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Nonparametric Fourier Series Regression for Unemployment Analysis in Banten Province

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Abstract- The Open Unemployment Rate (OUR) is a vital indicator of regional economic performance, particularly in Banten Province, which faces disparities in education and poverty. This study models the unemployment rate using two predictors: average years of schooling and poverty level, through a nonparametric Fourier series regression for the 2017–2024 period. This method provides greater flexibility in capturing the nonlinear and fluctuating patterns often observed in socio-economic data. The analysis used secondary data from Statistics Indonesia (BPS), beginning with descriptive statistics and data visualization. Models were evaluated using Generalized Cross-Validation (GCV) and the coefficient of determination (R^2). The optimal model was found at K = 3, with a GCV of 2.4057 and an R^2 of 0.5155. The model effectively captured the non-linear relationships between unemployment, education, and poverty. Although the R^2 value is moderate, this indicates that including additional explanatory variables could enhance the model's performance. These findings support the use of Fourier series regression as an alternative approach for labor market analysis, especially when linear methods fall short and provide insights for developing more targeted employment policies.

1. Introduction

Unemployment remains one of the foremost challenges in the economic development of a region. The Open Unemployment Rate (OUR) is a critical indicator for assessing the economy's ability to absorb its labor force (World Bank, n.d.). A high OUR reflects an imbalance between job availability and the labor supply, which may in turn disrupt social stability, reduce productivity, and exacerbate poverty and inequality (Arifin & Soesatyo, 2020).

Banten Province, located in the western part of Java and directly adjacent to Jakarta, is one of Indonesia's strategic regions within the Jabodetabek metropolitan area. It experiences a relatively high rate of urbanization and industrial growth. Despite favorable macroeconomic indicators, employment-related challenges remain substantial. Several cities in Banten, such as Cilegon and Tangerang, consistently report high unemployment rates (Masruri, 2022). This situation indicates that economic growth has not been entirely equitable or inclusive, making the OUR a crucial issue that requires further investigation.
One factor presumed to influence unemployment is the level of education, represented in this study by the average years of schooling. According to human capital theory, higher levels of education improve individual skills and productivity, thereby increasing employment opportunities. However, in practice, higher education does not always lead to lower unemployment. The phenomenon of overeducation, in which educational qualifications exceed job requirements, may prolong job search duration (Friska & Damayanti, 2021). Additionally, other studies have found that graduates of vocational high schools (SMK) tend to have a lower risk of unemployment than those from general education backgrounds (Yoana et al., 2024), highlighting the importance of aligning educational pathways with labor market demands.

Apart from education, poverty is another key variable in understanding unemployment dynamics. Individuals living in poverty often have limited access to quality education and job training. Higher poverty levels can reduce the chances of entering the formal labor market, thus reinforcing cycles of unemployment and social inequality (Syahza, 2012). Therefore, it is essential to analyze the simultaneous influence of education and poverty on OUR, particularly in regions like Banten.
According to data from Statistics Indonesia (BPS) from 2017 to 2024, the average years of schooling in Banten ranged from 6.20 to 11.86 years, with a mean of 8.865 years. The OUR ranged from 4.67 percent to 13.06 percent, with an average of 8.505 percent. Poverty levels varied widely, from 13.20 to 867.23, with a mean value of 168.50. These figures show inconsistent trends in the relationship between educational attainment and poverty relative to OUR, calling for a more flexible analytical approach that does not rely solely on linear assumptions.

In this regard, nonparametric regression offers greater flexibility than traditional parametric methods, as it does not assume a predetermined functional form of the relationship between the independent and dependent variables. It enables estimation of unknown and complex patterns in socio-economic data (Octavia et al., 2024). One type of nonparametric regression is the Fourier series regression, which uses sine and cosine functions to approximate cyclical or fluctuating patterns in the data (Salim et al., 2022). This method is particularly useful for modeling unemployment, education, and poverty indicators that often display nonlinear and irregular patterns over time. As demonstrated by Utami and Nur (2017), Fourier regression has been effectively applied to model fluctuating water level data, illustrating its strength in handling cyclical patterns.

A previous study conducted by Adrianingsih et al. (2020) modeled the OUR in East Nusa Tenggara Province using Fourier series regression. By employing predictors such as the number of people in poverty, the gross regional domestic product growth rate, and the higher education participation rate, the study found that the optimal model had an oscillation order of $K = 3$, resulting in an R-squared value of 84.08 percent. Prahutama (2013) also applied nonparametric Fourier regression to model the OUR in East Java using Sakernas data with various economic and social factors, and the results indicated that the best model was obtained at $K = 1$ with an R-squared of 96.76 percent, confirming that Fourier regression is effective for cyclical data while still yielding a parsimonious model. Furthermore, Salim et al. (2022) applied Fourier regression to model OUR in South Sulawesi and achieved an R-squared of 80.13 percent with three oscillation points. While the model demonstrated relatively strong predictive accuracy, none of the predictor variables were statistically significant, likely due to high parameter variance and the presence of outliers. Collectively, these studies reinforce the potential of Fourier series regression in capturing complex non-linear socio-economic patterns and highlight its adaptability across regions in Indonesia.

While previous studies have applied Fourier series regression to model unemployment in several provinces of Indonesia, such as East Nusa Tenggara, East Java, and South Sulawesi, its application to provincial-level unemployment data in Banten remains limited. This study contributes by offering a nonparametric modeling alternative that flexibly captures complex and fluctuating socio-economic relationships.

This study aims to model the Open Unemployment Rate (OUR) in Banten Province, based on average years of schooling and the number of people living in poverty, during the 2017 to 2024 period, using the Fourier series regression method. It is expected that this model will better represent the non-linear relationships among these variables and provide useful insights for public policy aimed at reducing unemployment and enhancing social welfare in the province.

2. Methods

The method used in this study is nonparametric regression using the Fourier series estimator.

(a) Data and Variables

This study uses secondary data from the Central Statistics Agency (BPS) of Banten Province. This data includes the Open Unemployment Rate, Average Length of Schooling, and Number of Poor People in Banten Province from 2017 to 2024. The variables analyzed further in this study are attached in Table 1 (BPS Banten, 2024a; BPS Banten, 2024b; & BPS Banten, 2024c):

Table 1. Research Variable

Variable	Definition	Unit
Y	Open Unemployment Rate	Percentage
X_1	Number of People Living in Poverty	Thousand people
X_2	Average Years of Schooling	Years

(b) The Steps of Analysis

This study employs a nonparametric regression approach using the Fourier series estimator to model the relationship between the Open Unemployment Rate (OUR) and two predictor variables, namely Number of People Living in Poverty (NPP) and Average Years of Schooling (AYS) in Banten Province. The data analysis was conducted using R software. The following outlines the analytical steps carried out in this study:

1. Initial Data Exploration

The initial stage of the analysis involved descriptive statistical exploration and data visualization. Descriptive statistics were used to obtain a general overview of each variable, including minimum and maximum values, mean, and data distribution. Visualization in the form of boxplots was employed to detect data distribution, the presence of outliers, and the tendency toward symmetry or skewness of each variable (Alhempi et al., 2024). This step is essential as a basis for understanding the data's characteristics before proceeding to the modeling stage.

2. Examination of the Relationship Patterns Between Variables

After understanding the basic characteristics of each variable through descriptive statistics and boxplot visualization, the next step was to evaluate the relationship patterns between the response variable and the predictor variables. This evaluation was carried out by constructing scatter plots between the Open Unemployment Rate (OUR) as the response variable and Average Years of Schooling (AYS) and the Number of People Living in Poverty (NPP) as predictor variables.

This visualization aimed to identify the initial form of the relationship between the variables. If the observed pattern indicated a linear relationship, a parametric regression approach could be considered. However, if the relationship did not follow a straight-line pattern or exhibited fluctuating, complex tendencies, a nonparametric regression approach would be more appropriate (Salshabila, 2023).

The use of scatter plots at this stage is exploratory and serves as a crucial part of the initial model diagnostics. It assists researchers in selecting a modeling approach that aligns with the data's characteristics and helps avoid imposing models with unmet assumptions.

3. Nonparametric Fourier Series Regression

Based on the evaluation of the relationship patterns between variables through scatter plots, if the relationship between the response and predictor variables does not exhibit a consistent linear pattern, the use of parametric regression becomes unreliable. Therefore, a nonparametric regression approach is applied, which does not require any specific functional form between the independent and response variables (Anandari, 2023).

Several estimators can be used in nonparametric regression, including spline, kernel, Fourier series, and wavelet. One of the estimators employed in this study is the Fourier series regression. This estimator uses a combination of sine and cosine functions to construct the regression curve, which can capture fluctuating, cyclic, or nonlinear relationships. This approach is particularly suitable for socio-economic data, which often do not meet the classical assumptions of parametric regression (Adrianingsih et al., 2020).

Budiantara et al. (2019) successfully applied a mixed kernel–Fourier nonparametric regression to model poverty rates in Indonesia, achieving an R^2 of approximately 0.63, which highlights the estimator's capacity to handle complex socio-economic data patterns.

Fourier regression has been successfully applied in various economic contexts. For example, Mardianto et al. (2025) utilized Fourier series to forecast inflation in Indonesia, demonstrating its effectiveness in modeling periodic patterns in economic data.

The general model of nonparametric Fourier series regression is expressed in Equation 1.

$$y_i = \delta(x_i) + \varepsilon_i \tag{1}$$

Where:
y_i : Response variable
x_i : Predictor variable
ε_i : Random error

$\delta(x_i)$ is the regression curve function based on the Fourier series, where x_i denotes the independent variable. The Fourier regression function used in this study includes the full trigonometric components (sine and cosine) and is expressed in Equation 2.

$$\delta(x_i) = a_0 + \sum_{k=1}^{K} [a_k \cos(kx_i) + b_k \sin(kx_i)] \tag{2}$$

Where:
a_0 : Model constant
a_k and b_k : Regression coefficients for the cosine and sine components, respectively
K : Number of oscillations used in the model

In the context of Fourier regression, selecting an appropriate number of oscillations K is essential to avoid underfitting (when K is too small) and overfitting (when K is too large).

4. Model Selection Using GCV and R^2

The choice of the appropriate number of oscillations greatly influences the selection of the optimal Fourier series estimator. One method used to determine the optimal oscillation is Generalized Cross-Validation (GCV). In a comparative study, Mardianto et al. (2022) showed that Fourier series regression outperformed spline regression in modeling the distribution of social aid in Indonesia, with lower GCV and better fit, supporting the estimator's flexibility and accuracy. An appropriate choice of oscillation generally results in a higher coefficient of determination (R^2). The GCV value is calculated using the following formula in Equation 3.

$$GCV(K_{opt}) = \frac{n^{-1}\sum_{i=1}^{n}(y_i - \hat{y}_i)^2}{(n^{-1}trace[\boldsymbol{I} - [\boldsymbol{A}(K)])^2} \tag{3}$$

math.ppj.unp.ac.id Rangkiang Mathematics Journal Vol 5, No. 1, 2026

$$= \frac{n^{-1}[\vec{Y}^T(\boldsymbol{I} - [\boldsymbol{A}(K)]))^T(\boldsymbol{I} - [\boldsymbol{A}(K))\vec{Y}]}{(n^{-1}trace[\boldsymbol{I} - [\boldsymbol{A}(K)])^2}$$

Additionally, model selection can be supported by examining the coefficient of determination, calculated as in Equation 4.

$$R^2 = 1 - \frac{\sum_{i=1}^{n}(y_i - \hat{y}_i)^2}{\sum_{i=1}^{n}(y_i - \bar{y}_i)^2} \quad (4)$$

Thus, the best Fourier series regression model is obtained by selecting the number of oscillations that minimizes the GCV value and maximizes the coefficient of determination (Adrianingsih et al., 2020).

5. Visualization and Interpretation of Model Results

The best model is used to predict the Open Unemployment Rate based on the Average Years of Schooling and the Number of People Living in Poverty. The predicted values are subsequently compared with the actual data through visual plots. This visualization is useful for assessing how well the model captures the actual pattern in the data and for evaluating the model's ability to represent the dynamics of the Open Unemployment Rate in Banten Province.

3. Results and Discussion

(a) Initial Data Exploration

To gain an initial understanding of the distributions of the variables used in this study, Figure 1 presents boxplots of the Open Unemployment Rate, Average Years of Schooling, and the Number of People Living in Poverty in Banten Province. These visualizations are useful for detecting outliers, assessing data spread, and examining the central tendency of the analyzed data.

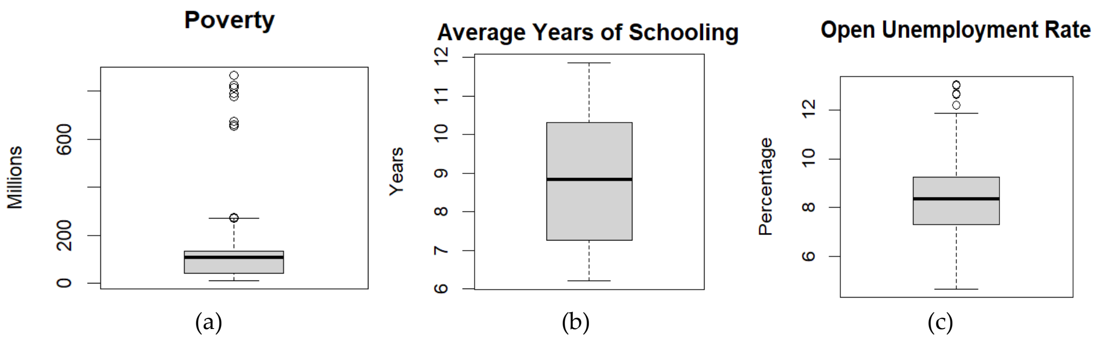


Figure 1. Boxplot of Open Unemployment Rate(a), Boxplot of Average Years of Schooling(b), Boxplot of Number of People Living in Poverty (c).

Figure 1 presents boxplots of the three main variables in this study, namely the Open Unemployment Rate (OUR), Average Years of Schooling (AYS), and the Number of People Living in Poverty (NPP) in Banten Province during the 2017–2024 period. The distribution of the Open Unemployment Rate appears relatively symmetrical, with the median positioned at the center. However, several outliers are present at the upper end, indicating that some regions have significantly higher unemployment rates than others.

For the Average Years of Schooling variable, the distribution is generally even and symmetric, with the median slightly above the box's center line. This suggests a left-skewed distribution, indicating that most regions fall within the upper-middle range in terms of average schooling years.

In contrast, the distribution of the Number of People Living in Poverty exhibits pronounced disparity. The boxplot reveals numerous extreme outliers at the upper end, while most data points are concentrated within a narrow range at the lower end. This indicates that the majority of regions have relatively low poverty levels, but a few areas experience very high levels of poverty, resulting in a highly right-skewed distribution. This finding aligns with Wiguna et al. (2023), who found that poverty and unemployment in Indonesia are heavily concentrated in specific regions, leading to spatial inequality that affects labor market dynamics.

The figure above demonstrates variations in distribution and the presence of outliers across several variables, particularly in the number of poor people. To further explore the quantitative characteristics of these data, Table 2 presents the minimum, maximum, and mean values for each variable.

Table 2. Descriptive Statistics on Research Variables

Variable Name	Notation	Minimum	Maximum	Mean
Open Unemployment Rate	Y	4.670	13.06	8.505
Number of People Living in Poverty	X_1	13.20	867.23	168.50
Average Years of Schooling	X_2	6.200	11.86	8.865

Table 2 shows substantial variations across cities and regencies in Banten Province in socio-economic conditions. The Open Unemployment Rate ranges from 4.67% to 13.06%, indicating disparities in labor market absorption. The Average Years of Schooling ranges from 6.20 to 11.86 years, reflecting inequalities in access to education. Meanwhile, the Number of People Living in Poverty varies significantly, ranging from 13.20 to 867.23 thousand, suggesting considerable disparities in regional welfare levels.

(b) Examination of the Relationship Pattern Between Variables

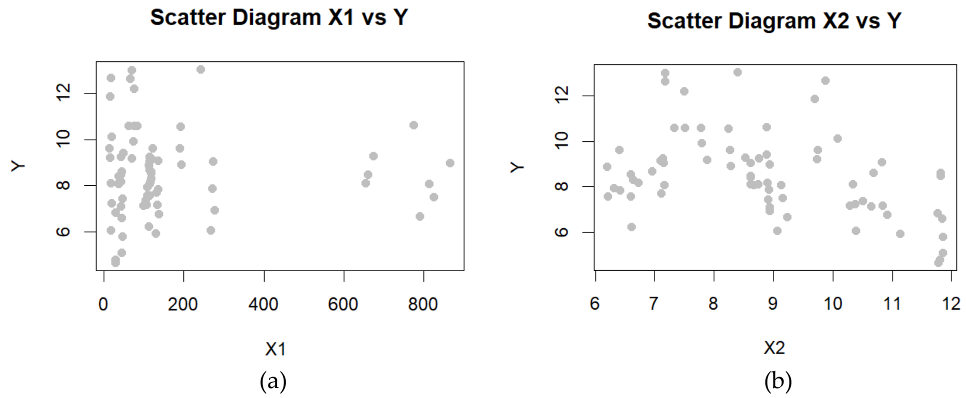


Figure 2. Scatter plot between NPP and OUR (a), Scatter plot between AYS and OUR (b)

Figure 2 shows that the relationship between the Open Unemployment Rate and each predictor variable does not exhibit a visually clear linear pattern. The data distribution appears scattered and fluctuating. This irregular pattern indicates that parametric regression is not appropriate, and a nonparametric regression approach is better suited to capture the more complex relationships.

(c) Fourier Series Regression Modeling

After exploring the relationship between variables through scatter plots, the next step was to construct a nonparametric regression model using the Fourier series estimator. The modeling process began with determining the number of oscillations (K) to be tested. In Fourier regression, oscillations represent the complexity of the trigonometric functions (sine and cosine) used to capture data patterns.

To maintain a balance between model accuracy and simplicity (parsimony), the number of oscillations tested ranged from K = 1 to K = 3. This range was deemed sufficient to avoid overfitting while maintaining model stability, given the moderate sample size. Once the Fourier basis functions were defined, model parameters, such as sine and cosine coefficients, were estimated using the Least Squares method. This technique aims to minimize the sum of squared differences between observed and predicted values.

math.ppj.unp.ac.id Rangkiang Mathematics Journal Vol 5, No. 1, 2026

Model selection was based on two main criteria: Generalized Cross Validation (GCV) as an indicator of prediction error, and the coefficient of determination. R^2 As a measure of the proportion of variance explained by the model, the ideal model has the lowest GCV. R^2 values. Table 3 presents the performance of the Fourier regression model across different oscillation levels.

Table 3. GCV and R² Values for Different K

Oscillation (K)	GCV	R^2
K=1	2.8788	0.2524
K=2	2.4873	0.4289
K=3	2.4057	0.5155

Based on the results in Table 3, the best model was obtained with K = 3 oscillations, yielding the lowest GCV of 2.4057 and the highest R^2 of 0.5155. This combination indicates that the model with three oscillations provides the best balance between prediction accuracy and the ability to explain data variation. The R^2 value of 0.5155 indicates that approximately 51.55% of the variation in OUR is explained by the two predictor variables in the model. While this value is moderate, it indicates that the model captures part of the relationship, though other factors not included in the model may also influence OUR.

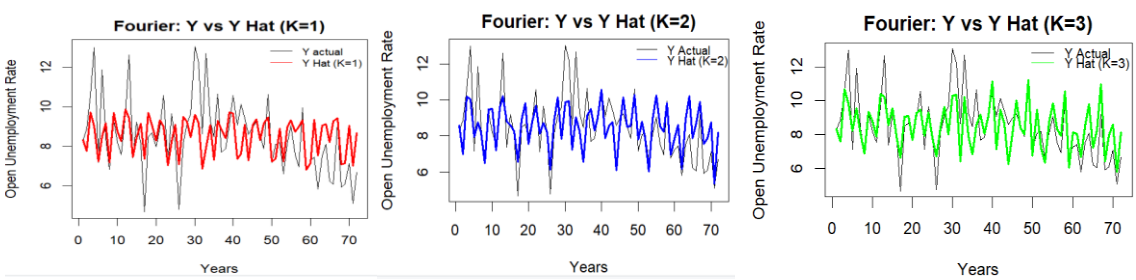
Therefore, the model with three oscillations was selected as the optimal model in this study. The Fourier model was constructed additively for the two predictor variables, with each approximated using trigonometric functions up to the third oscillation order. The general form of the Fourier series regression model with three oscillations and two predictor variables is as follows:

$$\begin{aligned}\hat{y} = \; & 8.4273 - 0.4194\cos(x_1) + 0.2493\ \sin(x_i) + 0.3214\cos(2x_i) + 0.1668\sin(2x_i) + 0.2019\cos(3x_i) \\ & - 0.1687\sin(3x_i) - 0.6468\cos(x_2) + 0.9625\ \sin(x_2) + 1.7138\cos(2x_2) \\ & + 0.1378\sin(2x_2) - 0.3032\cos(3x_2) - 0.7694\sin(3x_2)\end{aligned}$$

(d) Model Interpretation and Visualization

The model results show that the Number of People Living in Poverty has a significant influence on variations in the Open Unemployment Rate in a nonlinear pattern. Increased education, as measured by Average Years of Schooling, tends to reduce OUR, but its effect is weaker and not always consistent. The inclusion of the third-order oscillation component indicates that the relationships among variables are complex and vary across regions or over time.

The model with three oscillations was then used to predict OUR based on the two predictor variables. Figure 3 presents the visual comparison between actual values and model predictions, illustrating how closely the model fits the observed data.



(a) (b) (c)

Figure 3. Actual vs predicted Open Unemployment Rate using Fourier series (a) K = 1, (b) K = 2, (c) K = 3

In this section, the authors describe data or models derived from the study's results. Describe the data that has been obtained clearly and concisely, which can be in the form of formulas, tables, pictures, or diagrams. Furthermore, the discussion must not be separate from the results. The discussion reviews the theory's results, both relevant to and contradictory to the study's results.

4. Discussion: Comparison with Previous Studies

(a) In the study by Lidyanti & Hanifa (2022), the open unemployment rate was found to have a significant negative effect on economic growth in Sidoarjo Regency, where a 1% increase in unemployment reduced economic growth by 1.128%. This finding illustrates that high unemployment can hinder productivity and reduce public purchasing power, thereby slowing economic performance. This result aligns with the findings of the present study, which also emphasizes the role of unemployment as a key determinant influencing socio-economic disparities in Banten Province.

(b) Pradipta & Dewi (2020) found that open unemployment had a significant positive effect on poverty levels in Banten Province, reinforcing the view that rising unemployment increases the likelihood of poverty. This aligns with the current study's findings, which emphasize unemployment as a critical socio-economic indicator and support its relevance in regional policy formulation.

(c) Azzahra et al. (2022) found that the open unemployment rate had no significant effect on poverty levels in Banten during the COVID-19 pandemic. This supports the current study's view that the relationship between unemployment and socio-economic indicators is complex and nonlinear. Thus, the use of Fourier series regression is justified to capture such fluctuating patterns better.

(d) In the study conducted by Ardian et al. (2022), it was revealed that economic growth does not have a statistically significant effect on the open unemployment rate (OUR) in Indonesia. Although the regression coefficient indicated a negative relationship, the t-test results showed a p-value above the 0.05 significance level, suggesting that increases in economic growth do not necessarily lead to a reduction in unemployment. This finding aligns with the present study, which also emphasizes the complexity of the relationship between unemployment and other macroeconomic variables, such as education and poverty. The inability of linear models to fully capture these nonlinear and fluctuating patterns further supports the application of nonparametric approaches, such as the Fourier series regression. This method offers a more flexible framework for modeling the open unemployment rate, accounting for cyclical and irregular variations often present in socio-economic data.

(e) Adrianingsih et al. (2020) applied Fourier series regression to model open unemployment in East Nusa Tenggara and achieved a high R^2 of 84.08% using three oscillations. Their study confirms the strength of Fourier regression in capturing repeated patterns and irregular trends in unemployment data. In comparison, the present study also utilized Fourier regression with three oscillations, yielding an R^2 of 51.55%. Although the predictive power is lower, this result reinforces the applicability of the Fourier method for modeling unemployment rates across different regional contexts.

(f) Salim et al. (2022) applied nonparametric Fourier regression to model open unemployment in South Sulawesi, achieving a high R^2 of 80.13% with three oscillation points. While the model demonstrated strong predictive accuracy (MAPE = 18%), none of the predictor variables were statistically significant, likely due to high parameter variance and data outliers. In contrast, the present study applied the same Fourier approach to unemployment data in Banten Province and obtained a lower R^2 of 51.55%, but with more interpretable results and a smoother fit, suggesting that Fourier regression performs best with continuous, well-behaved data and careful variable selection.

(g) Dani et al. (2022) conducted both simulation and application studies using the Fourier series estimator and demonstrated its high flexibility in capturing repeated and irregular patterns. In their application to average years of schooling data in East Nusa Tenggara, the optimal model with four oscillations achieved an R^2 of 89.18% and the lowest GCV of 0.27. These results further support the robustness of the Fourier estimator in nonparametric regression, particularly when the predictor-response relationship lacks a clear functional form. This aligns with the present study, which also effectively applied Fourier regression to model the open unemployment rate.

(h) The study by Wisisono et al. (2018) showed that Fourier series regression provided a better fit than the ARIMA model in capturing the fluctuating pattern of river discharge data. With a higher explanatory power (R^2 = 72.95%) and lower prediction error, this method proved more effective for data with repeating or wave-like trends. These results reinforce the relevance of using the Fourier approach in the present study to model complex and dynamic behaviors, such as open unemployment rates.

(i) Utami & Nur (2017) applied Fourier series nonparametric regression to model high water level (HWL) data in Semarang, achieving an R^2 of 94% with optimal smoothing at K = 276. Their study confirmed that Fourier regression is highly effective in capturing cyclic and fluctuating data patterns. This supports the present study's use of the same method for modeling open unemployment, which also exhibits irregular and periodic trends.

(j) Fitri et al. (2025) compared Fourier series regression with elastic net regression to model the Total Fertility Rate (TFR) in Indonesia. Fourier regression performed better, achieving an R^2 of 97.91% compared to 85.88% from elastic net regression. This not only underscores the superior flexibility of the Fourier method but also confirms its effectiveness in modeling socio-economic indicators influenced by complex, nonlinear interactions—similar to those observed in the present study.

5. Conclusion

This study aimed to model the Open Unemployment Rate (OUR) in Banten Province for the period 2017–2024 using a nonparametric Fourier series regression approach, with two main predictor variables: Average Years of Schooling and the Number of People Living in Poverty. Based on the analysis, the best model was obtained after three oscillations (K = 3), with a Generalized Cross-Validation (GCV) value of 2.4057 and a coefficient of determination (R^2) of 0.5155.

The model moderately captures the nonlinear relationship between OUR and the two predictor variables. The moderate R^2 value indicates that the model explains more than half of the variation in the data, although a portion remains unaccounted for. This suggests that while the Fourier series regression model can capture fluctuations in socio-economic data, other influential factors are not included in the current model.

Therefore, Fourier series regression has proven to be a relevant and effective approach for analyzing regional labor market dynamics, particularly when the data do not exhibit clear linear relationships. For future research, it is recommended to use panel data across districts/cities and to include additional variables, such as informal-sector structure, labor migration, and regional investment levels, to enhance model accuracy. This study's novelty lies in applying Fourier series regression to model regional unemployment using education and poverty indicators, a method rarely used in analyses of Indonesian provincial data. The use of GCV for model selection further enhances the robustness of the approach.

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