Available online at http://www.ajol.info/index.php/njbas/index
Nigerian Journal of Basic and Applied Sciences (December, 2022), 30(2):126-133
DOI: http://dx.doi.org/10.4314/njbas.v30i2.17
ISSN 0794-5698

Full Length Research Article

Comparison of Cox and Extended Cox Models on Age at First Marriage among Nigerian Women

*[1]A. A. Abiodun,[1]O. J. Ayodele and [2]I. A. Ishaq
[1]Department of Statistics, University of Ilorin, Ilorin, Nigeria.
[2]Department of Statistics, Ahmadu Bello University, Zaria, Nigeria.
[*Corresponding Author: E-mail: alfredabiodun1@gmail.com]

ABSTRACT
Cox model is widely used for analysis of factor effects on censored survival time such as age at first marriage. In most practical situations, the fundamental assumption of the proportionality of hazard in Cox model, which implies that the covariates whose effects are to be investigated have a constant impact on the hazard ratio over the time is not always feasible. For example, the values of some of the covariates for individuals may be different over time and these may cause a break-down of proportionality assumption in the hazard model. Ignoring such violation may result in misleading effects of estimates. In this study therefore, Extended Cox models have been used to analyze data on age at first marriage among Nigerian women between 2013 and 2018 waves of Nigerian Demographic and Health Surveys (NDHS). The standard Cox model as well as Extended Cox models under four distinct time functions, namely, t, t^2, log(t) and Heaviside were considered in the analysis and compared using Akaike Information Criterion (AIC) and Bayesian Information Criterion (BIC). The standard Cox model was found to perform worst among all the models considered and Extended model with log(t) time function was best fit for the data.
Keywords:Time dependent covariate, Survival time, Baseline hazard, Partial likelihood, Hazard ratio

INTRODUCTION
The timing of first marriage is an important dimension of women's reproductive behaviour with far-reaching consequences, particularly with their reproductive health and social status. Age at first marriage is a crucial population dynamic that is associated with age at which marriageable opposite sexes are connected, family formed and children expected to be born, especiallyin Sub-Saharan Africa (Amoo, 2017). Age at first marriage could possibly be a factor of exposure to multiple sexual partnerships, especially when such marriage occurs very early in one's life (Garenne, 2004; Nahar *et al*., 2013; Howard *et al*., 2018). One important research emphasis over the past few decades has been a growing Black–White gap in marriage in which African Americans have lower marriage rates than Whites (Smock and Schwartz, 2020). Reaseach involving analysis of data on age at first marriage has become a direction of interest in the recent times. For example, Zaimen (2021) examines the effect of socio-economic factors such as education, place of residence, region of woman and woman cohort on age at first marriage among Algerian women and the relative effects between generations of women.

Hossain *et al*. (2015) and Howard *et al*. (2018) used logistic regression to study the determinants of age at first marriage. The use of survival analysis approach to analysing data on age at first marriage among women is similarly becoming popular. Tessema *et al.* (2015) employed Gamma and Inverse Gaussian shared frailty with exponential, Weibull and log-logistic baseline models to analyze the risk factors associated with age at first marriage using 2011 Ethiopia Demographic and Health Survey Data. Manda and Meyer (2005) employed hierarchical discrete time survival model to assess the determinants of transition to marriage among women in Malawi using 2000 Malawi Demographic and Health Survey data. Adebowale *et al.* (2012) used Cox model for analysis of Nigeria 2008 Demographic and Health Survey dataset on married women aged 15-49.

Cox model (Cox, 1972) has been quite popular in modelling survival time data. The model relies on the proportionality assumption regarding the hazard, which implies that the covariates being investigated have constant impact on the hazard over the entire timeline. Non-proportional hazards can arise if some covariates no longer have constant impact on the hazard over the time but only affect survival up until sometime *t* or if the size of their effects change over time. If such time-dependent covariates are included without appropriate modelling, the Proportional Hazard (PH) assumption is violated (Bellera *et al*., 2010) and this may lead to unreliable results. In such a situation, an alternative modelling strategy needs to be sought. To the best of our knowledge, studies involving modelling age at first marriage under nonproportional model framework has not been known in the literature. However, Rahman and Hoque (2015) fitted Extended Cox models to the data on age at first birth among Bangladesh women.

Correctly accounting for time-dependent covariates is important because it allows one to avoid the problem of survivor-treatment bias (Suissa, 2007; Beyersmann, *et al*., 2008; Austin *et al*., 2006). We have therefore in this study used Extended Cox regression model in modelling age at first marriage among Nigerian women aged 15-49 by incorportating some covariates as time-dependent into the model to investigate the inclusion versus ignoring time-dependent covariates in the model, and to assess the perfomances of different forms of time-functions.

MATERIALS AND METHODS

Data

Datasets on age at first marriage were extracted from the 2013 and 2018 waves of Nigeria Demographic and Health Surveys (NDHS). The survey used the sampling frame of the list of enumeration areas (EAs) provided by the National Population Commission as prepared for the 2006 Population Census of the Federal Republic of Nigeria. The sample was designed to provide population and health indicator estimates at the national, zonal, and state levels. Data were available for 31482 and 33924 women of reproductive age (15-49 years) for the 2013 and 2018 surveys, respectively.

The variables used in the study include the following:

Response variable: Age at first marriage
Year of survey: 2013, 2018
Region: North Central, North-East, North -West, South-South, South-East, South-West
Educational Level: None, Primary, Secondary, Higher
Wealth Index: Poorest, Poorer, Middle, Richer, Richest
Religion: Catholic, Other Christian, Islam, Traditionalist, Other
Place of residence: Rural, Urban

Model Formulation

Survival time in this study is defined as the time (age in years) at first marriage or union of a woman aged 15-49 years. A woman who had never married or had a union with a husband at the time of the survey is said to be censored. Cox proportional hazards model utilizes the hazard function, denoted $h_0(t)$ as the baseline distribution in the modelling of survival data. Generally, the function is defined as the conditional probability of experiencing an event in the small interval $(t, t+\Delta t)$, given that such an event has not been experienced prior totime t (the beginning of the interval). In the context of this study, event denotes having first marriage union.

The hazard function is mathematically expressed as:

$$h(t) = \lim_{\Delta t \to 0} \Pr\left\{\frac{t \le T < t + \Delta t \middle| T \ge t}{\Delta t}\right\} \quad (1)$$

Supposethat one is interested in the association of hazard function in (1) with a set of covariates, $Z_1, Z_2, \ldots, Z_p$, then the Cox proportional hazards model can be given by

$$h(t, Z_i) = \mathrm{h}_0(t)\exp(\beta Z_i), \quad (2)$$

where the baseline hazard $h_0(t)$ is an unspecifiednon-negative function of time. It is the time-dependent part of the hazard which corresponds to the hazard rate when all covariate values are equal to zero. Also, $\beta = [\beta_1, \beta_2, \ldots, \beta_k]$ are the coefficients of the regression functions $\beta Z_i = \beta_1 Z_{i1}, \beta_2 Z_{i2}, \ldots, \beta_k Z_{ik}$ and $\exp(\beta Z_i)$ is the relative risk of individual i with covariate vectorZ_i.The model in (2) implies that Z_i has a constant impact on the hazard over the entire time line. In this model, covariates act multiplicatively on the baseline hazards. The coefficient vectors of the covariates can be estimated by maximizing the partial likelihood function. Thehazard ratioof the model parameter, which is denoted ($\exp(\beta)$) and assumed to be constant over time,is defined as the effect of one-unit increase in the covariate Z on the hazard of the failure event. This is expressed as

$$HR = \frac{\hat{h}(t, Z^*)}{\hat{h}(t, Z)}, \quad (3)$$

where Z^* is the set of predictors for one individual and Z is the set of predictors for the other individual.

Extended Cox Model for Time-dependent Variables

When the hazard ratio is no longer constant but varies with time, the assumption of proportional hazards is violated, therefore methods that do not assume proportionality must be used to investigate the effects of covariates on the hazard of the survival time. Cox (1972) extended the model in (2) to contain bothtime-independent covariates $Z_1,\ldots,Z_p$ and time dependent covariates $Z_1(t),\ldots,Z_q(t)$ where the latter are functions of time. The covariates for consideration under this framework may then be written as

$$Z_i(t) = (Z_1,\ldots,Z_p; Z_1(t),\ldots,Z_q(t)) \quad (4)$$

By incorporating (4) into (2) we have

$$h(t, Z_i(t)) = h_0(t)\exp(\beta' Z_i + \gamma' Z_i(r_t)) \quad (5)$$

where r_t is a function of time, and is selected according to the information level of the researcher. The common choices include $r_t = t$,t^2, $\log(t)$ and Heaviside (step) function of the form

$$r_t = \begin{cases} 1 \; if \;\; t \ge t_c \\ 0 \; if \; < t_c \end{cases},$$

Maximum Partial Likelihood Estimation

Let t_i denote the minimum of the censoring time C_i and the survival time T_i, and let $Z_i(t)$ be as given in (4). Also let the censoring incator δ_i be such that

$$\delta_i = \begin{cases} 1 & \text{if individual } i \text{ enters into first marriage union at age } t_i \\ 0 & \text{if individual } i \text{ has never entered into marriage union by age } t_i \end{cases} \quad (6)$$

Denote by $\beta = (\beta_1, \cdots, \beta_p)'$, the p × 1 vector of regression coefficients of time-independent covariates $Z_1, \cdots, Z_p$ and by $\gamma = (\gamma_1, \cdots, \gamma_q)'$, the q × 1 vector of regression coefficients of time-dependent covariates

$Z_1(r_t),\cdots,Z_p(r_t)$, where r_t is as given in (5). Then, the partial likelihood for individual *i* is given as

$$L(\Theta \mid D_{obs}) = \prod_{i=1}^{n}\left[\frac{\exp(\beta' Z_i + \gamma' Z_i(r_t))}{\sum_{j\in R(t_i)}\exp(\beta' Z_j + \gamma' Z_j(r_t))}\right]$$

,(7)

where $\Theta = (\beta,\gamma)$, *n* is the total number of observations, $D_{obs} = \{t_i, \delta_i, Z_i(t)$ is the observed right censored survival data and $R(t_i) = (i : t_i > t)$ is the set of subjects at risk at time *t*. For the completely observed data D_{obs}, the maximum partial likelihood estimate is given as $\hat{\Theta} = \arg\max_{\Theta}(\Theta \mid D_{obs})$.

Statistical Analysis

Descriptive analyses, including the median survival time and Log rank test were first carried out on each of the categorical variables described earlier. For the data under study, the median survival time gives the age within which half (50%) of the respondents in the study had their first marriage. Schoenfeld residuals test for proportional hazard assumption were also carried out to detect, if any, the covariates that violate the assumption. Modelling of the data was then done using the standard Cox proportional hazard model and Extended Cox models using the four time functions as earlier given,

RESULTS AND DISCUSSION

In the presence of censored survival times the median survival time is estimated by first calculating the Kaplan-Meier survival probabilities $S(\hat{t})$ for each covariate, then finding the value of *t* that satisfies the equation $S(\hat{t})$ = 0.5. The Log rank test compares the survival probabilities of two or more groups by testing the hypothesis of equality of survival functions $S_1(t) = S_2(t) = S_g(t)$, where *g* is the number of groups. The results of the median survival time and Log rank test are displayed in Table 1. The median age at first marriageof the women for the two years under study (2013 and 2018) remained at 17 years and this corresponded to the national median age at first marriage. The median age at first marriage for women in the Northern part of the country were generally lower than their counterparts in the South.

Also the median age at first marriage for women with no educationwas lowest (15 years), and highest for those with higher education. Across the wealth index, the median age at first marriage for women in the poorest income category was 15 years compared to 22 years for those in the richest income category. The median age at first marriage for women residing in the rural area was 16 years compared to 19 years for the urban dwellers. The log rank results are shown in columns 3-6 of Table 1. As observed, the survival experiences regarding the age at first marriage of the women weresignificantly different for all the factors under study as the p – values were all < 0.0001. Proportional hazards assumptions were checked using the scaled Schoenfeld residuals test defined by Schoenfeld (1982). The residuals were calculated at every failure of time under the proportional hazard assumption. The idea behind the statistical test is that if the PH assumption holds for a particular covariate then the Schoenfeld residuals for that covariate will not be related to survival time *t* (Rho = 0). The p-value is shown for each covariate as well as the p-value associated with the global test of non-proportionality are reported in Table 2.

From the results presented in Table 2, it is observed that variables region, educational level, wealth index and place of residence contributed to the violation of proportionality assumption. Also, the global test suggested strong evidence of non-proportionality (p-value <0.0001). So, we created time-by-covariate interactions for the covariates on which the assumption was violated. Four functions of time $r(t)$ were used, namely t, t^2, log(t) and Heaviside

The Heaviside function was defined from the fact that effect of different covariate tends to change at different time point, Therefore, the cut-point for the data on age at first marriage used in the study was put at the national median age of 17 years as given in Table 1. Thus, we have

$$r_t = \begin{cases} 1\, if\ \ t \geq 17 \\ 0\, if\ \ t < 17 \end{cases} \quad (8)$$

Five models were fitted altogether, which includedthe standard Cox model and Extended Cox models by incorporating the four time functions into (5).

.

Table 1: Median survival time and log-rank test

COVARIATE	MEDIAN AGE	EVENT OBSERVED	EVENT EXPECTED	CHISQ VALUE	P-VALUE
Year					
2013 (ref)	17	30721	28887.64	252.66	<0.0001
2018	17	33235	35068.36		
Region					
North Central (ref)	18	10305	11566.66		
North East	16	13523	9430.44	18975.5 7	<0.0001
North West	15	20133	10819.43		
South East	21	6355	10856.85		
South South	20	6431	9524.17		
South West	21	7209	11758.46		
Educational Level					
No education (ref)	15	29961	17848.34		
Primary	17	11479	11069.25	17127.8 7	<0.0001
Secondary	20	18045	25322.99		
Higher	24	4471	9715.42		
Wealth Index					
Poorest (ref)	15	14963	8744.36		
Poorer	16	14828	11034.19	11909.3 3	< 0.0001
Middle	17	13013	13056.47		
Richer	19	11641	14372.81		
Richest	22	9511	16748.17		
Religion					
Catholic	20	5254	8016.11		
Other christian	20	19471	29397.95	13474.4 0	<0.0001
Islam	15	38670	25983.62		
Traditionalist	16	417	348.27		
Other (ref)	19	144	210.05		
Place of residence					
Rural (ref)	16	21506	28853.02	4165.54	<0.0001
Urban	19	42450	35102.98		

The model comparing metrics used were Akaike Information Criterion (AIC) Bayesian Information Criterion (BIC) for the various models which were computed as follows

$$AIC = -2\log L(\hat{\theta}) + 2k$$

$$BIC = -2\log L(\hat{\theta}) + k\log(n),$$

where

$L(\hat{\theta})$ is the likelihood of the candidate model given the data when evaluated at the maximum likelihood estimate of θ . k is the number of estimated parameters in the candidate model and *n* is the sample size. The results are presented in Table 3.

As observed from Table 3, the standard Cox model performed worst compared to all the Extended Cox models with the highest AIC and BIC of 460831.2 and 461951.6 respectively. However, from among the Extended Cox models, the model with function $r_t = \log(t)$ performed overall best with the least AIC and BIC of 432732.7 and 433340.7 respectively. Therefore, further discussions of effects of the observed factors on log hazard of age at first marriage were based on thismodeland the results are as presented in Table 4.

Table 2: Schoenfeld residuals testfor proportional hazard assumption

COVARIATE	RHO	CHISQ	P-VALUE
Year			
2013	-	-	
2018	0.02413	10.20	<0.0001
Region			
North Central (ref)	-	-	-
North East	-0.0327	65.09	<0.0001
North West	-0.0513	72.21	<0.0001
South East	-0.313	6.16	0.0018
South South	-0.0323	45.34	<0.0001
South West	0.0125	38.64	<0.0001
Educational level			
No Education (ref)	-	-	-
Primary	0.0279	12.11	0.0002
Secondary	0.0354	241.31	<0.0001
Higher	0.1093	272.54	<0.0001
Wealth Index			
Poorest (ref)	-	-	-
Poorer	0.1263	0.42	0.0345
Midle	-0.0024	2.61	0.0218
Richer	-0.0342	1.87	0.0166
Richest	-0.0412	1.54	0.1255
Religion			
Catholic	0.0437	1.76	0.0656
Other christian	0.0542	1.92	0.0952
Islam	0.0241	2.75	0.0542
Traditionalist	0.0664	1.78	0.0876
Other (ref)	-	-	-
Place of residence			
Rural (ref)	-	-	-
Urban	0.0221	8.346	0.0034
Global test		428.34	<0.0001

Table 3: The values of akaike information crierion and bayesian information criterion for the various models

FUNCTION OF TIME r_t	AIC	BIC
Cox	460831.2	461951.6
t	445215.0	445412.7
t^2	444554.2	444751.4
log(t)	432732.7	433340.7
Heaviside	444786.4	443973.5

Table 4. Estimated coefficients of time-independent and time-dependent covariates of Extended Cox regression model with time function $r_t = \log(t)$ for women age at first marriage

COVARIATE	$\hat{\beta}$	STD. ERROR	P VALUE	$\hat{\gamma}$	STD. ERROR	P VALUE
Year						
2013	0			0		
2018	0.6432	0.023	<0.001	- 0.0258	0.182	<0.0001
Region						
North-Central	0	-	-	0		
North-East	0.8104	0.201	0.0023	-0.0404	0.094	<0.0001
North-West	0.7032	0.501	0.0318	-0.0510	0.106	<0.0001
South-East	0.6711	0.430	<0.0001	-0.0443	0.142	<0.0001
South-South	0.3063	0.245	0.0021	-0.0237	0.133	<0.0001
South-West	0.2743	0.218	<0.0001	-0.0193	0.142	<0.0001
Educational level						
None	0	-	-	0	-	-
Primary	0.1947	0.032	0.0041	-0.0168	0.116	<0.0001
Secondary	0.4852	0.027	0.0501	-0.0234	0.122	<0.0001
Higher	0.6613	0.040	0.0161	-0.0309	0.121	<0.0001
Wealth Index						
Poorest	0	-	-	-	-	-
Poorer	0.1895	0.022	0.0942	-0.0176	0.342	<0.0001
Midle	0.3788	0.019	0.0253	-0.0263	0.152	<0.0001
Richer	0.4089	0.030	<0.0001	-0.0210	0.231	<0.0001
Richest	0.4501	0.018	0.0453	-0.0221	0186	<0.0001
Religion						
Catholic	0.3210	0.398	0.3461	-0.0267	0.261	0.0623
Other Christian	0.1372	0.059	<0.0001	-0.0341	0.166	0.1324
Islam	0.2170	0.046	0.2318	-0.1947	0.202	0.0802
Traditionalist	0.2011	0.445	0.0463	-0.0408	0.398	0.2351
Other	0	-	-	-	-	-
Place of residence					-	
Rural	0	-	-	0	-	-
Urban	0.1314	0.421	<0.0001	-0.0124	0.091	<0.0001

From the results of Extended Cox regression model presented in Table 4. The estimated coefficients associated with the time independent covariates ($\hat{\beta}$) are shown in column 2 while for the time-dependent covariates ($\hat{\gamma}$) are shown in column 5. It is observed that the covariate-time interactions were significant for year, region, educational level and wealth index, which implied that the covariates were time dependent. It is also observed that the estimated coefficients associated with the time-covariate interactions were negative, suggesting that the hazard ratios were decreasing over time. The estimated hazard ratio of the model with function $r_t = \log(t)$ for any covariate was obtained from $HR = \exp(\hat{\beta} + \hat{\gamma}\log(t))$. For example, the estimated hazard ratio associated with year 2018 versus 2013 survey as a function of time was HR = exp(0.6432-0.0258 log(t)). These were similarly obtained for other significant time-dependent covariates. Thus for women with age at first marriage of 15, 20 and 30 years, the estimated hazard ratios were computed for all the signicant covariates and the results were presented in Table 5.

From the table, the estimated hazard ratios associated with 2018 compared to 2013 for women with first marriage ages 15, 20 and 30 were 1.29, 1.14 and 0.88 respectively. This implies that women were 1.29 more likely to have their first marriage at age 15 in year 2018 compared to 2013, 1.14 times more likely at age 20 years and 0.88 less likely at age 30 years.

Table 5: Hazard ratios of the Extended Cox regression model with timefunction $r_t = \log(t)$ for women age at first marriage 15, 20 and 30 years

COVARIATE	AGE AT FIRST MARRIAGE		
	15	20	30
Year			
2013	1	1	1
2018	1.2920	1.1356	0.8773
Region			
North-Central	1	1	1
North-East	1.2268	1.0024	0.6692
North-West	0.9400	0.7284	0.4374
South-East	1.6160	0.8066	0.5179
South-South	0.9519	0.8456	0.6671
South-West	0.9849	0.8943	0.7373
Educational Level			
None	1	1	1
Primary	0.9443	0.8682	0.7339
Secondary	1.1436	1.0173	0.8050
Higher	1.2187	1.0442	0.7666
Wealth Index			
Poorest	1	1	1
Poorer	0.9282	0.8500	0.7128
Midle	0.9844	0.8631	0.6635
Richer	1.0984	0.9889	0.8016
Richest	1.1259	1.0813	0.8082
Place of Residence			
Rural	1	1	1
Urban	0.9468	0.8899	0.7861

Also, compared to women in the North-Central, the estimated hazard ratios associated with women at age 15 years in the North-East, North-West, South-East, South-South and South-West were respectively 1.23, 0.94, 1.62, 0.95, 0.99. Compared to women without education, women with primary, secondary and higher education had estimated hazard ratios of 0.87, 1.02 and 1.04 respectively at age 20 years. Also women in the urban areas were 0.95, 0.89 and 0.79 times less likely to have their first marriage at ages 15, 20 and 30 years respectively compared to their rural counterparts. The results in Table 5 also reveal that the covariates were indeed time dependent with decreasing hazards. For example, for covariate year of study, the hazard ratio associated with women at age 15 years was 1.29, age 20 years was 1.13 and age 30 years was 0.88. Similarly, the hazard ratio for women in the richest income group compared to those in the poorest group was 1.13 at age 15 years, 1.08 at age 20 years and 0.81 at age 30 years. This decreasing trend in the hazard over the study period was evident for all the time dependent covariates considered in the study. This suggested that these those covariates were actually time dependent and fitting Extended Cox regression model with log(t) function of time was found to be more appropriate thanfitting the standard Cox regression model to the data.

This finding was similar to that of Rahman and Hoque (2015) who fitted Extended Cox model to data on age at first birth among Bangladesh women where log(t) function of time was also found to fit the model best on the basis of the AIC value.

CONCLUSION

Standard Cox and four extended Cox regression models with different time functions were compared in this study to model data on age at first marriage among Nigerian women. The standard Cox model which completely ignored violation of proportionality assumption was found to perform worst among all the fitted models and the Extended Cox model that utilized log(t) time function was found to be superior to others in modelling the data. Basing discussions on this model, it was found that covariates year of study, region, educational level, wealth index and place of residence actually had time dependent effects on age at first marriage and fitted best among other competing models. Therefore, from the findings of this study and the study of Rahman and Hoque (2015), Extended Cox with log(t) time function is recommended for modelling survival data such as ages at first mariage, first birth, first pregnancy and more others in this series.

REFERENCES

Adebowale, S. A., Fagbamigbe, F. A., Okareh, T. O. and Lawal, G. O. (2012).Timing of first marriage among women of reproductive age in Nigeria: regional differences. *African Journal of Reproductive Health / La Revue Africaine de la Santé Reproductive*, **16**(4), 95-107,

Amoo, E. O. (2017). Trends and determinants of female age at first marriage in Sub-SaharanAfrica (1990-2014): What has changed? *African Population Studies,* **31**(1) Supp. 2: 3565-3577.

Austin, P.C., Mamdani, M.M., van Walraven C. and Tu, J.V. (2006). Quantifying the impact of survivor treatment bias in observational studies. *Journal of Evaluation in Clinical Practice,***12**(6): 601– 612.

Bellera, C. A., MacGrogan, G., Debled, M., de Lara, C. T.,Véronique Brouste, V.and Mathouli Pélissier, S. (2010). Variables with time-varying effects and the Cox model: Some statistical concepts illustrated with a prognostic factor study in breast cancer. *BMC Medical Research Methodology.***10**:20.

Beyersmann, J., Wolkewitz, M. and Schumacher M. (2008). The impact of time-dependent bias in proportional hazards modelling. *Statistics in Medicine,* **27:**6439–6454.

Cox, D.R.(1972). Regression models and Life-tables (with discussion). *Journal of Royal Statistical Society Series. B.* **34:** 187-220.

Garenne, M. (2004). Levels, trends and factors of female age at first marriage in 32 sub-Saharan countries over the past five decades. Population Association of Southern Africa, *Southern African Journal of demography*, ***9***(2): 59-79.

Hossain, M. T., Haque, M. A. and Nasser, M. (2015). Modelling age at first marriage of female adolescents in Bangladesh. *Asian Journal of Applied Sciences*, **3**(5): 651-655.

Howard, N., R. Sackey, R. and Nkansh, B. K. (2018). Modelling Age at first marriage among Ghanaians in urban southern Ghana. *Mathematical Theory and Modeling*, **8**(3): 1-17.

Manda, S. and Meyer, R. (2005). Age at first marriage in Malawi: a Bayesian multilevel analysis using a discrete time- to-event model. *Journal of Royal Statistical Society Series A.***168(***2):439–455.*

Nahar, M.E., Zahangir, M.S. and Islam, S.M.S. (2013). Socioeconomic and demographic factors of age at first marriage linkage to reproductive behaviour of Bangladesh women.*Chinese Journal of Population Resources and Environment*, **11**(3): 227-235.

Rahman, Md. A. and Hoque, Md. R. (2015). Fitting time to first birth using extended cox regression model in presence of nonproportional hazard. *Dhaka University Journal of Science,* **63***(1):25-30.*

Schoenfeld, D. (1982). Partial residuals for the proportional hazards regression model. *Biometrika,* **69*:*** 239-241.

Smock, P. J. and Schwartz, C. R. (2020). The demography of families: A review of patterns and change. *Journal of Marriage and Family*, **82**(1): 9- 34.

Suissa, S. (2007). Immortal time bias in pharmacoepidemiology. *American Journal of Epidemiology*, **167**(4): 492–499.

Tessema, B., Ayalew, S. and Mohammed, K. (2015). Modeling the determinants of time-to-age at first marriage in Ethiopian women: a comparison of various parametric shared frailty models. *Science Journal of Public Health*, **3** (5): 707-718.

Zaimen, I. (2021). Age at First Marriage of Algerian Women: Socio-Economic Determinants. *Les Cahiers du Cread*, **37**(2): 5-34.