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Unobserved Heterogeneity in the Determinants of Under-five Mortality in Nigeria: Frailty Modeling in Survival Analysis

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Abstract. Childhood mortality is one of the measure of socio-economic status of a population. Several studies have been conducted to identify determinants of childhood mortality but the random effect and heterogeneity nature in most clustered survey data has not been well documented. The present study was designed to use shared frailty model to assess determinants of Under-Five Mortality (U5M) using an hierarchical data in Nigeria.

Key words: Shared frailty Model; Under-Five Mortality; individual factors; community factors; clustered survey data
AMS 2010 Mathematics Subject Classification Objects : 00A22; 62-07; 62N01.

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Full Abstract

Introduction: Childhood mortality is one of the measure of socio-economic status of a population. Several studies have been conducted to identify determinants of childhood mortality but the random effect and heterogeneity nature in most clustered survey data has not been well documented. The present study was designed to use shared frailty model to assess determinants of Under-Five Mortality (U5M) using an hierarchical data in Nigeria.

Methods: This study analyzed a sample of 119,386 childbirths to women aged 15-49 years in within 5 years prior to the 2013 Nigeria Demographic and Health Survey dataset. Background characteristics were summarized using descriptive statistics; Cox proportional hazard (PH) and shared frailty models were employed to identify the risk factors of U5M at 5% significance level. Akaike Information Criteria (AIC) was used to select the better model.

Results: The region of residence, place of residence, and household wealth status are the important determinants of U5M in Nigeria. Residing in rural communities increases the hazard of U5M by 9% (adjusted Hazard Ratio (aHR): 1.09, CI: 1.01 - 1.23). While children that were not breastfed exclusively (aHR = 9.96, CI: 8.95 - 11.10) had higher risk of death, being female and born to mothers aged 40-49 years were protective of U5M. Childhood mortality is generally higher in Northern Nigeria compared to the Southern Nigeria. Shared frailty model showed that being from North-West (0.0549) and rural area (0.0345) had the highest frailty for U5M. The shared frailty model (AIC= 44266.0) compared with the Cox PH model (AIC= 44375.9) was more adequate in modeling U5M among Nigeria children.

Conclusion: The study demonstrated the importance of the characteristics of household, state and regions in explaining the risk of under-five mortality in Nigeria. The results of this study showed the need to look beyond individual-level factors in addressing the challenge of U5M in Nigeria. In order to realize some of the sustainable development goals in Nigeria, particular attention must be paid to the community-level interventions aimed at improving under-five survival in the country's socially and economically disadvantaged areas.

Résumé complet (Full Abstract in French).

Introduction: La mortalité infantile est l'une des mesures du statut socioéconomique d'une population. Plusieurs études ont été menées pour identifier les déterminants de la mortalité infantile, mais la nature de l'effet aléatoire et de l'hétérogénéité dans la plupart des données d'enquêtes en grappes n'a pas été bien documentée. La présente étude a été conçue pour utiliser un modèle de fragilité partagée afin d'évaluer les déterminants de la mortalité des moins de cinq ans (U5M) à l'aide de données hiérarchiques au Nigéria.

Méthodes: Cette étude a analysé un échantillon de 119 386 accouchements chez des femmes âgées de 15 à 49 ans moins de 5 ans avant le jeu de données de l'enquête sur la démographie et la santé au Nigéria de 2013. Les caractéristiques de base ont été résumées à l'aide de statistiques descriptives; Des modèles de risque proportionnel de Cox et de fragilité partagée ont été utilisés pour identifier les facteurs de risque de M5 à un niveau de signification de 5%. Akaike Information Criteria (AIC) a été utilisé pour sélectionner le meilleur modèle.

Résultats: La région de résidence, le lieu de résidence et la richesse du ménage sont les déterminants importants de la mortalité des moins de 5 ans au Nigéria. Le fait de vivre dans des communautés rurales augmente le risque de M5 + de 9 % (adjusted Hazard Ratio (aHR): 1,09, IC: 1,01 - 1,23). Alors que les enfants non allaités exclusivement (aHR = 9,96, IC: 8,95 - 11,10) avaient un risque de décès plus élevé, le fait d'être une femme et de donner naissance à une mère âgée de 40 à 49 ans protégeait U5M. La mortalité infantile est généralement plus élevée dans le nord du Nigéria que dans le sud du Nigéria. Le modèle de fragilité partagée a montré que le fait d'être originaire du Nord-Ouest (0,0549) et des zones rurales (0,0345) présentait la fragilité la plus élevée pour les moins de 5 ans. Le modèle de fragilité partagée (AIC = 44266.0) comparé au modèle PH de Cox (AIC = 44375,9) était plus adéquat pour modéliser la mortalité des enfants de moins de 5 ans chez les enfants nigérians.

Conclusion: L'étude a démontré l'importance des caractéristiques des ménages, des états et des régions pour expliquer le risque de mortalité des moins de cinq ans au Nigéria. Les résultats de cette étude ont montré la nécessité de dépasser les facteurs individuels pour relever le défi de la mortalité des moins de 5 ans au Nigéria. Afin de réaliser certains des objectifs de développement durable au Nigéria, une attention particulière doit être accordée aux interventions communautaires visant à améliorer la survie des moins de cinq ans dans les zones socialement et économiquement défavorisées du pays.

1. Introduction

Childhood mortality is one of the measure of socio-economic status of a population. It is among the major public health challenges facing Nigeria from time immemorial, with children who live in rural area and in northern geopolitical zones in Nigeria been the worst hit. For instance, Fagbamigbe and Alabi (2014) in a recent study, found that the infant mortality rate in the North East zone was 108 per 1000 live births compared to 59 in the South West Nigeria and the probability of a child from North East and South West Nigeria surviving first year was estimated as 0.890 and 0.940 respectively. Similar assertions were made in Fagbamigbe and Akinyemi (2016). The burden of negative child health outcomes in Nigeria appeared to be divided by the heterogeneous nature of the country.

Studies have long established a significant relationship between child survival and individual-level characteristics such as maternal education and other socio-economic characteristics (see Adedini *et al.* (2014) and Akinyemi *et al.* (2015)). Another study showed that some attributes of the community where children are raised tend to influence the mortality risks of the children (Adekanmbi *et al.* (2011)). Growing body of evidence also suggests that living in an economically and socially deprived neighbourhood is associated with increased risk of Under-Five Mortality (U5M) as reported by Antai and Moradi (2010) and Aremu *et al.* (2011).

Although much progress has been made with respect to morbidity and mortality prevention among children globally, U5M rates in Nigeria remained high compared to the mortality rate of 6 per 1000 live births observed in the industrialized countries as of 1998 (see details in UNICEF (2001)). Interestingly, Nigeria has realized impressive gains in child survival over the last two decades. However, the country failed to achieve the Millennium Development Goal (MDG)-4 which aims to reduce U5M rates by two-thirds between 1990 and 2015. Besides, at the current pace, it is uncertain that Nigeria will meet the newly defined sustainable development goal on ensuring health for all.

Several studies have employed varying statistical methodologies to identify determinants of U5M (see Adedini *et al.* (2012, 2014); Kayode *et al.* (2012)). Multivariate logistic regression was used to determine risk factors and a predictive model for U5M in Nigeria. Likelihood Ratio (LR) test was used to assess the goodness-of-fit of the model and receiver operating curve (ROC) was employed to examine the predictive power of the model by Kayode *et al.* (2012). Also, a pooled cross-sectional analysis 2003, 2008 and 2013 of the Nigeria Demographic and Health Survey (NDHS) data was conducted to determine the risk factors for post-neonatal, infant, child and U5M in Nigeria by Osita *et al.* (2014).

While these studies showed that children with different background characteristics have different levels of vulnerability to child mortality, the diverse nature and effects of these characteristics were not sufficiently and adequately determined. One of the ways of doing this is the use of multi-level analysis which introduces both the mixed and random effects. A random effect describes excess risk or frailty for distinct categories but the above stated studies have failed to account for such random effect. In addition, most of the previous studies on child mortality using survival analysis approach mainly adopted the Cox Proportional Hazard (PH) models and the likes which do not account for random effect and the heterogeneity nature of the different clusters found in NDHS data. It is imperative to note that the multilevel or hierarchical structure of the data should not be neglected since child mortality cannot be truly studied and assessed without a thorough evaluation and incorporation of such structures.

Literature has stipulated some factors affecting children mortality, most of which showed that child mortality in developing countries was mainly associated with measurable socio-economic conditions. Whereas, knowledge about the determinants of child mortality at the individual level is insufficient to address the problem of child mortality (see Omariba *et al.* (2007)). This is because the contextual characteristics of the community or neighbourhood where a child is raised tend to modify individual- and household-level factors and therefore affect child survival. Furthermore, some unmeasurable genetic, environmental and behavioural components still remain non-negligible. Children belonging to the same family, region, and even geo-political zones share certain correlation and unobserved characteristics or simply heterogeneity. Therefore, there is need to explore the influence of the multilevel structure so as to identify the hidden gems in the data and determine the effect of such gems on the children. Hence, the current study is aimed at employing the shared frailty model to assess U5M with focus on hierarchical structure of the nationally representative clustered dataset in Nigeria.

2. Methodology

2.1. Study design and study population

We used the 2013 Nigeria Demographic and Health Survey (NDHS) data to carry out a retrospective analysis of all births to all the 38948 women of reproductive age who participated in the cross-sectional survey. The data of each distinct birth to all the participants were obtained, recoded as single record and stored in the 2013 NDHS birth recode file. The file contains information of all live births by women aged 15-49 years sampled in the survey.

The survey utilized three-stage stratified cluster sampling and covered all the regions and states in Nigeria. A total of 904 clusters, with 372 and 532 in urban and rural areas respectively. A representative sample of 40,680 households was selected for the survey, with a minimum target of 943 completed interviews per each of the states from the 25 clusters that were randomly selected from each state irrespective of their population sizes and numbers of Local Government Areas (LGAs). Only 4 cluster was selected from the Federal Capital Territory, Abuja. For the full details of the survey methodology, see National Population Commission, Nigeria (2014). Due to this nested structure, the likelihood of child's death may not be independent, because children from the same cluster may share common exposure to community characteristics. Similar narration and justification has been documented earlier (see Fagbamigbe and Bakre (2018)).

2.2. Variables

The primary outcome in the current study is the U5M. Child survival time was calculated as the time from birth to date of death if child died before their 5^{th} birthday or at 5 years if they were alive as of their 5^{th} birthday. In essence, we censored children who were alive as of their 5^{th} birthday and their censoring indicator was coded as "0" while the deaths before age 5 years were assigned censoring code "1".

The independent factors considered in this study were mostly based on the **?** framework of factors influencing child survival in developing countries. These variables comprised of geographic location of place of residence (categorised as urban-rural residence), a household measure of income and a range of individual-level factors as used in previous studies on childhood mortality particularly in the sub-Saharan Africa region (Fagbamigbe and Alabi (2014); Akinyemi *et al.* (2015); Fagbamigbe and Akinyemi (2016)). The explanatory variables are well described in Table 1.

Table 1. Potential Predictors

Variables	Description of Categories
Demography Factors	
Mother's Residence	Urban, Rural
Mother age at 1st birth	<15,15-20, 20 years and above
Sociocultural factors	
Religion	Muslim, Christian, others
Region/ Geopolitical zone	North West, North East, North Central, South South, South East, South West,
Socio-economic factors	
Mother's education	No education, Primary, Secondary and Higher
Mother's work status	Working, Not working
Wealth Quintiles	Poorest, poorer, Medium, Richer, Richest
Father's education	No education, Primary, Secondary and Higher
Environmental factors	
Source of drinking water	Improved and Unimproved Sources
Toilet facility	Improved and Unimproved Sources
Cooking fuel	Clean and Unclean fuel
Mother smokes	Yes, No
Proximate/Biological factors	
Sex of the child	Male, Female
Birth order	1,2,3,4,5, 5+
Preceding birth interval	No previous birth, < 18, 18 - 30, > 30 months
Child is a Twin	Yes, No
Mother's age at birth	Under 20, 20-29. 30-39, 40-49 years
Place of delivery	Homes, Public sector, Private sector, Others
Breast Feeding	Exclusive, not exclusive, None
Contraceptive Use	Not Using, Using

2.3. Methods of Analysis

The analysis method for this study is based on an analytical framework in which child mortality has a possibility of changing overtime because of unavoidable changes in background characteristics of children. These operates through proximate determinants (**?**). All statistical tests in this study were conducted at 5% level of significance.

The two most prominent tools for analysing time to event data are the survival function $S(t)$ and hazard function $h(t)$, where t is a non-negative random variable taking on the exact event time and having the probability density function (pdf) $f(t)$. Assuming a continuous time to event

$$S(t) = Pr[T>t] = \int_t^{\infty} f(u)du \Leftrightarrow f(t) = -\frac{d}{dt}S(t)$$

The hazard function also known as instantaneous failure rate is defined as

$$h(t) = \lim_{\Delta t \to 0} \frac{[Pr[t \le T \le t + \Delta t | T > t]}{\Delta t}$$

The hazard function is the conditional probability of experiencing the event of interest within a very small time interval of size Δt having survived up to time t. It estimates the likelihood that the event will occur immediately after time t, provided the event did not occur before time t. The integration of the hazard function from 0 to t produces the cumulative hazard function denoted by $H(t)$ and defined as

$$H(t) = \int_0^t h(u)du$$

This is defined as the accumulation of the hazard over time. Thus the relationship between survival and hazard function could be expressed as

$$S(t) = \exp(-H(t)).$$

The survival function could be estimated using the Kaplan-Meier estimator given by

$$S(t) = \prod_{t_{(j)} \leq t} \frac{n_j - d_j}{n_j}$$

where $t_1 < t_2 < \cdots < t_{(r)}$ are the r ordered distinct event times, d_j is the number of events that occurred and n_j is the number of individuals at risk at time $t_{(j)}$.

2.4. Cox proportional hazards model

The Cox proportional hazards (PH) model Cox (1972), is based on $h(t)$. For the i^{th} individual, the model is

$$h_i(t|X) = h_0(t)\exp(\beta' X_i) = h_0(t)\exp(\eta_i)$$
$$= h_0(t)\exp\left(\sum_{j=1}^{p} \beta_j X_{ji}\right); \qquad j = 1, \ldots, p; \qquad i = 1, \ldots, n$$

where

$$\beta = (\beta_1, \beta_2, \ldots, \beta_p)'; \qquad X_i = (x_{1i}, x_{2i}, \ldots, x_{pi})'$$

and η_i is the linear component or linear predictor, X_i is a vector containing p characteristics of the i^{th} individual and $h_o(t)$ is the baseline hazard function. This could be further expressed as

$$\psi = \frac{h_i t}{h_0 t} = \exp(\beta' X_i) = \exp\left(\sum_{j=1}^{p} \beta_j X_{ji}\right); \qquad j = 1, \ldots, p; i = 1, \ldots, n$$

For a sample of n individuals with m distinct observed and ordered survival times; $t_1, t_2, \ldots t_m$ and δ_i an event indicator such that $\delta_i = 0$ if the j^{th} survival time $t_{(j)}$ is right-censored and $\delta_i = 1$ otherwise.

Cox showed that the parameter estimates β in the model can be obtained by maximizing the partial likelihood function

$$L(\beta) = \prod_{i=1}^{n} \left\{ \frac{\exp(\beta' X_i)}{\sum_{l \in R(t_{(j)})} \exp(\beta' X_l)} \right\}^{\delta_i}; \qquad i = 1, \ldots, n; \quad j = 1, \ldots, m$$

as shown in Cox (1972), where $R(t_{(j)})$ is the risk set and X_i the vector of covariates for the individual who fails at time $t_{(j)}$.

Alternatively, the partial log-likelihood function cam be maximized using iterative methods such as the Newton-Raphson procedure to obtain

$$\log L(\beta) = \sum_{i=1}^{n} \delta_i \left[\beta' X_i - \log\left(\sum_{l \in R(t_{(j)})} \exp(\beta' X_l) \right) \right]$$

.

2.5. Modelling the unobserved heterogeneity as a random effect

One of the short comings of the Cox PH model in the analysis of datasets from clustered surveys such as the DHSs and other multi-purpose surveys is its inability to provide all the specific information about all prognostic factors been studied. More so, the independent nature of data obtained in clustered surveys often violates the hazards proportionality assumptions of the Cox model.
A way out is to extend the Cox PH model to accommodate a random effect term through the linear component. These extension may then account for the unobserved heterogeneity. As stated in Long *et al.* (2009) and Wienke (2003), the model can then be classified into two components: marginal or random effects model. The extended Cox PH model with a frailty term can be written in the form

$$h_{ij}(t|X,Z) = h_0(t) Z_{ijk} \exp(X'_{ijk}\beta)$$

where z_{ijk} is the frailty effect of the i^{th} individual in the j^{th} group or cluster embedded in another k^{th} upper level cluster, with Z being a positive random variable having a probability density function $g(z)$ with mean 1 and variance θ. When frailties z_{ij} are jointly shared among the individuals i^{th} of a particular area, group or cluster j embedded in cluster k, the derived shared frailty model takes the form

$$h_{ijk}(t|X,Z) = h_0(t) Z_j Z_k \exp(X'_{ijk}\beta)$$

where Z_j and Z_k are the j^{th} and the k^{th} group frailty effects respectively. Those individuals who shared frailty $Z_j > 1$ and $Z_k > 1$ are more frail for reasons left unexplained by the covariates. They might therefore have an increased risk of failure all things being equal.

It is worth noting that by integrating out frailties, the unconditional survival function $s(t)$ is independent of frailties Z_j and Z_k but dependent of its variance θ. For example, the marginal hazard function for gamma frailties can be expressed as

$$h(t|X) = \frac{h_0(t)\exp(X\beta)}{1 + \theta H_0(t)\exp(X\beta)}$$

The methods of penalized partial log-likelihood can be used to estimate the frailty. The penalized partial likelihood model for the gamma frailty, with penalty function

$$g(w,\theta) = \frac{1}{\theta} \sum [\omega_j - \exp(\omega_j)]$$

coincides with the EM algorithm solution for any fixed value of θ.

Therefore, in this study we applied the penalized partial log-likelihood approach by assuming that the data for the i^{th} child, member of j^{th} the woman's cluster follows a proportional hazards shared frailty model

$$h_i(t) = h_0(t)\exp(X_{ij}\beta + \omega_{ij}\psi) = h_0(t) z_{j(i)} \exp(X_i\beta)$$

$j(i)$ specifies that child i belongs to woman j, $z_{j(i)} = 1$ if i belongs to j and $z_{j(i)} = 0$ otherwise.

For more details, see Hougaard (1995) and Oakes *et al.* (1989). Also, descriptive statistics were used to show the distribution of mothers by socio-demographic, economic, environmental, and biological factors across the geopolitical regions in Nigeria as shown in Tables 2 and 3. We also provided result of the bivariate analysis between these independent characteristics and U5M. Data was weighted to reflect differences in population sizes of each state in Nigeria.

3. Result

3.1. The background characteristics of the children and their parents

In all, 119,386 births were reported in the survey. The male children were 52%. Proportion of males compared to females across the regions of residence were almost equally distributed. Only 1% of the under-five children were delivered in a caesarean section, while most (63%) deliveries happened at home. There were more women from the North West (33%) compared to the other regions, and from the rural (68%) compared to urban area. The wealth quintile of under-five mothers were about equally dispersed. However, mothers from the households within the richest wealth quintile constituted the least (14.0%) proportion. Meanwhile, most (42.8%) participants' husbands were uneducated, majority (n=26932; 70.4%) of the women were from the North West region (Tables 2 and 3).

3.2. The Cox proportional hazard model

Table 4 shows the summary output of the Cox proportional hazard model used to identify the factors influencing U5M. The analysis showed that children from region North West region have higher risk of U5M compared to children in the South West (aHR = 1.37, 95% CI: 1.04 - 1.78). However, children from the South South region had 25% times lower risk of U5M (aHR = 0.75, 95% CI: 0.62-0.92). Also, children of mothers aged 40-49 years have lower risk of childhood mortality (aHR = 0.55, 95% CI: 0.45 0.66). Being a female child lowers the risk U5M by 12% (aHR = 0.88, 95% CI: 0.82 - 0.95). Children whose birth order is more than 5 have higher risk of mortality than those with lower birth order (aHR = 1.14, 95% CI: 1.00 - 1.30). Children who are twins have higher likelihood of death compared to those who are not twins. The analysis indicates that multiple birth increases the risk of death (aHR = 2.47, 95% CI: 2.16 - 2.81) compared with singletons. Children

Table 2. Distribution of Parents' Socio-demographic Characteristics by Regions

Characteristics	Regions (Geopolitical Zones)						
	North Central	North East	North West	South East	South South	South West	Nigeria
Number	16143 n (%)	24180 n (%)	38757 n (%)	11219 n (%)	14857 n (%)	14230 n (%)	119386 n (%)
Residence							
Urban	28.4	20.5	20.9	65.0	29.3	67.0	32.5
Rural	71.6	79.5	79.1	35.1	70.7	33.1	67.5
Mother's Age							
Below 20	1.1	1.8	1.7	0.5	1.3	0.6	1.3
20 - 29	40.3	23.8	19.2	47.9	37.3	54.7	32.2
30 - 39	2.0	0.8	0.5	3.6	2.1	3.2	1.6
40 - 49	56.6	73.7	78.6	47.9	59.4	41.5	64.9
Mother's Age @1st Birth							
Below 15	8.3	15.7	16.4	7.7	9.4	4.5	12.0
15 - 19	49.4	59.8	63.9	40.9	51.2	37.6	54.2
Above 19	42.4	24.6	19.7	51.7	39.4	57.9	33.8
Religion							
Catholic	14.3	2.4	1.5	40.4	7.9	4.2	8.2
Other Christian	36.5	16.0	2.6	55.6	87.9	62.1	32.6
Islam	46.1	80.1	94.6	0.2	2.5	33.1	57.4
Traditionalist	3.1	1.5	1.4	3.8	1.8	0.6	1.8
Wealth Index							
Poorest	8.8	40.4	41.7	7.0	0.8	2.5	24.0
Poorer	21.0	30.0	30.4	17.5	11.7	8.5	22.9
Middle	33.2	15.3	14.1	29.3	30.4	15.9	20.6
Richer	21.0	9.0	9.3	27.8	34.8	32.9	18.6
Richest	16.0	5.2	4.5	18.4	22.3	40.2	14.0
Father Education							
No education	26.3	61.5	70.4	13.7	7.5	13.3	42.8
Primary	21.7	14.0	12.5	48.1	31.2	24.9	21.1
Secondary	29.3	13.6	10.6	30.1	46.5	43.7	23.9
Higher	22.8	10.9	6.6	8.1	14.9	18.1	12.2
Mother Education							
No education	38.9	71.3	82.6	13.8	10.9	14.6	50.9
Primary	30.8	16.5	10.4	38.7	43.0	29.9	23.4
Secondary	21.9	9.2	5.9	38.8	38.8	43.9	20.4
Higher	8.4	3.1	1.2	8.7	7.3	11.6	5.3
Mother Work Status							
Not Working	17.6	39.1	30.9	11.2	12.7	6.5	23.7
Working	82.4	60.9	69.10	88.8	87.3	93.5	76.3
Total	13.5	20.3	32.5	9.4	12.5	11.9	100.0

Table 3. Distribution of Parents' & Children' Biological & Environmental Characteristics

	Region (Geopolitical Zones)						
Characteristics	**North Central** n (%)	**North East** n (%)	**North West** n (%)	**South East** n (%)	**South South** n (%)	**South West** n (%)	**Nigeria** n (%)
Sex of Child							
Male	51.2	51.6	51.2	51.9	51.7	50.7	51.3
Female	48.8	48.4	48.9	48.1	48.3	49.3	48.7
Status							
Dead	10.7	19.8	23.4	13.9	10.4	10.9	17.0
Alive	89.3	80.2	76.6	86.1	89.6	89.1	83.1
Birth Order							
1	26.0	21.1	20.0	23.4	25.8	28.0	23.0
2	21.5	18.1	17.4	19.1	20.6	23.1	19.3
3	17.2	15.2	14.9	16.0	16.4	18.2	16.0
4	13.2	12.5	12.4	13.0	12.9	13.1	12.7
5	9.5	10.0	10.1	10.0	9.4	8.2	9.7
More than 5	12.5	23.2	25.3	18.5	15.0	9.5	19.3
Child is a Twin							
No	96.3	97.1	97.1	95.8	95.9	95.4	96.5
Yes	3.7	3.0	2.9	4.2	4.1	4.6	3.5
Place of Delivery							
Home	46.5	78.2	88.7	20.4	54.6	25.1	62.3
Govt hospital/clinic	34.2	19.3	9.9	35.1	33.0	39.3	24.0
Private hospital/clinic	18.1	1.3	0.4	42.9	11.2	34.9	12.5
Other	1.2	1.1	1.1	1.60	1.2	0.8	1.2
Caesarean Delivery							
No	99.0	99.6	99.7	98.8	99.0	97.8	99.2
Yes	1.0	0.4	0.3	1.2	1.0	2.2	0.8
Child birth size							
Large	51.2	39.7	42.2	31.9	47.4	46.1	43.2
Average	35.8	9.3	38.8	53.4	38.4	43.6	40.3
small	11.0	19.3	16.8	12.4	12.4	9.1	14.6
Don't know	2.0	1.8	2.2	2.4	1.8	1.2	1.9
Breastfeeding Duration							
Exclusive Breastfeeding ^	63.3	63.3	61.8	68.8	68.6	67.8	64.5
Unexclusive Breastfeeding	3.0	2.9	1.7	3.6	3.1	2.8	2.6
No Breastfeeding at all	33.7	33.8	36.6	27.6	28.3	29.4	32.9
Drinking Water							
Unimproved sources	39.9	51.1	43.6	33.6	44.2	18.7	40.8
Improved sources	60.1	48.9	56.4	66.4	55.8	81.3	59.2
Toilet Facility							
Unimproved sources	61.1	54.7	46.0	51.0	58.1	46.0	51.8
Improved sources	38.9	45.3	54.0	49.0	41.9	54.0	48.2
Cooking Fuel							
Unclean/Biomass	81.5	96.4	95.4	82.7	68.9	42.6	82.9
Clean fuel	18.6	3.6	4.6	17.3	31.1	57.4	17.1
Mother Smokes							
No	99.0	99.2	99.5	99.4	99.5	99.6	99.4
Yes	1.0	0.7	0.5	0.7	0.6	0.4	0.6

with very small birth weight have higher likelihood to die as an before attaining age 5 years compared to those who have large birth weight (aHR = 1.27, 95% CI: 1.14 - 1.42). Also children who were not breastfed exclusively have higher risk of death compared to those who had exclusive breastfeeding (aHR = 9.18, 95% CI: 8.28 - 10.17) as shown in Table 4.

Table 4:Determinants of Under-five Mortality using Cox Proportional Hazard Model

Covariates	Coeff	aHR	SE(coeff)	95% CI	p-value
Region					
North Central	-0.012	0.988	0.109	0.798-1.224	0.913
North East	0.062	1.063	0.128	0.828-1.367	0.631
North West	0.312	1.367	0.137	1.045-1.787	*0.023
Souht East	0.066	1.068	0.102	0.874-1.305	0.520
South South	-0.281	0.755	0.103	0.618-0.923	***0.006
South West^					
Residence					
Urban^					
Rural	0.092	1.096	0.060	0.976-1.232	0.122
Mother's Age					
Below 20^					
20- 29	-1.140	0.320	1.009	0.044-2.312	0.259
30- 39	-1.048	0.351	1.016	0.048-2.566	0.302
40- 49	-0.603	0.547	0.094	0.455-0.658	***0.000
Mother Age at 1st Birth					
Below 15	-0.735	0.480	1.006	0.067-3.446	0.465
15-19	-0.570	0.565	1.004	0.079-4.043	0.570
Above 19^					
Religion					
Catholic^					
Other Christian	-0.068	0.934	0.088	0.786-1.110	0.439
Islam	-0.206	0.814	0.100	0.669-0.990	*0.039
Traditionalist	-0.147	0.863	0.182	0.605-1.233	0.419
Wealth Index					
Poorest^					
Poorer	0.027	1.028	0.052	0.929-1.137	0.596
Middle	-0.088	0.916	0.070	0.799-1.051	0.212
Richer	0.027	1.027	0.091	0.859-1.228	0.770
Richest	-0.137	0.872	0.131	0.675-1.127	0.296
Husband Education					
No education	-0.033	0.967	0.094	0.805-1.163	0.722
Primary	-0.095	0.909	0.094	0.757-1.093	0.311
Secondary	-0.054	0.948	0.086	0.801-1.121	0.529
Higher^					
Mother Education					
No education	0.101	1.106	0.149	0.827-1.481	0.497
Primary	0.227	1.255	0.143	0.949-1.660	0.111
Secondary	0.201	1.222	0.131	0.946-1.580	0.125
Higher^					
Mother Work Status					
Not Working^					
Working	-0.016	0.984	0.043	0.904-1.071	0.705
Sources of Drinking Water					
Unimproved sources^					

Improved sources	-0.021	0.979	0.043	0.901-1.066	0.629

........../Table 4 continues

Covariates	Coeff	aHR	SE(coeff)	95% CI	p-value
Toilet Facility					
Unimproved sources					
Improved sources	-0.076	0.927	0.045	0.849-1.011	0.087
Type of Cooking Fuel					
Unclean/Biomass^					
Clean fuel	0.092	1.097	0.088	0.923-1.303	0.294
Sex of Child					
Male^					
Female	-0.125	0.882	0.039	0.818-0.952	**0.001
Birth Order					
1^					
2	-0.013	0.987	0.069	0.862-1.130	0.850
3	-0.178	0.837	0.075	0.723-0.969	*0.017
4	-0.032	0.968	0.076	0.834-1.124	0.671
5	-0.142	0.868	0.083	0.738-1.020	0.085
More than 5	0.133	1.142	0.065	1.004-1.298	*0.043
Child is a Twin					
No^					
Yes	0.905	2.472	0.067	2.17-2.816	***<0.001
Place of Delivery					
Home^					
Govt hospital/clinic	-0.020	0.981	0.061	0.87-1.106	0.750
Private hospital/clinic	-0.042	0.959	0.088	0.808-1.139	0.634
Other	0.736	2.088	0.145	1.571-2.774	***<0.001
Delivery by Caesarean Section					
No^					
Yes	0.248	1.282	0.117	1.02-1.611	0.033
Size of Child at birth					
Large^					
Average	0.087	1.091	0.045	0.999-1.192	0.054
small	0.245	1.277	0.055	1.146-1.424	***<0.001
Don't know	0.765	2.149	0.127	1.675-2.757	***<0.001
Duration of Breastfeeding					
Exclusive BF^					
BF but not Exclusive	2.217	9.182	0.052	8.283-10.180	***<0.0001
No BF at all	-1.426	0.240	0.087	0.202-0.285	***<0.0001

BF Breast Feeding, p significant at *$\alpha<0.05$, **$\alpha<0.001$, ***$\alpha<0.0001$, ^Reference category, aHR adjusted Hazard Ratio, CI Confidence Interval

Table 4: Determinants of Under-five Mortality using Cox Proportional Hazard Model

3.3. The shared frailty model

Being born of older mothers aged 40-49 years (aHR = 0.543, CI: 0.450 - 0.655) and being a female child (aHR = 0.878, CI: 0.813 - 0.948) lowers the risk of U5M by 46.0% and 12.0% respectively. However, twins children had higher risk of under-five death than singletons (aHR = 2.528, CI: 2.211 - 2.890). Also, children delivered through caesarean operations have higher risk of dying before attaining age 5 years compared to those delivered

Table 5: Factors affecting Under-five mortality using Mixed effect Frailty model

Covariates	Coeff	aHR	SE(coeff)	95% CI	p-value
Mother's Age					
Below 20^					
20 - 29	-1.206	0.300	-1.013	0.041-2.179	0.230
30 - 39	-1.075	0.341	-1.019	0.046-2.516	0.290
40 - 49	-0.610	0.543	-0.096	0.450-0.655	***<0.001
Mother Age @ 1^{st} Birth					
Below 15	-0.788	0.455	-1.009	0.063-3.289	0.440
15-19	-0.620	0.538	-1.007	0.075-3.874	0.540
Above 19^					
Religion					
Catholic ^					
Other Christian	-0.111	0.895	-0.090	0.750-1.067	0.220
Islam	-0.157	0.855	-0.101	0.701-1.041	0.120
Traditionalist	-0.227	0.797	-0.184	0.556-1.143	0.220
Wealth Index					
Poorest ^					
Poorer	0.022	1.022	0.053	0.921-1.134	0.690
Middle	-0.097	0.908	-0.072	0.788-1.046	0.180
Richer	0.046	1.047	0.092	0.874-1.255	0.620
Richest	-0.149	0.862	-0.133	0.664-1.117	0.260
Father Education					
No education	-0.032	0.969	-0.096	0.804-1.169	0.740
Primary	-0.076	0.927	-0.094	0.770-1.115	0.420

Secondary	-0.037	0.964	-0.086	0.814-1.142	0.670
Higher ^					
Mother Education					
No education	0.104	1.109	0.150	0.827-1.489	0.490
Primary	0.207	1.230	0.144	0.928-1.631	0.150
Secondary	0.188	1.207	0.132	0.932-1.562	0.150
Higher^					
Mother Work Status					
Not Working^					
Working	-0.017	0.983	-0.045	0.901-1.072	0.700
Drinking Water Source					
Unimproved sources ^					
Improved sources	-0.015	0.985	-0.045	0.902-1.076	0.740
Toilet Facility					
Unimproved sources ^					
Improved sources	-0.025	0.975	-0.048	0.887-1.072	0.600

.........../Table 5 continues

Covariates	**Coeff**	**aHR**	**SE(coeff)**	**95% CI**	**p-value**
Cooking Fuel					
Unclean/Biomass ^					
Clean fuel	0.072	1.075	0.089	0.902-1.280	0.420
Smokes Cigarettes					
No ^					
Yes	-0.669	0.512	-0.345	0.261-1.007	0.052
Sex of Child					
Male ^					
Female	-0.130	0.878	-0.039	0.813-0.948	***<0.001
Birth Order					
1 ^					
2	0.015	1.015	0.070	0.885-1.163	0.830
3	-0.145	0.865	-0.076	0.745-1.003	0.055
4	0.000	1.000	0.077	0.859-1.163	1.000
5	-0.086	0.917	-0.083	0.779-1.080	0.300
More than 5	0.162	1.176	0.066	1.032-1.339	*0.015
Child is Twin					

No ^					
Yes	0.927	2.528	0.068	2.211-2.89	***<0.001
Place of Delivery					
Home ^					
Govt hospital/clinic	-0.007	0.993	-0.062	0.879-1.122	0.910
Private hospital/clinic	-0.026	0.974	-0.088	0.820-1.157	0.760
Other	0.831	2.295	0.148	1.716-3.07	***<0.001
Caesarean Delivery					
No ^					
Yes	0.240	1.271	0.118	1.009-1.602	*0.042
Size of Child at birth					
Large ^					
Average	0.073	1.076	0.046	0.983-1.177	0.110
small	0.280	1.323	0.057	1.184-1.479	***<0.001
Don't know	0.808	2.243	0.129	1.742-2.890	***<0.001
Breast Feeding Duration					
Exclusive BF ^					
BF but not Exclusive	2.300	9.969	0.055	8.950-11.10	***<0.001
No BF at all	-1.437	0.238	0.089	0.200-0.283	***<0.001

BF Breast Feeding, significant at * α<0.05, ** α<0.001, *** α<0.0001, ^Reference category, aHR adjusted Hazard Ratio, CI Confidence Interval

Table 5: Factors affecting Under-five mortality using Mixed effect Frailty model

naturally (aHR = 1.271, CI: 1.009 - 1.602). Likewise, children with small birth sizes had higher risk of death compared to those with large birth size (aHR = 1.323, CI: 1.184 - 1.479); and those who were not breastfed exclusively (aHR = 9.969, CI: 8.950 - 11.105) had higher risk of under-five death compared to those who were exclusively breastfed (Table 5).

Also, random effect within households and states of residence of the under-five children respectively had estimated excess risk of 1.20 and 1.23 times higher than the expected average risk respectively (Table 6). Although random effect within the region and the type of residence respectively had moderate excess risk, North West region (0.0549) and rural area (0.0345) had the highest risk of under-five mortality (Table 7). Among the states, Zamfara (0.4176) followed by Ebonyi (0.3525) and Adamawa (0.2778) had the highest frailty (Table 7). As shown in Table 6, shared frailty model of under-five had lower AIC (44266.0) compared with the Cox model; this suggests shared frailty model as being adequate in modeling U5M and perhaps by extension to neonatal & infant mortality in Nigeria.

Table 6. Random Effect for Under-five Mortality and Model Adequacy

Group	Variable	Std Dev	Variance	
Region	Intercept	0.0673	0.0045	
Household	Intercept	0.1841	0.0339	
Place of Residence	Intercept	0.0582	0.0034	
State of Residence	Intercept	0.2034	0.0414	
Model	AIC	X^2	Df	P(>$\|Chi\|$)
Model 1 (U5M Cox)	44375.8700			
Model 2 (U5M Frailty)	44266.0400	55.6740	2.0000	0.0000

Table 7. Frailty Severity for Under-five Mortality by place, regions and states of residence

Region	**Frailty**			**Location**	**Frailty**
South West	0.0064			Urban	-0.0345
North East	-0.0281			Rural	0.0345
South East	0.0281				
North Central	-0.0156				
North West	0.0549				
South South	-0.0458				
State	**Frailty**	**State**	**Frailty**	**State**	**Frailty**
Sokoto	0.1098	FCT-Abuja	-0.2193	Anambra	-0.1001
Zamfara	0.4176	Nasarawa	0.1525	Enugu	-0.0376
Katsina	-0.1880	Plateau	0.0153	Ebonyi	0.3525
Jigawa	0.1486	Taraba	0.1027	Cross River	0.0201
Yobe	-0.1140	Benue	0.1045	Akwa Ibom	-0.1405
Borno	-0.3661	Kogi	-0.1001	Abia	-0.0350
Adamawa	0.2778	Kwara	0.1118	Imo	0.0773
Gombe	-0.0742	Oyo	-0.0910	Rivers	-0.0400
Bauchi	-0.0829	Osun	-0.1680	Bayelsa	-0.0925
Kano	0.0076	Ekiti	-0.0545	Delta	0.0404
Kaduna	-0.0794	Ondo	0.0594	Lagos	0.2360
Kebbi	0.0852	Edo	-0.2058	Ogun	0.0766
Niger	-0.2070				

4. Discussion

This study used the Cox PH and shared frailty models to investigate determinants of U5M among children in Nigeria. The shared frailty model was employed to account for the hierarchical nature of the data. According to the literature, characteristics including the socio-demographic, economic, environmental and biological factors at the household, state and regional level were considered in the analysis. Fixed effects models were compared to the Cox PH model and random effects which models and uncovers the variations in levels as stated by Merlo *et al.* (2005) were employed to interpret our findings.

The study found that U5M risk factors were higher among children living in the North West region, living in a rural area and having a mother with no education. More so, under-five deaths were also associated with having pregnancy delivery in places other than the Government/Private hospital, being perceived as a small or very small newborn by their mothers, and having a higher birth order with a birth interval ≤ 2 years. Previous delivery by caesarean section and being a male child were significantly associated with under-five child mortality.

The fitted Cox regression model revealed that children in North West region had more likelihood of under-five mortality compared to those from the southern region. We found that children from mothers in North West and North East area of the country were mostly affected. Similar finding has been reported earlier (Antai (2011)). This could be as a result of complications experienced during birth which could also be the consequence of poor exposure of mothers to modern health facility and inability of mothers to comply or to understand prenatal care as advised by health practitioners.

In addition, rural-urban location, mothers' education, multiple birth, place of delivery, mode of delivery, size of child at birth and exclusiveness of breastfeeding significantly influenced U5M. Children whose mothers live in the rural area have higher propensity to die before fifth birthday. This finding is in consonant with that of UNICEF reports (see UNICEF (2018)). This significant higher risk of death among under-five children who who were born to women in rural areas in Nigeria, noted in the present study, may be attributed to limited access to healthcare facilities, poor educational and transport services, unavailability of safe water supply and inadequate basic sanitation facilities (see Omo-Aghoja *et al.* (2010)). Such conditions disproportionally hinder rural dwellers from receiving adequate healthcare and social and economic services, which adversely affects child survival. These findings are in agreement with previous studies (Fagbamigbe and Alabi (2014); Akinyemi *et al.* (2015); Fagbamigbe and Akinyemi (2016)) which argued that provision of both prenatal and postnatal care are essential for child's survivorship. Also children who were delivered in caesarean sessions have a higher risk of under-five mortality.

Furthermore, the shared frailty model revealed a significant relationship between mothers' age, multiple birth, place and mode of delivery, size of child at birth and duration of breast feeding as it influence risk of under-five death. This findings established an elevated influence of breastfeeding manner as it affects U5M. Children who were not exclusively breastfed have high risk of under-five death compared to those who were breastfed exclusively. Exclusive breastfeeding provides ideal nutrition for neonates, infants and under-five children. Failure to give exclusive breastfeeding could impact negatively on child health outcomes.

The shared frailty model also revealed that U5M were most common in North West (Zamfara), North East (Adamawa) and South East (Ebonyi). Many of these deaths could be averted if warning signs were well recognized by mothers, appropriate feeding practices undertaken in addition to accessibility of skilled health workers and facility-based care. In the North East region with the highest U5M rates, access to postnatal care is abysmally low. In states like Zamfara and Jigawa fewer than half of mothers and babies receive a postnatal health check. The random effect component of the shared frailty model also showed that the place, regions and states of residence of the children greatly influenced U5M among Nigeria children and the frailty severity differed significantly. The model adequacy check suggested that heterogeneity caused by the place, regions and states of residence of the children should be taken into consideration through used of shared frailty model rather than leaving them unobserved. Similar findings were reported by Yadav and Janak (2015).

5. Conclusion

Our study has demonstrated the significant roles of children household, state and regional characteristics in explaining the risk of under-five moralities in Nigeria. These roles are more visible in the shared frailty models than in the Cox proportional hazard model. The results of this study stress the need to look beyond the influence of individual-level factors in addressing the problem of under five mortality and by extension the neonatal and infant mortalities in the country. In order to realize the sustainable development goal on health for all in Nigeria, attention also needs to be focused on community-level interventions aimed at improving under-five survival in the country's socially and economically disadvantaged areas. We recommend the use of shared frailty model in the identification of prognostic factors in similar data structures.

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