Estimation of the Family and Community Unobserved Heterogeneity Effects on the Risk of Under-Five Mortality in Nigeria using Frailty Model

Anthony I. Wegbom¹,* , Isaac D. Essi¹ and Victor A. Kiri¹,²

¹Department of Mathematics, Rivers State University, Port Harcourt, Nigeria
²Department of Mathematics, Physics & Electrical Engineering, Northumbria University, Newcastle Upon Tyne, UK

Abstract: The Under-five mortality (U5M) rate is an important determinant of societal and national advancement- a key marker of wellbeing, value, and access. In spite of efforts to identify the predictors of U5M to reduce its high level in Nigeria, the problem remains a major cause for concern. This study estimated the potential role of unmeasured/unobserved factors at both family and community levels, using shared frailty models on the 2013 Nigeria Demographic and Health Survey (2013 NDHS) data. The Log-rank test was used to identify variables associated with U5M- hazard ratio estimates with P<0.05 were considered as statistically significant. Our findings suggested region, marital status, place of residence and place of delivery were significant determinants of U5M in both frailty models. We also found evidence of frailty effect on the risk, particularly at the community level- heterogeneity due to unmeasured/unobserved factors, which are generally ignored when we assess the risk using only observed variables. We, therefore, suggest that to achieve the sustainable development goals relating to child health in Nigeria, more significant efforts should be directed at identifying more determinants, such as to reduce the influence of unobserved factors and facilitate an extension of interventions to these factors.

Keywords: Under-five mortality, Unobserved heterogeneity, Frailty model, Determinants, Nigeria.

INTRODUCTION

The Under-five mortality (U5M) rate is an important determinant of societal and national advancement- a key marker of wellbeing, value, and access. The wellbeing and survival of children are essential measures of the social prosperity and wellbeing status of the community [1,2]. Although U5M levels continue to decline globally, those for Sub-Saharan Africa remain very high [3]. It was because of the lack of sufficient reduction in many developing countries during the era of Millennium Development Goals (MDGs), that the problem became one of the key focus areas of the Sustainable Development Goals (SDGs), to reduce under-five mortality to at most 25 deaths for every 1,000 live births by 2030; known as SDG 3.2 [4].

Nigeria is one of the countries in sub-Saharan Africa with high under-five mortality [5,6]. For instance, the under-five mortality rate in 1990 was 201 deaths per 1000, declining to 128 deaths per 1000 in 2013 [5] and increasing to 132 deaths per 1000 in 2018 [7]. This represented a 34% decline within the 28 years. Hence, Nigeria is still far short of achieving the SDG on under-five mortality.

Under-five mortality remains a daunting public health challenge in Nigeria. Several studies have been conducted to identify the factors that account for high rates of under-five mortality and to find the best strategies to adopt in combating the problem [8-13]. In spite of the concerted international and national efforts on reducing the undesirably high levels of under-five mortality, the issue of poor child health continues to be a significant cause for concern in Nigeria. Indeed, Nigeria may not be on course to achieving the SDG target. Hence, there is an urgent need to deploy appropriate techniques that will unravel the comprehensive determinants of under-five mortality in Nigeria, as this will guide policymakers in planning their interventions.

It is a known fact that not all covariates associated with child survival are usually captured in a Survey. Thus, using survey data to study the factors associated with under-five mortality without recourse to missing elements may produce biased inference [14-16]. In the applications of statistical techniques on survey data, usually, only a few covariates are measured or included in the models. It is known that many other factors that can influence child survival, such as those of biological, genetic, behavioural and environmental natures, as well as the quality of healthcare provisions, among others [2]. Most of these factors are often unquantifiable, and some may even be unknown, and

*Address correspondence to this author at the Department of Mathematics, Rivers State University, Port Harcourt, Nigeria; Tel: +1238032565971; E-mail: wegbiomanthony@gmail.com
hence, they cannot be included in the analysis. However, when such important factors are ignored, the result may be a biased estimate.

There are very few documented studies on the likely influence of family and community-level unobserved factors on the risks of under-five mortality in Nigeria, and these are all based on survey data [8-10, 17-22]. In other words, the findings from such studies may be susceptible to bias due to the exclusion of key unquantified influential factors. Nevertheless, these studies can be useful in informing the decisions of policymakers in their efforts at developing appropriate public health interventions to implement. Our research aims to assess the influence of unobserved family and community-level factors on the risks of under-five mortality in Nigeria. Our hope is for results that would make a meaningful addition to the pool of information available to policymakers in their quest for effective strategies for achieving the Sustainable Development Goals.

METHODS

The 2013 Nigeria Demographic and Health Survey (2013 NDHS) dataset was used for this study. As a national representative data, the 2013 NDHS is cross-sectional and elicited information on demographic and health indicators both at State and national levels, such as, family planning, maternal and child health, fertility, gender, malaria, HIV/AIDS and nutrition [5]. The Demographic and Health Survey (DHS) is one that collects data on the assessment of the above indicators in developing countries, like Nigeria, where adequate and reliable vital registration system is missing [23].

The population (i.e. sample size) of our study data was 31,482 children born within the last five years before the survey (i.e. under-five children) in Nigeria. The information was derived from women age 15-49 years who had at least one live birth within this period in the 36 states of Nigeria. We used the Weibull frailty model which is a subset of the Weibull proportional hazards model from the family of parametric survival models, having been found as adequate for estimating the determinants of under-five mortality in the DHS dataset [15, 20-22, 24].

The Weibull Proportional hazard model expressed as:

$$h_i(t, X) = \lambda \exp(\beta^T x_i) pt^{\alpha - 1}$$  \hspace{1cm} (1)

Where,

$$h_i(t, X)$$ is the hazard of death for child \(i\) at time \(t\);

\(\lambda\) and \(\lambda\) are the shape and scale parameters respectively, estimated from the data,

\(\beta\) is the vector of unknown coefficients of the explanatory variables \(x_i\).

In this model, the hazard increases or decreases monotonically [25].

In the frailty model, frailty is a random factor designed to account for changeability due to unobserved factors that are unaccounted for by the other predictors in the model.

As stated in [14], the frailty \(\alpha\) is an unobserved multiplicative effect on the hazard function that follows gamma distribution \(g(\alpha)\) with \(\alpha > 0\) and unit mean. The variance of \(g(\alpha)\) is a parameter \(\theta\) (theta) that is usually estimated from the data. The model assumes that the individual risk of death is a function of known factors.

The frailty model expressed as:

$$h_j(t, x_j, \alpha_j) = \alpha \cdot h_j(t, x_j)$$ \hspace{1cm} (2)

Children \(i\) in a family (or community \(j\)), are supposed to share the same frailty. If the variance estimate \(\theta\) is not zero it shows that unobserved family (or community) factors affect the risk of death which implies that their survival risks are correlated; And if the variance estimate \(\theta\) is zero, all families (or communities) have the same risk of death. Also, children with frailty \(\alpha > 1\) have a higher risk of death and hence, a lower chance of survival than those with frailty \(\alpha = 1\); whereas children with frailty \(\alpha < 1\) have a lower risk of death and therefore a higher chance of survival than those with frailty \(\alpha = 1\) [14, 25].

The hazard between two individuals with different values of predictors \(x\) is known as a hazard ratio. The hazard ratio (HR) is defined as the hazard for one individual divided by the hazard for a different individual. It expressed as:

$$HR = \frac{h(x')}{h(t, x)}$$ \hspace{1cm} (3)

Where \(x'\) denotes the set of predictors for one individual, and \(x\) denotes the set of predictors for the other individual.
### Table 1a: Log-Rank Test for Equality of Survival Time among the Demographic Covariate According to Death of Under-Five Children

| Demographic Covariates                              | Number of Deaths (2886) | Percentage | P-value ($X^2$) |
|-----------------------------------------------------|--------------------------|------------|-----------------|
| Sex of child                                        |                          |            |                 |
| Male                                                | 1578                     | 54.7       | 0.04 (3.93)     |
| Female                                              | 1308                     | 45.3       |                 |
| Region                                              |                          |            |                 |
| North-central                                       | 328                      | 11.4       | 0.00 (198.91)   |
| North-east                                          | 661                      | 22.9       |                 |
| North-west                                          | 1146                     | 39.7       |                 |
| South-east                                          | 263                      | 9.1        |                 |
| South-south                                         | 249                      | 8.6        |                 |
| South-west                                          | 239                      | 8.3        |                 |
| Maternal age at childbirth                          |                          |            |                 |
| <20 years                                           | 535                      | 18.5       | 0.00 (23.45)    |
| 20-34 years                                         | 1857                     | 64.4       |                 |
| 35 and above                                        | 494                      | 17.1       |                 |
| Number of children ever born                        |                          |            |                 |
| ≤2                                                   | 668                      | 23.2       | 0.00 (69.62)    |
| 3-4                                                  | 798                      | 27.6       |                 |
| 5 and above                                         | 1420                     | 49.2       |                 |
| Preceding birth interval                             |                          |            |                 |
| First birth                                         | 607                      | 21.1       | 0.00 (133.77)   |
| <24 months                                          | 803                      | 27.8       |                 |
| 24-35 months                                        | 864                      | 29.9       |                 |
| >35 months                                          | 612                      | 21.2       |                 |
| Size of child at birth                               |                          |            |                 |
| Small                                               | 584                      | 21.6       | 0.00 (36.87)    |
| Average                                             | 1110                     | 41.0       |                 |
| Large                                               | 1012                     | 37.4       |                 |

### Table 1b: Log-Rank Test for Equality of Survival Time among the Socioeconomic Variables According to the Death of Under-Five Children

| Socio-economic covariate                        | Number of Deaths (2886) | Percentage | P-value ($X^2$) |
|------------------------------------------------|--------------------------|------------|-----------------|
| Maternal educational level                      |                          |            |                 |
| No education                                    | 1657                     | 57.4       | 0.00 (195.05)   |
| Primary education                               | 596                      | 20.7       |                 |
| Secondary or higher education                   | 633                      | 21.9       |                 |
| Wealth index                                    |                          |            |                 |
| Poor                                            | 1722                     | 59.7       | 0.00 (276.22)   |
| Middle                                          | 502                      | 17.4       |                 |
| Rich                                            | 662                      | 22.9       |                 |
### Table 1b: Continued.

| Socio-economic covariate | Number of Deaths (2886) | Percentage | P-value ($X^2$) |
|--------------------------|-------------------------|------------|-----------------|
| **Marital status**       |                         |            |                 |
| Never married            | 160                     | 5.5        | 0.41 (0.67)     |
| Married                  | 2726                    | 94.6       |                 |
| **Place of residence**   |                         |            | 0.00 (128.11)   |
| Rural                    | 2220                    | 76.9       |                 |
| Urban                    | 666                     | 23.1       |                 |
| **Type of toilet facility** |                       |            | 0.00 (31.40)    |
| Unimproved               | 1619                    | 56.8       |                 |
| Improved                 | 1230                    | 43.2       |                 |
| **Source of water supply** |                       |            | 0.00 (26.22)    |
| Unimproved               | 1419                    | 49.9       |                 |
| Improved                 | 1427                    | 50.1       |                 |

### Table 1c: Log-rank Test for Equality of Survival Time among the Health Care Seeking Related Covariates According to Death of Under-Five Children

| Health Care Related Covariate | Number of Deaths (2886) | Percentage | P-value ($X^2$) |
|--------------------------------|--------------------------|------------|-----------------|
| **Place of delivery**         |                          |            | 0.00 (88.49)    |
| Home                          | 1975                     | 68.4       |                 |
| Hospital/clinic               | 911                      | 31.6       |                 |
| **Slept under Mosquito net**  |                          |            | 0.07 (3.35)     |
| No                            | 2303                     | 79.8       |                 |
| Yes                           | 583                      | 20.2       |                 |
| **Number of ANC visit**       |                          |            | 0.00 (46.39)    |
| None                          | 497                      | 42.1       |                 |
| 1-3 times                     | 130                      | 11.0       |                 |
| Four times and above          | 553                      | 46.9       |                 |

**Figure 1:** The plot of the overall estimate of Kaplan-Meier Survivor Function of under-five mortality in Nigeria.
All analyses were done using Stata (version 15). The log-rank test used to ascertain which variable is significantly related to U5M whereas, the frailty model using hazard ratio was used to assess the impact of the individual variable on the risk of under-five mortality moreover P<0.05 and 95% confident interval not including one was seen statistically significant.

RESULTS

Descriptive Analysis

To estimate the effects of unobserved heterogeneity on the risks of under-five mortality, it is important to examine the relationship between the selected variables and the risk of under-five mortality. Table 1a to 1c shows the results of the Log-rank tests on the lists of demographic, socio-economic and healthcare-related variables and their associations with under-five mortality in Nigeria based on the 2013 NDHS data. We found that all the variables except marital status (Table 1b) and slept under a Mosquito net (Table 1c) were significantly related to under-five mortality (p<0.05). However, the two variables were retained in our frailty models because earlier studies had reported on marital status and use of Mosquito net as significantly related to under-five mortality in Nigeria [8,13,17].

Figure 1 displays the overall Kaplan Meier estimate of the survival function. It shows that most deaths occurred in the early months of birth and the risk gradually declined as they aged, but which became less obvious as they approached the age of five- thus, justifying the choice of the Weibull model.

Frailty Model Results

Table 2 shows the fitted frailty models for both family and community-level variables. The models were fitted to assess not only the influence of the demographic, socio-economic and health care factors on the risk of under-five mortality in Nigeria but also those that were unobserved and unmeasured as family and community heterogeneity. In both models, the same sets of variables were used. The family frailty estimated the influence of unobserved/unmeasured variables on the risk among siblings, such as maternal care and genetic factors, while the community frailty estimated the influence of unobserved/unmeasured variables on the risk among children from the same community, such as cultural, climatic and environmental factors.

The results of the log-likelihood ratio tests suggested the community frailty model produced a better fit to the data than the family version. The ratio was -3103.09 for the family model whereas, that of the community was -3099.69. The frailty effect for under-five mortality at the family level was 0.035, and it was not statistically significant- suggesting the risk of under-five mortality between households in this data did not differ significantly even after adjusting for possible unmeasured/unobserved factors. In contrast, the community frailty effect was statistically significant at 0.175 and (P<0.05)- suggesting unobserved community factors might account for the risk of death among children aged under five by as much as 17.5%.

The study further identified the region, marital status, place of residence (urban or rural) and place of delivery as significantly associated with the risk of under-five mortality in both models. Also, we found no difference in the magnitude of the estimated risk from the two models. For instance, we obtained the same hazard ratios from both models for the South-East region of Nigeria (HR=2.18), married women (HR=0.68) and birth at hospital/clinic (HR=0.75). The ratios from the two models were also similar for the North-West region (HR=1.43 and 1.40) and rural versus urban residents (HR=1.47 and 1.46) from the family and community frailty models correspondingly.

DISCUSSIONS

The recently released 2018 NDHS reports suggest determinants of under-five mortality should be assessed beyond the observed pool of determinants, bearing in mind the lack of sufficient momentum in the declining trend of the risk between 1990 and 2013. The results from our study seemed to add weight to the suggestion by the finding of a possible association between the risk of under-five mortality and some unknown, unobserved/unmeasured factors at both family and community levels.

The frailty effect on under-five mortality at the family level was 0.035. Though, not statistically significant, this implied that the measured covariates accounted for 96.5% of the variation in under-five mortality at the family level. In contrast, the frailty effect on under-five mortality at the community level was statistically significant at 0.175- implying the measured covariates accounted for 82.5% of the variation in under-five mortality at the community level, thus leaving as much as 17.5% attributable to unknown, unmeasured factors. These results suggest unobserved/unmeasured
### Table 2: Estimating the Effect of Family and Community Frailty on Under-Five Mortality

| Covariates                      | Family Frailty (Model I) | Community Frailty (Model II) |
|--------------------------------|--------------------------|------------------------------|
|                                | RR                       | 95% CI for RR                | RR                          | 95% CI for RR                |
| **Sex of child**               |                          |                              |                             |                             |
| Male                           | 1.00                     |                              | 1.00                        |                              |
| Female                         | 0.92                     | 0.78-1.08                    | 0.92                        | 0.78-1.08                    |
| **Region**                     |                          |                              |                             |                             |
| North-central                  | 1.00                     |                              | 1.00                        |                              |
| North-east                     | 1.11                     | 0.80-1.53                    | 1.09                        | 0.77-1.53                    |
| North-west                     | 1.43*                    | 1.05-1.95                    | 1.40*                       | 1.01-1.94                    |
| South-east                     | 2.18*                    | 1.49-3.20                    | 2.18*                       | 1.46-3.25                    |
| South-south                    | 1.07                     | 0.73-1.57                    | 1.07                        | 0.72-1.60                    |
| South-west                     | 1.07                     | 0.72-1.59                    | 1.08                        | 0.72-1.64                    |
| **Maternal age at childbirth** |                          |                              |                             |                             |
| <20 years                      | 1.00                     |                              | 1.00                        |                              |
| 20-34 years                    | 0.78                     | 0.58-1.04                    | 0.77                        | 0.57-1.03                    |
| 35 and above                   | 0.91                     | 0.63-1.31                    | 0.90                        | 0.62-1.29                    |
| **Number of children ever born** |                          |                              |                             |                             |
| <=2                            | 1.00                     |                              | 1.00                        |                              |
| 3-4                            | 0.82                     | 0.62-1.09                    | 0.83                        | 0.62-1.10                    |
| 5 and above                    | 1.05                     | 0.79-1.40                    | 1.05                        | 0.79-1.39                    |
| **Preceding birth interval**   |                          |                              |                             |                             |
| First birth                    | 1.00                     |                              | 1.00                        |                              |
| <24 months                     | 1.37                     | 0.98-1.93                    | 1.38                        | 0.98-1.94                    |
| 24-35 months                   | 1.22                     | 0.88-1.68                    | 1.23                        | 0.89-1.70                    |
| >35 months                     | 0.94                     | 0.67-1.32                    | 0.95                        | 0.68-1.33                    |
| **Size of child at birth**     |                          |                              |                             |                             |
| Large                          | 1.00                     |                              | 1.00                        |                              |
| Average                        | 1.01                     | 0.84-1.21                    | 1.01                        | 0.84-1.21                    |
| Small                          | 1.20                     | 0.95-1.51                    | 1.21                        | 0.96-1.53                    |
| **Maternal educational level** |                          |                              |                             |                             |
| No education                   | 1.00                     |                              | 1.00                        |                              |
| Primary education              | 0.89                     | 0.70-1.15                    | 0.89                        | 0.69-1.15                    |
| Secondary or higher education  | 0.75                     | 0.56-1.02                    | 0.75                        | 0.55-1.02                    |
| **Wealth index**               |                          |                              |                             |                             |
| Poor                           | 1.00                     |                              | 1.00                        |                              |
| Middle                         | 0.79                     | 0.62-1.02                    | 0.79                        | 0.61-1.02                    |
| Rich                           | 0.78                     | 0.57-1.07                    | 0.77                        | 0.56-1.06                    |
| **Marital status**             |                          |                              |                             |                             |
| Never married                  | 1.00                     |                              | 1.00                        |                              |
| Married                        | 0.68*                    | 0.50-0.93                    | 0.68*                       | 0.50-0.93                    |
### Table 2. Continued

| Covariates                  | Family Frailty (Model I) | Community Frailty (Model II) |
|-----------------------------|--------------------------|-----------------------------|
|                             | RR           | 95% CI for RR | RR           | 95% CI for RR |
| Place of residence          |              |              |              |              |
| Urban                       | 1.00         |              | 1.00         |              |
| Rural                       | 1.47*        | 1.15-1.88    | 1.46*        | 1.13-1.88    |
| Type of toilet facility     |              |              |              |              |
| Unimproved                  | 1.00         |              | 1.00         |              |
| Improved                    | 1.03         | 0.85-1.23    | 1.04         | 0.86-1.26    |
| Source of water supply      |              |              |              |              |
| Unimproved                  | 1.00         |              | 1.00         |              |
| Improved                    | 0.95         | 0.80-1.13    | 0.95         | 0.79-1.13    |
| Place of delivery           |              |              |              |              |
| Home                        | 1.00         |              | 1.00         |              |
| Hospital/clinic             | 0.75*        | 0.59-0.96    | 0.75*        | 0.58-0.96    |
| Slept under Mosquito net    |              |              |              |              |
| No                          | 1.00         |              | 1.00         |              |
| Yes                         | 0.83         | 0.67-1.03    | 0.82         | 0.66-1.03    |
| Number of ANC visit         |              |              |              |              |
| None                        | 1.00         |              | 1.00         |              |
| 1-3 times                   | 0.91         | 0.67-1.22    | 0.90         | 0.66-1.22    |
| Four times and above        | 1.09         | 0.88-1.35    | 1.07         | 0.86-1.33    |
| Frailty Effect              | 0.035        |              | 0.175*       |              |
| Log-likelihood              | -3103.09*    |              | -3099.69*    |              |

*P<0.05.

Factors, particularly at the community level might be responsible for the elevation and variations in the risk of under-five mortality in Nigeria. This is consistent with those reported by studies conducted in some other developing countries, such as Bangladesh, Kenya and Zimbabwe [2, 15, 26]. The unobserved heterogeneity effect summarizes the influences of a likely long list of various unobserved/unmeasurable candidates too numerous to specify, such as parental competence, genetic, behavioural and environmental factors, as well as quality of health facilities and professional care provisions at health facilities, among many others [2]. None of these could be accounted for at specific levels in our models since they were not captured in the survey.

Our findings also suggested that the risk of death before age five was significantly higher for those residing in the north-west, south-east and rural areas of Nigeria. At the same time, married women and women that gave birth at Hospital/clinic had a significantly lower risk of losing their children before the age of 5. Thus, confirming the finding of earlier studies [8, 12, 23, 24, 27, 28].

The differentials on social factors, population density and regional economic resources might partly account for the higher risk of U5M in the north-west, south-east and rural areas of Nigeria [11, 13]. The reasons for higher risk of U5M in the rural areas than in the urban areas might also be due to improved water supply, improve sanitation facilities, healthcare and other social amenities which those residing in the rural areas might not have access to [12, 29]. Furthermore, delivery at a hospital/clinic would avail such women the opportunity of supervision by trained medical professionals which could enhance the chance of childhood survival outcomes [24, 30]. Also, as reported in a previous study, antenatal care visit to hospital/clinic could, at large extent, result in better delivery outcomes and reduction in the risk of childhood mortality [31].
CONCLUSION

This study has demonstrated the influence of family and community factors on the risk of under-five mortality. The results suggest that there are factors other than the observed covariates we usually include in our assessment models on survey data, which could affect under-five death among children at both family and community levels. That, there are some unobserved/unmeasured factors that could affect the risk at these levels- unknown factors that are generally ignored when we assess the risk using models that are based only on observed variables. Indeed, we found that unmeasured factors were significantly associated with high risks of children dying before reaching the age of five. We, therefore, suggest that to achieve the sustainable development goals relating to child health in Nigeria, substantial efforts should be directed at identifying more determinants, such as to reduce the influence of unobserved factors and facilitate an extension of interventions to these factors, particularly at the community level.

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