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EFFECT OF "TAX ON CASE OF BEER", "MINIMUM LEGAL DRINKING AGE" AND "AVERAGE MILES PER DRIVER" ON TRAFFIC FATALITIES IN UNITED STATES

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Abstract

The US is straggling to reduce road traffic fatalities to zero. Not only is not reaching the target, but also some movements are claiming destitution of some legal measures aiming at reducing drunk-impaired fatalities. There are discrepancies among scholars. The present research contributes to the debate by using Generalized Additive Model to quantify the effects of "tax on case of beer", "minimum legal drinking age", and "average miles per driver" on the traffic fatality rate. Findings show that tax on a case beer, to be effective needs to be fixed at more than USD 2.7 which is about 3.2 to 46 times the actual rate. The Minimum Legal Drinking Age is effective at 21 years old. However, it should be more effective at 20 years old. And the "average miles per driver" has an effective deterrent effect for people who drive at least 17,000 miles/year. Research limitations are presented, and recommendations made.

Keywords: *Road traffic fatalities, Minimum Legal drinking age, Excise tax on Alcoholic beverage, average miles per driver, Vision zero*

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1. INTRODUCTION

Injury and death from road traffic crashes are major public health problems [1]. In fact, every year 1.3 million people worldwide lose their lives in road traffic crashes [2]. And road traffic crashes are the leading cause of death among children and adolescents aged 5-29 years [2]. Since the 1970s, according to Saffer and Grossman [3], the United States (US) has made great efforts to prevent these unwanted deaths. However, the United Nations' vision of zero fatalities by 2050 is far from being achieved in the US [4]. In the US, at least one person is killed in a traffic crash every 13 minutes. 31.17% of fatalities are alcohol-related. The trend is unfortunately increasing since 2019, and that of drunk driving is worse. While the total number of victims increased by 10% from 2020 to 2021, the number of drunk driving victims increased by 14.2% [5]. According to NHTSA [6], the fatality rate per 100 million vehicle miles travelled (VMT) related to alcohol-impaired driving traffic crashes increased by 38.7%.

However, some policies aimed at reducing drink-driving, such as raising the legal drinking age and increasing alcohol prices or taxes, are now controversial [7]. While some researchers [8, 9] support the effectiveness of the 21-year-old as the "legal drinking age" in reducing road crashes, others researchers [10, 11] reject it. Similarly, researchers had a debate on whether the tax on case beer effectively reduces road crashes. More research is needed to better understand how the tax on case beer and the minimum legal drinking age affect traffic fatality rate. The present research will investigate the effect of the two factors "tax on case of beer", "minimum legal drinking age", in the presence of another exposure "the average miles per driver on traffic fatalities in United States.

2. DEFINITION OF TERMS

The minimum legal drinking age (MLDA) in the USA is the age at which individuals may legally purchase and possess alcohol in public [12]. In our dataset, the minimum legal drinking age indicates whether the legal drinking age is 18, 19, 20 or 21.

The tax on a case of beer is the tax on a liter of beer divided by 2.25. It is one of the Excise Taxes on Alcohol (ETA) in the US, which is a type and volume-based beverage tax levied by the federal government and each state [13]. All states and the District of Columbia have this tax except the state of Utah. The ETA levied on the quantity, which is the case in this paper, is a "specific excise tax", while that levied on the price of the beverage is an "ad valorem excise tax" [14].

The total distance per driver (vehicle) is the distance travelled by a driver in one year. It reflects an exposure variable in epidemiology [15]. Its impact on road fatalities is commonly reported as the number of fatalities per 100 million vehicle miles travelled [16].

In our dataset the average miles per driver is the average of the total vehicle miles travelled annually by state. The traffic fatality rate is the number of traffic deaths in a given state, given year per 10,000 people.

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3. LITERATURE REVIEW

3.1. Effect of the Minimum legal drinking age on road traffic fatalities

Voas, et al [17], highlighted that since the 1930s, some US states have prohibited the consumption of alcohol by persons under 21 years of age. Between 1970 and 1975, 29 states lowered the minimum legal drinking age (MLDA) to 18-20 years of age, which led to many studies confirming the negative effects of lowering the MLDA, and many states abandoned the lowering trend. In 1989, after the federal government passed a law penalizing any state that did not comply with the 21-year-old as MLDA (MLDA-21), all states and the District of Columbia adopted the same law. Except for the state of Louisiana, which did so in 1995 [12]. Research by Peck et al [9], Gicquel et al [8] and Keyes et al [7] confirmed the effectiveness of MLDA-21 in reducing alcohol-related crashes and fatalities among young drivers.

However, conflicting perspectives emerged. Carpenter and Dobkins [10] and Fitzpatrick et al [11] questioned the effectiveness of MLDA-21, suggesting an increase in fatalities among 18–20-year-olds. The debate continued, with Dejong and Blanchette [18] whose findings supported the effectiveness of MLDA-21 and concluded that the debate should be closed. However, Pitts, Johnson and Eidson [19] responded that the debate should remain open. Chenge and Antony [20], in an empirical study, showed that fixing MLDA at 21-year-old is psychological incorrect because young people who try their first glass at the age of 14 are likely to repeat irresponsible drinking within 12 months and would not wait until the age of 21. It can lead to worse situations like increasing of drugs' consumption. Meanwhile, Fell, at al. [21], in their study of 20 laws related to the MLDA-21, found that 2 contributed to an increase in motor vehicle crash fatalities. Ruhm [22] accused many researchers supporting the effectiveness of the MLDA-21 of overstating its effects by neglecting other confounding factors that may be more effective than the MLDA in reducing motor vehicle crash fatalities.

3.2 Effects of excise taxes on alcohol on road deaths

Studies on excise taxes on alcohol (ETA) have focused on beer. It is the Americans' first choice among alcoholic beverages [23,3]. Researchers' findings on this issue are very mixed. Saffer and Grossman [3] found a large statistical significance of ETA and MLDA on the rate of fatal alcohol-related motor vehicle crashes (FARMVCs). Chalupka et al [23] found that the effect of ETA was more pronounced in reducing alcohol-related motor vehicle crashes in the 15-24 age group. Differences in results persisted. Young and Bielińska-Kwapisz [24] examined data from only one state and found that high alcohol prices were negatively correlated with MVCs, but the effect depended on age and time of day. For adolescents aged 16-20 years, the effect was found during weekend nights. Wagenaar et al [2] and Elder et al [25] reported different correlations, whether positive or negative, between taxes and alcohol-related fatalities.

Discrepancies continue to emerge in the results of subsequent research. Wagenaar, et al [26] examined the impact of the Illinois tax reform in September 2009 on FARMVCs over the following 48 months. They found a 26% decrease in the average number of deaths related to vehicle crashes. Lavoie et al [27], after conducting conclusive research in the state of Maryland, proposed not to increase the ETA but to increase the sales tax because it is much more effective: 12% deduction of FARMVCs in the 16-20- year-old group. This tax is very effective in the 21-34-year-old age group. Roodman [28] raised many doubts and concluded that the effect of ETA on FARMVCs Fatalities Alcohol Related Motor Vehicle Crashes was significantly mixed. Nelson and McNall [29] emphasized that the main problem was the inappropriate methodology used by the researchers.

3.3. Impact of average annual miles driven on FARMCVs

Average miles driven per vehicle per year reflects an exposure concept in epidemiology [15]. Its impact is commonly recorded as the number of fatalities per 100 million vehicle miles driven [16]. According to O'Connor [30], this averaged 14,300 miles per year in the USA and was influenced by age and sex.

Table 1: The average mileage per year based on age and gender.

Age group	Gender	Miles/year
16-19	Male	8.206
	Female	6.873
20-34	Male	17.976
	Female	12.004
35-54	Male	18.858
	Female	11.464
55-64	Male	15.859
	Female	7.780
65 <	Male	10.304
	Female	4.785

Massie, et al. [31] used multivariate modelling techniques and found that average annual mileage, controlling for three other factors (age, gender & time of day), was statistically associated with fatalities, injuries and property damage in motor vehicle crashes only. They stated that women are less risky because of their lower average annual mileage. As a result, they are more likely to be involved in non-fatal than fatal accidents. Beck, et al. [32] used the rate/100person-trips measure to avoid the bias of mis-estimation of distance in self-reported data, but they concluded a strong positive correlation between average trip as an exposure factor and FARMVCs. Redelmeier [16] cautioned policy makers by showing that even if the risks of dying in a road traffic crash increase with the length of the trip, the relationship is more complex. Some other factors may intervene, such as the presence of adequate road safety features and the absence of complex junctions. However, using ratio considerations, drivers with higher average mileage seem to have fewer accidents per mile driven than drivers with low average mileage [33]. In fact, the latter very often drive in high-risk environments such as busy city center roads, two-way roads with multiple junctions. The former drive on safer and more protected roads without complex junctions. They use vehicles with adapted technology. Their drivers are usually more experienced and more regulated [16]. This explains why Kalyoncuoğlu and Tiğdemir [34] found in their study in Turkey that the risk per kilometer decreases as the average distance travelled per day increases.

Other complementary factors should be considered or included in the model to better capture the risk exposure. For example, Jovanis and Delluer [35] included in their model, in addition to the length of the journey, the condition of the journey, the characteristics of the driver and the vehicle used. Rolison and Montari [36] suggested using the risk exposure density index, which includes distance in miles, frequency, and duration of travel. Matteos-Granados et al. [37] used the induced exposure method, which includes spatio-temporal factors such as weather conditions, type of road, time of day, etc. to complete the exposure satisfaction. And the fact that Huebner, Porter, and Marshall [38], studying the accuracy of an On-Board Diagnostic System (OBDII) called Car Chip used not only driven distance but also, added velocities variables to the model can inspire to develop a study that add to the average miles driven other risky behaviours like drunk driving or its supposed reducing factors like MLDA and ETA. In some cases, the literature review showed discrepancies in the findings on all three factors. Each factor was studied in isolation, very often without considering the existence of confounding factors or the possibility of interaction between the three laws. Some authors showed that the used methods were very often inappropriate to the problem and to the available data. For this reason, the present research will try to use a different methodology that can include all 3 factors together in a statistical model.

4.DATA MANAGEMENT AND METHODOLOGY

4.1 Description of the data

The data used to examine the effect of beer taxes, the minimum legal drinking age and average miles driven per driver on road fatality rates in the United States were obtained from the Department of Economics, University of North Carolina. The dataset “Carolina, from 1982 to 1988. “was found in the Ecdat package under the name of “fatalities.csv.” It contains 10 variables, four of which are of interest for our research: "traffic fatality rate", "tax per case of beer", "minimum legal drinking age" and "average mileage per driver". Number of observations (n) = 336. 7 years of data from 48 states (excluding Hawaii and Alaska).

The traffic fatality rate, denoted as nmrall, is a numeric response variable and the predictor variables used are as follows: 1) beertax: a numeric variable indicating the tax on a case of beer. 2) mlda: a numeric variable indicating the minimum legal drinking age. 3) vmiles: a numeric variable indicating the average number of miles driven per driver.

As for the quality of the dataset, the existing data in the Ecdat package were imported into R studio, where the variables of interest were checked for missing information and errors using the skim() function, the output indicating that the dataset has no missing or NA values. A correlation matrix analysis revealed no multicollinearity among the three predictor variables. Graphs were used in data exploration to visualize and understand the characteristics of the data and their distribution. The data displayed non-linear patterns. Table 2 provides an overview of the descriptive statistics.

Table 2. Overview of descriptive statistics

	Sample size	mean	Standard deviation	Minimum	Maximum
nmrall	336	2.04	0.57	0.82	4.22
beertax	336	0.51	0.48	0.04	2.72
mlda	336	20.46	0.9	18	21
vmiles	336	7.89	1.48	4.58	26.15

4.2 Methodology

This study adopts a quantitative approach to analyse the impact of the tax on a case of beer, the minimum legal drinking age, and average miles per driver on traffic fatality rates. Employing the Generalized Additive Model (GAM), known for accommodating non-linear functions of variables when linear model assumptions are unsuitable [39]. The GAM framework enables the incorporation of smooth functions for tax on case of beer, minimum legal drinking age, and average miles per year, allowing for flexible modelling of their effects on traffic fatality rates.

Tensor product interactions generated through ti() function assessed interaction effects. However, the log transformation of the response variable."nmrall" normalized its distribution for more reliable regression analysis. Penalized splines with an ample number of basic functions, as recommended by Chen et al. [40], improved model regularization. The model involved adequate tuning of parameters, including the number of knots and degrees of freedom, to balance model complexity and flexibility.

Model assessment involved evaluating adequacy and selecting the final model. Stepwise selection method with step.gam() was used to identify the best model. And at each selection step, ANOVA II was performed and summary () function generated characteristics indicating the model's fit. All variables with p.value>0.05 were removed from the model. The final step delivered the final model. This model, expressed as a GAM equation, included beertax, vmiles, mlda, and their interactions.

Calculation of adjusted R^2 of the final model indicated the contribution of predictors, aligning with Cohen's observations [41] in behavioural sciences. In the latter context even $R^2 = 0.26$ is considered significant. Through gam.check () function residual patterns were assessed to ensure model assumptions were met (see figure 1). Generalized Cross Validation (GCV) via gam() function assisted in selecting the smoothing parameter.

All variables were statistically significant with $p < 0.05$ (see table 3). The adjusted R^2 was 0.543, explaining 57.5% of deviance, and GCV = 0.037517. To estimate the traffic fatalities rates various R packages were used, including gam() function and Fisher tests.

This comprehensive model evaluation delineates the impact of predictors on road fatality rates, shedding light on alcohol-related policies' implications for traffic safety..

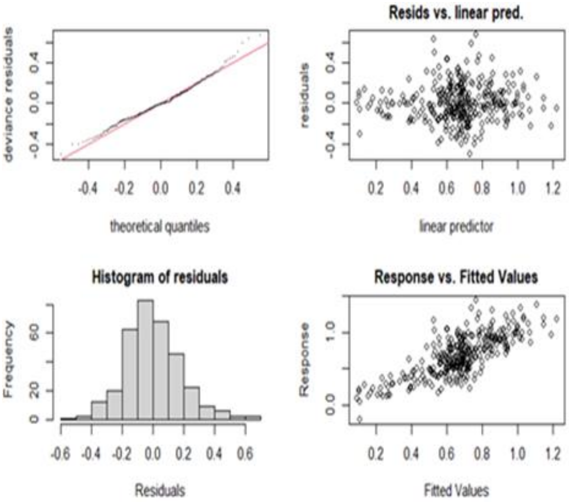
4.2.1 Final model

GAM final model is:

$$\text{Log.}Y=\beta 0+s(\text{beertax},bs=\text{"cr"},k=12)+s(\text{mlda},bs=\text{"cr"},k=12)+s(\text{vmiles},bs=\text{"12"})+s(\text{vmiles}*\text{mlda},bs=\text{"cr"},k=12)+s(\text{vmiles}*\text{beertax}\ bs=\text{"cr"},k=12)+\varepsilon. \qquad (1)$$

Where,
Y is traffic fatality rate (death per 10,000 inhabitants)
β is unknown coefficient to be estimated
k is number of knots
bs is a basis-penalty smoother
cr is penalized regression cubic spline
S is unknown univariate function to be estimated as penalized spline
ε is error term

Figure 1. QQ plots and histogram of Residuals



5.ANALYSIS OF FINDINGS

Table3 shows the significant of estimate term and their effective degree of freedom (edf). Edf provides a quantitative measure of flexibility or the smoothness of a non-linear term in a GAM. An edf between 1 and the maximum specified degrees of freedom, indicates a moderate level of non-linearity in the model. The smoothing term for "beertax", "mlda" and "vmiles" with edf = 4.74, 2.97 and 2.66 respectively, implies that the model is allowing for a moderate level of complexity of each variable beertax, malda and vmiles in capturing the relationship. For interaction terms, the edf increased, imply that the relationship is modeled with higher complexity.

All estimate terms in the model are statistically significant. For s(beertax),*F*=9.84 with *p-value* < 2e-16, s(mlda), *F*= 5.39 with *p-value* = 0.000881 and s(vmiles), *F*= 31.9 with *p-value* < 2e-16, means there is a significant effect of tax on case beer, minimum legal drinking age and average miles per driver on traffic fatalities rates. This means also variations in tax on case beer, minimum legal drinking age and average miles per driver are associated with significant changes in beer consumption.
Interaction ti(vmiles,beertax), *F*=6.56 with *Pvalu*e = 0.000325, and ti(mlda,vmiles), *F*= 0.33 with *p-value* = 0.014492 have significant interaction effect on traffic fatalities rates.

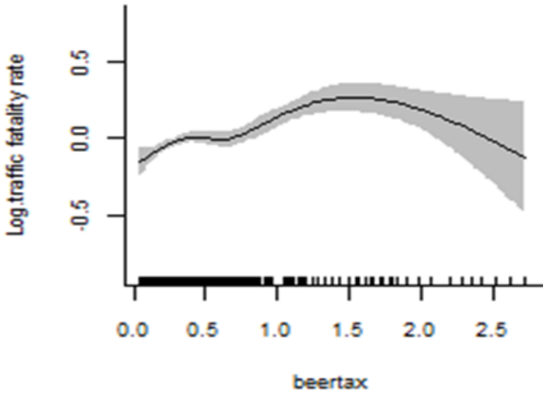
Table 3: Significance of estimate terms

	Edf	Fisher	P-value
s(beertax)	4.74	9.84	< 2e-16
s(mlda)	2.97	5.39	0.000881
s(vmiles)	2.66	31.9	< 2e-16
ti(vmiles,beertax)	6.56	3.81	0.000325
ti(mlda,vmiles)	7.13	0.33	0.014492

5.1. Effect of beer tax on traffic fatality rate

Figure 2 shows the effect of the beer tax on the road fatality rate. Analyzing the graph (beertax), we found that when the tax on case of beer is increased from 0 to 0.3, the log fatality rate is less than or equal to zero, which means that deaths occur up to 1/10,000 inhabitants (0.6-1.0 person). When the tax per case of beer increases from 0.3 to 0.8, there is a small deterrent effect; it is very small, so we can say that the effect is to stabilize the fatality rate rather than to reduce it (around 1/10,000 inhabitants). When the tax rises from 0.8 to 1.7, the log fatality rate rises up to 0.3 (2.0/10,000 inhabitants); and when the tax rises above 1.7, the log fatality rate falls and reaches zero or 1.0/10,000 inhabitants when the beer tax is around 2.4. This means that the actual beer tax applied in the US (0.27 - 0.83 per case of beer) has a mixed effect. It should increase road fatalities (0.27-0.3 & 0.81-0.83) or stabilize road fatalities around 1.0/10,000 population (0.3-0.8). Such low taxes are worse than no beer tax. With no beer tax, the death rate is around 0.6/10000 inhabitants. To have a better effect, the US should set the beer tax at more than 2.7 per case of beer (which is 3.24 to 46.7 times the actual tax)".

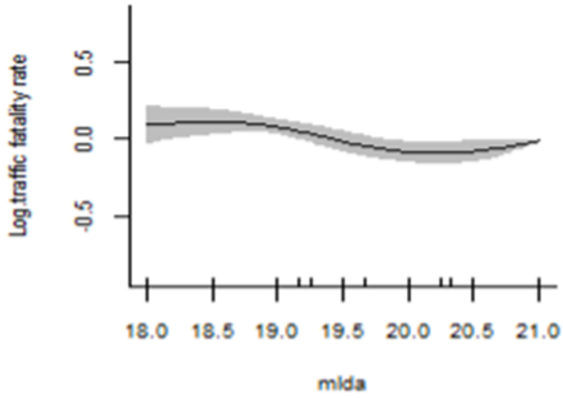
Figure 2. Effect of beer tax on traffic fatality rate



5.2. Effect of minimum legal drinking age on traffic fatality rates

Figure 3 shows the effect of the minimum legal drinking age on road fatality rates. The graph (mlda) shows that as the minimum legal drinking age increases from 18 to 21 years, the logarithm of the traffic fatality rate decreases to approximately zero (1.0/10,000 inhabitants). We observe a slight increase in the effect with mlda equal to 18.3-18.7. Then we see a decreasing effect to reach the starting point at mlda-19. At mlda-19.5 we have almost the same effect as at mlda-21. This means that mlda-21 is a very effective (no residuals) deterrent to road deaths. But it could also be reduced to mlda-19.5. Our model shows that mlda-20 may be more effective (fatality rate is estimated to be <1/10000 inhabitants) than both mlda-21 and mlda-19.5 (fatality rate is estimated to be around 1/10000 inhabitants).

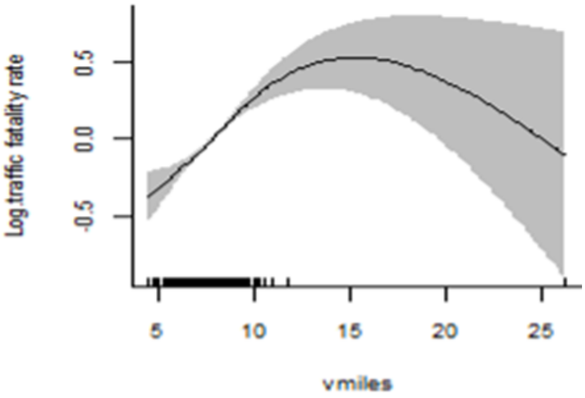
Figure 3. Effect of minimum legal drinking age on traffic fatality rates



5.3 Effect of average miles per driver on traffic fatality rate

Figure 4 shows the effect of average miles per driver on the fatality rate. The graph (vmiles) shows that for drivers travelling less than 15000 miles/year, the log fatality rate rises up to 0.5 (3/10,000 inhabitants) and decreases continuously for drivers travelling more than 15 miles/year. It is around log y=0,(1.0/10,000 inhabitants). Between 15000 and 17000 miles/year the effect stabilizes. Then the curve decreases continuously. This factor has a mixed effect, with a deterrent effect for people who drive at least 17 miles/year. A better effect starts at more than 25 miles/year. Special measures should be taken for people who drive less than 25 miles/year.

Figure 4. Effect of average miles per driver on traffic fatality rate



Log y=0.5 means y=3.16 death/10000 ; Log y=0.0 means y=1; Log y = -0.5 means y=0.316

6. DISCUSSION AND LIMITATIONS OF THE RESEARCH

The best statistical model that can help to estimate the rate of traffic fatalities in the US based on the 3 factors: "tax per case of beer", "minimum legal drinking age" and "average miles per driver" was presented.

Usually our model has limitations:

In this paper we have estimated the road fatality rate using a few factors. Few factors in the model cannot give a good prediction compared to more factors in the model; therefore, future research should include other factors such as weather conditions, driver experience, travel time, etc. to see if the prediction improves.

A logarithmic function was used to transform the data to be approximately normal, but the assumptions were not met quite perfectly, which means that the quality or accuracy of the estimate output will not be very high.

The model cannot contribute to achieving zero fatalities in the USA. And this is normal, with an R-squared =0.543, our model explains only 54.3% of the variation in the dependent variable (traffic fatality rate). But it is quite important in our case. Comparing our model with the actual data from the US Department of Transportation's National Highway Traffic Safety Agency (NHTSA), we found that the estimation results from our model are very close to their reported numbers from the digital and manual annual census.

For example, in 2019, when all states had MLDA-21, the traffic fatality rate was 1.1 per 10,000 population [27]. In our model, it is estimated to be around 1.0/10,000 Inhabitants when the mlda is 21.In the same year, the beer tax is set by the US federal government at USD 0.06-0.58, adding different additional rates by state governments, it will be USD 0.27-0.83 (calculated from data of APIS [14]. The average is USD 0.40). And if we observe in our beer tax model, the estimate of such beer tax effect on fatality rate is about 1.0/10,000 population.

Comparison with the literature review: The results of the present research agree with authors such as Ruhm [22], who said that the effect of tax on the case of beer should be set necessary very high in order to be able to influence the traffic fatality rate. They disagree with authors who showed that the beer tax was a good deterrent to road deaths [3,4,26] etc. The present research highlights the mixed effect, where some low beer taxes (0.0-0.3; 0.8-1.7) even have the opposite effect. They also disagree with Colon and Rao [42] who said that the tax should be increased at least at USD 1 to be effective. The deterrent effect starts at USD 1.7 and the effective effect is at least beer tax = USD 2.4. Given the impact that such a high beer price should have on the US macroeconomy, the results of the present research would support the proposal of Lavoie et al [29] to replace an excise tax on beer with a sales tax: The present research did not capture the effect of other factors such as changes in per capita income, inflation and future psychological adjustment to the price.

Our findings are also in agreement with scientists who have stated the effectiveness of mlda-21 [43, 44, 12,45,46]. However, we disagree with those who stated that it could not be reduced [10,11] and those who stated that MLDA was meaningless [20]. In fact, our results showed that setting the MLDA at 18 years may not be advisable because of the presence of young deaths at this age, as claimed by the Amenthyst Initiative (2008). However, it can be set at 19.5 years of age, with even greater effectiveness at 20 years of age, where a significant decrease in deaths is observed, potentially reaching zero deaths.

The present research results agree with Kalyoncuoğlu and Tiğdemir [37], who said that the risk of traffic fatalities decreases as the average distance travelled per day increases. They do not fully agree with Beck, Dellinger and O'Neil [35] who found a negative correlation between the average mile driven and traffic fatalities. We observed such a correlation when the average is equal to or higher than 15 miles/year. High risk drivers are those who drive infrequently and for very short distances. The present results confirm the learning effect of long and regular journeys [32].

7. CONCLUSION

Despite the limitations highlighted, this research will be useful for policy makers to find out where to focus their efforts in order to make better decisions, implement these policies and work towards zero road deaths.

Our research shows that there is a low deterrent and stabilizing effect of beer taxes of 0.3-0.8 and that better results require a tax rate of more than USD 2.7/case of beer. Considering the economic and psycho-political consequences of such a tax increase, we recommend evaluating whether this tax cannot be replaced by the sales tax, which according to Lavoie et al. [29] is more effective and not well applied in the US.

We found that the MLDA can be more effective at the age of 20 than at the age of 21. It can also be reduced to 19.5 years of age and still have the same effect as MLDA-21. Policy makers will make a better decision considering other economic and political issues. However, lowering it to 18 would be a big mistake, because we found that the actual average miles driven per year in the US (14,300 miles) is not yet in the range where it can have a deterrent effect on traffic fatalities. Only men in the 20-64 age group drive average distances that have a deterrent effect. Both men and women in the 16-19 and over 65 age groups drive very few kilometers in the range of average distances that increase the number of road deaths. The findings suggest that US policy makers could promote public transportation to reduce traffic fatalities. The latter can travel more than 25,000 miles/year (a range with a strong deterrent effect); drivers are more experienced and more regulated.

We do not fail to suggest that future research should include more factors and address other limitations acknowledged in the present study. These may provide stronger results.

8. ACKNOWLEDGMENTS

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