
LINEAR HIERARCHY REGRESSION USING SLICE SAMPLING MARKOV CHAIN MONTE CARLO

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Abstract: Multilevel regression analysis is a regression analysis that assumes there is data that has a hierarchical structure with one response variable measured at the lowest level and predictor variables at various levels. The simplest multilevel linear regression model consists of 2 hierarchical levels, where level 1 is the lowest level data, and level 2 is the data that has a higher level. The Human Development Index (HDI) is one indicator that can be used to measure the success of a particular country or region in efforts to improve the quality of life of its population. This study aims to determine the factors that influence the HDI in East Java, Central Java, and West Java. The data used in this study are the HDI, per capita expenditure adjusted at the district or city level categorized at level 1, while the growth rate of Gross Regional Domestic Product (GRDP) at the provincial level categorized at level 2. The results of the multilevel linear regression analysis indicate that the variables of per capita expenditure and GRDP growth rate significantly influence the HDI in East Java, Central Java, and West Java.

Keywords: GRDP, HDI, MCMC, Multilevel Regression, Per Capita Expenditure, Slice Sampling.

Abstrak: Analisis regresi multilevel adalah analisis regresi yang mengasumsikan adanya data dengan struktur hierarkis, di mana satu variabel respons diukur pada tingkat terendah dan variabel prediktor berada pada berbagai tingkat. Model regresi linear multilevel yang paling sederhana terdiri dari dua tingkat hierarkis: tingkat 1 merupakan data pada tingkat terendah, sedangkan tingkat 2 merupakan data pada tingkat yang lebih tinggi. Indeks Pembangunan Manusia (IPM) merupakan salah satu indikator yang dapat digunakan untuk mengukur keberhasilan suatu negara atau wilayah dalam upaya meningkatkan kualitas hidup penduduknya. Penelitian ini bertujuan untuk mengetahui faktor-faktor yang memengaruhi IPM di Jawa Timur, Jawa Tengah, dan Jawa Barat. Data yang digunakan dalam penelitian ini meliputi IPM serta pengeluaran per kapita yang disesuaikan pada tingkat kabupaten/kota (dikategorikan sebagai tingkat 1), sedangkan laju pertumbuhan Produk Domestik Regional Bruto (PDRB) pada tingkat provinsi dikategorikan sebagai tingkat 2. Hasil analisis regresi linear multilevel menunjukkan bahwa variabel pengeluaran per kapita dan laju pertumbuhan PDRB berpengaruh signifikan terhadap IPM di Jawa Timur, Jawa Tengah, dan Jawa Barat.

Kata kunci: GDP, HDI, MCMC, Regresi Multilevel, Pengeluaran Per Kapita, Pengambilan Sampel Irian.

INTRODUCTION

The Human Development Index (HDI) measures human development achievements based on several basic components of quality of life. The HDI is calculated based on data that illustrates

four components: life expectancy, which represents the health sector; expected years of schooling and mean years of schooling, which measure development achievements in education; and the community's purchasing power for basic necessities, as measured by average per

capita expenditure, as an income approximation that represents development achievements for a decent standard of living.

Expenditure is an activity whose amount is influenced by income. Naturally, high income will result in higher expenditure. If income decreases, individuals also tend to reduce consumption. Therefore, upon further analysis, an increase in real expenditure indicates an increase in income, while an increase in real income indicates an increase in a person's well-being. This increase in per capita expenditure will increase the value of the Human Development Index, as expenditure is one of the variables used to calculate the Human Development Inde.

In human development, high economic growth is a primary goal because economic growth is closely related to the increase in goods and services produced within a society. Therefore, with more goods and services produced, social welfare will increase. The growth rate of Gross Regional Domestic Product GRDP at constant prices can be used as a benchmark for determining economic growth in a region.

This study will conduct a hierarchical linear regression analysis to determine the relationship between per capita expenditure and the growth rate of Gross Regional Domestic Product GRDP at constant prices and the Human Development Inde in the provinces of East Java, Central Java, and West Java using the MCMC slice sampling method. In general, simple linear regression models are less appropriate for analyzing hierarchical data because observations in hierarchical data are not completely independent. This is because in hierarchical data, the units studied within the same group generally have similar characteristics compared to units observed in different groups. Therefore, for hierarchical data, the appropriate regression model to use is a multilevel regression model.

Multilevel modeling is a statistical technique that has evolved from simple regression analysis. This development is based on the fact that the data used in the analysis has a multilevel, hierarchical, or clustered structure, and there are relationships between variables at different levels. This condition results in hierarchical data. Analyzing hierarchical data using simple regression will result in incorrect interpretations and statistical analysis because in hierarchical data, individuals within the same group tend to have similarities, thus violating the assumptions. Slice sampling is a family of Markov Chain Monte Carlo MCMC algorithms used to generate samples from a comple target distribution by representing that distribution as slices of a more easily sampled distribution. The essence of slice sampling is to use one or more auxiliary variables or slices to simplify the sampling process, thus allowing for more efficient exploration of the target distribution compared to other MCMC methods.

Previous research on factors influencing the Human Development Inde and multilevel regression has been conducted and applied to real-world data. Budi Laksono et al. stated that partial economic growth does not significantly influence the Human Development Inde in Asia-Pacific using a panel data regression approach, while Zainal Arifin et al. stated that per capita expenditure had a significant effect on the Human Development Inde in North Sumatra using a panel data regression approach. Marwah Masruroh & Bayun Matsaany stated that per capita expenditure significantly influenced the Human Development Inde in Central Java using a multilevel model approach where level 1 was the year and level 2 was the district. The application of hierarchical or multilevel regression methods is still rarely applied in various studies. Some studies use a panel data regression approach. In theory, better economic growth and higher per capita expenditure should have an impact on the Human

Development Index. However, differences in research results can also be caused by various factors, such as the choice of predictor variables, field data, inaccuracies in estimation, and so on. Therefore, in this study, a hierarchical regression analysis was conducted with the variables of per capita expenditure and GDRP on the Human Development Index using the hierarchical regression method with MCMC slice sampling to compare how the estimation results differ from the OLS method.

METHODS

The data sources used in this assignment are the official websites of the Badan Pusat Statistik BPS. The data used are from 2018. The Level I hierarchical regression analysis used 100 data points, while the Level II hierarchical regression analysis used 3 data points. The predictor variables used in this assignment are per capita expenditure in thousands of rupiah X and the Gross Regional Domestic Product growth rate percent W . The response variable used is the Human Development Index Y .

The per capita expenditure and HDI variables were used for the Level I hierarchical regression analysis, with regencies/cities in the provinces of East Java, Central Java, and West Java as the research units a total of 100 data points, with East Java comprising 38 regencies/cities, Central Java comprising 35 regencies/cities, and West Java comprising 27 regencies/cities. Meanwhile, the Gross Regional Domestic Product growth rate variable was used for level II hierarchical regression analysis, with provinces as the research unit three sets of data, each representing the provinces of East Java, Central Java, and West Java.

The stages of hierarchical linear regression analysis using OLS are as follows:

1. Formulate the problem.

2. Conduct level I regression analysis, regressing the per capita expenditure variable against the HDI for each province the research unit is the district/city in each province, resulting in three models, which can generally be written as equation 1.

RESULTS AND DISCUSSION

The following is a description of the linear hierarchical regression analysis at level I district/city level and level II provincial level.

Level I Linear Regression

The results of the linear regression modeling at level I for each province using the HDI as the response and per capita expenditure as the predictor are as follows:

East Java Province

The regression model for the relationship between per capita expenditure and the Human Development Index HDI in East Java is shown in equation 4

$$Y = 43.37758 + 0.002455108 X \quad 4$$

To determine the significance of the regression parameters, partial testing was conducted using the t-test statistic. The hypothesis used was $H_0: \beta_1 = 0$ vs. $H_1: \beta_1 \neq 0$. The test results showed a p-value of 2.2×10^{-6} . Using $\alpha = 0.05$, H_0 can be rejected because the p-value $< \alpha$. Therefore, the conclusion is that per capita expenditure significantly influences the Human Development Index in East Java.

The parameter coefficient β_1 is positive, indicating a positive correlation between per capita expenditure and the Human Development Index in East Java. An increase in per capita expenditure of Rp 1,000 results in an increase in the Human Development Index in East Java of 0.002455108 units. Per capita expenditure indicates a person's purchasing power to meet their living needs. According to

Keynes's theory, if someone receives additional income, they will naturally increase consumption, but the amount of this additional consumption will not be as large as the additional income. Based on this statement, it can be concluded that an increase in per capita expenditure is followed by an increase in per capita income. Naturally, if per capita income increases, prosperity will be achieved, and the HDI will tend to increase.

Furthermore, the parameter coefficient β_0 is 43.37758. The β_0 value indicates East Java's HDI when the per capita expenditure variable is equal to zero. Therefore, when per capita expenditure in East Java is equal to zero, the HDI value in East Java is 43.37758. Figure 1 below shows a scatter plot along with a linear regression model line between per capita expenditure and HDI in East Java.

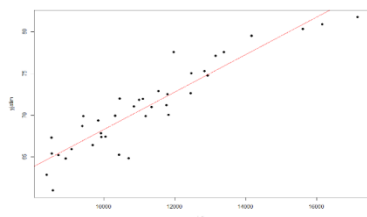


Fig 1 Scatter Plot between Per Capita Expenditure and Human Development Inde in East Java

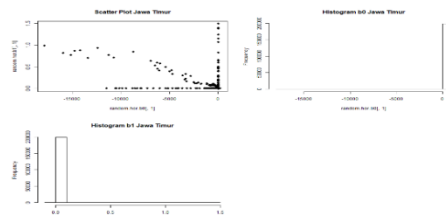


Fig. 2 Scatter Plot and Histogram of Parameters β_0 and β_1 of East Java

The Goodness of Fits test is conducted to determine whether the parameters β_0 and β_1 converge to a normal distribution or not. The hypothesis used is H_0 : parameter β_k , $k = 0, 1$ converges to a normal distribution vs. H_1 : parameter β_k does not converge to a normal distribution. The test results show that the p-value of the Goodness of Fits test for parameters β_0 and β_1 is 2.2×10^{-6} , respectively. By using $\alpha = 0.05$, it can be

decided to reject H_0 because the p-value $< \alpha$, so it can be concluded that the parameters β_0 and β_1 do not converge to a normal distribution.

Central Java Province

The regression model for the relationship between per capita expenditure and the Human Development Inde in Central Java is shown in equation 5.

$$Y = 46.62472 + 0.002322472 X$$

To determine the significance of the regression parameters, a partial test was conducted using the t-test statistic. The hypothesis used was $H_0: \beta_1 = 0$ vs. $H_1: \beta_1 \neq 0$. The test results showed a p-value of 2.2×10^{-6} . Using $\alpha = 0.05$, H_0 can be rejected because the p-value $< \alpha$. Therefore, the conclusion is that per capita expenditure has a significant effect on the Human Development Inde in Central Java.

The parameter coefficient β_1 is positive, indicating a positive correlation between per capita expenditure and the Human Development Inde in Central Java. An increase in per capita expenditure of Rp 1,000 increases the Human Development Inde in Central Java by 0.002322472 units.

Furthermore, the parameter coefficient β_0 is 46.62472. The β_0 value indicates the HDI for Central Java when the per capita expenditure variable is equal to zero. Therefore, when per capita expenditure in Central Java is equal to zero, the HDI value in Central Java is 46.62472. Figure 3 below shows a scatter plot and a linear regression model line between per capita expenditure and the HDI in Central Java.

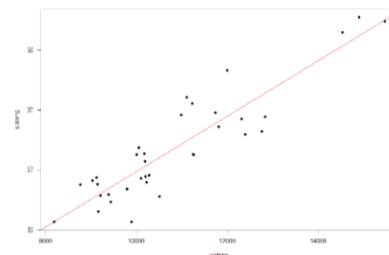


Fig. 3 Scatter Plot between Per Capita Expenditure and HDI in Central Java

Visually, the model of the relationship between per capita expenditure and the HDI in Central Java in Figure 3 shows a positive linear relationship, where an increase in per capita expenditure will increase the HDI in Central Java.

Figure 4 below shows a scatter plot between horizontal and vertical random sampling in the slice sampling process to obtain the parameters β_0 and β_1 , as well as a histogram of the β_0 and β_1 parameters in the regression model between per capita expenditure and the HDI in Central Java.

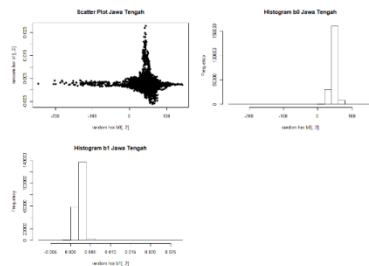


Fig. 4 Scatter Plot and Histogram of Parameters β_0 and β_1 in Central Java

West Java Province

The regression model for the relationship between per capita expenditure and the Human Development Inde in West Java is shown in equation 6.

$$Y = 50.44870 + 0.001943238 X \quad 6$$

To determine the significance of the regression parameters, a partial test was conducted using the t-test statistic. The hypothesis used was $H_0: \beta_1 = 0$ vs. $H_1: \beta_1 \neq 0$. The test results showed a p-value of 2.2×10^{-6} . Using $\alpha = 0.05$, H_0 can be rejected because the p-value $< \alpha$. Therefore, the conclusion is that per capita expenditure has a significant effect on the Human Development Inde in West Java.

The parameter coefficient β_1 is positive, indicating a negative correlation between per capita expenditure and the Human Development Inde in West Java. An increase in per capita expenditure of Rp 1,000 leads to an increase in the

Human Development Inde in West Java of 0.001943238 units.

The parameter coefficient β_0 is 50.44870. The β_0 value indicates West Java's HDI when the per capita expenditure variable is equal to zero. Therefore, when per capita expenditure in West Java is equal to zero, the HDI value in West Java is 50.44870. Figure 5 below shows a scatter plot and a linear regression model line between per capita expenditure and the HDI in West Java.

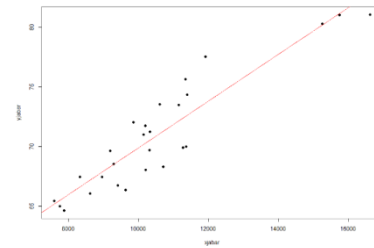


Fig. 5 Scatter Plot between Per Capita Expenditure and HDI in West Java

The relationship between per capita expenditure and the HDI in West Java is positive linear, as shown in Figure 5, where an increase in per capita expenditure will increase the HDI in West Java.

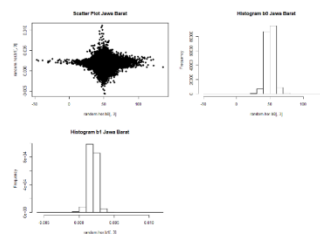


Fig. 6 Scatter Plot and Histogram of Parameters β_0 and β_1 in West Java

Based on the analysis described above, it can be concluded that when per capita expenditure in East Java, Central Java, and West Java is equal to zero, West Java is the province with the highest Human Development Inde HDI among East Java and West Java, at 50.44870.

Next, the 95% confidence intervals for the parameters β_0 and β_1 in the provinces of East Java, Central Java, and West Java are presented, as shown in Table 1. While, Table 2 compares the results of linear regression parameter estimation using the OLS and MCMC methods.

Table 1. Summary of 95% Confidence Intervals for Parameters β_0 and β_1

Province	β_0	CI 95% for β_0	β_1	CI 95% for β_1
East Java	43.37758	[42.77980, 43.97535]	0.00245108	[0.00240298, 0.002507235]
Central Java	46.62472	[46.58544, 46.66401]	0.002322472	[0.002318897, 0.002326048]
West Java	50.44870	[50.42079, 50.47662]	0.001943238	[0.001940651, 0.001945826]

Table 2. Comparison of Parameters β_0 and β_1 Using The OLS and MCMC Methods

Province	OLS		MCMC	
	β_0	β_1	β_0	β_1
East Java	45.85831658	0.00224163	43.37758	0.00245108
Central Java	46.73838504	0.00231219	46.62472	0.002322472
West Java	50.23550930	0.00196295	50.44870	0.001943238

Level II Linear Regression

The results of the level II provincial regression modeling are explained below.

Linear Regression between β_0 and the GRDP Growth Rate Variable

In level II linear regression, the research unit is the province. The results of the regression modeling between β_0 the coefficient vector β_0 of the level I regression in East Java, Central Java, and West Java Provinces and the GRDP growth rate variable are shown in equation 7.

$$\beta_0 = -14.139994 + 11.1097668 W \quad 7$$

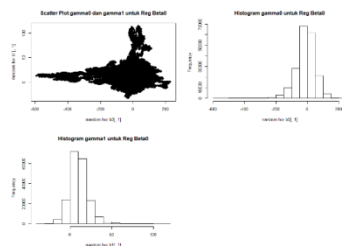


Fig. 7 Scatter Plot and Histogram of γ_{00} and γ_{10} Parameters in Regression Against β_0

Linear Regression between β_1 and the GRDP Growth Rate Variable

In level II linear regression, the research unit is the province. The results of the regression modeling between β_1 the coefficient vector β_1 of the level I regression in the provinces of East Java, Central Java, and West Java and the GRDP growth rate variable are shown in equation 8 below.

$$\beta_1 = 2.191295 - 0.3989273 W \quad 8$$

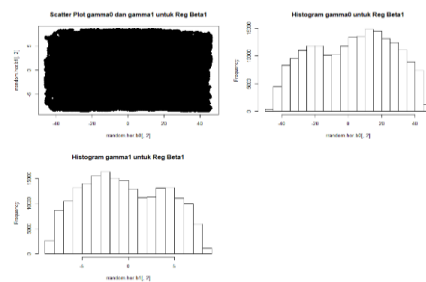


Fig. 8 Scatter Plot and Histogram of Parameters γ_{01} and γ_{11} in Regression Against β_1

Hierarchical Linear Regression Model

The hierarchical linear regression model is obtained by substituting the level II regression model into the level I regression model, as shown in equation 9.

$$Y_{ij} = \beta_0 + \beta_1 X_{ij}$$

$$Y_{ij} = (\gamma_{00} + \gamma_{10} W_j) + (\gamma_{01} + \gamma_{11} W_j) X_{ij}$$

$$Y_{ij} = \gamma_{00} + \gamma_{10} W_j + \gamma_{01} X_{ij} + \gamma_{11} W_j X_{ij}$$

Based on equation 9, the resulting hierarchical linear regression model is:

$$Y_{ij} = -14.139994 + 11.1097668 W_j + 2.191295 X_{ij} - 0.3989273 W_j X_{ij} \quad 10$$

From equation 10, it can be concluded that a 1% increase in the GRDP growth rate W and constant per capita expenditure X and the interaction between per capita expenditure and GRDP growth rate will result in a constant increase in the HDI in the provinces of East Java, Central Java, and West Java. Meanwhile, if per capita expenditure increases by Rp 1,000, and the GRDP growth rate and the interaction

between per capita expenditure and GRDP growth rate are held constant, the HDI in the provinces of East Java, Central Java, and West Java will increase by 2,191,295 units. Furthermore, if the interaction between per capita expenditure and GRDP growth rate increases by 1 unit, and the growth rates of GRDP and per capita expenditure are assumed constant, the HDI will decrease by - 0.3989273 units.

The results of linear regression parameter estimation using slice sampling using MCMC are close to those of linear regression parameter estimation using the OLS method. Theoretically, the HDI value is never negative, but modeling results indicate that the intercept of the hierarchical linear regression model is - 14.139994.

This means that when the GRDP growth rate, per capita expenditure, and the interaction between GRDP growth rate and per capita expenditure are equal to zero, the HDI in East Java, Central Java, and West Java will tend to decline. Furthermore, if the interaction between GRDP growth rate and per capita expenditure increases, then an increase in the HDI should be followed by an increase in East Java, Central Java, and West Java. However, the results of the linear regression modeling show the opposite. This indicates a condition of looped economic growth, where high economic growth is not accompanied by high human development, and a condition of looped human development, where high human development is not accompanied by high economic growth.

These two conditions can be directly reviewed using HDI data and per capita expenditure in East Java, Central Java, and West Java, where several districts/cities in these three provinces have low per capita income but have a high HDI, and several other districts/cities have high per capita income but have a low HDI.

CONCLUSION

A hierarchical linear regression model shows that per capita expenditure and GRDP growth rate significantly influence the HDI in East Java, Central Java, and West Java. The estimation results of the regression model using Markov Chain Monte Carlo MCMC are proven to be close to the OLS model. MCMC is able to calculate the high-dimensional integrals needed to characterize the posterior distribution of the model.

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