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Bivariate probit analysis of the relationship between driver and passenger's seatbelt use

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Abstract

Vehicle seatbelt has been shown to have a beneficial impact on occupants. However, some occupants do not use the seatbelt when driving. Despite the numerous investigation on the risk factors associated with seatbelt use by occupants, little is known about the relationship between driver and passenger seatbelt use. This study addresses this gap by analysing road side observational survey data on driver and front-right seat passenger's seatbelt use behaviour using bivariate probit model. The use of the bivariate probit model is based on the premise that the front-right passenger's seatbelt use is endogenously related to that of the driver. Out of the 5,433 vehicles observed, it was found that the prevalence rate of driver and front-right passengers' seatbelt use were 81% and 33%, respectively. In addition, it was found that there is a positive relationship between driver and passenger's seatbelt use and that the unobserved factors that increase the probability of a driver seatbelt use also increase their front-right passenger's seatbelt use propensity.

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Keywords: Seatbelt; bivariate probit; driver; front-right passenger; Ghana.

1. Introduction

Aside the lives which are lost and their associated social consequences such as suffering, loss of breadwinners and quality of family life, reducing road traffic deaths and injuries is essential on economic grounds. In Ghana, it is estimated that road traffic crashes cost the nation 1.6% of its gross domestic products (Afukaar et al. 2008). The statistics available indicate that about 1,900 persons are killed in road traffic crashes every year (Agyemang et al. 2017). The statistics further indicate that approximately 34% of these fatalities were occupants of cars, buses and

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trucks who were mostly unbelted. Nearly two-thirds (65.3%) of the victims were in the economically active group, between the ages of 20 and 50 years old.

One of the main risk factors for vehicle occupants is the non-use of seatbelt (Koushki et al. 2003, WHO 2004, 2015). The mechanism involved in the death or severe injury of unbuckled front vehicle occupants is either being thrown forward to hit the steering wheel or wind screen or even completely being ejected from the vehicle (Nabipour et al. 2014). For rear-seat car occupants, unstrained passengers could slam into the driver or front passenger or even be ejected from the vehicle. For both passengers, the ejection increases the probability of severe injuries or death. Seatbelt use has been shown to be highly effective in decreasing severe and fatal injuries during road traffic crashes. It has been established that seatbelt reduces the risk of death among front seat occupants by 40-50% and rear-seat car passengers by 25-75% (WHO 2015).

Notwithstanding the advantages in using seatbelts, some vehicle occupants drive without putting their seatbelts on. Evidence suggests that the rate of seat belt usage in Ghana is low and this trend contributes to the road traffic fatality and injury statistics. The findings from previous observational survey showed that 17.6% and 4.9% of drivers and front-right passengers of vehicles, respectively were belted (Afukaar et al. 2010). Although there is legislation (Republic of Ghana 2004 (Act 684)) on the compulsory use of seatbelts in Ghana, the rate of seatbelt wearing is still low, particularly for passengers. Mandatory seatbelt laws and their strict enforcement is supposed to effectively increase the rate of seatbelt wearing.

Increasingly, many studies are being conducted to investigate the possible risk factors associated with drivers and their passenger's seatbelt usage (Bhat et al. 2015, Goetzke and Islam 2015a, Agu et al. 2016) and it has been established that the presence of passenger's in a vehicle influences driver's seatbelt usage (Goetzke and Islam 2015a). Despite the increasing studies on seatbelt usage, there is limited studies addressing the interrelationship between driver and passenger seatbelt use and the related contributing factors. Previous studies have used univariate modelling approaches (logit/probit) to determine the contributing factors of driver and passenger seatbelt use. If the correlation between driver and passenger seatbelt use is due to unobserved characteristics of the driver and the passenger, then the univariate may produce bias estimate (Greene 2003). This study addresses this gab in the literature by determining the interrelationship between driver and passenger seatbelt use and the related factors using bivariate probit model. The use of the bivariate probit model is based on the premise that the passenger's seatbelt use is endogenously related to that of the driver.

2. Material and Methods

2.1. Bivariate probit modelling

In the presence of interdependency between driver and passenger seatbelt use, models without the capability to appropriately account for such correlation might yield bias parameter estimates. To account for this interdependence, a bivariate probit model was developed to simultaneously estimate the effect of the selected covariates on driver and passenger seatbelt use. The two dependent variables considered in this study are the driver seatbelt usage (coded as 1 if use and 0 if not use) and passengers seatbelt usage (coded as 1 if use and 0 if not use). The bivariate probit model is defined as:

$$\begin{aligned} y_1^* &= X_1\beta_1 + \varepsilon_1 \\ y_2^* &= X_2\beta_2 + \varepsilon_2 \end{aligned} \tag{1}$$

where $y_j^*, (j = 1,2)$ denote unobserved variables; X_j denote vectors of independent variables (covariates); β_j denote vectors of estimable model parameters and ; ε_j represent the error term (residuals) associated with the model. The observed two binary dependent variables y_j relates to the unobserved variables through a measurement model:

$$y_j = \begin{cases} 1 \text{ if } y_j^* > 0 \\ 0 \text{ if } y_j^* \le 0 \end{cases} \qquad j = 1, 2. \tag{2}$$

The parameters of the model are estimated using full information maximum likelihood estimation technique (Greene 2003). The residuals are assumed to be bivariate normally distributed with mean vector $\boldsymbol{0}$ and correlation matrix with variance components 1 and correlation coefficient ρ. If there exist a correlation between the two error terms, then the estimated value of ρ will be significantly different from zero. The significance of ρ can be tested using Wald chi-square test.

2.2. Data description and collection

Estimating the relationship between driver and passenger seatbelt use requires observing these occupants in vehicles. The data used in this study were collected through an observational survey conducted in Accra , Ghana. Accra is the largest city of Ghana with an urban population of over two million inhabitants (GSS 2012). Accra doubles as the capital town of Ghana and the Greater Accra region. The city has the highest number of vehicle fleet in the country (DVLA 2014). Data were collected by observing traffic by the roadside at randomly selected locations within Accra. The study sites comprised of signalised intersections identified from road network map of Accra. Signalised intersections were selected for the survey as vehicles come to a complete stop or slow down considerably at such locations to allow effective observation to take place. A total of 6 observation sites were selected including highway and non-highway intersections (i.e. Arterials and Collector/Distributor roads), within the central business district (CBD) (≤1 km) and outside the CBD.

During data collection, trained research assistants were stationed at each survey location to record the seatbelt use status (use/non-use) of the driver and front-right seat passenger in each targeted vehicle using a pro former check list. The survey included only vehicles with front-right seat passenger (hereafter referred to as passenger). To avoid difficulty in recording the characteristics of very large vehicle occupants, the study was restricted to the following vehicle types: car, sport utility vehicle (SUV) and pickups. Other data recorded include gender of the driver and the passenger, vehicle type (car/ other), road type (highway/non-highway), vehicle ownership (private/ commercial), location setting (within CBD/outside CBD), time of day (morning (06:30-08:30 am)/ afternoon (12:00-2:00pm)/ evening (4:30-6:30pm)), and day of week (weekday / weekend).

Out of the 5,433 vehicles observed, about 81% of the drivers were wearing their seatbelts whereas 33% of the passengers were found wearing seatbelts (Table 1). Among those drivers wearing seatbelts, only 39% of their passengers were using their seatbelts whereas 8% of the passengers used seatbelts in a vehicle where the driver was not wearing seatbelt. Majority of female drivers (85%) and passengers (51%) were found using seatbelts compare to male drivers and passengers. The rate of seatbelt usage was high among private vehicles.

Table 1: Frequency and percentage distribution of seatbelt wearing rate among drivers and passengers classified by other measured variables

Variable	Frequency	% Of total	Driver (%)	Passenger (%)
Overall	5,433	100	80.97	32.74
Driver's belt use				
Wearing	4,407	80.97	-	38.53
Not wearing	1,036	19.03	-	8.11
Passenger's belt use				
Wearing	1,782	32.74	95.29	-
Not wearing	3,661	67.26	74.00	-
Driver's gender				
Male	5,069	93.13	80.69	31.37
Female	374	6.87	84.76	51.34
Passenger's gender				
Male	3,115	57.23	79.84	30.43
Female	2,328	42.77	82.47	35.82

Table 1: Continued

Variable	Frequency	% Of total	Driver (%)	Passenger (%)
Vehicle type				
Car	4,113	75.56	80.16	27.89
Other (SUV/Pickups)	1,330	24.44	83.46	47.74
Vehicle ownership				
Private	3,303	60.68	82.83	43.75
Commercial	2,140	39.32	78.08	15.74
Time of day				
Morning	2,375	43.63	82.57	31.71
Afternoon	1,289	23.68	82.23	33.28
Evening	1,799	32.68	77.91	33.73
Day of week				
Weekday	3,599	66.12	83.25	33.01
Weekend	1,844	33.88	76.52	32.21
Location setting				
Outside CBD	3,109	57.12	83.21	41.40
Within CBD	2,334	42.88	77.98	21.21
Road type				
Highway	2,057	37.79	80.99	38.60
Other	3,386	62.21	80.95	29.19
Presence of police				
No	3,382	62.13	79.27	32.08
Yes	2,061	37.87	83.97	33.82

3. Results and discussion

To determine the relationship between driver and passenger's seatbelt use and the contributing factors influencing their seatbelt use simultaneously, a bivariate probit model was developed. The parameters and their corresponding marginal effects of the fitted bivariate model are summarised in Table 2. The fitted model was found to be satisfactory compared to the null model (model with intercept only) based on the likelihood ratio test results presented as the goodness-of-fit statistics. From the Table 2, the *p*-value of the Wald chi-square test of the correlation coefficient (ρ) of the disturbance terms suggest that passenger's seatbelt use is endogenously related to driver's seatbelt use. Thus, the use of two univariate probit model will not yield a consistent parameter estimate. The positive sign of the correlation coefficient suggests that the unobserved factors that increase the probability for a driver to use seatbelt also increase their passenger's seatbelt use propensity. These results wouldn't have been seen if driver and passenger seatbelt use were modelled as two independent binary outcomes. Among the nine (9) variables considered in the model, only drivers gender and vehicle type were found not to significantly influence driver's seatbelt use whilst time of day was also found not to be a significant factor for passengers seatbelt use.

Gender was found to have a significant impact on seatbelt wearing, with drivers and passengers having 2% and 10% more likelihood to use seatbelt, respectively when the vehicle is being driven by female compared to male. However, the result for drivers was not statistically significant at 5% level. On the other hand, when the passenger is a female, both the driver and passenger were 3-4% more likely to use seatbelt. Our findings are consistent with the results of several existing studies (Shinar et al. 2001, Russo et al. 2014, Bao et al. 2015). In a recent study, Boakye et al. (2018) found that males showed a higher non-seatbelt use rate (about 21%) in the night-time compared to females (11%). They, however, found almost the same proportion of unrestrained passengers for both male and female drivers. The result can be explained by the fact that both male drivers and passengers perceive traffic situations as less risky than their female counterparts do. This is because men are braver in taking risk to violate the seatbelt law and engaging with unsafe driving behaviour. It is therefore no surprise that male drivers and passengers are more likely to commit traffic violations than female drivers and passengers (Glendon et al. 1996, Alm and Lindberg 2000).

Table 2: Parameters and marginal effect of the estimated bivariate probit seatbelt for driver and passenger seatbelt usage.

	Coefficient		**Marginal effects**	
Variable	Driver	Passenger	Driver	Passenger
Driver's gender (*Ref: Male*)				
Female	0.087	0.291***	0.022	0.097
Passenger's gender (*Ref: Male*)				
Female	0.088**	0.115***	0.030	0.037
Vehicle type (*Ref: Car*)				
Other (SUV/pickups)	0.067	0.251***	0.018	0.083
Vehicle ownership (*Ref: Commercial)*				
Private	0.125***	0.668***	0.034	0.215
Time of day (*Ref: Evening*)				
Morning	0.158***	-0.058	0.043	-0.019
Afternoon	0.167***	0.021	0.045	0.007
Day of week (Ref: weekday)				
Weekend	-0.239***	-0.213***	-0.065	-0.040
Location setting (*Ref*: *Outside CBD*)				
Within CBD	-0.415***	-0.659***	-0.112	-0.210
Road type (*Ref: Other*)				
Highway	-0.310***	-0.213***	-0.084	-0.067
Presence of police (*Ref: No)*				
Yes	0.148***	0.102**	0.039	0.033
Constant	1.102***	0.009	-	-
Goodness-of-fit statistics				
Number of observation	5443			
Log-likelihood at convergence	-5463			
Log-likelihood at intercept	-5878			
Likelihood ratio test	761***			
ρ	0.529			
Wald (χ^2)	316***			

Significance levels: *** $p<0.001$, ** $p<0.05$, * $p<0.1$

Important differences in seatbelt usage behaviour was also found among both drivers and passengers of different vehicle types. The analyses showed that drivers and passengers were 2% and 8%, respectively, more likely to use seatbelt when riding in SUV/Pickup compared to when using car. This was more pronounced when the vehicle used is a private vehicle. For example, drivers and passengers of private vehicles were 3% and 22%, respectively, more likely to use seatbelt compared to commercial vehicles users. Many past studies have demonstrated the differences in seatbelt use among vehicle types, however, the classification of vehicle types differ in most of these studies. A number of these past studies have consistently established lower seatbelt usage rates among occupants of pickup trucks compared to those of other vehicle types (sedans, SUVs, and minivans) (Begg and Langley 2000, Solomon et al. 2007, Nichols et al. 2009). Among vehicle types, pickup trucks have the highest seatbelt non-use and when drivers did not use seatbelts, about 56% of their accompanying passengers did not use seatbelts as well (Boakye et al. 2018). There is a myth suggesting that the use of pickup trucks and other 'big-sized' vehicles are safer compared with other vehicles (Boakye et al. 2018). This myth might be the reason for the lower usage of seatbelt by both drivers and passengers of pick-up and other 'big-sized' vehicles. Our results show that drivers and passengers of SUV/Pickup are more likely to use seatbelt than cars. In Ghana, majority of SUV/Pickup are official government and company vehicles. Although the law to wear seatbelt is mandatory for drivers and passengers in Ghana, government agencies and companies insist on their use, as drivers and passengers might lose any compensation due them in the event of a crash when not using the seatbelt.

The time of travel, (either day or night) is believed to affect travel behaviour of drivers. The results from the bivariate probit model suggest that time of day significantly influence driver's seatbelt use but not that of passengers. The results showed that drivers were 4-5% more likely to use seatbelt in the morning and afternoon compared to evening time. Our findings support several studies that reported that daytime seatbelt use rates are significantly higher than night-time rates (Kulanthayan et al. 2004, Chaudhary and Preusser 2006, Tison and Williams 2010). Although

the study by Vivoda et al. (2004) showed that seatbelt use was significantly higher for both the driver and passenger during daytime than night-time, they concluded that seatbelt use was statistically significantly higher for passengers than drivers. As the number of vehicles travelling during daytime is higher compared to night-time, law enforcement activities by the police are expected to follow similar pattern (Kulanthayan et al. 2004). The low usage of seatbelt during the night might be due to the low level of law enforcement during night-time. The attitude of drivers towards the use of seatbelts change during night-time travel, as violation of the law might be unnoticed at night-time when there is limited presence of law enforcement personnel. It is therefore no surprise that night-time fatality rate is most of the time higher than the daytime rate in most countries (Varghese and Shankar 2007).

With respect to day of week, it was found that both driver and passenger seatbelt use were significantly influenced by the day of week. That is, drivers and passengers were 6% and 4%, respectively, less likely to use seatbelt during weekends compared to weekdays. The result from this study confirms the work of Williams and Shabanova (2002) and Chliaoutakis et al. (2000), where seatbelt use rates were found to be slightly higher during weekdays compared to the rates during weekends. In a number of surveys conducted by Boughton et al. (1981) in Australia, they observed a significant higher seatbelt wearing rate for weekdays (81%) compared with the weekends (79%). Other studies, however, found weekend travellers are indistinguishable from weekday travellers with respect to seatbelt use (Hong et al. 1998, Petridou 1998, Boakye et al. 2018). The possible explanation for increased use of seatbelt during weekdays might be the number of vehicle travels made during weekdays compared to weekends.

The study also suggests that there is a strong relationship between compliance level of seatbelt use and driving location among drivers and their passengers. The marginal effect suggest that drivers and passengers were 11% and 21%, respectively were less likely to use seatbelt when riding within city-centers compared to when riding outside city-centers. Results from this study show that both drivers and passengers driving in city-centers were more likely to comply with seatbelt use compared with drivers and passengers driving outside city-center areas. This finding supports a study of seatbelt use among motorists in Great Britain where they found that the usage rate of seatbelt was higher in town centers compared to outside town-centers (Scott and Willis, 1985). In a study in Hawaii, Kim and Kim (2003) found out that drivers are 1.7 times more likely to be unbelted in rural areas than drivers in urban areas. The reason for higher seatbelt usage in the city-centers could be attributed partly to the perception of higher enforcement activity within city-centers. Police presence is usually high in the city-centers than outside city-centers due to limited police personnel. Enforcement activities are therefore lower in areas outside the city-centers and this might explain the lower compliance rate of seatbelt use outside city-center areas.

The type of road, which is largely determined by the level of urbanization, influences the level of seatbelt use. The results suggest that drivers and passengers driving on highways were 7-8% less likely to use seatbelt compared to when riding on other roads such as local or arterial road. Although previous studies (Sangowawa et al. 2010, Mohammadi et al. 2015) have found that drivers and passengers are more likely to seatbelt on highways, the current results contradict this findings. Possible explanation for this different could be the presence of police on low speed areas. However, future research may need to find out more on why such difference exist.

The presence or absence of police along the road significantly influence the seatbelt use among drivers and passengers. The study results suggest that drivers and passengers were 3-4% more likely to use seatbelt in areas where police are present. Law enforcement plays an important role in ensuring successful implementation of road safety legislation (Yannis et al. 2007, Hess et al. 2010). In Ghana, the Road Traffic Act, 2004 (Act 683) makes it compulsory for both drivers and passengers to wear seatbelt. The presence of law enforcement officers, especially the police are effective measure in increasing seatbelt use, not only for drivers but also for passengers. Similar results were found in other seatbelt related studies (Shults et al. 2004, Yannis et al. 2007). The result of a study into the relationship between seatbelt use and enforcement in Florida showed an increase in the use of seatbelt during heightened enforcement activities (Kaye et al. 1995). It is no secret in Ghana that, most commercial drivers (taxis or mini-buses (trotro)) mostly wear their seat belts when they notice the presence of the police on the road. These drivers remove the seat belts immediately after driving past the police. Recent evidence from other countries suggest that police presence and the

contingencies associated with being pulled over is a driving force of seatbelt use (Goetzke and Islam 2015b). The result can be explained using the standard theories of the economics of law enforcement. This theory describe how the likelihood of violation decreases as the level of resources devoted to enforcement increases (Ng et al. 2013). This indicates that the presence of enforcement activities by police is able to reduce violations and increase compliance (Riedel et al. 1988). Our result therefore confirms that law enforcement is one powerful tool to change the behaviour of drivers, although admittedly the effect may be short-lived (Kulanthayan et al. 2004).

4. Conclusions

Seatbelt in vehicles are design to protect occupants or reduce the severity of injury in the event of crash. However, many people do not use this device when they are travelling in a vehicle and this pose challenges to policy makers and public health officials. Policy makers and public health officials have strong interest in encouraging vehicle occupants to use seatbelt in other to minimise the fatalities or burden due to road traffic crashes. The study explored the relationship between driver and passenger seatbelt use and the related contributing factors. Using an observation survey data collected in the city of Accra, Ghana, a bivariate probit model was developed to determine this relationship.

The results of the study suggest that the prevalence rate of seatbelt use among driver and their front-right passengers were 81% and 33%, respectively. These findings suggest that despite the legal requirement for all vehicle occupants in Ghana to use seatbelt, this regulation is not being adhered to. Thus, there is the need to enforce the existing law to promote its use. The study further found that there is a positive relationship between drivers' and front-right passengers' belt use. That is, the unobserved factors that increase the probability of a driver to use seatbelt also increase their front-right passengers' seatbelt use propensity. This suggest that any policy that intend to enforce drivers' seatbelt use will promote that of the front-right passenger. Among the variables considered, it was found that passenger's gender, vehicle ownership, day of week, location setting, road type and presence of police jointly influence seatbelt use of both drivers and passengers. Thus, any policy intended to aid seatbelt use should take these factors into consideration.

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