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COMPARISON BETWEEN SEMI-PARAMETRIC COX AND PARAMETRIC SURVIVAL MODELS IN ESTIMATING THE DETERMINANTS OF UNDER-FIVE MORTALITY IN NIGERIA: APPLICATION IN NIGERIAN DEMOGRAPHIC AND HEALTH SURVEY

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ABSTRACT: *The increasing application of survival analysis in estimating the determinants of under-five mortality, call for the need to use the most flexible and efficient model to estimate reliable determinants free from bias. Most population health and medical research that involve survival analytical techniques are based on the semi-parametric Cox models instead of the parametric versions because of the flexibility associated with the former which does not require specification of the baseline hazard function. In this study, we compare the semi-parametric Cox model and parametric models in estimating the determinants of under-five mortality (U5M) in Nigeria. The 2013 Nigeria Demographic and Health Survey data was used for this study. In order to identify determinants of U5M, the Cox and parametric (exponential, Weibull and Gompertz) models were fitted to the data. The Akaike's information criterion (AIC) and the Cox-snell residual were employed to find the best model. Based on the AIC and Cox-snell residual, the Cox model had the poorest and Gompertz model had the best fit to data. After controlling for demographic, socioeconomic and healthcare-related variables, residing in the North-west (HR=1.40, 95% CI=1.03-1.90) as well as residing in the South-east (HR=2.14, 95% CI=1.46-3.14); married women (HR=0.65, 95% CI=0.48-0.89); living in the rural areas (HR=1.46, 95% CI=1.14-1.86) and delivered in the health facility (HR=0.76, 95% CI=0.59-0.97) had significant effects on U5M in Nigeria. We conclude that for our data, the parametric models out performed that of the semi-parametric Cox model. We therefore recommend that researchers should conduct formal assessment of the goodness of fit for each of the models under consideration, to inform their decisions on most appropriate final model. As part of this process, we also recommend the involvement of a statistician for the selection of candidate models for their data.*

KEYWORDS: Survival Analysis, Parametric Models, Semi-Parametric Model, Model Performance, Under-Five Mortality

INTRODUCTION

Sub -Saharan African nations are confronted with excessive under-five mortality (U5M) when compared to countries in other regions of the world, specially the developed nations amongst them (GHO, 2017). Despite the fact that, there is a worldwide under-5 mortality decline to approximately fifty-eight percentage, from ninety-three deaths per 1,000 live births in 1990 to 39 deaths which is consistent with one thousand live births in 2017, the tempo of development continues to be gradual and uneven across countries, with the worst statistics consistently found in Sub-Saharan Africa (GHO, 2017; UNICEF, 2017). This is the reason under-five mortality remains one of the focus of the Sustainable Development Goal (SDG), whose goal is the lowering of under-five mortality to at most 25 for every 1,000 live births by 2030 (United Nations, 2015). The discrepancy in under-five mortality rates across nations is more than fiftyfold between the developing and developed nations. For example, while Afghanistan has about 110 deaths per 1000 live births, Japan has only 2 deaths per 1000 live births (World Fact Book, 2017).

In Nigeria, about 240,000 children die in their first month of life (FMOH, 2016). Although, the under-five mortality rate in Nigeria declined from 201 deaths per 1000 live births in 1990 to 128 deaths per 1000 live births in 2013 (NPC and ICF, 2014), it sadly increased to 132 deaths per 1000 live births in 2018 (NPC and ICF, 2019). Based on the UNICEF (2017) report, Nigeria was ranked as the third-highest infant mortality rate in the world, next to India and Pakistan. These statistics have shown that Nigeria, like other countries in sub-Saharan Africa, may not be on course to achieving the SDG3 if programmes and interventions are not intensified to reduce under-five mortality in Nigeria.

As a result of the increasing application of survival analysis in estimating the determinants of under-five mortality, there is the need to use the most flexible and efficient model to estimate reliable determinants free from bias. Most population health and medical research that involve survival analytical techniques are based on the semi-parametric Cox models instead of the parametric versions because of the flexibility associated with the former which does not require specification of the baseline hazard function. Although the distribution of observed survival time is not required by the Cox regression model, its assumption on the proportionality of the hazards ought to be investigated (Ravangard et al., 2011). The violation of the proportional hazards (PH) assumption will endanger validity of the Cox regression results and conclusions derived from estimates of the model will be biased and misleading (Collet, 2003). Hence it would be better to use the parametric models such as Exponential, Weibull and Gompertz instead of the Cox model in such settings (Saeed et al., 2017; Almasi-Hashiani et al., 2013). When appropriate to apply them, estimates from parametric models would not only be valid, they do not require the proportional hazard assumption (Zare et al., 2013). In parametric proportional hazard modelling, any of Weibull, exponential or Gompertz models can be used to estimate the baseline hazard and where such is found to be indeterminate, then the semi-parametric Cox model can be used (Saeed et al., 2017; Hougaard, 1999).

Although there have been a number of studies that have compared the semi-parametric Cox and parametric survival models, there is none that has involved the estimation of the determinants of under-five mortality using Demographic and Health Survey data. Ours aims to compare the semi-parametric Cox proportional hazard model with parametric models in estimating the determinants of under-five mortality in Nigeria using the 2013 Nigeria demographic and health survey (2013 NDHS) data.

METHODS

The study utilized the 2013 Nigeria Demographic and Health Survey (2013 NDHS) which is a nationally representative data. The NDHS is cross-sectional and elicited information on a wide range of issues on demographic and health indicators both at the state and national levels, for instance, family planning, maternal and child health, fertility, gender, malaria, HIV/AIDS and nutrition.

The outcome variables in this study were the risk of under-five death (i.e. risk of death before age five), measured as the time of survival since birth in months. The explanatory variables were demographic, socio-economic and healthcare-related variables. The demographic factors are child's sex, region, maternal age at birth of the child, preceding birth interval and the number of children ever born. The socioeconomic factors considered were maternal education, wealth index, marital status, place of residence, type of toilet facility and source of water and child size at birth. Health-related factors included the place of delivery, use of mosquito bed net and numbers of ANC visit.

The semi-parametric Cox is given as

$$h_i(t, X) = h_0(t)\exp\left(\beta_1 X_1 + \beta_2 X_2 + \beta_3 X_3 + \cdots + \beta_p X_p\right) \quad (1)$$

Where

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

$h_0(t)$ is the baseline hazard function

$X = (x_1, x_2, x_3, \ldots x_p)$, are the selected demographic, socioeconomic and health care variables

β is the vector of unknown coefficients of the explanatory variables x_i

The parametric models utilized in this study are the exponential, the Weibull, and the Gompertz.

The exponential proportional hazard model

The exponential proportional hazard model can be expressed as

$$h_i(t, X) = \lambda\exp\left(x\beta\right) \quad (2)$$

The Weibull Proportional hazard model

$$h_i(t, X) = \lambda\exp(\beta' x_i)\mathrm{p}t^{p-1} \quad (3)$$

Where:

P and λ are the shape and scale parameters respectively, estimated from the data,

The Gompertz proportional hazard model

The Gompertz proportional hazards model, for the hazard of death at time t for the *ith* of *n* individuals, is given by

$$h_i(t, X) = \exp\left(\beta_1 x_{1i} + \beta_2 x_{2i} + \beta_3 x_{3i} + \cdots + \beta_p x_{pi}\right)\lambda e^{\theta t}, \quad (4)$$

λ and θ are scale and shape parameter respectively.

To compare the semi-parametric and parametric survival models, we utilized Akaike information criterion (AIC), which is a measure of model goodness of fit; the smaller the value, the better the model fits the data. The AIC is calculated thus:

$$AIC = -2Log\ likelihood + 2k \quad (5)$$

Where k is the number of parameters (Kleinbaum & Mitchel, 2012)

In addition to AIC, Cox-Snell residuals were used to evaluate model goodness of fit. If the model fits the data well, the cumulative hazard of the Cox-Snell residuals will be a straight 45-degree line or closer to 45-degree diagonal line (Clever, et al 2010). Furthermore, according to Ansin (2015), the best fitting model would generate a plot that lies directly on top of the diagonal line. To assess the effect of each variable on under-five mortality, Relative Risk (RR) or Hazard Ratio was estimated. All analyses were performed using Stata (version 15). P-value < 0.05 and the 95% CI not including one was considered statistically significant.

RESULTS

Table 1 showed that of the four models, the Cox model had the highest AIC and lowest log-likelihood while the Gompertz model had the lowest AIC and highest log-likelihood. Weibull and Exponential models had almost the same AIC. For instance, Cox model had AIC (11046.55) and among parametric models, Weibull and Exponential were slight differences, with AIC (6264.18) and (6277.03) respectively, while Gompertz model had AIC (6207.03). On the other hand, plots of Cox-Snell residual for semi-parametric Cox model and parametric models are showed in figures 1 to 4 The graphs for the parametric models are closer to 45-degree diagonal line than the Cox model. Thus, indicates that the Cox model has the poorest performance than the parametric models for the data. Specifically, the Gompertz gave the best fit- much better than the semi-parametric Cox and also when compared with the Weibull and exponential models.

Table 1: Comparison of AIC between Semi-Parametric Cox Model and Parametric Models in Estimating Determinants of Under-Five Mortality in Nigeria using 2013 NDHS

Model	Log-Likelihood	AIC
Cox	-5496.27	11046.55
Weibull	-3103.09	6264.18
Exponential	-3110.52	6277.03
Gompertz.	-3074.69	6207.37

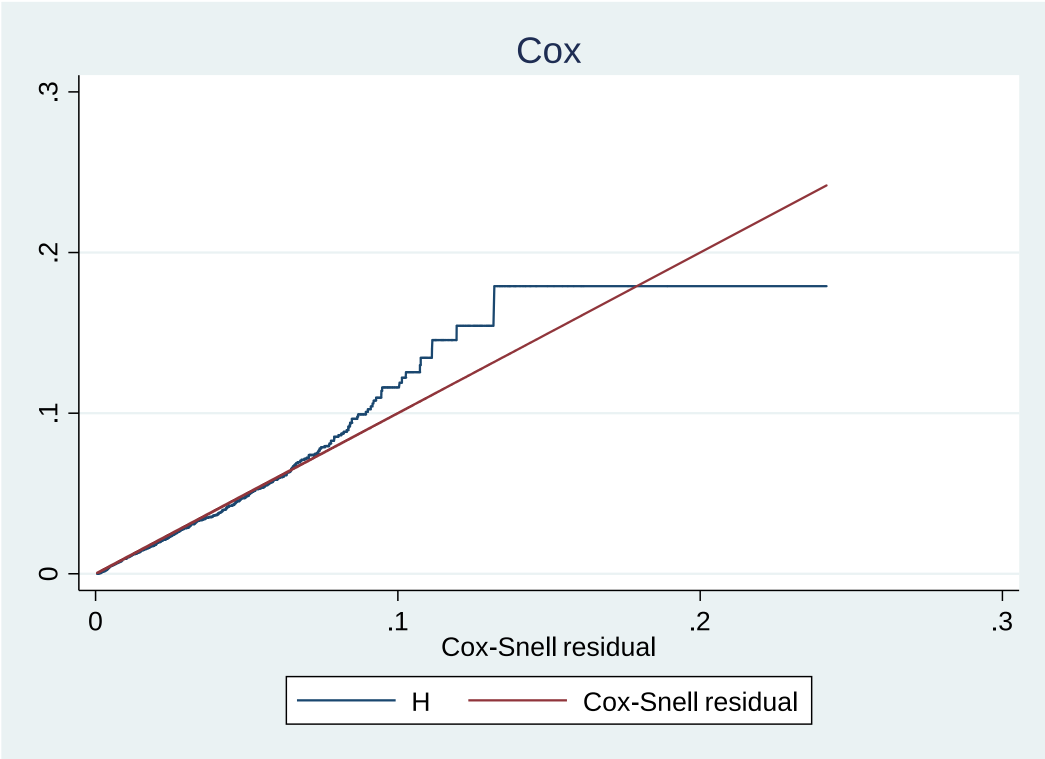

Figure 1: The Cox-Snell Residual Plots for Fitting Cox Model

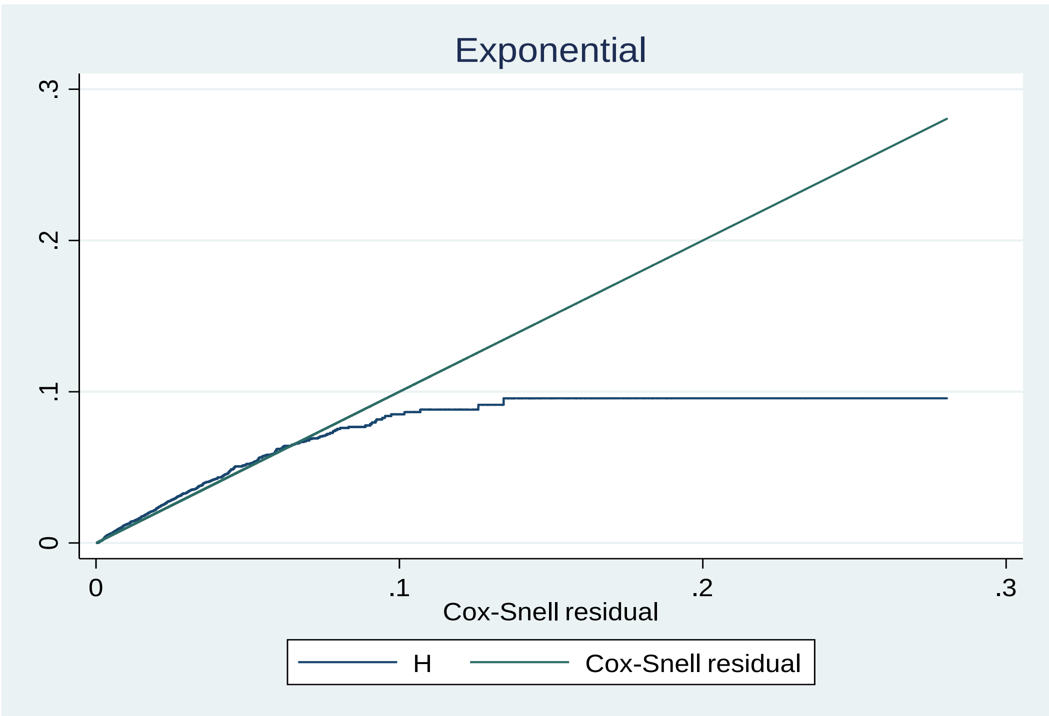

Figure 2: The Cox-Snell Residual Plots for Fitting Exponential Model

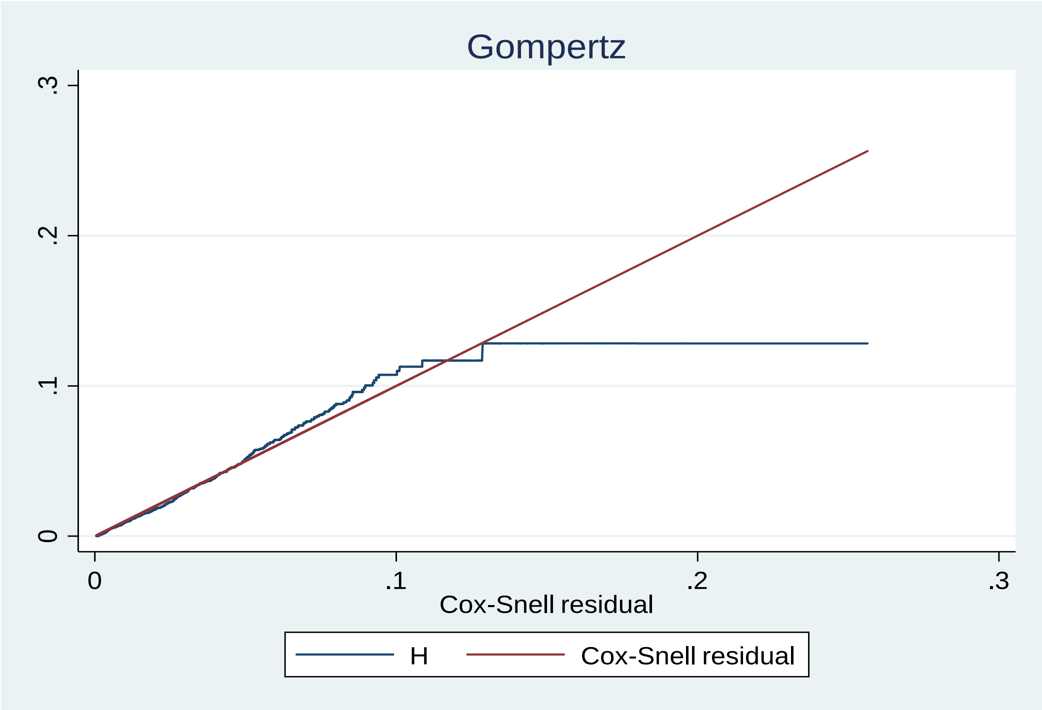

Figure 3: The Cox-Snell Residual Plots for Fitting Gompertz Model

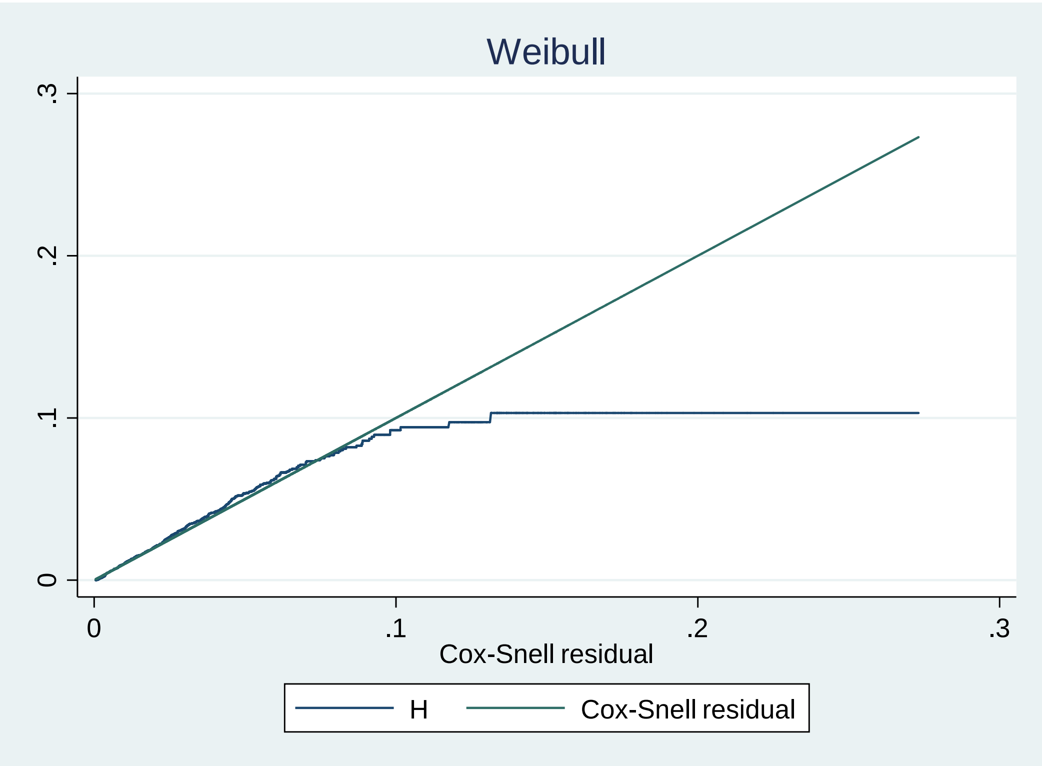

Figure 4: The Cox-Snell Residual Plots for Fitting Weibull Model

The impact of demographic, socioeconomic and health care factors after adjusting for each other is shown in Tables 2. From the Table, only region, marital status, place of residence and place of delivery are found to be significant. The analysis showed that living in the North-west region was significantly 1.40 times more likely at risks of dying before age five than living in the North-central (P<0.05). Similarly, living in the South-east has the highest risk of U5M death than living in the North-central (RR=2.14; 95% CI=1.46-3.14) and these are statistically significant (P<0.05). Children of married mothers were less likely to die before reaching age five than children whose mothers were never married and this is statistically significant at P<0.05 (RR=0.65; 95% CI=0.48-0.89).

The results further showed higher risks of death for children of mothers residing in rural areas compared to those in the urban areas. Results in Table 2 indicated that risk of dying before age five was significantly 1.46 times more for children of mothers' resident in rural areas relative to children of mothers in the urban areas (95% CI= 1.14-1.86; p<0.05). The result reveals that babies delivered at hospital/clinic are 0.76 times less likely to die during the first five years of life compared to the babies delivered at home (95% CI= 0.59-0.97; P<0.05).

Table 2: Impact of Demographic, Socioeconomic and Health Care Seeking Related Variables on Under-five Mortality, Hazard Model Estimates of Relative Risks (RR)

	Cox Model		Weibull Model		Exponential Model		Gompertz Model	
Covariates	**R R**	**95% C I**	**R R**	**95% C I**	**R R**	**95% C I**	**R R**	**95% C I**
Sex of Child								
Male	1.00		1.00		1.00		1.00	
Female	0.93	0.79-1.09	0.92	0.78-1.08	0.92	0.78-1.08	0.93	0.79-1.09
Region								
North Central	1.00		1.00		1.00		1.00	
North East	1.09	0.79-1.51	1.11	0.80-1.53	1.12	0.81-1.54	1.10	0.79-1.51
North West	1.39*	1.02-1.89	1.43*	1.05-1.95	1.45*	1.07-1.97	1.40*	1.03-1.90
South East	2.13*	1.45-3.13	2.18*	1.49-3.20	2.21*	1.51-3.25	2.14*	1.46-3.14
South South	1.08	0.73-1.58	1.07	0.73-1.57	1.08	0.73-1.56	1.07	0.73-1.57
South West	1.08	0.73-1.61	1.07	0.72-1.59	1.07	0.72-1.59	1.08	0.72-1.60
Maternal Age at Child Birth								
<20 years	1.00		1.00		1.00		1.00	
20-34 years	0.79	0.59-1.06	0.78	0.58-1.04	0.78	0.58-1.04	0.78	0.59-1.05
35 and above	0.98	0.72-1.61	0.91	0.63-1.31	0.89	0.62-1.28	0.95	0.66-1.37
Number of Children Ever Born								
<=2	1.00		1.00		1.00		1.00	
3-4	0.84	0.63-1.11	0.82	0.62-1.09	0.82	0.62-1.08	0.84	0.63-1.11
5 and above	1.07	0.80-1.42	1.05	0.79-0.40	1.04	0.79-1.39	1.07	0.80-1.42

Preceding Birth Interval								
First birth	1.00		1.00		1.00		1.00	
<24 months	1.38	0.98-1.94	1.37	0.98-1.93	1.36	0.97-1.91	1.39	0.99-1.95
24-35 months	1.21	0.87-1.67	1.23	0.88-1.68	1.22	0.88-1.68	1.21	0.88-1.68
>35 months	0.94	0.67-1.31	0.94	0.67-1.32	0.94	0.67-1.32	0.94	0.67-1.31
Size of Child at Birth								
Large	1.00		1.00		1.00		1.00	
Average	1.01	0.84-1.20	1.01	0.84-1.21	1.01	0.84-1.21	1.01	0.84-1.21
Small	1.19	0.95-1.51	1.20	0.95-1.51	1.21	0.96-1.52	1.19	0.95-1.50
Maternal Educational Level								
No education	1.00		1.00		1.00		1.00	
Primary education	0.89	0.70-1.15	0.89	0.69-1.15	0.89	0.70-1.15	0.89	0.70-1.15
Secondary or higher education	0.74	0.55-1.01	0.75	0.56-1.01	0.76	0.56-1.02	0.74	0.55-1.01
Wealth Index								
Poor	1.00		1.00		1.00			1.00
Middle	0.80	0.62-1.03	0.79	0.62-1.02	0.79	0.61-1.01	0.80	0.62-1.03
Rich	0.79	0.58-1.09	0.78	0.57-1.07	0.77	0.56-1.06	0.79	0.58-1.08
Marital Status								
Never married	1.00		1.00		1.00		1.00	
Married	0.64*	0.47-0.87	0.68*	0.50-0.93	0.70*	0.51-0.95	0.65*	0.48-0.89
Place of Residence								
Urban	1.00		1.00		1.00		1.00	
Rural	1.45*	1.14-1.85	1.47*	1.15-1.88	1.48*	1.16-1.89	1.46*	1.14-1.86
Type of Toilet Facility								
Unimproved	1.00		1.00		1.00		1.00	
Improved	0.95	0.85-1.23	0.96	0.85-1.23	0.96	0.85-1.23	0.95	0.85-1.23
Source of Water Supply								
Unimproved	1.00		1.00		1.00		1.00	
Improved	0.95	0.85-1.23	0.95	0.80-1.13	0.95	0.80-1.13	0.96	0.81-1.14

Place of Delivery								
Home	1.00		1.00		1.00		1.00	
Hospital/clinic	0.76*	0.59-0.97	0.75*	0.59-0.96	0.75*	0.59-0.96	0.76*	0.59-0.97
Slept Under Mosquito Net								
No	1.00		1.00		1.00		1.00	
Yes	0.81	0.65-1.01	0.83	0.67-1.03	0.83	0.67-1.04	0.82	0.66-1.01
Number of ANC Visit								
None	1.00		1.00		1.00		1.00	
1-3 times	0.89	0.66-1.21	0.90	0.67-1.22	0.91	0.68-1.24	0.89	0.66-1.21
Four times and above	1.06	0.86-1.32	1.09	0.88-1.35	1.10	0.89-1.36	1.07	0.86-1.33

DISCUSSIONS

Over the years, the U5 mortality rate has dropped constantly in Nigeria which determines the level of progress in the quality of life. These rates are additionally vital in identifying important factors for public health programs in Nigeria (Mosley & Chen, 1984; NPC and ICF, 2014; UNICEF, 2017). In any case, the recently published 2018 NDHS report showed that there is an increase in under-five mortality in Nigeria compared to 2013 NDHS report (NPC and ICF, 2019). This study has compared the performances of the semi-parametric Cox with those of some parametric survival models, in the estimation of the determinants of under-five mortality in Nigeria, using Nigerian Demographic and Health Survey data.

This study showed that survival of children to their fifth year in life was significantly worse among children residing in the north-west and south-east parts of Nigeria than those residing in the North-central and other regions (Wegbom *et al*, 2019; Wegbom *et al* 2016a; Kayode *et al*, 2012 Wegbom *et al*, 2016b). This might be attributed to social factors in the community, population density, as well as regional economic resources (Kayode *et al*, 2012; Adebayo *et al*, 2002; Antai, 2010). Furthermore, this study showed that mortality rates were higher in rural areas when compared to the urban areas. This concurs with previous studies in and outside Nigeria (Wegbom *et al*, 2019; Ezeh *et al* 2015; Kazembe *et al* 2012; Morakinyo & Fagbamigbe 2017; Dejene & Girma 2013; Alonso *et al*, 2006; Kayode *et al*, 2012; Adebowale et al 2017). There may be obvious reasons for the result: those living in the urban areas have access to improved water supply, improve sanitation facilities, unlimited access to healthcare as well as other social and economic services (Dejene & Girma 2013; Kayode *et al*, 2012).

Furthermore, the study also found that the marital status of the mother was related to child death. We found a lower mortality risk for children born of married mothers than those born of never-married mothers- a finding which has been previously reported elsewhere (Wegbom *et al*, 2019; Wegbom *et al*, 2016a; Argeseanu, 2004). This study also found significant association between the place of delivery and under-five mortality in Nigeria. Delivery at a health facility would avail women the opportunity to give birth under the supervision of trained professionals which could result in better obstetric and child survival outcomes (Tekelab *et al*, 2019).

Akaike information criterion (AIC) and Cox-Snell residuals plot were used to assess the performance of the Cox model and parametric (Weibull, Exponential and Gompertz) models. The plots of Cox-Snell residuals for the Demographic, Socio-economic and health care factors have shown that parametric models had better fitness. Also, the Akaike information criterion confirmed the results obtained from the Cox-Snell residuals plot. This is consistent with other studies around the globe (Saroj *et a*l, 2019; Orbe *et al,* 2002; Nardi and Schemper, 2003; Dehkordi, 2007; Ravangard *et al*, 2011).

CONCLUSIONS

More often than not, models are not general in their applications. They are situation-specific. In this study, we have observed from estimating the determinants of U5M in Nigeria using NDHS data, that the parametric versions such as the Gompertz, Weibull and Exponential models performed better than the semi-parametric Cox model. Indeed, we found the Gompertz model as the best for assessing the determinants of under-five mortality.

We are satisfied that policy makers will be better equipped by taking into account such determinants in their public health intervention programmes, to reduce under-five mortality in the country. This will invariably enable Nigeria to achieve the SDG 3 goals. We recommend that before using any method or model, the goodness of fit should be tested and where applicable, it should be compared with alternative models to establish the best model. In this regard, we particularly recommend the early involvement of a statistician to help them in their choice of models.

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