Determinants of Immunization Among Children Aged 12-23 Months in Ethiopia: A Proportional Odds Model Approach

Mesay Tefera* and M.K. Sharma

Department of Statistics, Addis Ababa University, Addis Ababa, Ethiopia

Abstract: Childhood immunization is recognized as one of the most cost-effective public health interventions to prevent morbidity and mortality caused by infectious diseases, particularly in a high-endemic setting. According to the 2011 EDHS report by the Central Statistical Agency (CSA) of Ethiopia, nationally, only 24 percent of children age 12-23 months was fully immunized at the time of the survey. The main objective of this study was to identify and describe the determinants of immunization among children aged 12-23 months in Ethiopia. The source of the data was the Ethiopian Demographic and Health Survey conducted in 2011 (EDHS) 2011. In order to meet our objectives descriptive, and ordinal logistic regression (proportional odds model) statistical techniques were used for data analysis using socio-economic and demographic variables as explanatory variables and immunization status of children aged 12-23 months as the response variable. The results of the analysis predicts that place of delivery, wealth index, possession of radio and region were found to be significant determinants for full immunization among children aged 12-23 months in Ethiopia.

Keywords: Immunization, Children aged 12-23 months old, Socioeconomic and Demographic factors, Proportional Odds Model.

1. INTRODUCTION

Childhood immunization is the initiation of immunity through application of vaccine [1]. It is recognized as one of the most cost-effective public health interventions to prevent morbidity and mortality caused by infectious diseases, particularly in a high-endemic setting [2-5]. Each year, immunization averts an estimated 2-3 million deaths from diphtheria, tetanus, pertussis (whooping cough) and measles [6].

Immunization has great potential to improve the health of people. It is considered important for improving child survival [7]. The inception of public immunization campaigns has contributed in reducing vaccine preventable diseases and deaths globally. It is enshrined as one of the utmost medical accomplish-ment that has succeeded to save more lives than any other health care intervention in the 20th century [8]. And also immunization is reported to be second to clean water in reducing the burden of infectious diseases [9]. It is said to be the single most efficient and cost effective means of controlling these diseases [10, 11]. This is evident in the drastic decline, and in some cases elimination, of certain infectious diseases since the introduction of vaccines in the 20th century [11, 12].

In 1974, World Health Organization (WHO) established the Expanded Programme on Immunization (EPI) to ensure that all children had access to routinely recommended vaccines [6]. Despite improvement in global coverage with the third dose of diphtheria– tetanus–pertussis vaccine (DTP) from 5%in 1974, about one fifth of the world's children had not completed the 3-dose DTP series by 2011. During 2012, an estimated 83% of infants worldwide received at least 3 doses of DTP vaccine, identical to estimates in 2010 and 2011. Among 194 WHO member states, 131 (68%) achieved 90% and above DTP3 coverage and 59 (30%) achieved 80% and above DTP3 coverage in every district. The EPI covers six most common vaccine preventable diseases which to a great extent affect children. These include tuberculosis, measles, poliomyelitis, whooping cough, diphtheria and tetanus, other diseases were also added to the EPI program. These include yellow fever and hepatitis. Currently, the EPI administers eight vaccines: BCG (tuberculosis vaccine), oral polio vaccine (OPV), diphtheria pertussis-tetanus (DPT) vaccine, hepatitis B (HepB) vaccine, measles vaccine, yellow fever vaccine, and haemophilias influenza type b and tetanus toxoid (TT) vaccines [5]. In Ethiopia, currently the EPI program has eight vaccine preventable diseases. And vaccination is given on routine. The routine vaccinations services are given starting from birth and should be completed before one year of life by all children [13].

Among the 22.6 million children who did not receive 3 DTP doses during the first year of life, 12.4 million (55%) lived in 3 countries. These are India (30%), Nigeria (17%) and Indonesia (7%) and 16.3 million

*Address correspondence to this author at the Department of Statistics Addis Ababa University, Addis Ababa, Ethiopia; Tel: +251946729198;
Fax: +251 116 670 662; E-mail: mesay.pi@gmail.com

E-ISSN: 1929-6029/15

(72%) lived in 10 countries. An estimated 12.6 million (56%) children did not receive the first DTP dose, while nearly 10 million (44%) started, but did not complete, the 3-dose DTP series [6].

An important aspect is that more than seventy percent of these children live in ten countries (including five African country) namely; Afghanistan, Chad, Democratic Republic of the Congo, Ethiopia, India, Indonesia, Nigeria, Pakistan, Philippines and South Africa. This makes these countries to be the hub of these virulent viruses and pose challenges on measures towards eradication [14]. Half of all unvaccinated children live in India, Indonesia and Nigeria. These countries have large child populations and their immunization programs are hampered by occasional problems with vaccine supply and inaccessibility to vulnerable populations [15]. The Ethiopia Expanded Program on Immunization was started in 1980 with an intention of reaching 100% coverage by 1990 [6]. The EPI program in Ethiopia is administered by the Ministry of Health with technical support from the WHO and other organizations. International partners provide extra support in expanding coverage of EPI. For instance, the Reaching Every District (RED) approach is collaboration with the WHO, USAID, UNICEF, Global Alliance for Vaccines and Immunization (GAVI), and Centers for Disease Control (CDC) [16]. The RED approach consists of strengthening social mobilization activities, and developing culturally appropriate behavioural change communication strategies [17].

Currently Ethiopia has recorded significant reduction in childhood mortality rate by increasing child immunization coverage. The DPT3 immunization coverage reached 84.9% in 2011/12 against the target of 90%. It is estimated that increasing immunization has the second highest impact (after access to clean water) on reducing child mortality and should be prioritized during the remaining few years in order for the country to reach the Millennium Development Goals (MDGs) target by 2015.

Determinants of childhood vaccination uptake still remain complex, and are dependent on various socioeconomic, demographic factors and also supply and demand factors. A multiregional study done in Malawi, Ethiopia, India, Bangladesh, and Philippines showed that there was a very significant general demand for better quality of vaccination services [18]. Maternal characteristics, sex of child and birth order of the child, place of delivery and antenatal care (ANC) follow up, wealth index, knowledge about vaccination and place of residence could influence immunization coverage among children [19]. Male infant mortality in Ethiopia is higher than the female infant mortality [20]. According to [16], Age of mother and sex of child were not significant factors in vaccination uptake. Children of low parity households in Ethiopia were also more likely to be vaccinated than those in high parity families [16, 21]. In their study in southern Ethiopia found that family size, age of mother, ethnicity, religion or educational statuses were not associated with child immunization. Presently, there is no further study that has explored the determinants of full immunization in children aged 12-23 months and in relation to several mothers or caregiver's and father or partner socio-demographic variables like mothers education, father/partner education sex of child, place of residence, wealth index (household), child place of delivery, birth order of the child and region of residence; as well as access to media factors by evaluating factors like radio ownership. Our objective is to explore the associations between these variables. The knowledge of association can substantially improve the practical interventions that are efficient and cost-effective in the healthcare delivery system of vaccines in Ethiopia. The knowledge would enable planning of cost effective and efficient vaccine programs in stopping vaccine preventable diseases like polio, measles, tetanus, pertussis, diphtheria and tuberculosis in children in Ethiopia.

2. DATA AND METHODOLOGY

2.1. Source of Data

The source of data for the study was the 2011 Ethiopia Demographic and Health Survey (EDHS) conducted by Central Statistical Agency (CSA). The 2011 Ethiopia Demographic and Health Survey was designed to provide estimates for the health and demographic variables of interest for the following domains: Ethiopia as a whole; urban and rural areas (each as a separate domain); and 11 geographic administrative regions (9 regional governments and 2 city administrations).

The 2011 EDHS sample was selected using a stratified, two-stage cluster design; enumeration areas (EAs) were the sampling units for the first stage. The sample included 624 EAs, 187 in urban areas and 437 in rural areas. Households comprised the second stage of sampling.

A complete listing of households was carried out in each of the 624 selected EAs from September 2010

through January 2011. A representative sample of 17,817 households was selected for the 2011 EDHS, of which 17,018 were covered during data collection. Of these, 16,702 were successfully interviewed, yielding a household response rate of 98 percent. All women aged 15-49 and all men aged 15-59 were eligible for interview. The 2011 Ethiopia Demographic and Health Survey used three questionnaires: the Household Questionnaire, the Woman's Questionnaire, and the Man's Questionnaire. These questionnaires were adapted from model survey instruments developed for the MEASURE DHS project to reflect the population and health issues relevant to Ethiopia. In addition to English, the questionnaires were translated into three major local languages-Amharigna, Oromiffa, and Tigrigna. In the interviewed households 17,385 eligible women were identified for individual interview; complete interviews were conducted for 16,515, yielding a response rate of 95%. Similarly, a total of 15,908 eligible men were identified for interview; completed interviews were conducted for 14,110, yielding a response rate of 89%. In general, response rates were higher in rural areas than urban areas, for both women and men. And for the analysis presented in this study, 1882 children aged 12-23 months captured by the data with the questions being answered by their mothers/caregiver.

2.2. Variables Considered in the Study

2.2.1. The Response Variable

The Response variable is immunization status. According to the World Health Organization (WHO), each child is expected to have completed an immunization schedule before celebrating his/her first birthday. Through this, a child is considered fully vaccinated (immunized) if he or she has received a BCG vaccination against tuberculosis, three doses of DPT, vaccine to prevent diphtheria, pertussis, and tetanus; at least three doses of polio vaccine; and one dose of measles vaccine within the first year. And partially immunized means if the child received only some of the vaccines mentioned above and not immunized means that the child did not received any vaccines. In order to meet the objective set in this study we create the following response variables.

$$Y_i = \begin{cases} 1, \text{ if a child aged } 12-23 \text{ months old has received all the recommended vaccines} \\ 2, \text{ if a child aged } 12-23 \text{ months old only received some of the recommended vaccines} \\ 3, \text{if a child aged } 12-23 \text{ months old did not received any vaccines} \end{cases}$$

2.2.2. Predictor/Variables

The predictor variables to be studied as determinants of immunization among children aged 12-23 months old in Ethiopia are listed in Table **1** below

Table 1: Description and Categories of Explanatory Variables

Variables and Categories representation of variables	Categories
Sex of child	0= Female 1= Male
Place of Residence	0=urban 1=rural
Mother's Education (EDUM)	0 = No education 1 =primary 2 =secondary and higher
Education of husband/partner (EDUP)	0 = No education 1 = Primary education 2 = Secondary and above
Wealth index	0= Poor 1= Medium 2= Rich
Place of delivery	0= Home / and other non health facility places 1= Hospital / and other health facility places
Birth order of the child	0 = 1 1 = 2-3 2 = 4-5 3 = 6+
Possession of Radio	0 = No 1= Yes
Region	1=Tigray 2=Afar 3= Amhara 4=Oromiya 5=Somali 6=Ben-Gumuz 7=SNNP 8=Gambela 9=Hareri 10=Addis Ababa 11=Dire Dawa

2.3. Methodology

In this study we have employed ordinal logistic regression (Proportional Odds) model.

2.3.1. Proportional Odds (PO) Model

Ordinal data are often analyzed using the Proportional Odds Model (POM). The Proportional

Odds model is a popular extension of logistic regression to ordinal data [22, 23]. The motivation of the models is the existence of an underlying continuous and perhaps unobserved random variable [23].

The proportional odds model assumes that the cumulative logits can be represented as parallel linear functions of the independent variables. That is, for each cumulative logit the parameters of the models are the same, except for the intercept. Consequently, according to the proportional odds assumption, the odds ratio is the same for all categories of the response variable.

Let Y takes categorical response variable with *K* ordered categories and assume

$(Y=1)=P_1,(Y=2)=P_2,\ldots,P(Y=j)=P_j;$ for j =1,2,…,K. Cumulative probabilities reflect the ordering, with $P(Y\le 1)\le P(Y\le 2)\le\cdots\le P(Y\le K)=1.$ and let the cumulative probability of the first of Y is P(Y≤ j| X) = ϕ_j (**X**), j = 1, 2,…, K-1

Then proportional odds model models the log odds of the first K-1 cumulative probabilities which is

$$\begin{aligned}&\log it\left[P(Y\le j|X\right]=\log\left[\frac{P(Y\le j|\mathbf{X})}{1-P(Y\le j|\mathbf{X})}\right]\\&=\log\left[\frac{P(Y\le j|\mathbf{X})}{P(Y>j|\mathbf{X})}\right]\\&=\log\left[\phi_1(\mathbf{X})+\ldots+\phi_j(\mathbf{X}))/(\phi_{(j+1)}(\mathbf{X})+\ldots+\phi_K(\mathbf{X}))\right]\\&=\alpha_j+\mathbf{X}'\beta_i=\alpha_j+\sum_i^p\beta_iX_i,\end{aligned}\quad(2.1)$$

$j=1,2,\ldots,K-1\ and\ i=1,2,\ldots,p$

Where P(Y≤ j| X) = ϕ_1(X) + ... + ϕ_k(X)

α_j term called the threshold

ϕ_1(X) + ... + ϕ_k(X) = 1

j =1, …, K denotes the number of response categories and *p* denote the number of explanatory variables .

The above Equation (2.1) is called proportional odds model and it has the same effect of vector β for each cumulative logit. In this model, each cumulative logit has its own α_j term called the threshold value and their values do not depend on the values of the independent variable for a particular case. The α_j are increasing in j, since $P(Y\le j|\mathbf{X})$ increasing in j for fixed **X** [1].

2.3.2. Estimation of Model Parameters

The maximum likelihood estimation (MLE) procedure is used to obtain estimates of the model parameters. Two iterative maximum likelihood algorithms are available in SAS PROC LOGISTIC. For this study the Fisher scoring method is used to get the maximum likelihood estimate parameters. The dependent variable (y) used in this study is the immunization status of children aged 12-23 months old in Ethiopia with value of 1 (fully immunized), 2 (partially immunized) and 3(not immunized). Let $p_1=P(y=1),p_2=P(y=2)$ and $p_3=P(y=3)$. Then the logit model has the form:

$$logit(p_1)\equiv\log\left(\frac{p_1}{1-p_1}\right)=\log\left(\frac{p_1}{p_2+p_3}\right)$$

$$=\alpha_1+\beta_1x_1+\beta_2x_2+\cdots+\beta_px_p$$

$$logit(p_1+p_2)\equiv\log\left(\frac{p_1+p_2}{1-(p_1+p_2)}\right)$$

$$=\log\left(\frac{p_1+p_2}{p_3}\right)=\alpha_2+\beta_1x_1+\beta_2x_2+\cdots+\beta_px_p$$

We see that while the intercepts are different the remaining regression parameters are the same. It is easy to see that the odds become

$$\frac{p_1}{1-p_1}=e^{\alpha_1}e^{\beta_1x_1+\beta_2x_2+\cdots+\beta_px_p},$$

$$\frac{p_1+p_2}{p_3}=e^{\alpha_2}e^{\beta_1x_1+\beta_2x_2+\cdots+\beta_px_p}=c\left(\frac{p_1}{1-p_1}\right)$$

Where $c=\exp(\alpha_2-\alpha_1)$. Hence the name proportional odds model implies that that odds ratios for y being fully immunized (1) versus partially immunized or not immunized (2 or 3) and y being fully immunized or partially immunized (1 or 2) versus not immunized (3), are the same.

After the parameters $\alpha_1,\alpha_2,\beta_1,\beta_2,\ldots,\beta_p$ are estimated, it is easy to compute predicted probabilities using the following formulas derived from the above equations.

$$\hat{p}_1=\frac{e^{\hat{\alpha}_1+\hat{\beta}_1x_1+\hat{\beta}_2x_2+\cdots+\hat{\beta}_px_p}}{1+e^{\hat{\alpha}_1+\hat{\beta}_1x_1+\hat{\beta}_2x_2+\cdots+\hat{\beta}_px_p}},$$

$$\hat{p}_1+\hat{p}_2=\frac{e^{\hat{\alpha}_2+\hat{\beta}_1x_1+\hat{\beta}_2x_2+\cdots+\hat{\beta}_px_p}}{1+e^{\hat{\alpha}_2+\hat{\beta}_1x_1+\hat{\beta}_2x_2+\cdots+\hat{\beta}_px_p}}\ and$$

$$\hat{p}_3=1-(\hat{p}_1+\hat{p}_2)$$

In standard practice, the null hypothesis of equal slopes (proportional odds) is tested with the score test for proportional odds. A statistically non-significant test is considered sufficient evidence that the proportional odds assumption was not violated. Because this test is sensitive to sample size and may be significant in cases with minimum deviation from proportionality, some authors recommend plotting the log odds generated by each cut point as a complementary analysis for proportionality of odds [24].

2.3.3. Proportional Odds (PO) Assumption

This assumption has many different names: proportional odds assumption [25] parallel regression assumption [26], and parallel line assumption [27]. It is important that we recognize these different names and realize that they refer to the assumption that the coefficients are equal across all cut points. For this study, we will use the word " proportional odds assumption" and "parallel line assumption" interchangeably .

2.3.4. Violation of the Proportional Odds Assumption (Parallel Line Assumption)

Prior to fitting the ordered logit model, the parallel line assumption can be tested. If the parallel line assumption is not violated, then the ordered logit model is estimated.

2.3.5. Partial Proportional Odds Model

As the proportional odds assumption is difficult to achieve in practice, the Partial Proportional Odds Model (PPOM) may be used as an alternative. This model allows some covariates with the proportional odds assumption to be modeled, but for those variables in which this assumption is not satisfied it is increased by a coefficient (γ), which is the effect associated with each i^{th} cumulative logit, adjusted by the other covariates. The general form of the model is the same as the PO model, but now the coefficients are associated with each category of the response variable.

Partial proportional odds model can be classified as Unrestricted Partial Proportional Odds Mode (URPPOM) and the restricted one. The unrestricted partial proportional odds model is used when proportional chances assumption is not valid and the coefficients are associated with each category of the response variable (in the case of both parallel and linear assumption are not fulfilled).

The model has the form:

$$P(Y_i \le j|X) = \frac{(\alpha_j + \beta_1 X_{1i} + \beta_2 X_{2i} + \beta_{3j} X_{3i})}{1+\exp(\alpha_j + \beta_1 X_{1ic} + \beta_2 X_{2i} + \beta_{3j} X_{3i})}, \quad (2.2)$$
$$j = 1,2,\ldots\ldots,K-1$$

where *i* represents the child, *j* is the different immunization status categories, and *m* is the number of immunization status categories. In the Partial Constrained Ordered Logit (PCOL) model, the parallel line assumption is relaxed for only those variables that violate the assumption; this means that some of the β's can be the same for all values of *j,* while other β's can differ across the different immunization status. For instance, equation (3.12) indicates that the coefficients for variables X_1 and X_2 are constant for all values of *j*, while X_3*'s* coefficient can vary across the different values of *j* [28].

2.3.6. The Odds Ratio

Logistic regressions work with odds so it is necessary to define both odds and odds ratio. The odds are simply the ratio of the probabilities for the two possible outcomes. Ifπ is the probability that the event will occur, then 1 – π is the probability that the event will not occur

$$odds = \frac{\pi}{1-\pi} \quad (2.3)$$

The odds ratio is a measure of association for 2×2 contingency table [29]. In 2×2 tables the probability of "success" is π_1 in row 1 and π_2 in row 2. Within row 1, the odds of success is defined as $odds_1 = \frac{\pi_1}{1-\pi_1}$ and within row 2 the odds of success equal $odds_2 = \frac{\pi_2}{(1-\pi_2)}$ [30, 31] [2]define the odds ratio in two groups of subjects as "the ratio of odds". Thus;

$$odds_2 = \frac{\pi_2}{(1-\pi_2)}$$
$$\theta = \frac{odds_1}{odds_2} = \frac{\pi_1(1-\pi_2)}{\pi_2(1-\pi_1)}$$

2.3.7. A Test of a Single Predictor

2.3.7.1. The Wald Test

The Wald test is an alternative test which is commonly used to test the significance of the individual logistic regression coefficients for each independent variable. That is, the Wald test is used to test

$H_0 : \beta_j = 0$ against $H_0 : \beta_j \neq 0$

j= 1,…,k

For a dichotomous independent variable, the Wald statistic (W) is

$$W = \left[\frac{\hat{\beta}_j}{se(\hat{\beta}_j)} \right]^2 , \text{ j=1,…, k} \quad (2.4)$$

For large sample size this statistic has an approximate chi-square distribution with one degree of freedom under the assumption that H_0 is true.

2.3.8. Goodness of Fit of the Model

[32] suggest a novel approach for testing the goodness of fit of the proportional odds models. This method is based on the notion of partitioning the subjects into groups or regions. To form the goodness of fit statistic used in this approach, firstly a score S_m is assigned to response category *m*. The assigned scores may in some instances be the actual numerical response or the midpoint of the interval when the response is crude grouping of an underlying continuous variable. When the response has no underlying numerical scale, such as a response with 3 levels: Fully immunized, Partially immunized, None immunized are often an integer score is used such as, 1= Fully immunized, 2= Partially immunized, 3= None immunized.

Then a fitted score or a predicted mean score can be defined as,

$$\hat{\mu}_t = \sum_{l=1}^{m} s_1 \hat{p}_{tl} \text{ ; t= 1, 2, ……., n} \quad (2.5)$$

Where n is the number of subjects and $\hat{p}_{t1}$, $\hat{p}_{t2}$,……, $\hat{p}_{tm}$ are the predicted probabilities for the t^{th} subject for the m response levels.

Then to form the goodness of fit statistic, the subjects should be partitioned or grouped into *G* regions based on the percentiles of the predicted mean scores $\hat{\mu}_t$. As a general rule, the value of *G should* be decided such that 6 ≤ *G* < n/5*m*. In practice, any *G* that satisfies the inequality can be used; for the Hosmer-Lemeshow statistic for binary responses, *G* = 10 has become popular. Given the partition of the data, the goodness of fit statistic is formulated by defining *G*–1 group indicators,

$$I_{tg} = \begin{cases} 1 \text{ ,if } \hat{\mu}_t \text{ is in region } g \\ 0 \text{ , otherwise} \end{cases}$$

Where g = 1, 2, …, *G* – 1.

Then to assess the goodness of fit of model (2.1) the following alternative model is constructed.

$$logit[P(Y \leq j|X)] = \alpha_j + \sum_{i}^{p} \beta_i X_i + \sum_{g-1}^{G-1} I_g \gamma_g \quad (2.6)$$

where g = 1, 2, …, *G* – 1, *j*= 1, 2, …K-1 and *i* = 1, 2, ……p

If the model (2.6) is correctly specified, then $H_0 : \gamma_1 = \gamma_2 \ldots = \gamma_9 = 0$ is not rejected.

2.3.1.4. Model Diagnostics

Regression model building is often an iterative and interactive process.

There are three ways that an observation can be considered as unusual, namely outlier, influence and leverage.

To identify if an observation is outlier or influential, the following rules of thumb were employed in this study.

- **Residuals:** Standard and deviance residuals are obtained for each observation. Observations with values larger than 3 in absolute value are considered as outliers [29].

- **Leverage Value (Hat Diagonal)** is a measure of how far an observation is from the others in terms of the levels of the independent variables (not the dependent variable). Observations with values larger than one are considered to be potentially highly influential [33].

- **DFBETA(S)** is a diagnostic measure which measures the change in the logit coefficients for a given variable when a case is dropped. If DFBETAs is less than unity, this implies no specific impact of an observation on the coefficient of a particular predictor variable, while DFBETA of a case greater than 1.0, and implies the observation is an outlier [34].

  Cook's D is a measure of aggregate impact of each observation on the group of regression coefficients, as well as the group of fitted values. In logistic regression, a case is identified as influential if its Cook's distance is greater than 1.0 [35].

Table 2: Distribution of Socioeconomic and Demographic Characteristics of Child Immunization

Variables	Level Children of Immunization Status						Total
	Fully immunized		Partially immunized		Not immunized		
	Count	%	Count	%	Count	%	
Child immunization Status	541	28.7	1028	54.6	313	16.6	1882
Sex of child							
Female	272	29.3	510	55.0	145	15.7	927
Male	269	28.2	518	54.2	168	17.6	955
Place of Residence							
rural	361	23.3	900	58.1	288	18.6	1549
urban	180	54.1	128	38.4	25	7.5	333
Mother's Education							
No education	304	23.9	693	54.6	273	21.5	1270
primary	164	33.2	293	59.3	37	7.5	494
secondary and higher	73	61.9	42	35.6	3	2.5	118
Education level of partner							
No education	215	22.9	507	54.1	215	22.9	937
Primary education	227	32.0	401	56.5	82	11.5	710
Secondary and above	99	42.1	120	51.1	16	6.8	235
Wealth index							
Poor	159	17.8	523	58.5	212	23.7	894
Medium	81	26.7	182	60.1	40	13.2	303
Rich	301	43.9	323	47.2	61	8.9	685
Place of delivery							
Home / No Health facility place	376	23.6	916	57.5	302	18.9	1594
Hospital / Health facility	165	57.3	112	38.9	11	3.8	288
Birth order of the child							
First born	118	34.3	181	52.6	45	13.1	334
Second to Third	191	30.7	344	55.2	88	14.1	623
Fourth to Fifth	121	27.7	240	54.9	76	17.4	437
Sixth and more	111	23.2	263	55.0	104	21.8	478
Possession of Radio							
No	258	22.3	683	58.9	218	18.8	1159
Yes	283	39.1	345	47.7	95	13.1	723
Region							
Tigray	114	57.9	79	40.1	4	2.0	197
Afar	10	5.8	66	38.6	95	55.6	171
Amhara	59	27.1	140	64.2	19	8.7	218
Oromiya	47	16.4	182	63.6	57	19.9	286
Somali	24	16.9	70	49.3	48	33.8	142
Ben-Gumuz	40	24.0	104	62.3	23	13.8	167
SNNP	58	23.2	161	64.4	31	12.4	250
Gambela	21	14.3	104	70.7	22	15.0	147
Hareri	38	33.6	66	58.4	9	8.0	113
Addis Ababa	61	79.2	14	18.2	2	2.6	77
Dire Dawa	69	60.5	42	36.8	3	2.6	114

Table 3: The Bivariate Analyses of Immunization Status According to Selected Characteristics in EDHS (2011)

Variables	Level of Children Immunization Status			P- value[a]	Total respondents
	Proportion of fully immunized	Proportion of partialy immunized	Proportion of Not immunized		
Sex of child					
Female	29.3	55.0	15.7	0.508	927
Male	28.2	54.2	17.6		955
Place of Residence					
rural	23.3	58.1	18.6	< 0.0001	1549
urban	54.1	38.4	7.5		333
Mother's Education					
No education	23.9	54.6	21.5	< 0.0001	1270
primary	33.2	59.3	7.5		494
secondary and higher	61.9	35.6	2.5		118
Education of partner					
No education	22.9	54.1	22.9	< 0.0001	937
Primary education	32.0	56.5	11.5		710
Secondary and above	42.1	51.1	6.8		235
Wealth index					
Poor	17.8	58.5	23.7	< 0.0001	894
Medium	26.7	60.1	13.2		303
Rich	43.9	47.2	8.9		685
Place of delivery					
Home / Non Health facility	23.6	57.5	18.9	< 0.0001	1594
Hospital / Health facility	57.3	38.9	3.8		288
Birth order of the child					
First born	34.3	52.6	13.1		334
Second to Third	30.7	55.2	14.1	< 0.0001	623
Fourth to Fifth	27.7	54.9	17.4		437
Sixth and above	23.2	55.0	21.8		478
Possession of Radio					
No	22.3	58.9	18.8	< 0.0001	1159
Yes	39.1	47.7	13.1		723
Region					197
Tigray	57.9	40.1	2.0		171
Afar	5.8	38.6	55.6		218
Amhara	59	64.2	8.7		286
Oromiya	27.1	64.2	8.7	< 0.0001	142
Somali	16.4	63.6	19.9		167
Ben-Gumuz	16.9	49.3	33.8		250
SNNP	24.0	62.3	13.8		147
Gambela	23.2	64.4	12.4		113
Hareri	14.3	70.7	15.0		77
Addis Ababa	33.6	58.4	8.0		114
Dire Dawa	79.2	18.2	2.6		197

All test ware based on Pearson X^2 test of differences of proportion.

3. STATISTICAL DATA ANALYSIS AND RESULTS

3.1. Summary of Descriptive Statistics

A total of 1882 children between the age of 12 and 23 months were included in the study. The mean age of the children is 17 months with standard deviation of 3.35. Male children accounted for 50.7% of the total children.

The major socio-economic and demographic characteristics of the respondents and children with their immunization status are presented in Table **2**.

Bivariate Analysis of the Explanatory Variables

In the bivariate analysis, the variables which are found to be significantly associated with immunization status of children are: place of residence of children, education of mother, education of partner/husband, wealth index, birth order of the child, place of delivery, possession of radio and region.

3.3. Determinants of Immunization: Results of Proportional Odds Model

A cumulative link log it model analysis with the stepwise selection procedure was performed to identify our significant variables. The statistical significance of the individual regression coefficients was tested using the Wald chi-square statistic. Accordingly, place of delivery, wealth, possession of radio and region were found to be significant predictors for immunization among child.

To select the model, here we consider AIC criterion comparison. The result based on Akaike's Information Criteria (AIC) shown in Table **4** suggest that the main effect model is best model as compare to null model and interaction model since a model with low AIC is preferred model.

Table 4: Comparison of Ordinal Logistic Regression Model Based on AIC Criterion

Model	AIC
Null model	3719.175
Main effect model	3161.957
Interaction model	3171.953

3.3.1. Parameter Estimation of the Ordinal Logistic Regression

The model takes Y values: 1(Fully immunized), 2(Partially immunized), and 3(Not immunized) and assume $\phi 1(X)=P(Y\leq 1)$ $\phi 2(X)=P(Y\leq 2)$ and $\phi 3(X)=P(Y\leq 3)$

The fitted proportional odds model of immunization status is given as below.

$$\log\left[\frac{\phi_1(X)}{1-\phi_1(X)}\right]=\alpha_j+\beta_{1p}Place\_Delivery_p +\beta_{2r}\ Possession\ of\ Radio_r+\sum_{i=0}^{2}\beta_{3i}\ Wealth_i+\sum_{j=1}^{11}\beta_{4j}REGION_j \quad (3.1)$$

where *j*= 1,2, ……, K-1

p = 0(Home/non health facility places), 1(Hospital /Health facility places),

r = 0(No), 1(Yes)

i = 0(Poor),1(Medium), 2(Rich),

j =1(Tigray), 2(Afar), 3(Amhara), 4(Oromiya), 5(Somali), 6(Ben-Gumuz), 7(SNNP), 8(Gambel), 9(Harari), 10(Addis Ababa), 11(Dire Dawa)

The above model can be rewritten as

$$\left.\begin{aligned}&\log\left[\frac{\phi_1(\mathbf{X})}{1-\phi_1(\mathbf{X})}\right]=\alpha_1+\beta_{1p}\ Place\_Delivery_p\\&+\beta_{2r}\ Possession\ of\ Radio_r+\sum_{i=0}^{2}\beta_{3i}\ Wealth_i+\sum_{j=1}^{11}\beta_{4j}REGION_j\ and\\&\log\left[\frac{\phi_1(\mathbf{X})+\phi_2(\mathbf{X})}{1-(\phi_1(\mathbf{X})+\phi_2(\mathbf{X}))}\right]=\alpha_2+\beta_{1p}\ Place\_Delivery_p\\&+\beta_{2r}\ Possession\ of\ Radio_r+\sum_{i=0}^{2}\beta_{3i}\ Wealth_i+\sum_{j=1}^{11}\beta_{4j}REGION_j\end{aligned}\right\} \quad (3.2)$$

where $\log\left[\frac{\phi_1(\mathbf{X})}{1-\phi_1(\mathbf{X})}\right]$ and $\log\left[\frac{\phi_1(\mathbf{X})+\phi_2(\mathbf{X})}{1-(\phi_1(\mathbf{X})+\phi_2(\mathbf{X})}\right]$ are the log odds for respective cumulative

logit model.

α_1 and α_2 are threshold values for each model, respectively.

The PROC Logistic procedure of SAS is used to generate coefficients of the estimated model. Table **5** shows the response information of proportional odds model

Table 5: Response Information of Proportional Odds Model

Ordered Value	Immunization status	Total Frequency
1	Fully immunized	541
2	Partially immunized	1028
3	Not immunized	313

Probabilities Modeled are Cumulated Over the Lower Ordered Values.

From the results of SAS output, we obtained the following regression equation consisting of the above variables:

$$\left.\begin{array}{l}\log\left[\dfrac{\phi_1(\mathbf{X})}{1-\phi_1(\mathbf{X})}\right]=-1.347+0.882\ Place\_Delivery_1\\ +0.324Wealth_1+0.641Wealth_2+0.319HHRadio_1+1.19REGION_1\\ -2.28REGION_2-0.88REGION_4-1.30REGION_5\\ -0.67REGION_8+1.094REGION_{10}+1.06REGION_{11}\\ \log\left[\dfrac{\phi_1(\mathbf{X})+\phi_2(\mathbf{X})}{1-(\phi_1(\mathbf{X})+\phi_2(\mathbf{X})}\right]=-1.837+0.882\ Place\_Delivery_1\\ +0.324Wealth_1+0.641Wealth_2+0.319HHRadio_1+1.19REGION_1\\ -2.28REGION_2-0.88REGION_4-1.30REGION_5\\ -0.67REGION_8+1.094REGION_{10}+1.06REGION_{11}\end{array}\right\} \quad (3.3)$$

4.3.2. Testing for Proportional Odds Model Assumption

The model (3.3) should satisfy the assumption of proportional odds to be fully accepted as a *'proportionalodds'* model. The test is designed to test the hypothesis,

H_0: The proportional odds assumption is valid. Vs

H_1: The proportional odds assumption is not valid.

The results of the score test given by the "SAS" proc logistic procedure is given in Table **6**.

Table 6: Results of Score Test for the Proportional Odds Assumption

Chi-Square	DF	Pr > ChiSq
23.3969	14	0.0541

Since the p-value of the score test is 0.0542 (> 0.05), H_0 cannot be rejected at 5% significant level. Thus, the model (3.3) satisfies the proportional odds assumption and hence it is not necessary to go for another model.

Moreover, the overall model fit evaluates the contribution of each effect to the model. The results of Likelihood ratio, Score and Wald test for model goodness of fit displayed in Table **10**, suggests that model is well fitted to the data.

Table 7: Summary of Stepwise Selection

Effect	DF	Wald Chi-Square	Pr > ChiSq
Place of Delivery	1	26.5786	<.0001
Wealth Index	2	26.4919	<.0001
Possession of Radio	1	8.9807	0.0027
REGION	10	330.4809	<.0001

3.3.3. Goodness of Fit Measures

In order to assess the goodness of fit of the fitted model (model 3.1) the following alternative model is constructed.

The alternative model (See model 3.6)

$$\log\left[\frac{\phi_j(\mathbf{X})}{1-\phi_j(\mathbf{X})}\right]=\alpha_j+\beta_{1p}\ Place\_Delivery_p+\beta_{2r}\ HHRadio_r$$
$$+\sum_{i=0}^{2}\beta_{3i}\ Wealth_i+\sum_{j=1}^{11}\beta_{4j}REGION_j+\sum_{g=1}^{9}I_g\gamma_g$$

and the fitted model (model 4.1 above):

$$\log\left[\frac{\phi_j(\mathbf{X})}{1-\phi_j(\mathbf{X})}\right]=\alpha_j+\beta_{1p}\ Place\_Delivery_p$$
$$+\beta_{2r}\ HHRadio_r+\sum_{i=0}^{2}\beta_{3i}\ Wealth_i+\sum_{j=1}^{11}\beta_{4j}REGION_j$$

If the fitted model is correctly specified, then $H_0:\gamma_1=\gamma_2=\ldots=\gamma_9=0$ is not rejected.

The alternative model was fitted using "SAS" proc logistic procedure and the testing of H_0 is carried out using the likelihood ratio, Wald and the score test statistic on the fitted model and the alternative model . By looking at the p-values of the three test results illustrated in Table **11**, it can be concluded that the fitted model is preferable to the alternative model. The hypothesis $H_0:\gamma_1=\gamma_2=\ldots=\gamma_9=0$ is not rejected at 5% significance level and hence, it can be concluded that the fitted model fits the data well.

3.3.4. Model Diagnostics for Proportional Odds Model

The diagnostic test results for detection of outliers and influential values are presented in Appendix 1. The DFBETAs for model parameters including the constant term and Cook's influence statistic were both less than unity. DFBETAs less than unity implyesspecific impact of an observation on the coefficient of a particular predictor variable, while Cook's distance less than unity showed that an observation had no overall impact on the estimated vector of regression coefficients β. A value of the leverage statistic less than one shows that no subject has a substantial large impact on the predicted values of the model. And none of the observation has standard and deviance residuals larger than 3 in absolute value. The residuals less than 3 in absolute value show the absence of an outlier observation. Thus, from the above goodness of fit tests and diagnostic checking we can say that our model is adequate

Table 8: Analysis of Maximum Likelihood Estimates

Covariate	Category	DF	Estimate	Standard Error	Wald Chi-Square	Pr > ChiSq
Intercept (threshold)	Intercept-1	1	-1.3468	0.1522	78.3248	<.0001
	Intercept-2	1	1.8370	0.1582	134.8945	<.0001
Place of Delivery	Hospital/Health facil.	1	0.8219	0.1594	26.5786	<.0001
Wealth Index	medium	1	0.3239	0.1397	5.3792	0.0204
	Rich	1	0.6407	0.1254	26.1206	<.0001
Possession of Radio	Yes	1	0.3191	0.1065	8.9807	0.0027
Region	Tigray	1	1.1906	0.2036	34.1939	<.0001
	Afar	1	-2.2857	0.2167	111.2263	<.0001
	Oromiya	1	-0.8835	0.1859	22.5768	<.0001
	Amhara	1	-1.3025	0.2227	34.2091	<.0001
	Somali	1	-0.6709	0.2199	9.3105	0.0023
	Gambela	1	1.0935	0.3342	10.7050	0.0011
	Addis Ababa	1	1.0656	0.2433	19.1815	<.0001
	Dire Dawa	1	-1.3468	0.1522	78.3248	<.0001

Table 9: Odds Ratio Estimates

Covariate	Category	Point Estimate	95% Wald Confidence Limits	
Place of Delivery	Hospilal/Health fac. vs Home/non Health	2.275	1.664	3.109
Wealth Index	Medium vs Poor	1.382	1.051	1.818
	Rich vs Poor	1.898	1.484	2.426
Possession of Radio	Yes vs No	1.376	1.117	1.695
Region	Tigray vs Amhara	3.289	2.207	4.902
	Afar vs Amhara	0.102	0.067	0.156
	Oromiya vs Amhara	0.413	0.287	0.595
	Somali vs Amhara	0.272	0.176	0.421
	Gambela vs Amhara	0.511	0.332	0.787
	Addis Ababa vs Amhara	2.985	1.550	5.746
	Dire Dawa vs Amhara	2.903	1.802	4.676

Table 10: Overall Measures of Goodness of Fit of the Final Model: BETA=0

Testing Global Null Hypothesis: BETA=0			
Test	**Chi-Square**	**DF**	**Pr > ChiSq**
Likelihood Ratio	585.2186	14	<.0001
Score	499.4866	14	<.0001
Wald	479.9393	14	<.0001

Table 11: Results of Testing Significance of the Alternative Model against the Selected Model

	Model	Test Statistics	Difference in Test Statistic	Difference in D.F.	P - value
Likelihood Ratio	fitted	585.2186	10.7010	9	0.2967
	alternative	574.4452			
Wald	fitted	499.4886	9.582	9	0.390
	alternative	489.9066			
Score	The fitted	479.939	6.06	9	0.734
	alternative	473.879			

3.3.5. Interpreting the Result of Proportional Odds Model

The interpretations of the parameters corresponding to different variables which are found significant in the final model are described in the following section and comparisons are made with the reference category.

Being a residence of Tigray region, Addis Ababa and Dire Dawa increases the likelihood of being in a fully immunized category (as opposed to partially immunized or not immunized category) by 3.289 times, 2.985 times and 2.903 times respectively as compare to being a residence of Amhara region while being a residence of Afar region, Oromiya region, Somali region and Gambela region reduces the likelihood of being in the fully immunized category (as opposed to partially immunized or not immunized category) by 89.8%, 58.7%, 72.8%, and 48.9% respectively than the reference region (Amhara region). Similarly, the odds of the combined of fully immunized and partially immunized versus not immunized is 3.289 times, 2.985 times and 2.903 times higher for children in Tigray, Addis Ababa and Dire Dawa respectively compared to children in Amhara given the other variables in the model are held constant.

For children born in hospital and /or other health facility places compared to those born at home and /or other non health facility places the odds of being fully immunized versus the combined partially immunized and not immunized are 2.275 times higher given the other variables are held constant. Likewise, the odds of the combined categories of fully immunized and partially immunized versus not immunized is 2.275 times higher for children born in hospital and /or other health facility places compared to those born at home and /or other non health facility places given the other variables model are held constant in the model.

The estimated odds ratio ($\widehat{OR}$ = 1.376) revealed that the odds of being in the fully immunized category (as opposed to partially immunized or not immunized category) for children who live in the household who possess radio increases by 37.6% than the reference group. Similarly, the odds of being in the fully immunized category or partially immunized category (as opposed to not immunized category) for children who live in the household who possess radio increases by 37.6% than the reference group holding all other variables constant. The 95% confidence interval also suggests that odds could be as minimum as 1.12 and as maximum as 1.69.

Wealth index have significant influences on child immunization status. Children from middle class and rich family compared to children from poor family the odds of being fully immunized (as opposed to partially or not immunized) 89.8% and 38.2% higher respectively controlling other variables model. Similarly, the odds of being fully immunized or partially immunized (as opposed to not immunize) for children from middle class and rich family 89.8% and 38.2% higher respectively compared to children from poor families, holding all other variables constant. The 95% confidence interval also suggests that odds could be as minimum as 1.05 and as maximum as 1.82 for children who from middle class family and as minimum as 1.48 and as maximum as 2.43 children from rich family.

4. CONCLUSION

The study identified that place of delivery, wealth index, possession of radio and region were found to be significant predictors of full child immunization among children aged 12-23 months old in Ethiopia.

APPENDIXES

Appendix 1: Results of Diagnostic Tests for Outliers and Influential Value for Standard logistic regression Descriptive statistics of model diagnosis

Descriptive Statistics of DFBETAS			
	N	**Minimum**	**Maximum**
DFBETA for constant	1882	-.02814	.02883
DFBETA for Wealth (1)	1882	-.01286	.02456
DFBETA for Wealth (2)	1882	-.01483	.01739
DFBETA for Place_Delivery (1)	1882	-.02091	.02107
DFBETA for HHRadio (1)	1882	-.01028	.01096
DFBETA for REGION (1)	1882	-.02563	.03194

DFBETA for REGION (2)	1882	-.02601	.11047
DFBETA for REGION (3)	1882	-.02488	.03098
DFBETA for REGION (4)	1882	-.02397	.03385
DFBETA for REGION (5)	1882	-.02488	.04929
DFBETA for REGION (6)	1882	-.02499	.03227
DFBETA for REGION (7)	1882	-.02490	.03209
DFBETA for REGION (8)	1882	-.02515	.05503
DFBETA for REGION (9)	1882	-.02246	.04086
DFBETA for REGION (10)	1882	-.06513	.04463
Valid N (listwise)	1882		

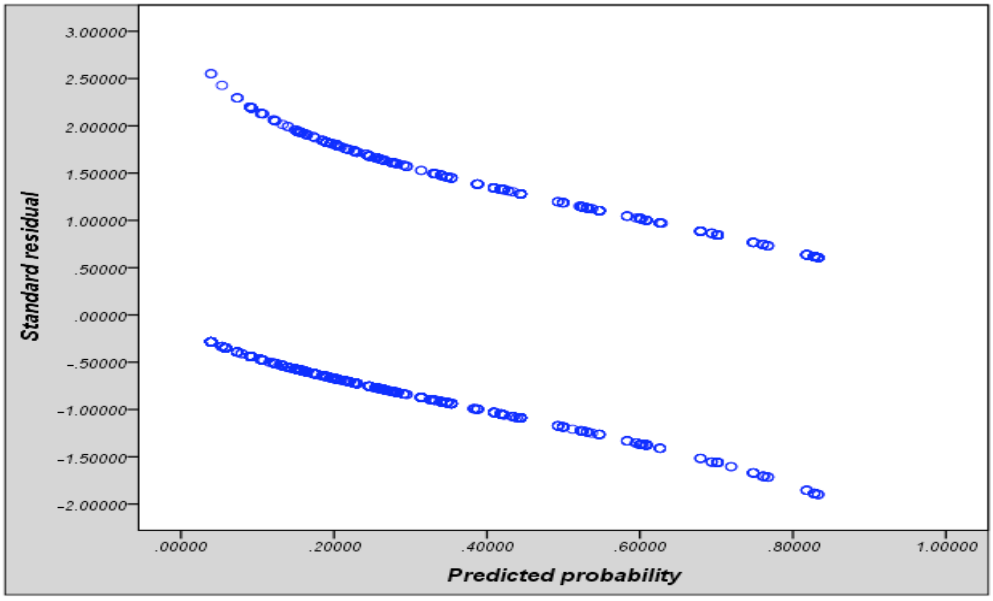

Figure 1: Plots of Standard residual by predicted probability.

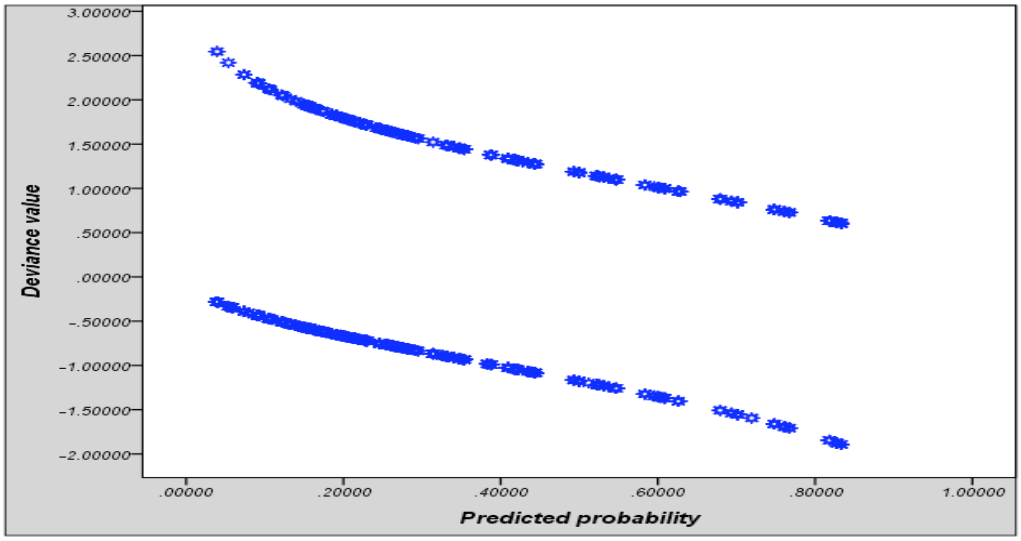

Figure 2: Plots of Deviance residual by predicted probability.

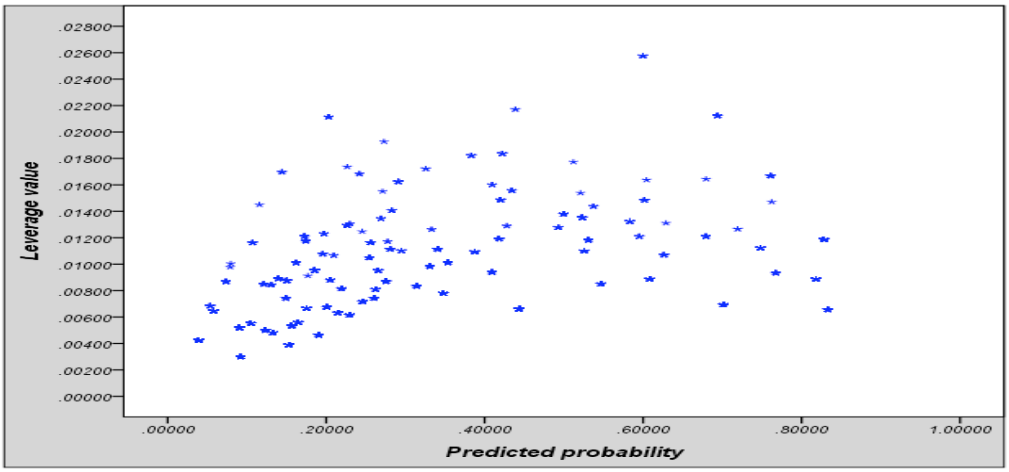

Figure 3: Plots of leverage value by predicted probability.

Appendix 2: SAS Codes

```
title ’Ordinal Main effects model’;
Proclogisticdata =SASUSER.IMMUNIZATION;
Class Place_Delivery(ref='0') Wealth(ref='0') HHRadio(ref='0') REGION(ref='3') /param= ref order =
internal;
model Complete_vaccination =Place_Delivery Wealth HHRadio REGION /link = clogit;
format Place_Delivery Wealth HHRadio Region ;
run;
title ’Ordinal Interaction effects model’;
Proclogisticdata =SASUSER.IMMUNIZATION;
Class Place_Delivery(ref='0') Wealth(ref='0') HHRadio(ref='0') REGION(ref='3') /param= ref order =
internal;
model Complete_vaccination =Place_Delivery Wealth HHRadio REGION Place_Delivery*HHRadio Wealth*HHRadio
REGION*HHRadio/link = clogit scale = none aggregate;
format Place_Delivery Wealth Radio Region ;
run;
title ’Goodness of Fit for Proportional Odds Model’;
/* Formulating predicted mean scores and Indicator variables
to separate the subjects into 10 regions */
data goodnes;
/*import data*/
set SASUSER.IMMUNIZATION;
/*import the predicted probabilities of the fitted model*/
set pred;
/*defining the 9 indicator variables*/
I1=0; I2=0; I3=0; I4=0; I5=0; I6=0; I7=0; I8=0; I9=0;
g=1882/10;
/*calculation of predicted mean score (m) from predicted
probabilities*/
m=(1*ip_1)+(2*ip_2)+(3*ip_3);
procsortdata=goodnes;
by m;
run;
data good;
set goodnes;
i=_n_;
/*Grouping the 1882 subjects into 10 regions by using the 9
indicator variables*/
if i<=g then I1=1;
elseif i<=2*g then I2=1;
elseif i<=3*g then I3=1;
elseif i<=4*g then I4=1;
elseif i<=5*g then I5=1;
```

```
elseif i<=6*g then I6=1;
elseif i<=7*g then I7=1;
elseif i<=8*g then I8=1;
elseif i<=9*g then I9=1;
/*Fitting the alternative model [Model-(M*)]*/
proclogisticdata=good;
class Place_Delivery Wealth HHRadio REGION I1-I9/param= ref order = internal ;
model Complete_vaccination=Place_Delivery Wealth HHRadio REGION I1-I9/link = clogit scale = none
aggregate;
run;
data good
set goodnes;
i=_n_;
/*defining a single indicator variable that separates the subjects
into 10 regions*/
if i<=g then I=1;
elseif i<=2*g then I=2;
elseif i<=3*g then I=3;
elseif i<=4*g then I=4;
elseif i<=5*g then I=5;
elseif i<=6*g then I=6;
elseif i<=7*g then I=7;
elseif i<=8*g then I=8;
elseif i<=9*g then I=9;
elseif i<=10*g then I=10;
procsortdata=good;
by I Complete_vaccination;
run;
/*printing the response level (K), predicted probabilities,
indicator that define 10 regions (I) and predicted mean score
(m)*/
```

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Received on 22-11-2014 Accepted on 30-01-2015 Published on 16-02-2015

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