Modeling of Exclusive Breastfeeding and Mother Working Status with Recursive Bivariate Probit Model (Case Study in Surabaya City 2017)

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Abstract. There are special cases in Bivariate Probit model where one dependent variable becomes the regressor endogenous variable for the other dependent variable. Therefore, recursive bivariate model is used to solve this case. Exclusive breastfeeding is measured to identify its characteristics so that policies can be formulated to increase the rate of exclusive breastfeeding. The variable of mother working status is endogenous. Therefore, a recursive model is used to model this case. Mother’s working status affects mother’s exclusive breastfeeding. Mothers who do not work increase the chances of a mother being able to give exclusive breastfeeding. The greater the age of the first pregnancy of the mother, the less the chances of mothers to not work. A mother with more child has more chance to not working. A medium number of family member affect a chance for a mother to working. A mother who has last education at the Elementary School has a high chance of exclusively breastfeeding their babies. This may be related to the ability of mothers to work with mother’s education. Early Initiation of Breastfeeding (EIB) affects the opportunity for mothers to exclusively breastfeed. It proves the importance of EIB shortly after the baby is born so that the baby does not confuse the nipple and the breastfeeding process becomes easy. A husband who has last education at Senior High School give a greater chance for the mother to exclusively breastfeed. Recursive Bivariate Probit models have smaller AIC values than Bivariate Probits, which are 522.226 and 526.414. This shows that the Recursive Bivariate Probit model is better at modeling cases of exclusive breastfeeding and the status of working mothers in Surabaya city than Bivariate Probit Model.

1. Introduction
The modeling method between two dependent binary variables that commonly used is the bivariate Probit method. But there are some special cases where one of the dependent variables becomes an endogenous regressor variable for the other dependent variable. The method that can be used in this case is recursive Bivariate Probit regression. Recursive Bivariate Probit regression is a method where two Probit equations whose errors are correlated, and one of the binary dependent variables becomes an endogenous regressor variable for the other dependent variable [1]. Interpretation of the parameter correlations of the Bivariate Probit model is different from the Recursive Bivariate Probit correlation.
The error correlation between the two response variables which approaches 0 can be interpreted that the two variables can be modeled independently of each other. Even though the small correlation could be the estimation error effect of the Bivariate Probit model which turns out to have an endogenous problem in it [2].

Breast milk is the most perfect or best food for babies because it contains nutrients that the baby needs in its growth and development to be optimal, so it needs to be given exclusive breastfeeding for babies. Exclusive breastfeeding is not giving food or other drinks to babies, including water, other than breastfeeding (except drugs and drops of vitamins or minerals; milk is also permitted) [3]. Giving breast milk as the main food for babies, especially babies less than 6 months old, gets special attention from Indonesian government. Through the Decree of the Minister of Health of the Republic of Indonesia No. 450 / MENKES / SK / IV / 2004, the government requires exclusive breastfeeding for babies from birth to 6 months of age. It is also recommended to continue until the child is two years old with appropriate supplementary feeding [4].

The percentage of exclusive breastfeeding in 2017 in the province of East Java is the lowest when compared to other provinces in Java, which amounted to 34.92%. Based on the 2016 Health Profile by the Surabaya City Health Office, the coverage of exclusive breastmilk infants in Surabaya amounted to 65.10% of 19,359 infants [4]. This means that almost half of the baby population in the city of Surabaya does not receive exclusive breast milk.

Many reasons can affect mothers to give exclusive breastfeeding. Things that affect mothers in breastfeeding can come from internal and external factors. The most common reason for not giving exclusive breastfeeding is that the mother has to work, the mother does not have enough milk or thinks she cannot provide enough milk, and minimal family support. In urban areas where relatively more mothers are working to make a living, mothers cannot breastfeed their babies properly and regularly. This is significant because the workplace situation does not yet support the practice of breastfeeding, for example the unavailability of milking and storing breast milk, and not yet widely available or the absence of babysitting so that workers can breastfeed their babies at certain times. The level of mother’s education and mother’s knowledge are important factors to support the success of exclusive breastfeeding for babies, because the higher the level of education, the easier it is to receive information so that more knowledge is possessed. otherwise, less education will prevent the development of one's attitude towards the values introduced [5].

In this study, cases of exclusive breastfeeding and working mother status were examined. It is suspected that working status variables can affect exclusive breastfeeding so that there are endogenous problems. This problem can cause bias in estimating Bivariate Probit models [6]. The method used is a recursive model, namely recursive Bivariate Probit regression to model this case.

2. Bivariate Probit Regression

Bivariate probit regression is a method that describes the relationship between two dependent variables that are qualitative and several independent variables that are qualitative, quantitative, or combined from qualitative and quantitative with a normal CDF distribution approach to estimate parameters so that a probit model is formed [7]. The response variables used are dichotomous or binary so it is assumed to have a binomial distribution.

The response variables are \( y_1 \) and \( y_2 \) where the two variables are formed from unobserved variables \( y_1^* \) and \( y_2^* \) so the equations for the two variables are

\[
\begin{align*}
y_1^* &= \beta_1^T x + \epsilon_1, \quad y_1 = 1 \text{ jika } y_1^* > \gamma \text{ dan } y_1 = 0 \text{ jika } y_1^* \leq \gamma \\
y_2^* &= \beta_2^T x + \epsilon_2, \quad y_2 = 1 \text{ jika } y_2^* > \delta \text{ dan } y_2 = 0 \text{ jika } y_2^* \leq \delta
\end{align*}
\]

where

\[
\begin{align*}
x &= [x_1 \quad \cdots \quad x_p]^T \\
\beta_i &= [\beta_{i0} \quad \beta_{i1} \quad \cdots \quad \beta_{ip}]^T
\end{align*}
\]
\[ \beta_2 = \begin{bmatrix} \beta_{20} \\ \beta_{21} \\ \vdots \\ \beta_{2p} \end{bmatrix}^T \]  
(2)

\[ \beta_1 \text{ dan } \beta_2 \text{ are vectors while } x \text{ is a row vector that has size } (p + 1) \times 1 \text{ where } p \text{ is number of predictor variables.} \]

1. \( E(\varepsilon_1) = E(\varepsilon_2) = 0 \)
2. \( \text{var}(\varepsilon_1) = \text{var}(\varepsilon_2) = 1 \)
3. \( \text{cov}(\varepsilon_1, \varepsilon_2) = \rho \)  
(3)

Error of each model follows a normal distribution. There are two random variables that follow the normal distribution so that a normal bivariate distribution is produced. PDF of the bivariate normal distribution is shown in formula 4 [8].

\[
\begin{align*}
    f(y_1^*, y_2^*) &= \frac{1}{2\pi \sqrt{|\Sigma|}} \exp \left( -\frac{1}{2} \begin{bmatrix} y_1^* - \beta_1^T x \\ y_2^* - \beta_2^T x \end{bmatrix}^T \Sigma^{-1} \begin{bmatrix} y_1^* - \beta_1^T x \\ y_2^* - \beta_2^T x \end{bmatrix} \right)
\end{align*}
\]  
(4)

with

\[
\Sigma = \begin{bmatrix} \sigma_{11}^2 & \sigma_{12} \\ \sigma_{21} & \sigma_{22} \end{bmatrix} = \begin{bmatrix} 1 & \sigma_{12} \\ \sigma_{21} & 1 \end{bmatrix} = \begin{bmatrix} 1 & \rho_{12} \\ \rho_{21} & 1 \end{bmatrix}
\]  
(5)

Then normal bivariate PDF standards are as follows:

\[
\phi(z_1, z_2) = \frac{1}{2\pi \sqrt{|\Sigma|}} \exp \left( -\frac{1}{2(1-\rho^2)} \left( z_1^2 - 2\rho z_1 z_2 + z_2^2 \right) \right)
\]  
(6)

So the joint probability of \( z_1 \) and \( z_2 \) is

\[
P(Y_1^* < \gamma, Y_2^* < \delta) = P(Z_1 < \gamma - \beta_1^T x, Z_2 < \delta - \beta_2^T x)
\]

\[
= P(Z_1 < z_1, Z_2 < z_2)
\]

\[
= \int_{-\infty}^{z_1} \int_{-\infty}^{z_2} \phi(z_1, z_2) \, dz_1 \, dz_2
\]

\[
= \Phi(z_1, z_2)
\]  
(7)

Where \( \Phi(z_1, z_2) \) is the cumulative distribution function of the bivariate standard normal distribution. The two-way contingency table variables \( Y_1 \) and \( Y_2 \) are shown in Table 1.

| Variable \( Y_1 \) | \( Y_2=0 \) | \( Y_2=1 \) |
|---------------------|-----------|-----------|
| \( Y_1=0 \)        | \( Y_{00} \) | \( Y_{01} \) |
| \( Y_1=1 \)        | \( Y_{10} \) | \( Y_{11} \) |

Based on Table 1 it is known that the variable \( Y = \begin{bmatrix} Y_{11} \\ Y_{10} \\ Y_{01} \end{bmatrix}^T \) following the distribution of multinomial distributions that can be denoted by \( Y \sim M \left( l; p_{11}(x), p_{10}(x), p_{01}(x) \right) \) [9].

There are various methods for estimating parameters such as ordinary least square (OLS), weighted least square (WLS), maximum likelihood estimation (MLE), and others. In binary probit modeling, this estimation method used is MLE [1]. This MLE method works with the principle of maximizing the likelihood function.
3. Recursive Bivariate Probit Regression

Recursive Bivariate Probit regression is a method where two Probit equations whose errors are correlated, and one of the binary dependent variables becomes an endogenous regressor variable for the other dependent variable. Suppose the model from recursive Bivariate Probit regression is as follows.

\[ y_1^* = \beta_1^T w + \varepsilon_1, \quad y_1 = 1 \text{ jika } y_1^* > 0 \text{ dan } y_1 = 0 \text{ jika } y_1^* \leq 0 \]  \tag{8}

\[ y_2^* = \beta_2^T x + \delta y_1 + \varepsilon_2, \quad y_2 = 1 \text{ jika } y_2^* > 0 \text{ dan } y_2 = 0 \text{ jika } y_2^* \leq 0 \]  \tag{9}

Where \( x \) and \( w \) are row vectors of exogenous variables. The assumption of recursive bivariate probit regression is

1. \( E[\varepsilon_1 | w, x] = E[\varepsilon_2 | w, x] = 0 \)
2. \( \text{var}[\varepsilon_1 | w, x] = \text{var}[\varepsilon_2 | w, x] = 1 \)
3. \( \text{cov}[\varepsilon_1, \varepsilon_2 | w, x] = \rho \)  \tag{10}

As with bivariate probit regression, the errors of each model follow a normal distribution.

According to Madala (1983) and Greene (2008), recursive bivariate probit models are special models. Greene (2008) denotes a recursive simultaneous equation model, because variable \( Y_1 \) appears in the equation \( Y_2 \) where another endogenous variable \( (Y_2) \) does not appear in the equation \( Y_1 \) [1,10]. The \( Y_1 \) variable in this study is the mother working status, with category 0 being non-working and category 1 working. The exclusive breastfeeding of mothers to their babies is a variable \( Y_2 \) with category 0 is that mothers give exclusive breastfeeding and the category 1 variable for mothers does not give exclusive breastfeeding. The probability of a recursive bivariate probit regression using a normal bivariate distribution to indicate the normal standard bivariate distribution function with correlation \( \rho \) is as follows [11].

\[ P(Y_1 = 1, y_2 = 1) = \Phi(\alpha^T w, \beta^T x + \delta, \rho) \]

\[ P(Y_1 = 1, y_2 = 0) = \Phi(-\alpha^T w, \beta^T x, -\rho) \]

\[ P(Y_1 = 0, y_2 = 1) = \Phi(\alpha^T w, -\beta^T x - \delta, -\rho) \]

\[ P(Y_1 = 0, y_2 = 0) = \Phi(-\alpha^T w, -\beta^T x, -\rho) \]  \tag{11}

Therefore, the expected value of \( y_1 \) given by vectors \( w \) and \( x \) is as follows.

\[ E(y_1 | w, x) = P[y_2 = 1]E[y_1 | y_2 = 1, w, x] + P[y_2 = 0]E[y_1 | y_2 = 0, w, x] \]

\[ = P[y_2 = 1]P[y_1 = 1 | y_2 = 1, w, x] + P[y_2 = 0]P[y_1 = 1 | y_2 = 0, w, x] \]

\[ = P[y_1 = 1, y_2 = 1] + P[y_1 = 1, y_2 = 0] \]

\[ = \Phi(\alpha^T w, \beta^T x + \delta, \rho) + \Phi(-\alpha^T w, \beta^T x, -\rho) \]  \tag{12}

In the Recursive Bivariate Binary Probit model, the estimated method used is MLE. The first step of the MLE method is to get the first derivative in likelihood of the parameter for \( \beta_1 \), \( \beta_2 \), and \( \rho \) by getting the gradient vector \( g \). After obtaining the \( g \) vector, then look for the Hessian matrix \( H(\beta) \) which is the second derivative of the vector \( g \) component for each parameter. The vector \( g \) and the Hessian matrix can be denoted as follows.
The estimation results are not close form, so Fisher Scoring iterations are carried out to converge. The Fisher Scoring information matrix is the expectation of the Hessian matrix.

\[
\beta^{(m+1)} = \beta^{(m)} - \left(-E\left[H\left(\beta^{(m)}\right)\right]\right)^{-1} g\left(\beta^{(m)}\right)
\]

The iteration process will stop if it has converged, that is if \( |\beta^{(m)} - \beta^{(m+1)}| \leq \delta \), where \( \delta \) is a very small number [12].

4. Exogeneity Test
Exogenous hypothesis testing is based on value \( \rho \), which is the correlation between unobserved variables in two equations. If \( \rho = 0 \) then \( \varepsilon_{i1} \) and \( \varepsilon_{i2} \) is not correlated which means that there is exogeneity. Conversely, if \( \rho \neq 0 \) then there is an endogenous problem in model. Testing the hypothesis to test exogeneity can be done with the Lagrange Multiplier Test with the following hypothesis.

H₀: \( \rho = 0 \)
H₁: \( \rho \neq 0 \)

With the Lagrange Multiplier test statistics as follows

\[
LM = d\left(\hat{\beta}_0\right)^\top I\left(\hat{\beta}_0\right)^{-1} d\left(\hat{\beta}_0\right) \sim \chi^2_{(k)}
\]

LM test statistics follow the Chi-Square distribution so the H₀ rejection area if \( LM > \chi^2_{(\alpha)} \) [13].

5. Data
The data used in this study are secondary data originating from the East Java Central Bureau of Statistics. The data used is the survey results by SUSENAS 2017 in the city of Surabaya, East Java province. In this study the research unit used was a mother aged 15-49 years who had a baby aged 6-59 months in the Surabaya city, East Java province. The variables used in this study are as follows.
### Table 2 Research Variables

| No. | Variable | Explanation | Category |
|-----|----------|-------------|----------|
| 1   | $Y_1$    | Mother working status | 0= Working  
|     |          |             | 1= Not working |
| 2   | $Y_2$    | Exclusive breastfeeding | 0= Not exclusive  
|     |          |             | 1= Exclusive |
| 3   | $X_1$    | Mother’s age | -         |
| 4   | $X_2$    | The first age of the mother got married | - |
| 5   | $X_3$    | Mother’s Last Education | 1= Elementary School  
|     |          |             | 2= Junior High School |
|     |          |             | 3= Senior High School  
|     |          |             | 4= Undergraduate |
| 6   | $X_4$    | The first age of the mother was pregnant | - |
| 7   | $X_5$    | Number of childbirth | 1= Small (<5 people)  
|     |          |             | 2= Medium (5-6 people) |
|     |          |             | 3= Big (>6 people) |
| 8   | $X_6$    | Number of family members | 1= Elementary School  
|     |          |             | 2= Junior High School  
|     |          |             | 3= Senior High School  
|     |          |             | 4= Undergraduate |
| 9   | $X_7$    | Husband’s Last Education | 0= Not working  
|     |          |             | 1= Strata 1  
|     |          |             | 2= Strata 2  
|     |          |             | 3= Strata 3  
|     |          |             | 4= Others |
| 10  | $X_8$    | Husband’s job | 0= Yes |
| 11  | $X_9$    | EIB (Early Initiation Breastfeeding) | 1= No |

### 6. Main Results

Recursive Bivariate Probit regression modeling is done if there is an endogenous problem, that is, one of the response variables affects the other response variables, and the errors of the two models are correlated with each other. There isn’t multikolinearity among the predictors. It shown from the small values of Rank Spearman correlation of predictor variables (less than 0.9). Endogeneity detection can be done by some testing, one of them is the Langrange Multiplier test. In cases of exclusive breastfeeding in the city of Surabaya 2017, it was found that there was an endogenous problem where the status of working mothers affected exclusive breastfeeding. The p-value from the Lagrange Multiplier test is 0 so it fails to reject $H_0$, which means that error errors from the exclusive breastfeeding model and maternal working status correlate with each other and the status of working mothers affects exclusive breastfeeding. Processing using Recursive Bivariate Probit regression method and Bivariate Probit regression method produces the following parameters.
Table 3. Estimation of Parameters of the Recursive Bivariate Probit Regression Model

| Working Mother Status | Recursive Bivariate Probit | Bivariate Probit |
|-----------------------|---------------------------|------------------|
|                       | Estimation | P value | Estimation | P value |
| (Intercept)            | -0.240     | 0.713   | -0.339     | 0.643   |
| X1                    | -0.019     | 0.375   | -0.025     | 0.239   |
| X2                    | 0.075      | 0.086   | 0.059      | 0.217   |
| X3(2)                 | -0.189     | 0.516   | -0.194     | 0.510   |
| X3(3)                 | 0.020      | 0.936   | -0.065     | 0.797   |
| X3(4)                 | 0.074      | 0.827   | 0.036      | 0.915   |
| X4                    | -0.069     | 0.033   | *          | 0.164   |
| X5                    | 0.478      | 0.000   | *          | 0.002   |
| X6(2)                 | -0.391     | 0.039   | *          | 0.002   |
| X6(3)                 | 0.151      | 0.532   | 0.249      | 0.372   |
| X7(2)                 | 0.184      | 0.547   | 0.229      | 0.458   |
| X7(3)                 | -0.272     | 0.318   | -0.230     | 0.404   |
| X7(4)                 | -0.228     | 0.485   | -0.162     | 0.624   |
| X8(1)                 | 0.02       | 0.952   | 0.387      | 0.444   |
| X8(2)                 | 0.267      | 0.516   | 0.439      | 0.415   |
| X8(3)                 | -0.293     | 0.536   | -0.263     | 0.664   |
| X8(4)                 | 0.295      | 0.437   | 0.433      | 0.405   |

| Exclusive Breastfeeding | Recursive Bivariate Probit | Bivariate Probit |
|-------------------------|---------------------------|------------------|
| (Intercept)             | -1.600                    | 0.009            |
| Y1(1)                  | 1.582                     | 0.000 *          |
| X1                      | -0.022                    | 0.369            |
| X2                      | 0.028                     | 0.360            |
| X3(2)                   | 0.620                     | 0.038 *          |
| X3(3)                   | -0.050                    | 0.840            |
| X3(4)                   | -0.167                    | 0.616            |
| X4                      | -0.102                    | 0.472            |
| X5                      | 0.980                     | 0.000 *          |
| X6(2)                   | -0.244                    | 0.436            |
| X6(3)                   | 0.579                     | 0.037 *          |
| X7(4)                   | 0.429                     | 0.192            |

From Table 3, it is known that the variables that are significant for $y_1$ in the Recursive Bivariate Probit model are the variables of the first age of marriage, the number of deliveries, and many family members; while the variables that are significant to $y_2$ are variables of working status for mother, mother's education, IMD and husband's education. In the Bivariate Probit model, the variable that is significant for $y_1$ is the number of deliveries; while the variables that are significant for $y_2$ are maternal education and IMD. From these results, the Recursive Bivariate Probit regression model is obtained following exclusive breastfeeding cases.
The value of classification accuracy is sought by comparing the actual data with the results of the Recursive Bivariate Probit regression model. Based on the Recursive Bivariate Probit regression model that has been formed, the probability predictive value of each working status category and exclusive breastfeeding is calculated. The value of the classification accuracy obtained is 48.357%.

Marginal effects are used to determine the effect of a predictor variable on the model. In cases of exclusive breastfeeding in Surabaya, the marginal effect values of the number of childbirth can be calculated on each data observation. Mothers in Surabaya who were pregnant and married for the first time at the age of 16 years with the number of childbirth as many as 4 times until 2017 and the last education is a high school has the following marginal effect.

\[
\hat{y}_1 = -0.240 - 0.019x_1 + 0.075x_2 - 0.189x_{3(2)} + 0.020x_{3(3)} + 0.074x_{3(4)} - 0.069x_4 + 0.478x_5 - 0.391x_{6(2)} + 0.151x_{6(3)} + 0.184x_{7(2)} - 0.272x_{7(3)} - 0.228x_{7(4)} + 0.020x_{8(1)} + 0.267x_{8(2)} - 0.293x_{8(3)} + 0.295x_{8(4)}
\]

\[
\hat{y}_2 = -1.600 + 1.582y_{1(1)} - 0.022x_1 + 0.028x_2 + 0.620x_{3(2)} - 0.050x_{3(3)} - 0.167x_{3(4)} - 0.102x_4 + 0.980x_{6(3)} - 0.244x_{7(2)} + 0.579x_{7(3)} + 0.429x_{7(4)} - 0.102x_5 + 0.980x_{9(1)}
\]

On the value of marginal effects, \( p_{01} \) is the highest value so that the variable is categorized into mothers who have working status and have given exclusive breastfeeding to their babies. If the number of childbirth increases by one unit, it will increase the probability of the mother to working and exclusively breastfeeding as much as 0.213.

Comparison of the two methods is done to see which model is good and appropriate. After knowing the results of Recursive Bivariate Probit regression, the data is also modeled by Bivariate Probit regression. The value used to compare the two methods is the AIC value. The AIC value of the Recursive Bivariate Probit regression model was 522.226 and the Bivariate Probit regression was 526.414. These results indicate that the Recursive Bivariate Probit regression model is better at...
modeling exclusive breastfeeding in Surabaya. In addition, it was also found that the results of Bivariate Probit regression modeling did not produce correlated errors between \( y_1 \) and \( y_2 \). This indicates that the two models should be modeled independently or there are cases of endogeneity in them. With the previous Recursive Bivariate Probit regression, the \( y_1 \) and \( y_2 \) models have been shown to have endogenous cases.

7. Conclusion

Based on the results and discussion of exclusive breastfeeding mother's case studies in Surabaya in 2017, the results are as follows:

Recursive bivariate regression models from exclusive breastfeeding cases are

\[
\hat{y}_1 = -0.240 - 0.019 x_1 + 0.075 x_2 - 0.189 x_3 + 0.020 x_4 + 0.074 x_5 - 0.069 x_6 + 0.478 x_7 - 0.391 x_8
+ 0.151 x_9 + 0.184 x_{10} - 0.272 x_{11} - 0.228 x_{12} + 0.020 x_{13} + 0.267 x_{14} - 0.293 x_{15} + 0.295 x_{16}
\]

\[
\hat{y}_2 = -1.600 + 1.582 y_{1(1)} - 0.022 y_1 + 0.028 y_2 + 0.620 y_{3(2)} - 0.050 y_{3(3)} - 0.167 y_{4(4)} - 0.102 y_3 + 0.980 y_{6(3)}
- 0.244 y_{7(2)} + 0.579 y_{7(3)} + 0.429 y_{7(4)}
\]

Recursive Bivariate Probit regression models are able to model exclusive breastfeeding cases better than Bivariate Probit regression.

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