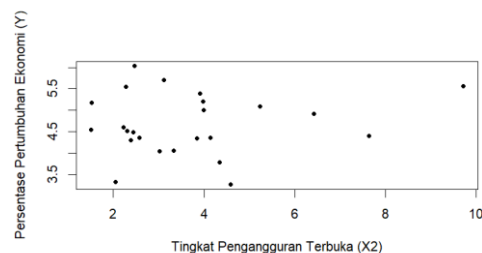
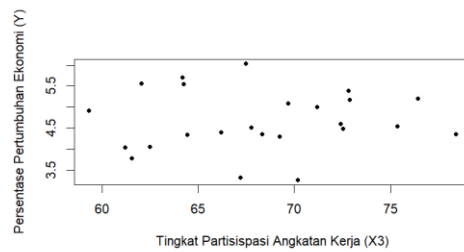
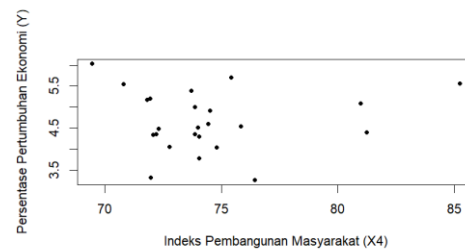


**Figure 2** Scatter Plot of the Response Variable  $y$  and  $x_2$

**Figure 3** Scatter Plot of the Response Variable  $y$  and  $x_3$ **Figure 4** Scatterplot of the Response Variable  $y$  and  $x_1$ 

Based on Figures 1–4, the scatter plots of economic growth against each of the predictor variables do not exhibit any distinct functional pattern. Therefore, truncated spline nonparametric regression is considered an appropriate approach for modeling the relationship between the response variable and its predictor variables, as it can accommodate complex relationships without requiring a predetermined functional form.

### 4.3. Truncated Spline Nonparametric Regression Modeling

#### 4.3.1 Modeling with One Knot Point

The optimal knot point was selected on the minimum GCV value for the truncated spline nonparametric regression model using one knot point is as follows.

$$\hat{y} = \beta_0 + \beta_1 x_1 + \beta_2 (x_1 - k_1)_+ + \beta_3 x_2 + \beta_4 (x_2 - k_2)_+ + \beta_5 x_3 + \beta_6 (x_3 - k_3)_+ + \beta_7 x_4 + \beta_8 (x_4 - k_4)_+ + \varepsilon$$

#### 4.3.2. Modeling with Two Knot Points

The optimal knot point for the truncated spline nonparametric regression model with two knots was selected based on the minimum Generalized Cross Validation (GCV) criterion, as presented below.

$$\hat{y} = \beta_0 + \beta_1 x_1 + \beta_2 (x_1 - k_1)_+ + \beta_3 (x_1 - k_2)_+ + \beta_4 x_2 + \beta_5 (x_2 - k_3)_+ + \beta_6 (x_2 - k_4)_+ + \beta_7 x_3 + \beta_8 (x_3 - k_5)_+ + \beta_9 (x_3 - k_6)_+ + \beta_{10} x_4 + \beta_{11} (x_4 - k_7)_+ + \beta_{12} (x_4 - k_8)_+ + \varepsilon$$

#### 4.3.3. Modeling with Three Knot Points

The optimal knot points for the truncated spline nonparametric regression model with three knots were selected based on the minimum Generalized Cross Validation (GCV) criterion, as presented below.

$$\hat{y} = \beta_0 + \beta_1 x_1 + \beta_2 (x_1 - k_1)_+ + \beta_3 (x_1 - k_2)_+ + \beta_4 (x_1 - k_3)_+ + \beta_5 x_2 + \beta_6 (x_2 - k_4)_+ + \beta_7 (x_2 - k_5)_+ + \beta_8 (x_2 - k_6)_+ + \beta_9 x_3 + \beta_{10} (x_3 - k_7)_+ + \beta_{11} (x_3 - k_8)_+ + \beta_{12} (x_3 - k_9)_+ + \beta_{13} x_4 + \beta_{14} (x_4 - k_{10})_+ + \beta_{15} (x_4 - k_{11})_+ + \beta_{16} (x_4 - k_{12})_+ + \varepsilon$$

### 4.4. Selection of the Optimal Knot Points

**Table 2** Minimum GCV Values for Each Model

| Number of Knot Points | GCV |
|-----------------------|-----|
|-----------------------|-----|

|              |             |
|--------------|-------------|
| One          | 1.27        |
| Two          | 1.90        |
| <b>Three</b> | <b>0.85</b> |

Table 2 shows that the smallest GCV value was obtained by the nonparametric spline regression model with three knot points. Therefore, it can be concluded that the truncated spline nonparametric regression model with three knot points is the optimal model.

#### 4.5. Model Parameter Testing

##### 4.5.1. Simultaneous Significance Test

**Table 3** Results of the Simultaneous Significance Test

| Source of Variation | Df | $R^2$ | F-Statistic | $p$ -value |
|---------------------|----|-------|-------------|------------|
| Regression          | 16 | 0.94  | 7.27        | 0.006      |

Based on the results of the simultaneous significance test presented in Table 3, the  $p - value < \alpha$ , indicating that at least one predictor variable has a statistically significant effect on the model.

##### 4.5.2. Partial Significance Test

**Table 4** Results of the Partial Significance Test

| Variable | Parameter    | Coefficient | $t$ -Statistic | $p$ -Value | Decision        |
|----------|--------------|-------------|----------------|------------|-----------------|
| $X_1$    | $\beta_0$    | -5.612      | 7.552          | 0.0001     | Significant     |
|          | $\beta_1$    | -0.460      | -7.346         | 0.0001     | Significant     |
|          | $\beta_2$    | 0.010       | 7.853          | 0.0001     | Significant     |
|          | $\beta_3$    | 0.075       | -1.693         | 0.134      | Not Significant |
| $X_2$    | $\beta_4$    | 0.047       | 4.160          | 0.004      | Significant     |
|          | $\beta_5$    | 2.999       | -3.872         | 0.006      | Significant     |
|          | $\beta_6$    | -2.521      | 3.680          | 0.007      | Significant     |
|          | $\beta_7$    | -0.008      | 4.857          | 0.001      | Significant     |
| $X_3$    | $\beta_8$    | -0.374      | -4.284         | 0.003      | Significant     |
|          | $\beta_9$    | 0.457       | 0.940          | 0.378      | Not Significant |
|          | $\beta_{10}$ | -0.055      | 4.502          | 0.002      | Significant     |
|          | $\beta_{11}$ | 0.092       | -3.992         | 0.005      | Significant     |
| $X_4$    | $\beta_{12}$ | -0.167      | 3.024          | 0.019      | Significant     |
|          | $\beta_{13}$ | 0.002       | 4.580          | 0.002      | Significant     |
|          | $\beta_{14}$ | -0.053      | -2.317         | 0.053      | Not Significant |
|          | $\beta_{15}$ | -0.38       | -2.250         | 0.059      | Not Significant |
|          | $\beta_{16}$ | 0.002       | -7.088         | 0.0001     | Significant     |

Table 4 presents the parameter estimates obtained using the Ordinary Least Squares (OLS) method for the truncated spline nonparametric regression model with three knot points. Based on the results of the partial significance test, 13 parameters were found to have a statistically significant effect, as each parameter had a  $p - value < \alpha$ . Meanwhile, the remaining four parameters did not have a statistically significant effect because their  $P - value > \alpha$ .

#### 4.6. Residual Assumption Testing

##### 4.6.1. Homoscedasticity Assumption

**Table 5** Glejser Test Results

| Source of Variation | df | F     | p-value |
|---------------------|----|-------|---------|
| Regression          | 16 | 3.180 | 0.063   |

Table 5 shows that the  $p\text{-value} > \alpha$ , indicating that the residuals satisfy the homoscedasticity assumption.

#### 4.6.2. Independence Assumption

**Table 6** Durbin-Watson Test Results

| DW      | $d_{L:0.05}$ | $d_{U:0.05}$ |
|---------|--------------|--------------|
| 1.77089 | 0.9249       | 1.9018       |

Based on the results presented in Table 6, the calculated  $DW > d_{L:0.05}$ , indicating that the residuals satisfy the independence assumption.

#### 4.6.3. Normality Assumption

**Table 7** Kolmogorov-Smirnov Test Results

| p - value | $\alpha$ |
|-----------|----------|
| 0.923     | 0.05     |

Based on Table 7, the  $p\text{-value} > \alpha$ , indicating that the residuals satisfy the normality assumption.

#### 4.7. Coefficient of Determination

Based on Table 3, the coefficient of determination obtained from the truncated spline nonparametric regression model is 0.94, or 94%. This value indicates that the predictor variables collectively explain 94% of the variation in economic growth in South Sulawesi in 2024, while the remaining 6% is explained by other variables not included in the model.

#### 4.8. Interpretation of the Truncated Spline Nonparametric Regression Model.

The truncated spline nonparametric regression model constructed using the optimal knot configuration, consisting of three knot points, is presented in the following equation.

$$\hat{y} = \beta_0 + \beta_1 x_1 + \beta_2 (x_1 - k_1)_+ + \beta_3 (x_1 - k_2)_+ + \beta_4 (x_1 - k_3)_+ + \beta_5 x_2 + \beta_6 (x_2 - k_4)_+ + \beta_7 (x_2 - k_5)_+ \\ + \beta_8 (x_2 - k_6)_+ + \beta_9 x_3 + \beta_{10} (x_3 - k_7)_+ + \beta_{11} (x_3 - k_8)_+ + \beta_{11} (x_3 - k_8)_+ + \beta_{12} (x_3 - k_9)_+ \\ + \beta_{13} x_4 + \beta_{14} (x_4 - k_{10})_+ + \beta_{15} (x_4 - k_{11})_+ + \beta_{16} (x_4 - k_{12})_+ + \varepsilon$$

The following presents the interpretation of each variable that has a statistically significant effect on economic growth.

1. Assuming that the other variables, namely  $x_2$ ,  $x_3$ , and  $x_4$  remain constant, the effect of the percentage of the poor population ( $x_1$ ) on economic growth is as follows.

$$\hat{y} = -0,4605x_1 + 0,0106(x_1 - 6,26)_+ + 0,0758(x_1 - 6,42)_+ + 0,0474(x_1 - 8,69)_+.$$

$$= \begin{cases} -0,4605x_1 & ; x_1 \leq 6,26 \\ -0,4499x_1 - 0,066356 & ; 6,26 \leq x_1 \leq 6,42 \\ -0,3741x_1 - 0,552992 & ; 6,42 \leq x_1 \leq 8,69 \\ -0,3267x_1 - 0,964898 & ; x_1 \geq 8,69 \end{cases}$$

Based on the estimated truncated spline nonparametric regression model, an increase in the percentage of the poor population generally tends to reduce the economic growth rate across all intervals. Although the magnitude of the effect varies among the intervals, the direction of the relationship remains consistently negative. This finding indicates that increasing poverty is a persistent factor hindering economic growth across the regencies and municipalities of South Sulawesi Province. These results are consistent

with the findings of Erdkhadifa (2022), who reported that an increase in the poverty rate has a negative effect on economic growth at the regency and municipal levels.

- Assuming that the other variables, namely  $x_1$ ,  $x_3$ , and  $x_4$  remain constant, the effect of the percentage of the open unemployment rate ( $x_2$ ) on economic growth is as follows.

$$\hat{y} = 2,9996x_2 - 2,5218(x_2 - 2,93)_+ - 0,0084(x_2 - 3,11)_+ - 0,3742(x_2 - 5,61)_+ \\ = \begin{cases} 2,9996x_2 ; x_2 < 2,93 \\ 0,4778x_2 + 7,38874 ; 2,93 < x_2 < 3,11 \\ 0,4694x_2 + 7,414998 ; 3,11 < x_2 < 5,61 \\ 0,0952x_2 + 9,51426 ; x_2 > 5,61 \end{cases}$$

Based on the estimated truncated spline nonparametric regression model, an increase in the Open Unemployment Rate (OUR) generally tends to increase the economic growth rate across all intervals. Although the magnitude of the effect varies among the intervals, the direction of the relationship remains consistently positive. This finding is consistent with the study by Sere and Tchereni (2020), which reported that the open unemployment rate may have a positive effect on economic growth. This condition suggests the presence of a jobless growth phenomenon, in which economic growth is not necessarily accompanied by increased employment opportunities due to structural changes in production systems and the adoption of new technologies (Martus, 2016).

- Assuming that the other variables, namely  $x_1$ ,  $x_2$ , dan  $x_4$  remain constant, the effect of the percentage of the labor force participation rate ( $x_3$ ) on economic growth is as follows.

$$\hat{y} = 0,4574x_3 - 0,0557(x_3 - 62,63)_+ + 0,0920(x_3 - 63,05)_+ - 0,1672(x_3 - 68,85)_+ \\ = \begin{cases} 0,4574x_3 ; x_3 < 62,63 \\ 0,4017 + 3,48891 ; 62,63 < x_3 < 63,05 \\ 0,4937x_3 - 2,312109 ; 63,05 < x_3 < 68,85 \\ 0,3265x_3 + 9,199611 ; x_3 > 68,85 \end{cases}$$

Based on the estimated truncated spline nonparametric regression model, an increase in the Labor Force Participation Rate (LFPR) generally tends to increase the economic growth rate across all intervals. Although the magnitude of the effect varies among the intervals, the direction of the relationship remains consistently positive. This finding indicates that a higher labor force participation rate is associated with a greater tendency for economic growth in the regencies and municipalities of South Sulawesi Province. These findings are consistent with those reported by Yuniarti et al., (2020), who found that the labor force participation rate has a positive and significant effect on economic growth. An increase in the labor force participation rate reflects a larger proportion of the working-age population participating in economic activities, thereby enhancing production capacity and promoting economic growth.

- Assuming that the other variables, namely  $x_1$ ,  $x_2$ , and  $x_3$  remain constant, the effect of the percentage of the Human Development Index ( $x_4$ ) on economic growth is as follows.

$$\hat{y} = 0,0026x_4 - 0,0534(x_4 - 72,19)_+ - 0,0384(x_4 - 72,53)_+ + 0,0022 (x_4 - 77,34)_+ \\ = \begin{cases} 0,0026x_4 ; x_4 < 72,19 \\ -0,0508x_4 + 3,854946 ; 72,19 < x_4 < 72,53 \\ -0,0892x_4 + 6,640098 ; 72,53 < x_4 < 77,34 \\ 0,087x_4 + 6,46995 ; x_4 > 77,34 \end{cases}$$

Based on the estimated truncated spline nonparametric regression model, the effect of the Human Development Index (HDI) on the economic growth rate generally exhibits a nonlinear pattern. An increase in the HDI tends to promote economic growth in the first and fourth intervals, whereas in the second and third intervals, higher HDI values are associated with a decline in economic growth. This finding indicates that the effect of the HDI on economic growth varies across intervals and is therefore not constant. These results are consistent with the findings of Erdkhadifa (2022), who reported that the HDI may have a negative effect on economic growth under certain conditions. This phenomenon suggests that improvements in human capital quality do not necessarily translate directly into higher economic growth

unless they are accompanied by the development of productive sectors and the regional economy's capacity to absorb an increasingly skilled workforce (Sabardin et al., 2025).

## 5. Conclusion

1. The best truncated spline nonparametric regression model for economic growth in South Sulawesi in 2024 was obtained using three knot points, with a minimum GCV value of 0.85 and a coefficient of determination of 94.32%. The resulting truncated spline nonparametric regression model is as follows.

$$\hat{y} = -5,6129 - 0,4605x_1 + 0,0106(x_1 - 6,26)_+ + 0,0758(x_1 - 6,42)_+ + 0,0474(x_1 - 8,69)_+ + 2,9996x_2 - 2,5218(x_2 - 2,93)_+ - 0,0084(x_2 - 3,11)_+ - 0,3742(x_2 - 5,61)_+ + 0,4574x_3 - 0,0557(x_3 - 62,63)_+ + 0,0920(x_3 - 63,05)_+ - 0,1672(x_3 - 68,85)_+ + 0,0026x_4 - 0,0534(x_4 - 72,19)_+ - 0,0384(x_4 - 72,53)_+ + 0,0022(x_4 - 77,34)_+$$

2. The factors that significantly affected economic growth in South Sulawesi Province in 2024 were the Percentage of the Poor Population ( $x_1$ ), the Open Unemployment Rate (OUR) ( $x_2$ ), the Labor Force Participation Rate ( $x_3$ ), and the Human Development Index (HDI) ( $x_4$ ).

## References

- Alwi, W., Irwan, Muh., & Musfirah. (2021). Penerapan Regresi Nonparametrik Spline Dalam Memodelkan Faktor-Faktor Yang Mempengaruhi Indeks Pembangunan Manusia (IPM) di Indonesia Tahun 2018. In *Jurnal Matematika dan Statistika serta Aplikasinya* (Vol. 9, Number 2). <https://doi.org/10.24252/msa.v9i2.23055>
- Astiti, D. A. W., Sumarjaya, I. W., & Susilawati, M. (2016). *Analisis Regresi Nonparametrik Spline Multivariat untuk Pemodelan Indikator Kemiskinan Di Indonesia*. 5(3), 111–116. <https://doi.org/10.24843/MTK.2016.v05.i03.p129>
- Dani, A. T. R., & Adrianingsih, N. Y. (2021). Pemodelan Regresi Nonparametrik dengan Estimator Spline Truncated vs Deret Fourier. *Jambura Journal of Mathematics*, 3(1), 26–36. <https://doi.org/10.34312/jjom.v3i1.7713>
- Erdkhadifa, R. (2022). Faktor-Faktor Yang Mempengaruhi Pertumbuhan Ekonomi Di Jawa Timur Dengan Pendekatan Spatial Regression. 11(2), 122–140. <https://doi.org/10.46367/iqtishaduna.v11i2.729>
- Fajriyyah, N., & Budiantara, I. N. (2015). *Pemodelan Indeks Pembangunan Gender dengan Pendekatan Regresi Nonparametrik Spline di Indonesia*. <https://doi.org/10.12962/j23373520.v4i2.10753>
- Habriyanto, Prasaja, A. S., & Rukanti, D. (2022). Faktor-Faktor yang Mempengaruhi Pertumbuhan Ekonomi di Kabupaten Batang Hari. 2(2). <https://doi.org/10.55606/jupumi.v2i2.720>
- Indayani, S., & Hartono, B. (2020). Analisis Pengangguran dan Pertumbuhan Ekonomi sebagai Akibat Pandemi Covid-19. 18(2). <https://doi.org/10.31294/jp.v17i2>
- Martus, B. S. (2016). *Jobless Growth: the Impact of Structural Changes*. 61, 244–264.
- Matdoan, M. Y., Balami, A. M., & Talakua, M. W. (2019). *Pemodelan Regresi Nonparametrik Spline Truncated Pada Faktor-Faktor yang Mempengaruhi Pertumbuhan Ekonomi di Provinsi Maluku*. 1(1). <https://doi.org/10.30598/variancevolliss1page27-37>
- Muhgni, M., Fadly, F., Adnan, A., & Harison. (2020). Pemodelan Tingkat Pengangguran Terbuka di Pulau Sumatera Dengan Menggunakan Regresi Nonparametrik Spline. *Jurnal Sains Matematika dan Statistika*, 6(1). <https://doi.org/10.24014/jsms.v6i1.9255>
- Pramesti, R. G., Ratna, M., & Budiantara, I. N. (2019). *Pemodelan Faktor-Faktor yang Mempengaruhi Angka Prevalensi Kusta di Jawa Timur dengan Menggunakan Regresi Nonparametrik Spline Truncated*. <https://doi.org/10.12962/j23373520.v8i2.44876>
- Rahayu, N. F., & Wachidah, L. (2022). Regresi Nonparametrik Spline untuk Memodelkan Faktor-faktor yang Memengaruhi Indeks Pembangunan Gender (IPG) di Jawa Barat Tahun 2020. *Bandung Conference Series: Statistics*, 2(2), 273–281. <https://doi.org/10.29313/bcss.v2i2.4037>
- Ramadhan, R., Imailyana, & Desiani, A. (2024). *Penerapan Regresi Nonparametrik Spline Truncated Dalam Memodelkan Hubungan Faktor-Faktor Yang Mempengaruhi Indeks Pembangunan Gender (IPG) di Provinsi Sumatera Utara*. 10(1).

- Rositawati, A. F. D., & Budiantara, I. N. (2019). *Pemodelan Indeks Kebahagiaan Provinsi di Indonesia Menggunakan Regresi Nonparametrik Spline Truncated*. <https://doi.org/10.12962/j23373520.v8i2.45160>
- Sabardin, Shabur, U., Hidayat, R., & Dly, M. W. A. (2025). The Impact of Human Development Index and Population Number on Economic Growth in South Sumatra Province 2018-2022. *Jurnal Ilmu Ekonomi Terapan*, 10(1), 1–10. <https://doi.org/10.20473/jiet.v10i1.54828>
- Sere, K. A., & Tchereni, B. H. M. (2020). *Nonlinear Modelling of Economic Growth and Unemployment in South Africa*. 16(6).
- Sholica, C. N., Budiantara, I. N., & Ratna, M. (2018). *Regresi Nonparametrik Spline Truncated untuk Memodelkan Persentase Unmet Need di Kabupaten Gresik*. 7(2). <https://doi.org/10.12962/j23373520.v7i2.35259>
- Sintia, I., Pasarella, M. D., & Nohe, D. A. (2022). *Perbandingan Tingkat Konsistensi Uji Distribusi Normalitas pada Kasus Tingkat Pengangguran di Jawa*.
- Tanaty, R. E., Darnah, & Sifriyani. (2023). *Regresi Nonparametrik Spline Truncated untuk Memodelkan Tingkat Pengangguran Terbuka di Pulau Kalimantan*. 7(2). <https://doi.org/10.21009/JSA.07211>
- Wardani, P. K., & Ratna, M. (2022). *Pemodelan Terhadap Faktor-Faktor yang Mempengaruhi Pertumbuhan Ekonomi di Nusa Tenggara Timur Menggunakan Pendekatan Regresi Nonparametrik Spline*. <https://doi.org/10.12962/j23373520.v11i3.77735>
- Widyastuti, D. A., Fernandes, A. A. R., & Pramoedyo, H. (2021). Spline estimation method in nonparametric regression using truncated spline approach. *Journal of Physics: Conference Series*, 1872(1). <https://doi.org/10.1088/1742-6596/1872/1/012027>
- Yuniarti, Wianti, W., & Nurgaheni, N. E. (2020). *Analisis Faktor-faktor yang Mempengaruhi Tingkat Pertumbuhan Ekonomi di Indonesia*. 2(3), 169–176. <https://doi.org/10.36407/serambi.v2i3.207>