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Research Article

Is Effective Enforcement of Seatbelt Law Helpful in Reduction of Road Crash Fatalities: An Exploratory Empirical Analysis using Aggregate Data

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Abstract: The risk of road traffic crashes (RTCs) has enhanced due to growing motorization worldwide. In addition to other road safety countermeasures, enforcing regulation on key risk factors like seatbelt use is critical in reducing road crash fatalities (RCFs) and road crash injuries (RCIs). In the present study, an ordered probit model is estimated to explore effectiveness of enforcement level of seatbelt law at global level using data from World Health Organization (2013) and International Road Federation (2012). In this study, the enforcement of seatbelt law is categorized into four levels including very low, low, medium and high. The outcomes of the estimated model revealed that high level of seatbelt enforcement is in inverse association with the number of RCFs per thousand registered vehicles. Factors which increase the probability of high level seatbelt law enforcement include; availability of training in emergency medicine for doctors, legislation on cell phone use while driving, the existence of funded national road safety lead agency, and existence of national or sub-national policy for promoting walking and cycling. Study results provide a preliminary insight on significance of seatbelt enforcement and associated road safety countermeasures.

Keywords: Road Crash Fatalities, Seatbelt Law Enforcement, Ordered Probit Model.

1. INTRODUCTION

Road traffic crashes (RTCs) are responsible for large number of road crash fatalities (RCFs) and road crash injuries (RCIs) across the globe. The ever startling unsafe global road culture has been portrayed by World Health Organization (WHO, 2018) which reports more than 1.35 million RCFs and between 20-50 million RCIs worldwide annually [1]. The main victims of RTCs are young individuals who suffer from huge loss in the form of fatalities and injuries [2]. Well-designed road facilities and existence of appropriate road safety counter measures (e.g. restraints in vehicles) can decrease RCFs. It has been a core area for researchers to investigate the primary causal factors of RTCs in an attempt to improve road safety, specially by improving road user’s adherence to key risk factors (i.e. seat belt law, helmet usage, speed limit law, drunk driving law, and child restrained law). Surprisingly, only 46 countries (i.e., comprising 3 billion population) have laws setting speed limits, 45 countries (i.e., comprising 2.3 billion population) have drink-driving laws, 49 countries (i.e., comprising 2.7 billion population) have regulations on helmet use for motorcyclists, and only 33 countries (i.e., comprising 652 million population) have laws regarding use of child restraint systems aligned with best practice [1]. It is nice to notice that 105 countries (i.e., representing 5.3 billion population) have laws on seatbelt use aligned with best practice

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[1].. Speed enforcement helps in achieving a significant decrease in RCFs [3], nevertheless only 95 out of 179 countries have implemented 50 kilometer per hour (KMPH) or less as an urban speed limit [1].

However, it can also be argued that use of seatbelts may trigger rush driving as drivers feel more secure and relax. Researches consider that use of seatbelts enhances the occupants' safety. In 2007, Zhu et al. determined that fastening of seatbelt by occupants lessens the likelihood of fatality during a crash for front seat passengers by 40-50% and that for rear seat passengers by 25-75% [4]. A study by Shabita and Fukuda (1994) reveals that seatbelt's use results in prevention of various head and facial injuries and also decrease their severities [5]. However, underestimation of hazard perception by drivers/occupants of involving in a crash decreases usage of seat belts [6]. Seatbelt laws, aligned with best practices, have been implemented in 105 countries (containing 5.3 billion population) to ensure occupants' safety [1].

Various studies reveal that seatbelt is the utmost effective restraint which helps in reduction of both RCFs and RCIs [8, 9]. Appropriate use of seatbelt saved more than 12,000 RCFs only in the United States in year 2012 [10]. The seatbelt law enforcement is either primary that involve issuance of ticket for not fastening seatbelt or secondary wherein drivers are stopped against some other traffic violation and then issuing ticket for not fastening seatbelt. Independent studies by Cohen and Einav (2003) and Dinh-Zarr et al. (2001) reveal that primary enforcement of seatbelt law is more effective in reducing RCFs and RCIs as compared to secondary enforcement [11, 12]. A conclusion can be made from the past literature that proper motivation is needed to persuade road users for utilizing seat belts for safer drive. Community events with awards and prizes are relatively more effective to persuade the occupants for using seatbelts [13]. In 2004, Maclennan et al concluded that occupant without a seatbelt acts like a projectile inside the vehicle and may hit a belted passenger who acts like a stationary target which increases the probability of injury for belted passengers [14]. Drivers who do not fasten their seatbelts are generally involved in other traffic violations which consequently increase the probability RCFs [15]. According to Sleet (1984), use of seat belts, child restraints and restriction from "drink and drive" reduce RCFs and RCIs [16]. Likewise, focus on other associated areas such as existence of funded lead agency, enforcement for child restraint laws and policies for maximum speed on rural and urban roads can help in controlling the RCFs [17]. A recent study by Wali et al. (2017) revealed that implementing high level enforcement of traffic regulations like speed limit laws can help in reduction of RCFs at country level [18]. Same study found that high level seatbelt enforcement can help to ensure high level enforcement of speed limit laws and drink driving laws which will consequently help in improving overall road safety at a country level [18]. In the past decades, researches focused on numerous analytical approaches for evaluating the effectiveness of seatbelt use. In 1990, Garbacz carried out a multivariate regression analysis on data collected through random telephonic interviews to understand factors affecting seat belt usage [19]. Hamed et al. (1998) analyzed factors influencing seat belt use while estimating separate models for short urban and long rural intercity trips in Jordan analyzing data survey data of 385 drivers [20]. The authors concluded that female and older drivers consider the seatbelt use effective [20]. Other factors which affect the level of seatbelt use include; children in family, vehicle possession, past experience of involvement in serious accident and degree of belief of drivers to use seat belt [20]. Moreover, in another independent study, it was concluded that mandatory laws enforcement is strongly associated with high level seatbelt and helmet usage, whereas, public campaigns were regarded not to result in high level seatbelt and helmet use [21]. Injury severity of older occupants is negatively associated with seatbelt use and there are five times more chances of older drivers to get severe injuries given a crash when unfastened [22]. A recent study revealed that seatbelt usage rate is positively associated with socio-cultural and educational level of a population [23]. Present research effort focused on checking the effectiveness of seatbelt law enforcement in reduction of RCFs and RCIs at global level and addresses the following questions:

- ✓ How does RCFs relate to effective enforcement of seatbelt law??
- ✓ What are the effects of high speed limits and other law enforcement measures on the seatbelt enforcement at global level?

2. MATERIALS AND METHODS

2.1 Dataset

In 2013, WHO presented a report (Global Status Report on Road Safety) after conducting a country level survey under the supervision of "National Data Coordinator" [7]. The report contains information for 178 countries however only 170 countries are considered for our final analysis as information for left over countries was incomplete. The dataset extracted from the WHO (2013) report contains information in the form of 36 different variables which include; population, total number of registered vehicles, hospitals per thousand people, gross national income per capita (GNI), speed limits on rural and urban roads, annual road crash fatalities and status of safety policies on roads. Report also contains particulars regarding the existence or lack of mandatory installation of seatbelts in vehicles for front and rear occupants, national seatbelt law, national helmet law, drink and drive law, national child restraint law, policy for promotion of walking and cycling, vital and vehicle registration system, road safety audits on existing and new roads and presence of funded lead agency in a country. However, road density i.e. kilometers of road length per square kilometer land of a country was added to the final data set by consulting report on road statistics of International Road Federation (2012) [24]. The effectiveness of seatbelt enforcement level is categorized on a four levels ordinal scale. The frequency distribution of the four levels of effectiveness of seatbelt enforcement (i.e. very low, low, medium and high) for 170 countries as shown in Fig.1.

Based on gross national income per capita (GNI per capita), the countries are classified into low, medium and high income countries. Low income countries have GNI per capita less than $ 935, middle income countries have GNI per capita in the range of US $ (936-11456) and high income countries have GNI per capita greater than US $ 11456. The percentage statistics of indicator variables which are significantly associated with the effectiveness of seatbelt enforcement law are presented in Table 1.

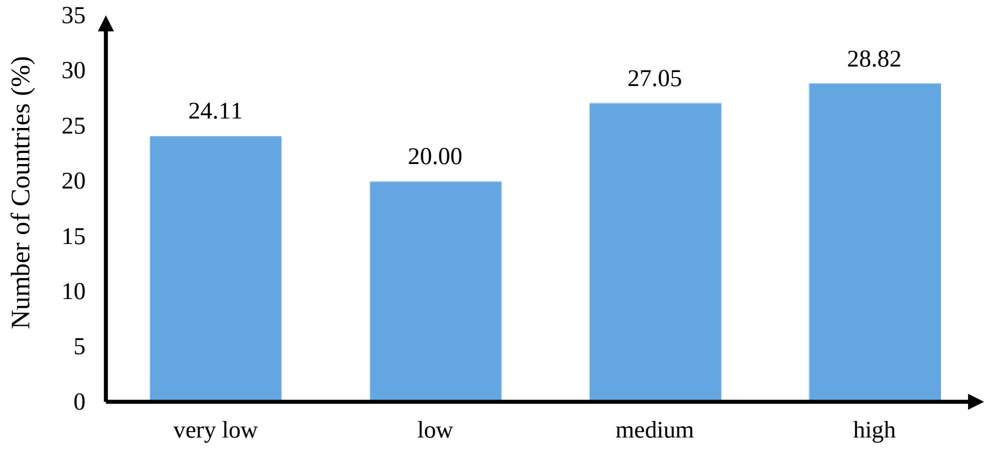

Figure 1. Frequency Distribution (%) of Effectiveness of Seatbelt Law Enforcement across the Globe

Table 1. Summary Statistics of Significant Variables

Variable	Description	Mean
Fatalities per 1,000 vehicles indicator	1 if fatalities per thousand registered vehicles greater 0.77, 0 otherwise	0.5294
National seatbelt law indicator	1 if national seatbelt law exists, 0 otherwise	0.9117
Mobile phone legislation indicator	1 if legislation on mobile use during driving exists, 0 otherwise	0.8000
Doctor training indicator	1 if training in emergency available for doctors, 0 otherwise	0.7058
Funded lead agency indicator	1 if lead agency is funded, 0 otherwise	0.6941
Walking and cycling indicator	1 if policy for promoting walking and cycling exists, 0 otherwise	0.2529
Maximum rural speed indicator	1 if maximum speed on rural road is greater than 90 KMPH, 0 otherwise	0.1176

2.2 Methodology

Various methodological approaches have been used for modeling seatbelt enforcement to investigate its association with contributing factors. These frequently used approaches can be categorized as nominal which include multinomial logit models, nested logit models and mixed logit models and ordinal which include ordered logit models, ordered probit and mixed logit models. Various independent studies show that ordinal approaches are useful for limited dataset specifically when sample size is lesser than 1,000 in estimating more accurate and reasonable results [27-29]. Considering the ordinal nature of the response variable and limited sample size (170 observations) an ordered porbit model was estimated to understand the association of effectiveness of enforcement level of seatbelt law and its contributing factors. In this study, the effectiveness of seatbelt enforcement is categorized on an ordinal scale into four levels; very low (0,1,2,3), low (4,5), medium (6,7) and high (8,9,10), whereas 0 representing the lowest and 10 representing the highest level of seatbelt enforcement. Following Washington et al. (2020), the latent variable "$Z_i{}^*$" (i.e. unobserved continuous variable) is associated with independent variable "X_i" as [30]:

$$Z_i{}^* = \beta' X_i + \varepsilon_i \tag{1}$$

Where "$Z_i{}^*$" is a latent variable showing the continuous measure of effectiveness of seatbelt enforcement in a country,"i". "X_i" is a vector of observed non-random independent variable affecting the enforcement of seatbelt law. "β'" is a vector of parameters to be estimated. The "ε_i" represents an error term following a standard normal distribution (mean=0 and variance=1). The probability density function $\emptyset(\varepsilon_i)$ and cumulative distribution function $\varphi(\varepsilon_i)$ are given in equation (2) and equation (3) respectively as:

$$\emptyset(\varepsilon_i) = \frac{1}{\sqrt{2\Pi}} \exp\left(\frac{-e^2}{2}\right) \tag{2}$$

$$\varphi(\varepsilon_i) = \int_{-\infty}^{+\infty} \frac{1}{\sqrt{2\Pi}} \exp\left(\frac{-t^2}{2}\right) dt \tag{3}$$

Given a specific level of seatbelt enforcement, an individual gets into category n, if $\mu_n - 1 < Z_i{}^* < \mu_n$. The latent variable, $Z_i{}^*$, is associated with observed seatbelt enforcement level , Zi, as follows:

$$Z_i = \begin{cases} 0 \text{ if } -\infty \le Z_i{}^* \le \mu_1 & \text{(very low enforcement level of seatbelt law)} \\ 1 \text{ if } \mu_1 < Z_i{}^* \le \mu_2 & \text{(low enforcement level of seatbelt law)} \\ 2 \text{ if } \mu_2 < Z_i{}^* \le \mu_3 & \text{(medium enforcement level of seatbelt law)} \\ 3 \text{ if } \mu_3 < Z_i{}^* \le +\infty & \text{(high enforcement level of seatbelt law)} \end{cases} \tag{4}$$

The probability of seatbelt law in a country "i", effectively implemented at enforcement level"j", is equal to the likelihood that latent enforcement level, $Z_i{}^*$, lies between two thresholds as follows [30]:

$$\mathrm{Prob}(Z_i = 1) = \varphi(\mu_1 - \beta' X_i)$$
$$\mathrm{Prob}(Z_i = 2) = \varphi(\mu_2 - \beta' X_i) - \varphi(\mu_1 - \beta' X_i) \tag{5}$$

$$\mathrm{Prob}(Z_i = n) = \varphi(\mu_n + 1 - \beta' X_i) - \varphi(\mu_n - \beta' X_i)$$
$$\mathrm{Prob}(Z_i = N) = 1 - \varphi(\mu_N - \beta' X_i)$$

Once the probabilities are estimated, the impact of explanatory variables on the response variable can be analysed. For instance, the probability of high enforcement level of seatbelt law may increase or decrease with an increase in the explanatory variable. However, ordered probit model can only estimate probabilities of extreme categories of the response variable. Marginal effects are estimated to understand the effects of unit increase in independent variable on intermediate categories of the response variable [30, 31]:

$$\frac{\partial \mathrm{Prob}(Z_i = n|x)}{\partial x} = [\varphi\,(\mu_n + 1 - \beta' X_i) - \varphi\,(\mu_n - \beta' X_i)]\beta \qquad n = 0,1,2,3 \tag{6}$$

The goodness of the model can be checked via maximum likelihood method. The (Adjusted ρ^2) can be calculated as:

$$\text{Adjusted } \rho^2 = 1 - \frac{\ln L_b}{\ln L_o} \quad (7)$$

Where lnL_b = log likelihood at convergence and lnL_O = restricted log likelihood. The value of adjusted ρ^2 lies between zero and one. Higher the value of adjusted ρ^2 shows better fit of the overall model

3. RESULTS AND DISCUSSION

In the present study, an ordered probit model is estimated to explore the significant association of effectiveness of enforcement level of seatbelt law and explanatory variables. The final model includes seven explanatory variables which show significant correlation with effective enforcement of seatbelt law. All of the seven variables were included in the final model on basis of parsimony, statistical significance, and intuition. After number of trials, seven variables were found statistically significant at 95% confidence level (Table 2). Nonetheless, the indicator variable for training in emergency available for doctor is marginally significant (i.e., as per 90% confidence level criteria), and is retained in the final model, being important [32, 33]. The positive coefficient of the explanatory variable in the results suggests that likelihood of high level of seatbelt enforcement increases whereas that of very low level of seatbelt enforcement decreases and vice versa.

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Table 2. Model Estimation Results

Variable	**Coefficient**	**t-stat**
Constant	-1.058	-2.479
Fatalities per 1000 vehicles indicator	-0.401	-2.201
National seatbelt law indicator	1.158	2.659
Mobile phone legislation indicator	0.552	2.128
Doctor training indicator*	0.392	1.946
Funded lead agency indicator	0.398	2.094
Walking & cycling indicator	0.479	2.208
Maximum rural speed indicator	-0.537	-2.008
μ_1	0.728	8.081
μ_2	1.565	13.547
Number of observations	170	
Degrees of freedom	7	
Log likelihood	-203.94	
Restricted log likelihood	-234.11	
Adjusted rho-squared (ρ^2)	0.1288	

Note: In Table 2, * indicates that the "doctor training indicator" variable is found to be marginally significant (i.e., satisfying 0.10 significance level criteria) while all the remaining explanatory variables in the model are found to have statistically significant correlation with the enforcement of seatbelt law as per 0.05 significance level criteria. The "doctor training indicator" variable provides useful insights due to which the variable is kept at 90% confidence criteria [33].

The variables which were found statistically significant include; estimated number of road traffic deaths per thousand registered vehicles, national policy for promoting walking and cycling, maximum speed on rural roads, legislation on mobile phone use while driving, training in emergency for doctors, national seat-belt law and presence/absence of funded lead agency. The model results revealed that probability of high level of seatbelt enforcement decreases with a unit increase in the indicator variable for estimated number of road traffic deaths per 1,000 registered vehicles while keeping all other variables at their mean values. The finding is intuitive showing negative association of effective enforcement of seatbelt law and RCFs [4, 8, 9, 15], as larger number of road traffic deaths per 1,000 registered vehicles corresponded to the inadequate road culture, inappropriate road safety policy and incompetency of the agency to administer reliable, safe, and comfortable level of service to road users [25]. While we recognize that road traffic deaths per 1,000 registered vehicles (RTDPTRVs) can be used as a response outcome with seatbelt use as independent variable, it can also be hypothesized that lower RTDPTRVs indicates existence of better health care system and safe driving culture in the country which would positively affect the seatbelt use, compliance with drink-driving, and speed-limits laws [18]. Also, estimation results suggest that probability of high level of seatbelt enforcement increases with a unit increase in indicator variable for existence of policy for promoting walking and cycling. The presence of such policies shows prosperity of a state and shall serve to encourage walking and cycling as an alternative to car travel especially in case of intra central business district (CBD) trips, which eventually increases the likelihood of high level of seat belt enforcement. Consequently, people with better financial conditions will use motorization and the enforcement level of seatbelt will be high. Model results revealed that higher the maximum allowable speed on rural roads, lesser would the probability of high level of seatbelt enforcement. This result is completely in accord with risk homoeostasis theory or zero risk theory according to which drivers have low propensity to safety measures and opt risks taking when encouraged for higher speed as road segments with high posted speed limits may persuade the drivers to consider the road safe enough for non-usage of seat belt [34]. The presence of legislation on mobile use during driving is found in positive relation with seatbelt law enforcement. Also, existence of national seatbelt law in a country can help increasing probability of high level seatbelt enforcement [35]. Also, presence of funded lead road safety agency increases the probability of high level of seatbelt enforcement. This is clear and understandable as funding and adequate resources are mandatory to run effective checkup programs for upgrading the effectiveness of seat belt enforcement in particular and overall safety policy in general.

Ordered probit model only estimates the probabilities of the extreme levels of the response variable thus marginal effects were estimated (Table 3) in this study following Washington et al. (2010) [30]. For example, if there is a unit increase in the indicator variable for doctors training (availability of emergency training for doctors), there is 11.27% increase and 11.71% simultaneous decrease in the probabilities of high level and very low level of seatbelt law enforcements respectively. Similarly, a unit increase in lead agency indicator (if a lead agency is funded in country), results 11.87% decrease while 11.48% increase in the probabilities of very low and high level of seatbelt enforcements respectively.

4. LIMITATIONS

Despite several limitations associated with the WHO (2013) data, the authors believe that it is the first and unique dataset providing detailed information related to road safety at a global scale. Furthermore, the authors consider that this research would provide useful insights related to effective enforcement of seatbelt law at country level. However, as discussed in the data limitation section of this paper, use of subjective and non-standardized data collection protocol, specifically in developing and underdeveloped countries, can lead to both systematic and random errors in modeling. The authors acknowledge that there could be potential unobserved heterogeneity which needs to accounted via more sophisticated heterogeneity based models [36, 37]. Similarly, there could be systematic (observed) heterogeneity in the effects of certain variables (i.e., road traffic deaths per 1,000 registered vehicles). Hence, it would be nice to account for such non-linearity (observed heterogeneity) in the modeling to get more accurate estimates [38]. While the authors acknowledge the significance of the aforementioned two issues, this paper does not account for both observed and unobserved heterogeneity. As a part of the future research, it would be nice to use more sophisticated modeling techniques to capture both systematic and random heterogeneity.

Table 3. Marginal Effects for the Ordered Probit Model

Variable	Very low	Low	Medium	High
Fatalities per 1000 vehicles indicator	0.1113	0.0466	-0.0343	-0.1236
National seatbelt law indicator	-0.4127	0.0005	0.1833	0.2289
Mobile phone legislation indicator	-0.1744	-0.0428	0.0697	0.1475
Doctor training indicator	-0.1171	-0.0384	0.0427	0.1127
Funded lead agency indicator	-0.1187	-0.0392	0.0431	0.1148
Walking and cycling indicator	-0.1208	-0.0638	0.0266	0.1580
Maximum rural speed indicator	0.1742	0.0368	-0.0723	-0.1386

4.1 Data Limitations

The WHO annual report (i.e., WHO 2013) provides significant and useful information regarding road safety and other socio-economic attributes at country level worldwide. Meanwhile, there are several key limitations associated with the WHO data which need be highlighted [17, 25]. One of the key limitations is that the data can have potential subjectivity issue due to different definitions and standards used by agencies in different countries [25]. For instance, the effectiveness of enforcement of seatbelt law and other key risk factors (i.e., drink-driving, motorcycle helmet laws, speed limit enforcement, and child restraint laws) were collected via questionnaire survey within each country asking safety experts to subjectively rate the enforcement levels of each of the five key risk factors on a scale of 0 to 10 (i.e, while 0 being the lowest and 10 being the highest level of effectiveness) [26]. The use of experts' opinion procedure lead to qualitative data which is liable to systematic and random errors and may lead inconsistent and erroneous estimates if appropriate modelling approaches are not followed which account for these issues [25]. Similarly, there could be potential underreporting issue related to birth and death records etc. in both the developing and underdeveloped countries. While the WHO does certain necessary adjustments to such incomplete data, still it cannot be actual representation of data [25]. Despite of the aforementioned limitations, the WHO (2013) data provide decent opportunity to explore effectiveness of enforcement of seatbelt law at a country level and to understand its key correlates.

5. CONCLUSIONS AND RECOMMENDATIONS

Present study investigated the factors associated with effectiveness of enforcement level of seatbelt law. The data were extracted from International Road Federation (2012) and WHO (2013). The final dataset contained information on 170 countries as few countries were excluded from the data due to incomplete information. An ordered probit model was estimated due to the ordinal nature of the response variable and limited sample size. The model results revealed that effective enforcement of seatbelt law can help in reduction of road crash fatalities. Also, legislation on mobile use during driving, availability of emergency training for doctors, existence of national policy for promoting walking and cycling and existence of funded national transportation agency were found in positive association with the response variable. In case of rural highways, probability of very low seatbelt enforcement level increases whereas that of the high level decreases provided that the maximum speed limit is greater than 90 KMPH. The authors believe that implementation of seatbelt law as primary enforcement tool at country level, and where applicable upgrading it from the secondary to primary enforcement can help reducing RCFs worldwide. State funding to transportation agencies and enforcement of laws on walking and cycling can also help in enhancement of seatbelt usage. Also there is a need of firm patrolling and surveillance on rural highways with higher speed limits to ensure use of seatbelt.

Present study provides a preliminary insight into seat belt use and associated factors using aggregate data. However, lack of consistency and definitions of some parameters in various countries may have affected the data collection. There is a room for improvement in the data of under developed and developing countries pertaining to total number of registered vehicles, population, exact vehicles miles travelled (VMT) and actual seatbelt fastening rates. It is believed that enhanced investment in highway safety and better data collection process, shall help in better understanding of factors associated with seat belt use, and improving overall road safety around the globe.

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