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Evaluation of Simultaneous and Simultaneous Spatial Autoregressive Equation with Three Stage Least Square Method (Case Study on GRDP, Poverty and Unemployment Data in Papua in 2018)

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Abstract

In the simultaneous equation (SM), the dependent variable in an equation could be an independent variable in another equation. Dependent variables are called endogenous variables and independent variables are called exogenous variables. If the observations in SM are locations and contain spatial autocorrelation, then a spatial dependency model can be added. Adding dependencies to endogenous variables is modeled as spatial autoregressive regression (SAR). Addition of SAR to the SM model hereinafter referred to as simultaneous spatial autoregressive regression (SM SAR). Estimation of parameters in the SM SAR can use the Three Stage Least Square (3SLS) method as used in SM. This study aims to predict this SM SAR model on GRDP, poverty and unemployment data in Papua in 2018. SM consists of three equations. The weight matrix used in each equation can be the same or a combination of inverse distance, rook contiguity, exponential weight and K-NN matrices. The results showed the addition of SAR in SM could reduce MSE by 0.31and an increase in R^2 by 4.68% compared to the SM model.

Keywords: simultaneous; simultaneous spatial autoregressive regression; three stage least square.

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1. Introduction

The Gross Regional Domestic Product (GRDP) is one among many indicators that can be used to determine the economic conditions in the specific area and period of time. Basically, GRDP can be defined as an added value generated by all business units in a certain area. Furthermore, GRDP is one of indicators of economic growth measurement that shows the extent to which economic activity can be utilized to reduce poverty and unemployment [1:5-9] Poverty and unemployment are important variables to measure the success of economic growth in improving the quality of human resources. There are many studies that examine the connection of these variables. Jonaidi [2:141-142] in her research argues that there is a two-way relationship between economic growth and poverty in Indonesia. Meanwhile, Okun's Law introduces a hypothesis that with an equal distribution of economic growth indicated by GRDP, the number of unemployed can be reduced to a lower level [3:142-143]. Finally, Susanti [4:4-6] argues that GRDP, unemployment and HDI also have significant effects on decreasing poverty levels. Based on the theories, it can be concluded that GRDP, poverty and unemployment are variables that have mutual connection. Despite of that, the Least Squares Method (LSM) which frequently used to examine variables in statistics cannot measure the relationship among dependent variables. In simultaneous equations (SM), dependent variables in an equation could be as independent variables for other equations. Therefore, the use of LSM to predict parameters in SM is not appropriate, because it could violates the assumption that there is no correlation between independent variables and stochastic errors. The estimation results will provide biased and inconsistent estimators, should the LSM is still be used to process it. Nevertheless, the Three Stage Least Square (3SLS) estimation method is believed to be a proper method for modeling the dependency relationship between several endogenous variables in SM model. Zellner and Theil [5:54] argue that the 3SLS method could generate parameter estimators that are more efficient than Two Stage Least Square (2SLS). The spatial SM are the development of SM which examine the effects of the region. Kelejian and Prucha [6:35-39] propose two methods of estimating parameters for spatial SM namely the Generalized Spatial Two Stage Least Square (GS2SLS) and the Generalized Spatial Three Stage Least Square (GS3SLS). Compared with the GS2SLS method, the GS3SLS method provides more efficient estimation results [6:35-40; 7:42-43]. General spatial SM are general simultaneous models that can utilize Spatial Autoregressive Models (SAR), Spatial Error Models (SEM), and Spatial Autoregressive Moving Average (SARMA). In this study, the simultaneous spatial autoregressive regression (SM SAR) equation is used as the spatial SM, which is a SM that has spatial dependence on endogenous variables. This study aims to find the best estimator by comparing the estimator method of 3SLS parameters on the SM and SM SAR equation using distance inverse weight, rook weight contiguity, the combination of the weight of the inverse distance and rook contiguity, the weight of the exponential distance, the weight of the k-nearest neighbor (k-NN), and the combination of the exponential weight and k-NN.

2. Materials and Methods

2.1. Materials

The source of data used in this study is secondary data collected from the annual publication of the Central Bureau of Statistics (CBS) of the Provinces of Papua and West Papua, Indonesia. This province is the easternmost province of Indonesia which borders directly with Papua New Guinea. The observation area of this study covered 42 regencies/cities in Papua and West Papua Provinces in 2018. The variables used in this study consisted of endogenous and exogenous variables as presented in Table 1.

Table 1: The endogenous and exogenous variables used

Variables	Variable labels	Units	Variable types
Y_1	GRDP of non mining at constant prices	Million IDR	Endogenous
Y_2	Percentage of Poor Population	Percentage	Endogenous
Y_3	Open Unemployment Rate	Percentage	Endogenous
X_1	Consumption	IDR	Exogenous
X_2	Capital Expenditure	Million IDR	Exogenous
X_3	Life Expectancy	Year	Exogenous
X_4	Education Expectancy	Year	Exogenous
X_5	Per capita Expenditure	IDR	Exogenous
X_6	Labour Force Participation Rate	Percentage	Exogenous
X_7	High School Participation Rate	Percentage	Exogenous

2.2. Research Methods

The stages of analysis in this study are as follows:

1. Exploring GRDP data, percentage of poor population, and open unemployment rate of Papua in 2018.
2. Perform multicollinearity testing on predetermined variables in structural equations.
3. Define structural equations based on the results of previous studies and identify SM.

SM in the structural form of each endogenous variable is formulated as follows:

$$Y_1 = \beta_{10} + \gamma_{12}Y_2 + \gamma_{13}Y_3 + \beta_{11}X_1 + \beta_{12}X_2$$

$$Y_2 = \beta_{20} + \gamma_{21}Y_1 + \gamma_{23}Y_3 + \beta_{23}X_3 + \beta_{24}X_4 + \beta_{25}X_5$$

$$Y_3 = \beta_{30} + \gamma_{31}Y_1 + \gamma_{32}Y_2 + \beta_{36}X_6 + \beta_{37}X_7$$

Meanwhile, the SM SAR equation of each endogenous variable is formulated as follows:

$$Y_{1i} = \beta_{10} + \gamma_{12}Y_{2i} + \gamma_{13}Y_{3i} + \beta_{11}X_{1i} + \beta_{12}X_{2i} + \rho_1 \sum_{1=1}^{n}\sum_{j=1}^{n} w_{ij}Y_{1i} + \varepsilon_{1i}$$

$$Y_{2i} = \beta_{20} + \gamma_{21}Y_{1i} + \gamma_{23}Y_{3i} + \beta_{23}X_{3i} + \beta_{24}X_{4i} + \beta_{25}X_{5i} + \rho_2 \sum_{i=1}^{n}\sum_{j=1}^{n} w_{ij}Y_{2i} + \varepsilon_{2i}$$

$$Y_{3i} = \beta_{30} + \gamma_{31}Y_{1i} + \gamma_{32}Y_{2i} + \beta_{36}X_{6i} + \beta_{37}X_{7i} + \rho_3 \sum_{i=1}^{n}\sum_{j=1}^{n} w_{ij}Y_{3i} + \varepsilon_{2i}$$

There are three possible results of identification, namely:

a. *Underidentified*, if $\mathrm{K} - \mathrm{k} \geq \mathrm{g} - 1$ and $rank(\Delta) < \mathrm{G} - 1$ or, if $\mathrm{K} - \mathrm{k} < \mathrm{g} - 1$
b. *Exactly Identified*, if $\mathrm{K} - \mathrm{k} = \mathrm{g} - 1$ and $rank(\Delta) = \mathrm{G} - 1$
c. *Overidentified*, if $\mathrm{K} - \mathrm{k} > \mathrm{g} - 1$ and $rank(\Delta) = \mathrm{G} - 1$

with:

G = total number of endogenous variables in a particular equation model

g = number of endogenous variables in a given equation

K = total number of exogenous variables in a given equation model

k = number of exogenous variables in a given equation

Table 2: Identification of structural equation models

Equations	K	k	g-1	K-k > g-1	*Rank* (Δ_i)	Identification Results
LnY_1	7	2	3-1	Yes	2	*Overidentified*
LnY_2	7	3	3-1	Yes	2	*Overidentified*
LnY_3	7	2	3-1	Yes	2	*Overidentified*

4. Perform simultaneous tests to see that the system of the equation models has a simultaneous relationship between structural equations. The steps for simultaneous testing [8:1264-1267] are as follows:

a. Predict the reduced form equation from the SM model. Regress each variable $\hat{Y}_t$, also save the remaining value u_t.
b. Because $\mathrm{Y_t} = \hat{\mathrm{Y}}_\mathrm{t} + \mathrm{u_t}$, substitute this value from the endogenous variable into the equation and the estimation with LSM follows the equation

$$Y_{it} = \hat{Y}_{it}\gamma_{it} + u_{it}\gamma_{it} + X_{it}\beta_i + \epsilon_{it}$$

c. Use the F test or T test for a regression coefficient to test the significance of the regression coefficient of u_t. If the test shows a significant coefficient then accept the H1 hypothesis (there is a simultaneous relationship).

5. Perform spatial dependency tests with the Moran test

Moran index is an indicator of spatial dependence to compare the value of a variable at one location with the same variable value at another location. The Moran Index formula is:

$$I = \frac{n}{\sum_{i=1}^{n}\sum_{j=1}^{n} w_{ij}} x \frac{\sum_{i=1}^{n}\sum_{j=i}^{n} w_{ij}(x_i - \bar{x})(x_j - \bar{x})}{\sum_{i=1}^{n}(x_i - \bar{x})}$$

Moran index values ranging from -1 to 1.

6. Determine the spatial weight matrix

Spatial weight matrix is a matrix that describes the relationship between regions. Spatial weighting matrices are symmetric matrices in which the main diagonal is always zero [9:165]. In this study, the spatial weighting matrix used is the weight matrix of the inverse distance, rook contiguity, exponential distance and k-Nearest Neighbor (k-NN).

a. Weight matrix of inverse distance

The distance weighting is based on the distance of the district city center which is calculated based on the latitude-longitude coordinates. Based on the latitude-longitude coordinates the euclidian distance is obtained from/to each district/city.

The weight opposite to distance is formulated as follows:

$$w_{ij} = \begin{cases} \frac{h_{ij}}{\sum_{j=1}^{n} h_{ij}}, for\ i \neq j \\ 0 \qquad\quad , for\ i = j \end{cases}$$

Where $h_{ij} = \frac{1}{d_{ij}}$, where d_{ij} is the distance between the i-th and j-j locations.

b. The spook weight rook contiguity matrix defines $w_{ij} = 1$ for areas adjacent to the area of concern while $w_{ij} = 0$ for regions …. .
c. Exponential distance matrix.

If, for example, d_{ij} is the distance between the spatial unit *i* and the spatial unit *j*, the spatial weighting matrix according to the exponential distance is:

$$w_{ij} = \frac{\exp(-cd_{ij})}{\sum_{k\neq j}\exp(-cd_{ik})}$$

The value of *c* used in this study is 2.

d. k-Nearest Neighbor (k-NN)

For example, the distance of the center for each spatial unit *i* with all units $j \neq i$ is sorted as follows: $d_{ij}(1) \leq d_{ij}(2) \leq \cdots d_{ij}(n-1)$. Based on the distance *k* closest neighbors, in this study used *k* = 2, which means that each area has two closest neighbors.

7. Estimating 3SLS parameters in SM and SM SAR equations

$$\boldsymbol{d}_{3SLS} = \left[\left[\widehat{\boldsymbol{Z}}'(\boldsymbol{V}^{-1})\widehat{\boldsymbol{Z}} \right]^{-1} \widehat{\boldsymbol{Z}}(\boldsymbol{V}^{-1})y \right]$$

$$\boldsymbol{d}_{3SLS\ SAR} = \left[\left[\widehat{\boldsymbol{Z}}_{\boldsymbol{n}}^{*}{}'(\rho)(\boldsymbol{V}^{-1})\widehat{\boldsymbol{Z}}_{\boldsymbol{n}}^{*}(\rho) \right]^{-1} \widehat{\boldsymbol{Z}}_{\boldsymbol{n}}^{*}{}'(\rho)(\boldsymbol{V}^{-1})y_n^{*}(\rho) \right]$$

8. Determine the best model with the following criteria:

a. The system's MSE (Mean Squared Error) value
b. The coefficient of determination or R^2.

The coefficient of determination is the proportion of diversity of endogenous variables that can be explained by all predetermined variables together, the formula is

$$R^2 = \frac{SSR}{SST} = 1 - \frac{SSE}{SST}$$

The coefficient of determination for SM is

$$R^2 = \frac{SSR}{SST} = \frac{\left[\widehat{\boldsymbol{\delta}}'\boldsymbol{Z}'\boldsymbol{y} - \frac{1}{n}\left(\sum_{i=1}^{n} y_i\right)^2 \right]}{\boldsymbol{y}'\boldsymbol{y} - \frac{1}{n}\left(\sum_{i=1}^{n} y_i\right)^2}$$

9. Test the assumptions of the best model residuals with various normality and homogeneity tests.
10. Interpret the best parameters from the best model.

3. Results

3.1. General description of GRDP, Percentage of poor people and Open Unemployment Rate (OUR) in Papua

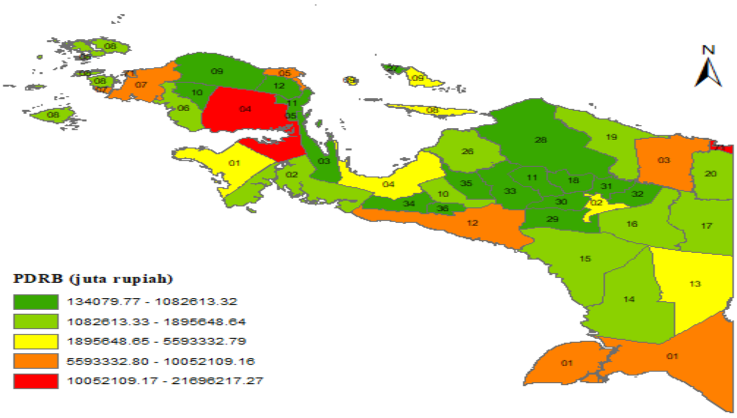

Figure 1: Map of the distribution of GRDP in Papua in 2018 (map not scaled)

GRDP is an indicator to determine the economy growth of a region. The highest GRDP on Papua Island achieved by Jayapura City and Bintuni Bay Regency with 21.96 trillion IDR and 15.76 trillion IDR respectively. In **Figure 1**, it can be seen that the GRDP within the same range, especially the highest range throughout the island of Papua was not clustered in one single area. This condition indicates that the GRDP of an area has no positive impact for its surrounding area.

In **Figure 2**, the highest percentage of poor people is in the districts of Deiyai, Intan Jaya, and Lanny Jaya which reached 43.49 percent, 42.71 percent and 40.06 percent sequentially. The three regions with the largest percentage of poor population are mountainous areas. In **Figure 2,** it can be seen that the percentage of poor people especially for the highest range on the island of Papua was clustered in an area, that indicates that the percentage of poor population in a regency/city will have a positive impact for its surrounding area.

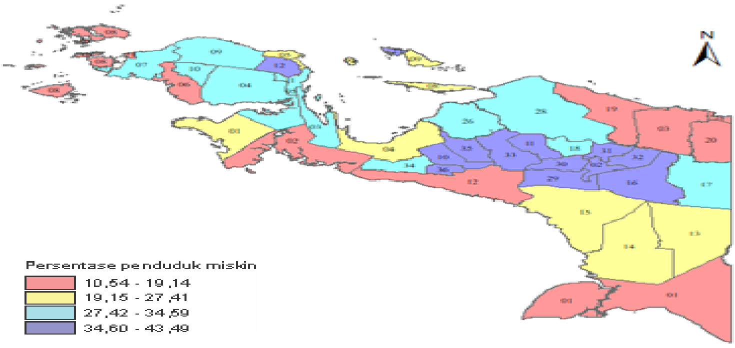

Figure 2: Map of the distribution of the percentage of poor people in Papua 2018 (map not scaled)

The highest OUR in 2018 was located in Sorong City, which is around 11.20 percent, then followed by Jayapura district and Jayapura City respectively by 10.71 percent and 10.22 percent. The lowest OUR in 2018 was in Tolikara district by 0.17 percent. In **Figure 3**, it can be seen that the regions which have the highest range of OUR was spread. However, for other categories, especially the lowest range of the region is clustered, it indicates that the OUR of an area will have positive impact for its surrounding area.

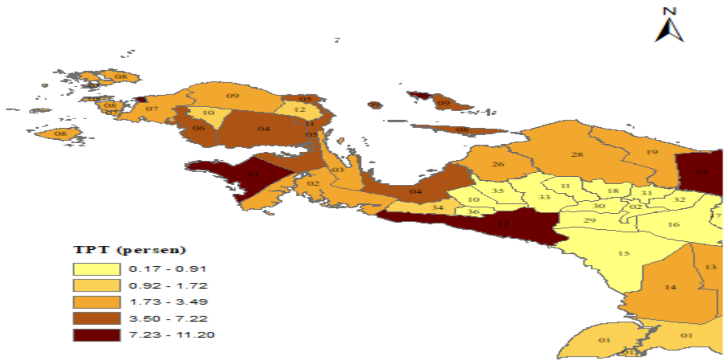

Figure 3: Map of the distribution of open unemployment rate in Papua in 2018 (map not scaled)

Box-Cox Transformation (**Figure 4, Figure 5 and Figure 6**) is used to see whether the endogenous variables need to be transformed or not. From the box-cox results for the GRDP variable Y_1 and the OUR variable Y_3, a minimum lambda value of 0 is obtained, so that the best transformation is transformation with a natural logarithmic function (ln). For the% of the poor population variable Y_2 the resulting lambda value is 1, this means there is no need to do a transformation on the variable Y_2, but for ease in interpreting the model and so that the MSE value between the equations does not have a broad gap, so Y_2 will also be transformed using ln.

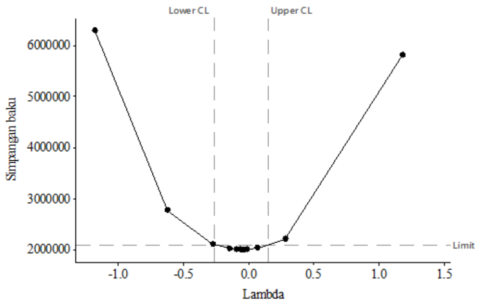

Figure 4: Transformation Box-Cox PDRB variable

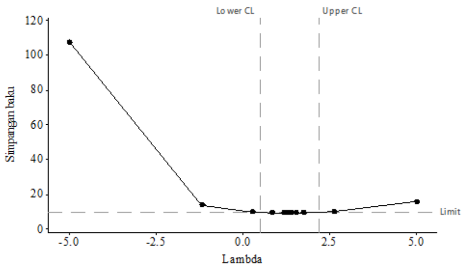

Figure 5: The Box-Cox Transformation changes the percentage of poor population

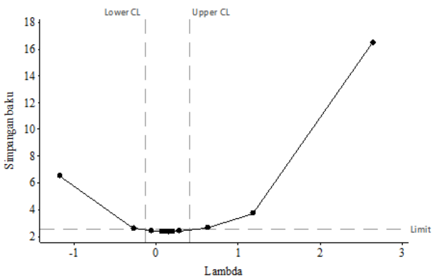

Figure 6: Box-Cox Transformation of OUR variables

3.2. Multicollinearity Test

Multicollinearity checking between predetermined variables can be done by looking at the VIF (Variance Inflation Factor) value. Multicollinearity between predetermined variables occurs if the VIF value obtained is greater than ten (VIF> 10). The existence of multicollinearity can make the suitability of the parameter estimator mark is not appropriate. According to Chatterjee and Hadi [10:61-62], the correlation between independent variables makes the interpretation of the regression coefficient incorrect. Based on **Table 3**, it can be seen that the VIF values of all predetermined variables are smaller than ten so that there is no multicollinearity.

Table 4: VIF values for each variable on structural equation

Equations	Variables	VIF
LnY_1	LnY_2	1.75
	LnY_3	1.61
	X_1	1.28
	X_2	1.07
LnY_2	LnY_1	3.82
	LnY_3	2.82
	X_3	1.36
	X_4	2.68
	X_5	5.57
LnY_3	LnY_1	1.71
	LnY_2	1.97
	X_6	2.42
	X_7	2.30

3.3. The Simultaneity of Hausman

In the simultaneous test, the residual element is included in each equation so that the effect of the residual can be acknowledged. **Table 5** shows the significance of the residual variables in each equation. All three equations have significant residuals at 5 percent level so that the conclusion is that there is a simultaneous relationship between the three equations, namely GRDP, percentage of poor population and OUR, so estimation of parameters using the 3SLS method on SM can be continued.

Table 5: Simultaneity test results

Equations	Variables	F_statistic	P_value	Explanations
$\mathrm{Ln}Y_1$	RES_Y_1	16.91	0.000	There are simultaneous effects
$\mathrm{Ln}Y_2$	RES_Y_2	7.26	0.000	There are simultaneous effects
$\mathrm{Ln}Y_3$	RES_Y_3	17.0	0.000	There are simultaneous effects

3.4. Moran Test

Moran test in this study is used for initial identification to see whether there is a spatial effect of endogenous lag lag on the equation. Spatial dependency test results with distance weights, rook contiguity weights, exponential weights and k-NN weights show that there is a spatial lag effect on the LnY_2 and LnY_3 equations. Moran test shows the parameter estimation by the 3SLS method in the SM SAR equation can be continued.

Table 6: Spatial SAR dependency test

Equations	Weighting							
	Reverse Distance		*Rook contiguity*		Exponential Distance		k-NN	
	I	p-value	I	p-value	I	p-value	I	p-value
LnY_1	-0.03	0.58	-0.06	0.61	-0.02	0.47	0.11	0.15
LnY_2	0.05	$0.73 \text{x} 10^{-2}$	0.24	0.01	0.27	$1.62 \text{x} 10^{-6}$	0.45	$0.22 \text{x} 10^{-3}$
LnY_3	0.16	$2.67 \text{x} 10^{-10}$	0.36	$0.43 \text{x} 10^{-3}$	0.15	$0.29 \text{x} 10^{-2}$	0.58	$5.17 \text{x} 10^{-6}$

3.5. Determine the Best Model

Table 7 presents a measure of the goodness of the 3SLS method in SM and SM SAR equations with various weights. Overall, it can be concluded that the 3SLS method in the SM SAR equation is better than the SM equation. This can be seen from the majority of the MSE values for the 3SLS method in SM SAR (equations 2, 4, 5 and 7) which are smaller than the MSE values for the 3SLS method in SM. Likewise, if seen from the R^2 value, most of the R^2 values of the 3SLS method in the SM SAR equation are greater than the R^2 value in the SM.

Table 7: Measuring model goodness (*goodness of fit*) 3SLS method

Equations	MSE System	R^2System
SM	1.57	76.04%
SM SAR (the weight of the inverse distance)	1.39	80.26%
SM SAR (the weight of *rook contiguity*)	1.57	83.15%
SM SAR (combination of weights of distance and *rook contiguity*)	1.50	80.67%
SM SAR (exponential weight)	1.28	72.96%
SM SAR (the weight of k-NN)	2.33	81.41%
SM SAR (combination of exponential weight and k-NN)	1.26	80.72%

The 3SLS method in the SM SAR equation using a combination of exponential weights and k-NN weights is the best method. The 3SLS method in the SM SAR combination of exponential weights and k-NN has the smallest MSE system value compared to other equations of 1.26, which means an average system error of 1.26 with an R^2 value of 80.72%, which means the predetermined variable is able to explain the model at 80.72% , the rest can be explained by other variables not included in the model.

3.6. Test The Assumptions of Normality And Homogeneity Of Variances

Testing the assumptions in the 3SLS SAR model is using the homoscedasticity test and the normality test of the residual. The test results show that both assumptions were fulfilled. The results of the assumption normality test are seen from the Shapiro-Wilk W test with a p-value greater than 0.01, this indicates that the distribution is normally distributed. Meanwhile, the assumption results of homogeneous variance assumptions using the White test show a p-value of more than 0.05, so that the SM SAR equation of the combination of exponential weights and k-NN satisfies the assumption of homogeneous residual variance.

Table 8: Examination of assumptions of SM SAR equation exponential weights and k-NN

Equations	Assumption of Normal Remaining			Variety of Homogeneous Assumptions		
	Test Statistics	p_ value	Decisions	Test Statistics	p_value	Decisions
LnY_1	Shapiro-Wilk W	0.28	Assumptions fulfilled	*White* Test	0.06	Assumptions fulfilled
LnY_2	Shapiro-Wilk W	0.03	Assumptions fulfilled	*White* Test	0.56	Assumptions fulfilled
LnY_3	Shapiro-Wilk W	0.66	Assumptions fulfilled	*White* Test	0.39	Assumptions fulfilled

3.7. Best Model Interpretation

The 3SLS method for estimating parameters in the SM SAR equation with a combination of exponential weights and k-NN is stated better. The estimation results of the parameters with 3SLS in the SM SAR equation show that at a real level of 0.05 the percentage of poor people (Y_2) negatively affected the GRDP of the non-mining sector in 2018 in Papua (Y_1). The spatial dependency of the lag in the GRDP equation is negative, meaning that an increase in the GRDP of the districts/cities in Papua does not have a positive effect on the surrounding area, this is in line with the initial description of the GRDP in Papua (**Figure 1**), which shows areas where the number of PDRB is in a certain range the location is not clustered in an area. The spatial dependency lag on the equation of the percentage of poor people (Y_2) is positive, meaning that an increase in the poverty of one of the districts/cities in Papua will increase the percentage of the poor population in the surrounding area. The open unemployment rate (Y_3) is only influenced by the TPAK (X_6) with a real level of 0.05, and the effect is negative. Based on the results of the parameter estimation by the 3SLS method, in the SM SAR equation a combination of exponential weights and k-NN in **Table 9**, then the SM SAR equation can be written as follows:

$$LnY_1 = 47.08 - 3.73LnY_2 - 0.18LnY_3 + 4.04x10^{-7}X_1 + 7.90x10^{-10}X_2 - 1.46\sum_{i=1}^{m} w_{ij}\, LnY_1$$

$$LnY_2 = 2.45 - 0.02LnY_1 - 0.06LnY_3 - 0.40x10^{-4}X_3 - 0.91x10^{-3}X_4 - 0.70x10^{-4}X_5 + 0.52\sum_{i=1}^{m} w_{ij}\, LnY_2$$

$$LnY_3 = 4.15 + 0.10Y_1 - 0.78Y_2 - 0.04X_6 + 0.01X_7 + 0.13\sum_{i=1}^{m} w_{ij}\, LnY_3$$

Table 9: Estimating parameters by the 3SLS method on SM SAR combination exponential weights and k-NN

Variables	LnY_1		Variables	LnY_2		Variables	LnY_3	
	Parameter Estimators	p_value		Parameter Estimators	Nilai-p		Parameter Estimators	p_value
Intercept	47.08	<0.1x 10^{-3} *	Intercept	2.45	0.15	Intercept	4.15	0.52
LnY_2	-3.73	0.40x 10^{-3} *	LnY_1	-0.02	0.84	LnY_1	0.10	0.65
LnY_3	-0.18	0.53	LnY_3	-0.06	0.55	LnY_2	-0.78	0.40
X_1	4.04x10^{-7}	0.38	X_3	-0.40x10^{-4}	0.99	X_6	-0.04	0.53x 10^{-2} *
X_2	7.90x 10^{-10}	0.37	X_4	-0.91x10^{-3}	0.97	X_7	0.01	0.22
			X_5	-0.70x10^{-4}	0.14			
wy1	-1.46	0.66x 10^{-2} *	wy2	0.52	0.02*	wy3	0.13	0.45

4. Conclusions

Addition of SAR in SM could reduce MSE by 0.31and an increase in R^2 by 4.68% compared to the SM model. The SM SAR equation with a combination of exponential weights and k-NN weights turns out to be a better estimation than using other weights. District/city GRDP in Papua is negatively affected by the percentage of poor population and lag spatial dependencies. The percentage of poverty is positively affected by the percentage of poverty in the surrounding districts/cities, whereas OUR is only influenced by labour force participation rate, and the effect is negative.

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