Comparison Modeling of the Number Population who have been Vaccinated in East Java using the Biresponse Fourier Series Estimator Method with the Trend Function

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Comparison Modeling of the Number Population who have been Vaccinated in East Java using the Biresponse Fourier Series Estimator Method with the Trend Function

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Keywords

Vaksinasi, Covid-19, Deret Fourier, GCV, MSE, Koefisien Determinasi

ABSTRACT

Vaksinasi adalah proses pemberian vaksin pada tubuh manusia yang bertujuan meningkatkan kekebalan tubuh secara aktif terhadap suatu penyakit agar tidak menjadi sumber penularan penyakit tersebut. Vaksinasi massal merupakan sebuah keharusan yang harus dipenuhi untuk menanggulangi permasalahan pandemi Covid-19 yang melanda seluruh dunia, termasuk Indonesia. Pada tahun 2021 pelaksanaan vaksinasi Covid-19 di Jawa timur hanya mencapai 50% dari total sasaran yang divaksin. Kekebalan imunitas tercapai ketika 70% penduduk telah divaksin. Sementara ini pelaksanaan program vaksinasi pemerintah sudah mencapai pada vaksin dosis kedua. Berdasarkan uraian tersebut peneliti bertujuan untuk membandingkan pemodelan jumlah penduduk yang telah divaksin dosis pertama dan kedua menggunakan metode deret Fourier Birespon dengan Fungsi Tren. Kriteria kebaikan model yang digunakan adalah nilai GCV dan MSE terkecil, serta nilai koefisien determinasi tertinggi. Model yang diperoleh dalam penelitian ini adalah model dengan basis sinus cosinus. Model tersebut mempunyai nilai GCV dan MSE lebih kecil dibandingkan nilai GCV dan MSE pada basis cosinus dan sinus. Koefisien determinasi model tersebut menunjukkan nilai yang besar.

Vaccination, Covid-19, Fourier Series, GCV, MSE, Coefficient of Determination.

Vaccination is a process carried out by the human body that aims to increase the body's active immunity against a disease so that people who are vaccinated will not get sick. The Covid-19 outbreak hit the whole world, including Indonesia. Currently, the implementation of the Covid-19 vaccination in East Java has only reached 50% of the total target being vaccinated. The requirement to achieve immunity must be that 70% of the population has been vaccinated. Based on this description, the researcher aims to compare the modeling of the population that has been vaccinated with the first and second doses using the Fourier series bi-response method with a trend function.

The criteria for the goodness of the model in this study used small GCV and MSE values and a high coefficient of determination. The model has smaller GCV and MSE values than the cosine and sine basis. The coefficient of determination of the model shows a large value.

INTRODUCTION

At the end of 2020, Indonesia was faced with quite disturbing health cases. People are worried about a disease caused by Corona Virus Disease (Covid-19). The Covid-19 pandemic is expected to continue to cause a very large burden of morbidity and mortality (Astuti, Nugroho, Lattu, Potempu, & Swandana, 2021). This disease has a very fast and widespread transmission intensity, attacks a person's respiratory system, and has claimed many lives (Novita & Ramadhani, 2021). Countries around the world are now very aggressively implementing various policies due to the Covid-19 pandemic. The Indonesian government has even declared this virus a non-natural disaster Covid-19 (Pujaningsih & Sucitawathi, 2020)

One of the government's real efforts in preventing and controlling Covid-19 is by administering vaccines to health workers (Dahlan, 2021). President Joko Widodo on 5 October 2020 formally launched the Republic of Indonesia Presidential Regulation (Perpres) Number 99 of 2020 concerning the Procurement of Vaccines and Implementation of Vaccinations in the Context of Mitigating the Covid-19 Pandemic to control the authority of the government, ministries/agencies, and officials in planning vaccination activities (Rachman & Pramana, 2020).

Mass vaccination is a must that must be fulfilled to overcome the problem of the Covid-19 outbreak which has hit the whole world, including Indonesia (Putri, et al., 2021). In 2021 the implementation of the Covid-19 vaccination in Indonesia has only reached 20% of the total target vaccinated. To achieve immunity with the condition that up to 70% of the population has been vaccinated (Yanuarti, 2021).

Vaccination is carried out in three stages. Following the first stage, the second stage is completed, and the third stage follows the second stage. In other words, the number vaccinated in the first stage will affect the number vaccinated in the second stage. This will affect the achievement targeted by the government. The achievement of three stages of vaccination in several cities, only the city of Jakarta has been realized while the city of East Java has not been realized because the second dose has not reached the target. Details of vaccination achievements in East Java as of 21 October 2021 were 40.94% for the first dose, and 21.61% for the second dose. This figure is still far from the figure set by the government, namely 70% of people have been vaccinated as of 17 October 2021 (Jatim Tanggap Covid-19, 2021)

Knowledge about predicting future vaccination outcomes is expected to assist the government in making policies related to handling Covid-19. Based on this, it is necessary to carry out an empirical study related to the prediction of the number of people vaccinated in the first and second stages. One method that can be used to predict two responses at once is nonparametric regression with the Fourier Series Biresponse estimator. Non-parametric regression is free from all data assumptions contained in parametric regression, so it is more flexible to use for all data (Ningsih, 2019).

The Fourier series is a trigonometric polynomial that has high flexibility, namely sines, and cosines, so that it can adapt the local properties of the data effectively. The Fourier series is also good for repeating curves (Dani & Adrianingsih, 2021) Along with the development of data analysis, Bilodeau (1992) developed a Fourier series for statistical data smoothing by accommodating the trend function.

Research related to nonparametric Fourier series regression was conducted by Fatima in 2019 to predict peak electricity loads in Madura during the day and night. Based on this research, the best model is obtained, namely the cosine basis with a GCV value of 0.00016, MSE of 0.85156, and a coefficient of determination of 99% compared to the cosine basis, and the basis of sine and cosine (Fatima, 2019). In the following year, Millah researched the comparison of vector autoregressive analysis (VAR) with nonparametric bi-response Fourier series regression on the number of passport applicants and passports issued during the Covid-19 pandemic. Based on this research it was

found that the Nonparametric *Biresponse Fourier* Series Regression model with a MAPE of 6.202x10-6 is better than the Vector Autoregressive Analysis (VAR) model with a MAPE of 3x10-3 (Millah, 2021). In 2022, Faisol will also compare the performance of VAR with bi-response nonparametric regression with the Fourier series estimator in modelling seawater salinity and temperature. Faisol's research states that the nonparametric bi-response regression model with the Fourier series estimator is better, where the MAPE value is 0.00496 (Faisol, Ukhrowi, Mardianto, Yudistira, & Kuzairi, 2022).

Based on this description, the researcher was interested in conducting a comparative analysis modelling the number of people who had been vaccinated with the first and second doses. The analytical method used is non-parametric bi-response Fourier series regression with a trend function. Mean square error (MSE), generalized cross-validation (GCV), and coefficient of determination (R^2) are the comparative metrics employed.

METHODS

Correlation Test

The initial requirement to form a nonparametric bi-response forecasting model is the existence of a correlation between the two response variables used. The hypothesis in the correlation test is

H_0 : ρ = 0 (there is no correlation between x and y)

H_1 : ρ ≠ 0 (there is a correlation between x and y)

The statistical form used for the correlation test above is

$$t_{hit} = r_{xy}\sqrt{\frac{n-2}{1-r_{xy}^2}}$$

t_{hit} spreads following the t distribution with degrees of freedom $(n-2)$

With

n : Number of observations

r_{xy} : Sample correlation coefficient between random variables X and Y which is calculated by the formula

$$r_{xy} = \frac{n\sum_{i=1}^{n} X_i Y_i - (\sum_{i=1}^{n} X_i)(\sum_{i=1}^{n} Y_i)}{\sqrt{[\{n\sum_{i=1}^{n} X_i^2 - (\sum_{i=1}^{n} X_i)^2\}\{n\sum_{i=1}^{n} Y_i^2 - (\sum_{i=1}^{n} Y_i)^2\}]}}$$

The decision-making criterion in this test is $\boldsymbol{H_0}$: ρ = 0 rejected if $|t_{hit}| \geq t_{o,5\alpha;(n-2)}$ and accept $\boldsymbol{H_0}$ if $|t_{hit}| < t_{o,5\alpha;(n-2)}$. (Rosyadi & Suyantiningsih, 2020)

Biresponse Nonparametric Regression Analysis

Nonparametric regression is used when it is assumed that the regression curve's shape is not known. If given paired data (t_i, y_i), then the general form of

nonparametric regression for the corresponding observations $i = 1,2,3,\dots,n$ is

$y_i = f(t_i) + \varepsilon_i; \varepsilon_i \sim N\ (0, \sigma^2)$

y_i = Response i

$f(t_i)$ = Representation of the regression curve approximated by certain functions in nonparametric regression

ε_i = Error (Faisol, Ukhrowi, Mardianto, Yudistira, & Kuzairi, 2022).

Regression analysis involving two response variables and among the response variables there is a strong correlation or relationship, both logically and mathematically, is called bi-response regression. In general, the model for bi-response nonparametric regression can be written as follows (Faisol, Ukhrowi, Mardianto, Yudistira, & Kuzairi, 2022).

$$\begin{cases} y_{i1} = f_1(x_{i1}) + \varepsilon_{i1} \\ y_{i2} = f_2(x_{i2}) + \varepsilon_{i2} \end{cases}$$

Estimations of Bi-response Nonparametric Models with Series Fourier

The Fourier series is a trigonometric polynomial function that has a high degree of flexibility. The Fourier series is a curve that shows the sine and cosine functions. With expansion into the form of a Fourier series, a periodic function can be expressed as the sum of several harmonic functions, namely the function of sine and cosine, including sinusoidal functions. (Mardianto, et al., 2019)

Definition 1.

If given that $f(x)$ is a function that can be integrated and differentiable on the interval $[a, a+2L]$, then the representation of the Fourier series on that interval with respect to $f(x)$ which contains the trigonometric components sine and cosine is as follows

$f(x) = \frac{a_0}{2} + \sum_{n=1}^{\infty}(a_n \cos k^* x + b_n \sin k^* x)$

with $k^* \approx \frac{n\pi}{L}; n = 1,2,3,\dots$

The Fourier coefficient is determined by the following formulation

$$a_0 = \frac{1}{L}\int_a^{a+2L} f(x)dx$$

$$a_n = \frac{1}{L}\int_a^{a+2L} f(x)\cos k^* x\, dx$$

$$b_n = \frac{1}{L}\int_a^{a+2L} f(x)\sin k^* x\, dx$$

The response nonparametric regression model with the Fourier series estimator has three bases, namely basis sine, cosine, and sine cosine. The following is the general form of the model for the sine and cosine basis

$\hat{y}_{1i} = \hat{f}_{1i} = \frac{\hat{a}_{01}}{2} + \gamma_1 t_{il} + \sum_{k=1}^{K}(\hat{a}_{k1}\, \mathrm{B}\, kt_{il})$

$\hat{y}_{2i} = \hat{f}_{2i} = \frac{\hat{a}_{02}}{2} + \gamma_2 t_{il} + \sum_{k=1}^{K}(\hat{a}_{k2}\, \mathrm{B}\, kt_{il})$

Where B is a sin if the basis model is sine and cos if the basis model is cosine. While the model with sin cos basis is

$$\hat{y}_{1i} = \hat{f}_{1i} = \frac{\hat{a}_{01}}{2} + \gamma_1 t_{il} + \sum_{k=1}^{K}(\hat{a}_{k1}\cos kt_{il} + \hat{b}_{k1}\sin kt_{il})$$

$$\hat{y}_{2i} = \hat{f}_{2i} = \frac{\hat{a}_{02}}{2} + \gamma_2 t_{il} + \sum_{k=1}^{K}(\hat{a}_{k2}\cos kt_{il} + \hat{b}_{k2}\sin kt_{il})$$

The nonparametric bi-response estimation model of the Fourier series is obtained by substituting the parameter values and the number of oscillation parameters k in the regression model.

Determination of the Best Model

The selection of the best model is done by looking at the GCV, MSE, and R^2 values of each model on a different basis (Ahadiyah, 2022). The best model is the model with minimum GCV and maximum R^2. GCV value with the amount of data n and k oscillation parameters is determined by the following equation:

$$\text{GCV(K)} = \frac{MSE\,(k)}{(n^{-1}trace(I-A[k]))^2}$$

where I is the identity matrix and $A[k]$ is the hat matrix (Kuzairi, et al., 2022).

Mean Square Error (MSE) is a value used to evaluate forecasting results. By using MSE, the existing errors show how much the estimation results are similar to the original data. MSE can be searched by the following formula (Zahrah, 2020):

$$MSE[k] = \frac{1}{n}\mathbf{y}^{\mathrm{T}}(\mathbf{I}-\mathbf{A}[k])^{\mathrm{T}}(\mathbf{I}-\mathbf{A}[k])\mathbf{y}$$

The coefficient of determination is a measure of the contribution of the predictor variables to the response variable. The coefficient of determination is calculated by the following formula:

$$\mathbf{R^2} = \frac{(\hat{y}-\bar{y})^T(\hat{y}-\bar{y})}{(y-\bar{y})^T(y-\bar{y})}$$

where $\bar{y}$ is a vector containing the average response. (Faisol, Ukhrowi, Mardianto, Yudistira, & Kuzairi, 2022) (Rosyadi & Suyantiningsih, 2020)

RESULT AND DISCUSSION

Descriptive Statistics

The data in this study is the proportion of the population that had been vaccinated at the first (y_1) and second (y_2) doses of vaccine in East Java for 6 months from August 2021-January 2022.

A descriptive analysis of the data can be seen in Table 1 below.

Table 1 Descriptive Statistics of First and Second Dose Vaccinations

Value	y_1	y_2
minimum	0.188	0.077

Maximum	0.677	0.496
Average	0.445	0.284
Standard Deviation	0.156	0.132

Based on Table 1 it can be seen that the variable y_1 has a minimum value of 0.188 occurring in August, and a maximum value of 0.677 occurring in January with an average of 0.445.

While the variable y_2 has a minimum value of 0.077 occurring in January, while the maximum value of 0.496 occurs in April with an average of 0.284.

Nonparametric Biresponse Fourier Series Regression Modeling with Trend

The estimator used is an estimator with the Fourier series approach. Modeling is done with three bases, namely the basis of cosine, sine, and sine cosine.

The first stage in nonparametric regression modeling with the Fourier series estimator is to determine the value of the oscillation parameter (k). The k value is determined based on the GCV value, where the optimum k is k with the minimum GCV value. GCV and R^2 values from models with three different bases can be seen in Table 2 below.

Table 2 Model GCV's (Cosine Base)

Cosine Base			
k	**GCV**	$\mathbf{R_k^2}$	$\Delta\mathbf{R_k^2}=\mathbf{R_{k+1}^2}-\mathbf{R_k^2}$
1	54,839,606	0.9872806	
2	54,149,560	0.9874795	0.0001989
3	53,059,849	0.9887600	0.0012805
4	52,627,397	0.9883728	-0.0003872
5	51,802,182	0.9890555	0.0006827
6	49,349,393	0.9925480	0.0034925
7	48,681,000	0.9930103	0.0004623

Table 3 Model GCV's (Sine Base)

Sine Base			
k	**GCV**	$\mathbf{R_k^2}$	$\mathbf{\Delta R_k^2}$
1	55,654,369	0.9847360	
2	54,910,561	0.9850968	0.000361
k	**GCV**	$\mathbf{R_k^2}$	$\mathbf{\Delta R_k^2}$
3	54,378,487	0.9849167	-0.00018
4	53,906,308	0.9846622	-0.00025
5	52,954,634	0.9857055	0.001043
6	50,476,907	0.9934282	0.007723
7	48,630,269	0.9969258	0.003498

Table 4 Model GCV's (Sine Cosine Base)

Sinus Cosinus Base			
k	**GCV**	$\mathbf{R_k^2}$	$\mathbf{\Delta R_k^2}$
1	53,752,237	0.9884667	
2	52,383,311	0.9889531	0.000486
3	50,848,171	0.989974	0.001021
4	49,974,043	0.9892881	-0.00069
5	48,352,734	0.9907769	0.001489
6	44,759,517	0.9987813	0.008004
7	43,390,163	0.9998565	0.001075

Based on Table 2 until Table 4, the minimum GCV value for the cosine basis is 49,349,393 with $k = 6$. The difference in the maximum R^2 value is found at $k = 6$, which is 0.0034925. The minimum GCV value for the sine basis is 50,476,907 with at $k = 6$. The difference in the maximum R^2 value is found at $k = 6$, which is 0.007723. While the minimum GCV value for cosine basis sine is 44,759,517 with $k = 6$. The difference in the maximum R^2 value is found at $k = 6$, which is 0.008004. Based on

these two criteria, the optimum k value for the nonparametric bi-response model on the basis of cosine, sine, and sine cosine d is 6.

Determination of the Best Model

The best model is selected by looking at the GCV, MSE, and R^2 values of each model. The better model is the one with the smallest GCV, MSE values and the largest R^2 values. The GCV, MSE, and R^2 values of the three models can be seen in Table 5 below.

Table 5 The Value Comparisson GCV, MSE dan R^2

Base	k	GCV	MSE	R^2
Cosinus	6	49,349,393	1.08230349	99.25%
Sinus	6	50,476,907	1.10703	99.34%
Sinus cosinus	6	44,759,517	1.052155	99.87%

Based on Table 5 it can be seen that the Fourier series estimator with sine cosine basis is the best of the three. There is

$$\hat{y}_{i1} = 0.1681587 + 0.0002957495t_{i1} + -0.0002421223\cos t_{i1} + 0.000002172553\cos 2t_{i1} + 0.0001387937\cos 3t_{i1} + 0.000007529672\cos 4t_{i1} - 0.0001727081\cos 5t_{i1} + 0.0002635696\cos 6t_{i1} + 0.00005279639\sin t_{i1} - 0.0001544323\sin 2t_{i1} + 0.00001466279\sin 3t_{i1} + 0.0001143536 - 0.0003968597\sin 6t_{i1}$$

$$\hat{y}_{i2} = 0.005417103 + 0.0002488172t_{i1} - 0.00003976347\cos t_{i1} - 0.000006973482\cos 2t_{i1} - 0.0000006953360\cos 3t_{i1} - 0.00001975733\cos 4t_{i1} + 0.00002335754\cos 5t_{i1} - 0.00003364084\cos 6t_{i1} + 0.000008645429\sin t_{i1} - 0.00002141447\sin 2t_{i1} + 0.000002156987\sin 3t_{i1} - 0.00001150052\sin 4t_{i1} + 0.00001003946\sin 5t_{i1} - 0.00003211487\sin 6t_{i1}$$

The model has GCV and MSE of 44,759,517 and 1.052155, respectively. This value is smaller than the GCV and MSE

values for cosine and sine. The R^2 model of 99.87% means that the model with a sine cosine basis can explain the relationship between the number of residents who have been vaccinated with the first and second doses and time, while the remaining 0.13% is explained by the residual variable. While the remaining 0.13% is explained by the residual variable.

CONCLUSION

The best model in nonparametric bi-response regression with the Fourier series approach for modeling comparisons of the number of people who have received the first and second dose of vaccine in East Java in 2021-2022 is a model with a sine cosine basis. The model has GCV=44,759,517, MSE=1.052155 and $R^2 = 99.87\%$.

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