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Modelling the effects of fuel price changes on road traffic collisions in the European Union using panel data

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A R T I C L E I N F O

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A B S T R A C T

Road deaths globally have steadily climbed in recent years with the increase in motorisation. Yet in many economically developed countries they have actually fallen. Explanations for this reduction include the role of improved vehicle and highway design, better enforcement and the impact of the economic downturn, whilst there is also some evidence that microeconomic factors like changes in road fuel prices could be contributing to this situation. This paper investigates the effects of fuel prices on road collision frequency in countries where fuel prices are relatively high. Monthly panel data from 28 EU member states from 2005 to 2018 was analysed for both petrol and diesel prices, and for fatalities, total injury collisions and total collisions using: 1) random effect negative binomial (RENB); and 2) population-averaged negative binomial using generalised estimating equations (GEE). The findings indicate that higher fuel prices lead to lower road traffic deaths, injury collisions and overall collisions across all 28 EU member states. Thus, for every 10 percent increase in fuel prices, there will be a 2.6 percent and 2.2 percent reduction in fatalities for petrol and diesel models, respectively. Similarly, total collisions fall by 1.4 percent for petrol and 1.2 for diesel models, and total casualties fall by 1.6 percent for petrol and 1.4 percent for diesel with every 10 percent rise in fuel price. These results could be due to drivers reducing speed to achieve better fuel efficiency and to people driving less to save money – in particular younger, riskier drivers – hence reducing exposure. These findings suggest that policies replacing petrol and diesel vehicles with alternative fuel sources over the next 20 years could have negative repercussions for road safety if not adequately considered.

1. Background:

More and better transportation facilities have benefited human beings by reducing distances and increasing prosperity. However, this increase in road traffic has contributed to more road traffic collisions globally. According to the World Health Organization, in 2016, 1.35 million people died on the world's roads, and many more were involved in road traffic injuries (World Health Organization, 2018). This is up from 1.2 million in 2008 making road traffic collisions the eighth leading cause of human life loss globally, with the societal cost of road traffic injuries estimated as being $USD1.8 trillion or 0.12 percent of global GDP (WHO, 2010; Chen et al., 2019).

Yet road traffic collisions and deaths have also actually fallen in most developed nations (e.g. OECD member countries, see Fig. 1) over the last decade, a trend attributed to improvements in vehicle and highway design, medical technology and care, driver education and training, as well as better enforcement and the impact of the economic downturn (Noland and Quddus, 2002; International Transport Forum, 2015). One possible additional influence is the role of changing fuel prices, whereby rising petrol and diesel costs have coincided with reductions in traffic collisions and vice versa (Department for Transport, 2020).

Fuel prices are influenced by two key factors: 1) the price of crude oil (largely out of the control of individual governments) and 2) fuel-related taxes which are very much under the control of public authorities. Thus, fuel prices vary significantly across different countries depending on the role of fuel taxes as a part of the tax base and the public policy objectives

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pursued.

Fuel-related taxes are recognised as an important source of revenue for many countries. Typically in oil rich countries fuel-related taxes contributed very little to Government revenues (e.g. in Russia fuel tax was not applied, though as of 2018 a fuel tax of 5.6 percent was applied – still nearly 90 percent lower than the average EU member state fuel tax (nearly 60 percent fuel tax) (OECD, 2021; IISD, 2019). In terms of public policy objectives meanwhile, in several countries (such as the Netherlands, South Africa, the UK) higher fuel taxes have been adopted as a means to directly reduce a range of externalities such as carbon, poor air quality, road damage, and traffic congestion (Smith, 2000; IISD, 2019; Bolton, 2020). In addition, one less understood relationship suggests that higher fuel taxes also reduce road traffic collisions, and this is what this paper will seek to explore.

2. Previous literature

The literature on fuel prices and traffic related factors is limited. Fuel prices have been conceptualized to effect road traffic collisions through several different causal links (see Fig. 2). Further, the literature related to fuel prices and road traffic collisions can be broadly divided into two main categories; indirect and direct studies.

The indirect literature on the fuel price in transport literature mainly focuses on how fuel price affects transport demand, road traffic volume, fuel consumption and driver behaviour, e.g. traffic mode choice whereby the assumption is that higher fuel prices will minimise fuel consumption, causing a reduction in road traffic volume, traffic emissions, road damage, congestions, and road traffic collisions (Li, 2014, p 60). For instance fuel price could have an impact on road traffic collisions through effects on road traffic volume (Wang and Chen, 2014; Goodwin et al., 2004). In addition, Litman (2014) explained that in the long run two thirds of the reduction in fuel consumption is due to people buying more fuel-efficient vehicles in response to high fuel prices and one third due to reduction in the vehicle miles travelled. Despite controlling for fuel efficiency of car fleets, changes in fuel consumption could be reflected through reduction of road traffic volume. A French study suggested that a 10 percent increase in fuel price caused a 1.4 percent reduction in road traffic miles travelled in the short run and 2.6 percent in the long run (Delsaut, 2014). The reduction in road traffic could increase the demand of other transport modes as people can shift modes from car to buses and trains. Several studies provide evidence of increase in transit ridership of trains and buses in response to high fuel prices as people trying to reduce travel cost (Currie and Phung, 2007; Haire and Machemehl, 2007; Delsaut, 2014; Jung et al., 2016; Nowak and Savage, 2013; Sun, 2016). Thus, fuel prices can affect the type of travel mode as people can switch cars for public transport during high fuel prices which can have positive effect on road safety. While high fuel prices can reduce motorists fatalities it may increase use of the more vulnerable mode of transport, e.g. motorcycles causing a surge in motorcyclists fatalities due to increase in number of motorcycles in the traffic (Hyatt et al., 2009; Safaei, 2021; Zhang and Burke, 2021). However, the gains in traffic safety through reduced motorists' collisions could be higher due to higher number of cars compared to number of motorcycles in the road traffic mix. Hence, indirectly high fuel prices could cause fluctuations in the traffic exposure through reduced miles and mode changes consequently triggering changes in road traffic safety through variation in the number of road traffic collisions.

More directly, according to Grabowski and Morrisey (2004), in the USA a 10 percent reduction in fuel price increased road traffic fatalities by 2.3 percent. Similarly, an international study using annual panel data of 144 countries found that a 10 percent increase in fuel prices caused an average reduction of 3 to 6 percent in total road traffic fatalities (Burke and Nishitateno, 2015). In addition to this, other US studies found similar results about the negative relationship of fuel prices not only on reducing road traffic fatalities but all different types of collisions like total collisions, serious collisions, property damage collisions (Chi et al., 2013, 2015). According to these sources, the effects were found to be stronger on reducing less severe types of collisions than on more serious crashes (see Fig. 3).

The changes in road traffic collisions could be due to differential effects of fuel prices on different geographical regions and demographical groups. For example, fuel prices were found to have a more substantial impact in reducing rural road collisions than the urban area of Minnesota in the USA due to differences in household income and public transport availability (Chi et al., 2013). Fuel prices were found to have both short term and long-term effects on road traffic collision. Chi et al. (2015) found that the long-term negative effects (after a period of 9 to 10 months) of fuel prices stronger than the short term effects on road traffic collisions. Another long term effect of higher fuel price could be residential relocation, as people decide to live closer to work to reduce travel costs which could impact urban sprawl and thus miles travelled (Chi and Boydstun, 2017).

High fuel prices seem to have immediate or stronger short term effects on young drivers due to increased travel costs and tight travel

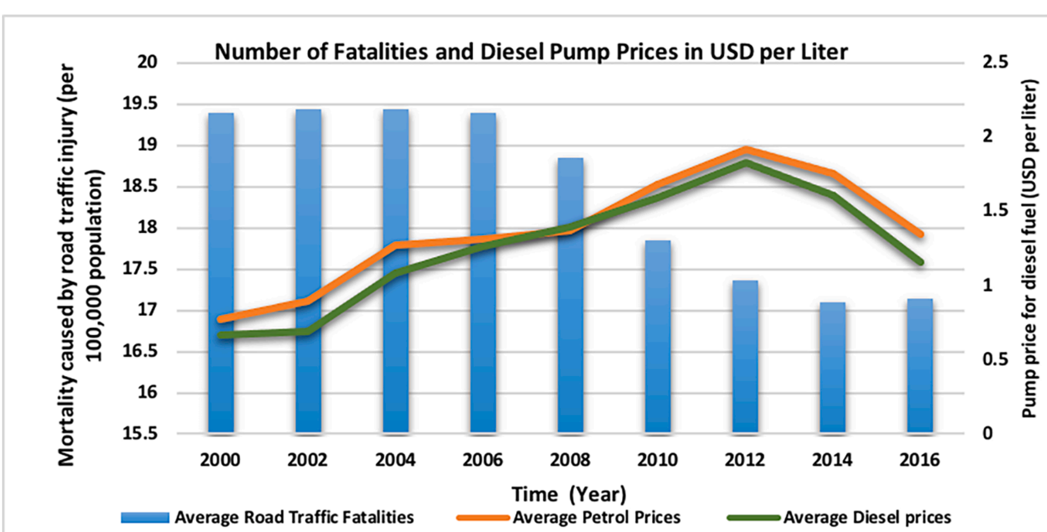

Fig. 1. Number of Fatalities (per hundred thousand) in OECD Member States and OECD Average Diesel Pump Prices in USD per litre (World Health Organization, 2022).

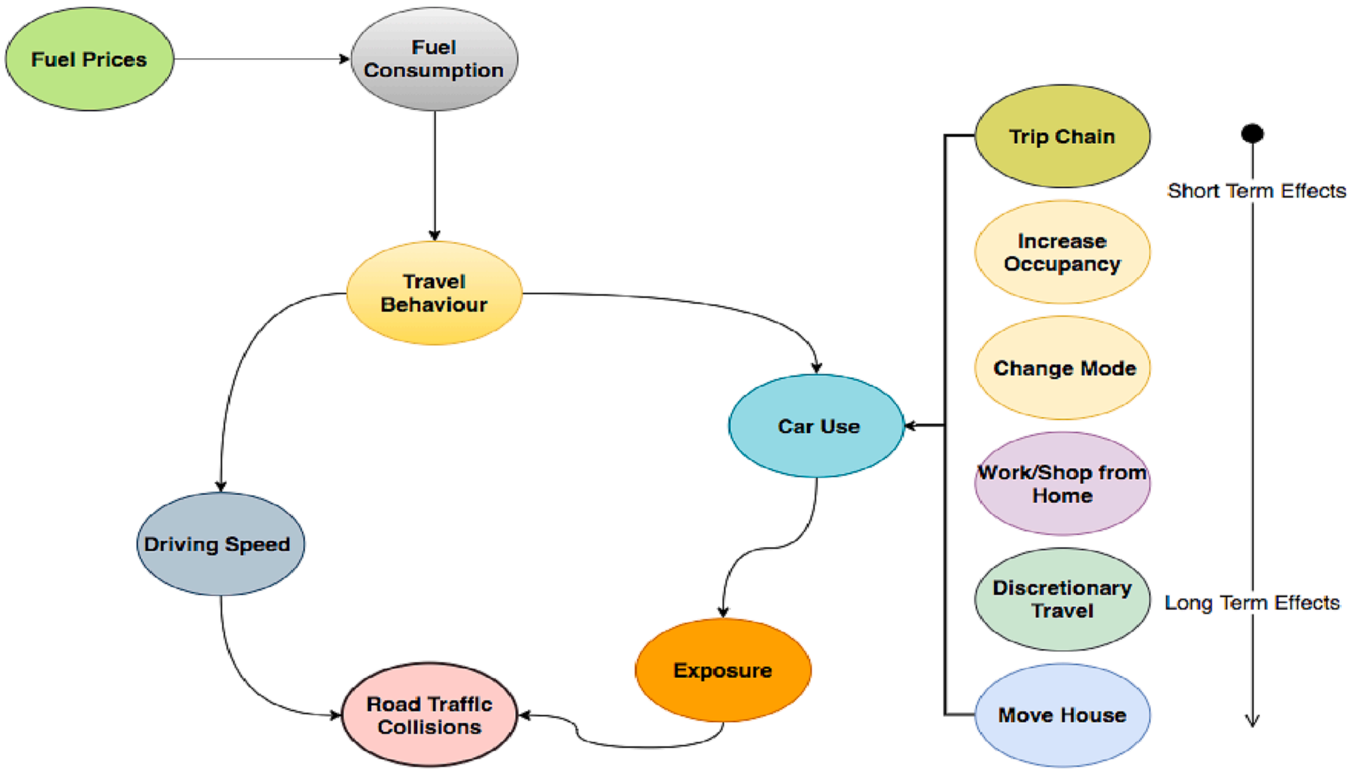

Fig. 2. Conceptualising the effect of fuel prices on road traffic collisions.

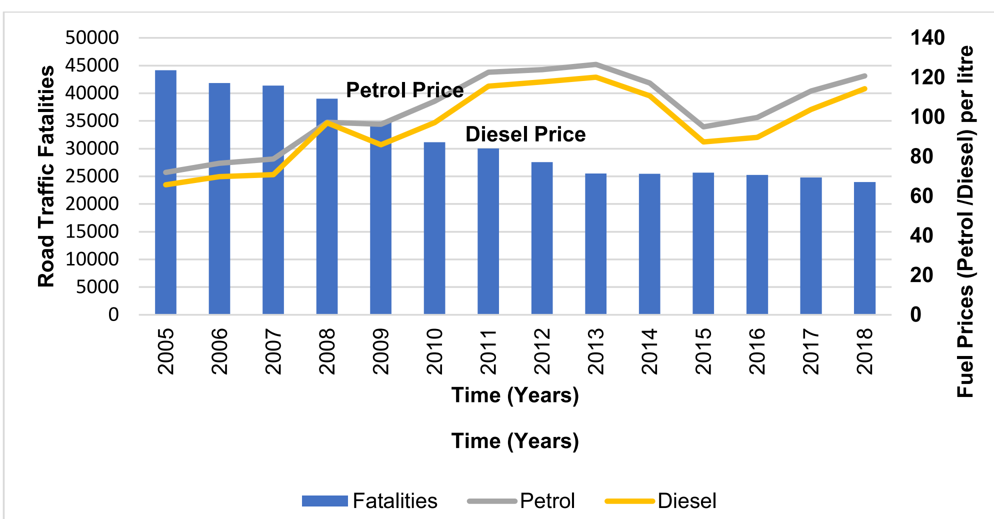

Fig. 3. Road traffic fatalities and average annual fuel price for the 28 EU member states (2005–2018).

budgets compared to senior drivers (Chi et al., 2010, 2012). And, as this group of young drivers is amongst the most vulnerable and high-risk group of drivers, controlling their number could negatively influence the overall number of road traffic collisions. Another causal link in the chain of fuel price and road traffic collision is through variation in driving speed. The fuel price and speed mechanism is quite complex. For instance, whilst Burger and Kaffine (2009) argue that higher fuel prices will not reduce driving speeds, Wolff (2014) finds the opposite, and states that people will adjust their speed to make fuel efficiency gains. Interestingly, the latter argument is recently supported by a quantitative study carried out in the UK aimed at understanding changes in driver behaviour during and after Covid-19 (Marsden et al., 2021), which found that 44 percent of drivers reported driving slower or more efficiently to save fuel during periods of high fuel prices.

These studies have highlighted several causal paths through which fuel prices could affect road traffic collisions while having a direct impact and have helped develop several links between fuel price and road traffic collisions. However, these studies have mostly been carried out in the USA, a low fuel price region, whilst the relationship between the fuel price and road traffic collisions appears to have been largely ignored in high fuel price regions.

It is hypothesised that higher fuel prices will lead to reduced road traffic collisions through changes in fuel consumption and miles driven. As, there is currently little evidence to support this theory in countries with high fuel taxes. This is particularly critical now that many countries are looking to phase out vehicles powered by petrol and diesel and replace them with cleaner fuelled vehicles to help meet zero emission targets as in the UK and the EU for example (Department for Transport, 2018; Hirst et al., 2020; European Commission, 2020). Whilst positive from an environmental standpoint, the shift from combustion engine vehicles could have a negative impact on road safety should the influence of fuel taxes be removed. Therefore, it is important to evaluate the impact of fuel prices on road traffic collisions to fully understand the impact of this new policy landscape. This study will help policy makers to understand the role of high fuel price on road traffic collisions and its implications.

3. Fuel prices and road traffic collisions in the EU

The adoption of road safety interventions has resulted in reducing road traffic collisions in several developed nations. In the European Union there was a 21 percent reduction in road traffic collisions over a period of 10 years (i.e. from 31,500 in 2008 to 25,100 in 2018) (European Commission, 2018). Road traffic collisions across the EU exhibit a wide variation in mortality rates. This could probably be due to the wide variety of political, economic, social, technological, legal, and environmental factors in this region. These country specific factors mentioned above also include choosing different policy responses. One such response that has been shown to impact road safety is the use of fuel taxes, whereby road users are normally charged per litre of fuel (petrol/diesel) consumed primarily to reduce transport emissions (Litman, 2014; Santos, 2017). This tax affects road safety through controlling road traffic exposure through variation in travel cost while generating useful revenue for road safety investments.

On average, EU member states generate 6 percent of their total tax revenue from fuel taxes (Santos, 2017; Cooper, 2020). Typically, fuel taxes are of two types: 1) fuel excise duty that is added to the price of fuel before it is sold, and 2) value-added tax (VAT). In the EU, there is a minimum level applied to the total tax on fuel (€ 0.359/litre unleaded petrol fixed on 1st January 2004 by energy tax directive 2003/96/EC); however, beyond that each country has the right to set its own fuel tax rates and currently all member states levy more than the minimum limit (Council of the European Union, 2003). The price of petrol is higher than diesel in all the EU member states except in the UK (Cooper, 2020). The difference in the price of the crude oil across the (pre2-Brexit) 28 EU member states is small as compared to the total pump price mainly due to the variation in the fuel taxes applied. Malta has the highest crude oil prices for both petrol (0.65 €/litre) and diesel (0.61 €/litre) and Slovenia the lowest crude oil prices for both petrol (0.25 €/litre) and diesel (0.32 €/litre) in the EU (Cooper, 2020). In the UK, the higher diesel prices are primarily due to higher diesel crude oil price as the amount of duty is equal for petrol and diesel fuels (Bolton, 2020). Building on this, the EU now has a new interim plan to half the road fatalities and serious injuries between 2021 and 2030 with a final goal to have zero road deaths and serious injuries by 2050 (European Commission, 2018). As fuel prices have been linked to negatively impact road traffic collisions, getting them out of equation in terms of policy changes could impact road safety of the EU member states. Accordingly, this aspect of the study is designed to measure the average fuel price impact on road traffic collisions across the 28 EU member states by analysing monthly data over a 14-year period. The following section provides details of the data used for this purpose.

4. Data

The panel data analysed was for 28 EU member states collected monthly over 14 years from 2005 to 2018 (168 months for each state). This data set has some gaps as some countries joined the EU later than January 2005 like Bulgaria, Romania and Croatia, and therefore some data is missing for those periods for that member states. In addition to this, there are gaps in data due to reporting issues on different occasions and thus the data set is unbalanced. The data for this purpose is collected from different secondary sources (see Table 1).

Road traffic collisions data is the dependent variable in this study. The monthly data for road traffic collisions is available from the United Nations Economic Commission for Europe (UNECE) in three major categories of number of collisions, total collisions, fatal collisions and total casualties, and these were adopted in defining the dependent variables. All three types of collisions are separately recorded and not as ordered or categorical variables. According to the UNECE, fatal collisions are collisions in which one or more persons have been killed immediately or within 30 days of the injury in a collision. The injury collisions involve all the collisions in which a person is injured in a collision between two or more vehicles, between a vehicle and a pedestrian, injury due to collision with a fixed object. However, an injury collision does not involve property damage collisions. One collision is recorded even if one or more vehicles have been involved in an collision (ITS, 2020). The data for fatal collisions is more comparable as compared to total collision and total causalities data among all the member states due to reporting variability across the countries.

The main independent variable is monthly fuel price (petrol and diesel) data for each member state over 14 years. Monthly fuel price data in (GBP) pounds for all the European countries is collected from the UK Department for Business, Energy and Industrial Strategy website (BEIS). Petrol and diesel prices (both with and without tax) were collected, as was the price of crude oil. Although petrol is the most popular fuel used in the cars in the EU region both types of fuel data were collected to see the differential effect of these two fuel types.

Gross domestic product per capita (GDP per capita), unemployment rate, population, total vehicle miles travelled, freight vehicle miles travelled, newly registered vehicles, newly registered cars, crude oil consumption and petrol consumption were also included as control variables. One limitation in this EU data set was the lack of available VMT data for 15 of the 28 EU member states. Additionally, there were big gaps in the freight VMT data. One consequence of this was that both total VMT and freight VMT (as well as one other control variable 'population') ended up being excluded during the preliminary analysis due to low significance and/or to avoid multicollinearity issues. As the data is cross sectional time series data, a time variable name trend has been introduced in the data set to avoid the issues related to serial correlation. Table 2 shows descriptive statistics of only variables used in the final models.

5. Methods

The purpose of this study was to measure the impact of fuel price fluctuation in the European member states on their number of road traffic collisions. The data for this study has some important characteristics, e.g. it is a count panel data which has number of panel $N = 28$ and number of time periods $T = 168$ per panel. Depending on the unique characteristics of the data, appropriate modelling approaches were investigated and developed in this study.

Traffic collisions over an entity for a time period are count data which is random, non-negative and may be sporadic. Collision count data has been widely recognised to follow a Poisson distribution and therefore, several studies have adopted Poisson models (and extensions) to analyse such data. In this study, the initial step was to consider extending the generalised linear models (GLM) for panel data, the first with the fixed effect and then with the random effect Poisson models. The results of the Hausman test suggested use of random effect models over fixed effect models and thus only Poisson random effect models were considered. However, Poisson models have an important assumption 'equidispersion' whereby the mean of the dependent variable (i.e. the count of traffic collisions) is equal to the variance of the same variable. When the data violates the equidispersion assumption, which was the case here, then the first step was to apply negative binomial models instead. Different types of negative binomial models have been extensively used in the safety analysis research (Noland and

Table 1
Data collected for the 28 EU member states.

Data Type	Variable	Description	Available Frequency	Source
Road & Traffic	Road traffic collisions and causalities (Dependent)	Total collisions, fatal collision and total causalities	Monthly	UNECE (2020)
	Total vehicle miles travelled (TVMT)	Total VMT of all the vehicles in a country in tonnes -kilometres-millions	Quarterly/ Monthly	OECD (2020)
	Freight vehicle miles travelled (FVMT)	Freight VMT of all the vehicles in a country in Tonnes-kilometres-millions	Quarterly/ Monthly	OECD (2020)
	Road length	Total motorway lengths in miles for each country	Annual	Eurostat (2020)
Socio-economic Variables	Unemployment rate	Rate of unemployment	Monthly	Eurostat (2020)
	GDP	Gross domestic product per capita	Quarterly	Eurostat (2020)
	Population	Population of 16 plus in thousands	Quarterly	Eurostat (2020)
	Fuel price	Pump prices of petrol and diesel fuels in pence per litre	Monthly	BEIS (2020)
	Tax on petrol	Tax on petrol in pence per litre	Monthly	BEIS (2020)
	Tax on diesel	Tax on diesel in pence per litre	Monthly	BEIS (2020)
	Crude oil price	Crude price of petrol/diesel at pump in pence per litre	Monthly	BEIS (2020)
	Petrol consumption	Petrol per thousand tonnes	Monthly	Eurostat (2020)
	Crude oil consumption	Crude oil per thousand tonnes	Monthly	Eurostat (2020)
	Newly registered vehicles	Number of new vehicles registered	Quarterly/ Monthly	(OECD, 2020)
	Newly registered cars	Number of new cars registered	Quarterly/ Monthly	(OECD, 2020)

Table 2
Descriptive statistics of variables selected for analysis.

Variable	Total obs.	Mean	Variance	Std. Dev.	Min.	Max.
Monthly total collisions	4504.00	3558.96	36338544.20	6028.15	24.00	34825.00
Monthly fatal collisions	4512.00	96.86	14491.06	120.38	0.00	659.00
Monthly total casualties	4456.00	4751.36	64372428.24	8023.24	25.00	43847.00
Petrol price	4530.00	103.98	470.36	21.69	47.36	154.80
Diesel price	4530.00	96.66	410.34	20.26	48.98	148.04
GDP per capita	4704.00	6389.61	17933234.61	4234.77	640.00	25930.00
Unemployment	4680.00	8.79	19.26	4.39	1.90	29.00
Population	4703.00	18553.50	510808817.17	22601.08	403.00	83033.00
Total VMT	1815.00	7.96	1.04	1.02	6.01	10.36
Freight VMT	4140.00	7.66	3.80	1.95	4.56	11.83
Petrol consumption	3633.00	248.96	135550.25	368.17	1.00	1820.00
Crude oil consumption	2156.00	380.85	948818.79	974.07	1.00	5957.00
Motorway length	4008.00	2831.90	16491566.68	4060.98	96.00	15585.00
New registered cars	4032.00	48352.22	5894263966.29	76774.11	123.00	556784.00

Quddus, 2004; Noland and Karlaftis, 2005), and the most popular type used for panel data analysis is random effect negative binomial models (RENB) (Chin and Quddus, 2003; Chi et al., 2013; Mohammadi et al., 2014).

$$Y_{it}\ Poisson(\mu_{it}) \tag{1}$$

$$\mu_{it} = \mu_{it}\delta_i \tag{2}$$

where,

Y_{it} = Observed number of collisions (i = 1,…………, N, t = 1, ……….., T_i).

X_{it} = Vector of independent or predictor variables.

μ_{it} = Expected number of collisions.

δ_i = Random location specific effect parameter

$$\mu_{it} = \mu_{it}\delta_i = exp(X_{it}\beta + \mu_i) \tag{3}$$

$$P(n_{i1}, \cdots\cdots\cdots.., n_{iT}/X_{i1}, \cdots\cdots\cdots.., X_{iT}) \tag{4}$$

where β' is the coefficient of vector to be estimated, μ_i= random effect across location and exp (μ_i) is gamma distributed with mean '1' and variance 'k', where 'k' is the over-dispersed parameter in the NB model. The number of road traffic collisions for a country 'i' at a time 't' is written as 'n_{it}' with an assumption of independent and identically distributed (i.i.d) with NB parameters $\delta_i\mu_{it}$ and ϕ_i, where $\mu_{it} = \exp(X_{it}\beta)$. Hence n_{it} with mean $(\delta_i\mu_{it}/\phi_i)$ and variance $((\delta_i\mu_{it}/\phi_i)/z$, where $z = \left(1+\left(\frac{\delta_i}{\phi_i}\right)\right)^{-1}$. To account for the location variation z is assumed to be a beta distributed random variable with distributional parameters (a, b) to take into account the variation in location over time. The probability density function of the RENB model for the i[th] country can be written using Hausman et al. (1984) as:

$$(n_{i1}, \cdots\cdots\cdots.., n_{iT}/X_i, \cdots\cdots\cdots.., X_{iT}) = \frac{\sqrt{a+b}\sqrt{a+\sum_T n_{it}}\sqrt{b+\sum_T n_{it}}}{\sqrt{a}\sqrt{b}\sqrt{a+b+\sum_T n_{it}}}\prod\frac{\sqrt{\mu_{it}+n_{it}}}{\sqrt{\mu_{it}+\mu_{it+1}}} \tag{5}$$

The random effect is added to the random effect NB model, assuming that the overdispersion is distributed across the countries. These negative binomial models have the capability to deal with the heterogeneity and distributional properties of the count data, but because long panel data is more likely to have serial correlation among different time points, as was the case in this panel study. Therefore, a time trend variable was introduced to account for this and hence make the RENB model more robust.

One further class of model used with count panel data are so-called generalised estimating equations (GEE). These models were first introduced by Liang and Zeger (1986) and usually constitute a class of negative binomial population averaged models for which the marginal effects are calculated (Hilbe, 2011). These marginal effects unlike RENB are averaged over all the entities (countries).

$$Var(Y_i) = \phi v(\mu_i) \tag{6}$$

where, the variance function of a GEE model is: ((Hilbe, 2011), p- 451)

$$V(\mu_{ik}) = \left[(D(\mu_{ik}))^{\frac{1}{2}} R_{(a)_{n_{i\times}n_i}} (D(\mu_{ik}))^{\frac{1}{2}}\right] n_{i\times} n_i \tag{7}$$

where,

$V(\mu_{ik})$ = Variance function and for a Poisson model $= \mu_i$

And for negative binomial model $= \mu_i + \alpha.\mu_i^2$

$R_{(a)_{n_{i\times}n_i}}$ = Correlation matrix which in case of GLM = In × n.

These negative binomial population averaged (NBPA/NBGEE) models have the capability to use different correlation structures e.g. identity, unstructured, exchangeable, autoregressive and stationary/non-stationary, and are estimated using generalised estimating equations with autoregressive (AR) structures. These NBGEE models are extended from GLMs by replacing the identity matrix with a correlation matrix. This extension made GEE able to accommodate different types of correlation matrices present in various kinds of data sets. The variance function in a GLM (equation (6)) relates the response variance to the response mean through a dispersion parameter 'ϕ'.

5.1. Model goodness of fit

In this panel study, data was analysed using two different types of methods and therefore to select the best model separate goodness of fit measures were employed. As RENB is a likelihood-based method, two likelihood-based goodness of fit measures were used to find the best model. The first was the Akaike information criteria (AIC) and Bayesian information criteria (BIC) comparison for different models where the one with the lowest value would be the best model. The second measure was the loglikelihood index (Chin and Quddus, 2003; Noland and Quddus, 2004).

$$\rho^2 = 1 - l(\beta)/l(0) \tag{8}$$

$$\rho^{-2} = 1 - [l(\beta) - m]/l(0) \tag{9}$$

here $\boldsymbol{l(\beta)}$ means the loglikelihood of full model and $\boldsymbol{l}(0)$ of the null or intercept model and 'm' represents number of parameters in the model. Both indexes should have relative values, and values should range from '0' to '1'.

Population averaged or GEE models are also called marginal models. Zheng suggested the use of Marginal R^2 goodness of fit as an extension of the GLM (Zheng, 2000). The marginal R^2 can be calculated using equation (10).

$$R^2_{marginal} = 1 - \frac{\sum_{t=1}^{T}\sum_{i=1}^{T}(Y_{it} - \widehat{Y_{it}})^2}{\sum_{t=1}^{T}\sum_{i=1}^{T}(Y_{it} - \overline{Y_{it}})^2} \tag{10}$$

The value of R^2_{marginal} indicates model explanatory power like R^2 for linear models. The higher the R^2_{marginal} value means better the model and the range lies between 0 and 1.

6. Findings

Two different modelling approaches namely random effect RENB and negative binomial GEE (NBGEE) models were developed and used for analysing this panel count data. Three different models for each modelling approach were developed for each collision type – total collisions, fatal collisions and total casualties. Due to the high correlation among the diesel and petrol prices, both variables could not be used in the same collision model and so each collision model was subdivided into petrol and diesel models. This resulted in 12 models overall. However, the random effect negative binomial model only worked well for the fatal collisions model, and so the results from only eight models are reported.

The first step in model evaluation was to check the significance of the model parameters. A number of models qualified based on the model parameter significance. To select the best model from this set of competing models, different goodness of fit criteria explained in the previous section were used to select the final models for all collision type. Both the random effect model (RENB) and NBGEE models use different methodological approaches to calculate variable parameters (Hilbe, 2014). As random effect models produce significant results for only fatal models with reasonable goodness of fit statistics, therefore only fatal models from both methodological approaches were compared. The results show that in all four models the fuel price has found to be statistically significant in reducing fatal collisions.

Some differences are observed from the comparison of both models. For example, the variable GDP per capita and unemployment have slightly higher coefficient values in the RENB model than the NBGEE models. After comparing the t-values estimated by these models, it is observed that the RENB models produced generally higher t-values than the NBGEE models. This could have inflated the significance levels of some variables in the RENB models leading to misinterpretation of these variables. Also, the standard errors in the NBGEE are higher compared to RENB models, which suggest the robustness of the NBGEE models. This concurs with the previous studies where the same conclusion regarding standard error was achieved (Hardin and Hilbe, 2002; Memon, 2012).

To choose the best method from RENB and NBGEE, four other model validation measures called mean absolute value (MAD), mean square error (MSE), root mean square error (RMSE), mean absolute percentage error (MAPE) are calculated. The best models should be selected based on the lowest values of these above measures. From Table 3 it can be seen that both NBGEE models for petrol and diesel has the lowest values for all four measures mentioned above, and thus NBGEE models are adopted as the best fatal models for both petrol and diesel fuels out of all the models compared. The RENB model developed for other total collisions and total casualties do not produce reliable results in any variable combinations and thus dropped for further analysis. Thus, NBGEE models are adopted as the final econometric model for analysing all other collisions models (see Table 4).

The findings align with the observed trends in the data with a negative sign in all the models indicating an inverse relationship between fuel price and road traffic collisions and causalities. The results from the NBGEE model show that *a 10 percent increase in the petrol price will reduce fatal collisions by 2.6 percent, total collisions by 1.4 percent and total casualties by almost 1.6 percent in the EU* for the petrol model. Similarly, *10 percent increase in diesel models will have a corresponding reduction of 2.2 percent in fatalities, 1.1 percent in total collisions and 1.4 percent in total casualties*. The petrol and diesel models for this study tend to produce similar results for collisions elasticity values with slightly higher values for petrol models. This could be due to more petrol car and higher average petrol price compared to diesel in the EU. The overall results that fuel prices are negatively related to road traffic collisions confirm previous literature findings on this topic in different countries (Chi et al., 2012, 2013; Naqvi et al., 2020). Fuel prices seemed to have more effect on reducing fatal collisions than other types of collisions which is contrary to previous related US studies and similar to the recent UK study (Chi et al., 2013; Naqvi et al., 2020).

Other important variables used in the study are unemployment and GDP of the country. The effect of GDP is found positive and significant on all types of road traffic collision. This is contrary to the previous

Table 3
Results from fatal collision models using RENB and NBGEE.

Dependent Variable = Fatal Collisions	Petrol Fatal Collision Model			
	RENB (FRP)		NBGEE (FGP)	
	Coefficient	t-stat	Coefficient	t-stat
Ln(petrol pump price)	−0.172	−6.370	−0.259	−5.460
Ln(unemployment rate)	−0.182	−11.790	−0.158	−3.520
Ln(GDP per capita)	0.389	11.640	0.356	2.460
Trend	−0.005	−40.550	−0.004	−11.200
Constant	1.644	5.550	2.368	1.740
Mean Absolute Value = MAD	80.980		20.933	
Mean Square Error = MSE	18222.188		2445.845	
Root Mean Square Error = RMSE	134.990		49.455	
Mean Absolute percentage Error = MAPE	297.144		30.203	
R^2 marginal	–		0.611	
Dependent Variable = Fatal Collisions	**Diesel Fatal Collision Model**			
	RENB (FRD)		**NBGEE (FGD)**	
	Coefficient	**t-stat**	**Coefficient**	**t-stat**
Ln(diesel pump price)	−0.154	−6.440	−0.220	−6.180
Ln(unemployment rate)	−0.191	−12.810	−0.174	−3.800
Ln(GDP per capita)	0.385	11.530	0.367	2.440
Trend	−0.005	−41.370	−0.004	−11.100
Constant	1.602	5.410	2.115	1.550
Mean Absolute Value = MAD	80.981		20.940	
Mean Square Error = MSE	18217.360		2451.324	
Root Mean Square Error = RMSE	134.972		49.511	
Mean Absolute percentage Error = MAPE	298.004		30.192	
R^2 marginal	–		0.611	

finding that favours the negative relationship between GDP and road traffic mortality in the EU (Yannis et al., 2014). On the other hand, these finding from this study concurs with few previous studies, particularly related to higher GDP could cause higher number of road traffic injury collisions (Bishai et al., 2006; Suphanchaimat et al., 2019). Higher prosperity levels could encourage more cars and the number of trips. Increasing traffic exposure and congestion could result in an increased number of road traffic collisions and injuries. One explanation could be that higher GDP could encourage more investment in road safety and health care and technologies. As a result, road traffic volume could increase which could increase congestion on roads. Higher congestion had been linked with increased total collisions and causalities but could reduce fatal collisions due to lower traffic speeds (Chao, 2010).

In this study, unemployment rate was found to have a significant and negative relationship with road traffic collisions. Thus increase in the unemployment rate will reduce all types of road traffic collisions. Increase in unemployment rate could cause reduction in traffic exposure as more people will travel less, and might change their travel times and/or their mode of travel as well. The findings agrees with the previous studies related to higher unemployment and increased road traffic safety (Scuffham, 2003).

7. Policy implications and Recommendations:

This research has provided evidence that fuel price policy has played an important part in reducing road traffic collisions externalities. Changes in this fiscal policy to achieve environmental goals of reaching net-zero transport emission targets of 2050, could have several short term and long term implications for road safety as depicted in Fig. 4. The new all electric fleet of vehicles with very low fuel prices will reduce the overall driving cost encouraging car use. In addition to financial aspect, people would drive more miles without feeling guilty about the environmental impact of driving. However, more cars will increase traffic exposure, more congestion and thus road traffic collisions. In the long run, to reduce congestion problem, one solution could be to introduce a countrywide mileage based tax in all the EU member states (Raccuja, 2017).

One major dilemma for policy makers in future that this paper helps to reveal, is that any transition from petrol and diesel to 'greener' fuels where the cost of driving is not maintained at current levels risks increasing the number and severity of road traffic collisions in two ways. First, by encouraging more people to driver further, thus increasing overall VMT and exposure levels. Second, by encouraging people to drive faster than they otherwise would. Yet replacing already unpopular taxes on driving with a new form of road user tax that might maintain some degree of control on driver speeds, particularly during a cost of living crisis in many parts of the world may politically be a step too far. Instead, Governments may need to focus much more on more on the widespread speed reduction measures such as more speed cameras and higher penalty charges like speeding tickets and fines, average speed checks, traffic calming measures (speed humps and narrowing streets, speed signs, 20mph speed limits where possible). In addition to this, educational campaigns targeted at speed reduction by focusing on consequences of higher speed in terms of higher fuel consumption/costs and most importantly higher chances of fatalities, etc., could help reduce road traffic fatalities.

During high fuel prices, people can switch towards more sustainable and safer travel modes like buses and cars. Recent surge in fuel prices due to Russian and Ukraine war has pushed several car users to public transport, and other sustainable transport modes like cycling etc. (The Guardian, 2022; World Economic Forum, 2022). Similarly, low fuel prices and reduced driving costs could increase car use and reduce public transport demand consequently negatively impacting road safety. In addition to this, loss of revenue from the fuel tax could also have a negative impact through reduced road safety investments, e.g. public transport provisions and fare subsidies (currently one third of fuel tax revenue is invested in road safety project).

In the long run, during periods of low fuel prices, people may prefer living away from work, thus increasing urban sprawl and related traffic problems which could also affect car use patterns and public transport use. As the literature on fuel price and car ownership reflects that fuel efficiency is an important characteristic in car choice. Due to high fuel

Table 4
Results of final selected models for fatal collisions, total collisions and total casualties model using negative binomial generalised estimating equations (NBGEE).

Dependent Variable = ln (monthly collisions)	Fatal Collisions Models				Total Collisions Models				Total Casualties Models			
	Petrol model		Diesel Model		Petrol model		Diesel Model			Petrol model	Diesel Model	
	Coef.	t-stat	Coef.	t-stat	Coef.	t-stat	Coef.	t-stat	Coef.	t-stat	Coef.	t-stat
Ln(fuel pump price)	−0.259	−5.460	−0.220	−6.180	−0.138	−3.660	−0.115	−3.280	−0.162	−4.160	−0.138	−3.800
Ln(unemployment rate)	−0.158	−3.520	−0.174	−3.800	−0.067	−2.750	−0.076	−3.160	−0.060	−2.600	−0.071	−3.090
Ln(GDP per capita)	0.356	2.460	0.367	2.440	0.425	6.710	0.431	6.700	0.457	6.650	0.465	6.650
Trend	−0.004	−11.200	−0.004	−11.100	−0.002	−4.670	−0.002	−4.860	−0.002	−5.450	−0.003	−5.620
Constant	2.368	1.740	2.115	1.550	5.117	9.360	4.969	8.810	5.192	9.010	5.023	8.440
R^2marginal	0.611		0.611		0.553		0.553		0.660		0.661	

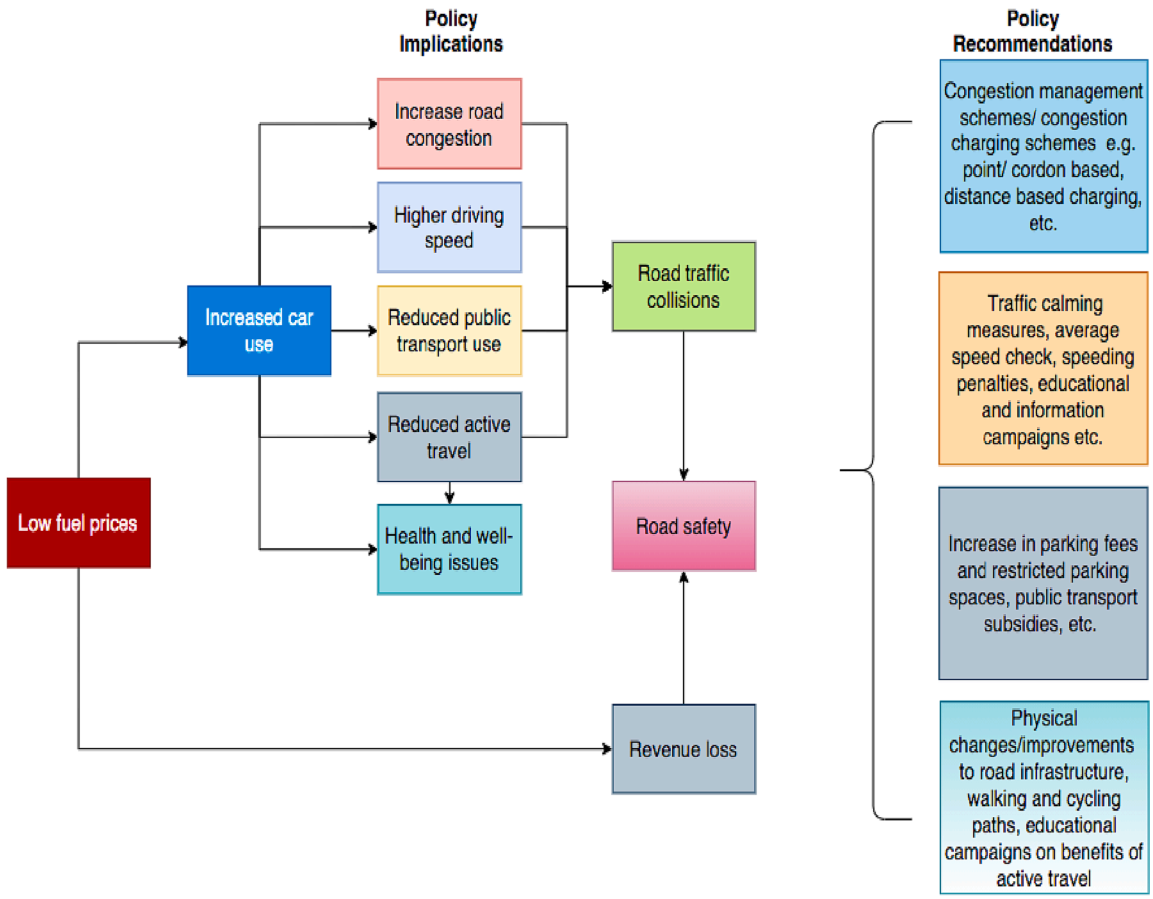

Fig. 4. Implications of changes in fuel price policy and future recommendations.

prices, people living in the high fuel price region tend to buy smaller cars to keep the fuel costs down. According to Jeihani and Sibdari (2010), a 10 percent increase in fuel prices could reduce the demand for SUVs to 13.5 percent. However, due to the low fuel cost of electric cars with more options of electric SUVs available in the future, drivers can switch smaller cars to bigger electric vehicles. As bigger cars are considered safer for car passengers, they could be more hazardous to other road user safety. The chances of getting serious or fatal collisions could increase with the change in the vehicle mix. The policy makers need to take this into account as well and can suggest some solutions like increased VED and other sales taxes on the bigger electric car, etc.

Recent research has linked higher fuel prices with increased car use which could also have negative impact on individual's health. Therefore, targeted campaigns to encourage walking and cycling and its related health benefits in addition to safeguarding our environment could be widely introduced.

Policy makers need to reduce car use by providing more attractive alternate transport modes, e.g. subsidized public transport fares. This needs to be coupled with restricted parking spaces, park and ride facilities, higher parking charges, toll taxes, and congestion charges. In addition to this planning policies to restrict urban sprawl and providing more walking and segregated cycling paths will be required. These measures could lead towards permanent changes in mode choice and may remain more effective in the long run.

8. Discussion and conclusion

Several road safety interventions had been implemented around the globe to reduce road traffic collisions directly and indirectly. This paper is focused on the effectiveness of fuel price policy in reducing road traffic collisions in the 28 EU member states. For this purpose, two separate methodological approaches (RENB AND NBGEE) for monthly panel count data of 28 EU member states had been adopted to analyse fatal collisions, total collisions and total causalities for petrol and diesel fuels separately.

The results of the study have provided evidence of the negative relationship between fuel prices and road traffic collisions. Thus the EU petrol model results suggest that for every 10 percent increase in fuel price, there will be a corresponding decrease of 2.6 percent in fatal collisions, 1.6 percent in total casualties, and 1.4 percent in total collisions. The findings from the diesel model suggest that a 10 percent increase in fuel prices will reduce fatalities by 2.2 percent, total casualties by 1.4 percent and total collisions by 1.2 percent. This general relationship, in the high fuel price regions of the UK and the EU, concurs with the previous findings of (Chi et al., 2011, 2012; Burke and Nishitateno, 2015), providing an overall consensus that higher fuel prices can reduce road traffic collisions. Burke and Nishitateno (2015), in an international study, found that a 10 percent increase in fuel price can reduce road traffic collisions by between 3 percent and 6 percent while some recent American studies (a low fuel price region) generally conclude that a 10 percent increase in fuel price on average reduces the rate of road traffic fatalities by around 2 percent. In conclusion, the results of this present study and previous studies generally agree that higher fuel prices lead to fewer road traffic collisions.

The results from this research study when compared to the previous and recent UK and American studies (Chi et al., 2013; Zhang and Burke, 2021), suggest that high fuel prices have a more pronounced effect on fatality reduction in high fuel price regions (the UK and the EU) than low fuel price regions (USA), as can be seen in Fig. 5. The vertical bars represent the mean fuel prices for all three studied regions. The small circles represent the elasticity values for fatality reduction for every 10 percent increase in fuel price. The average fuel price for the UK and the

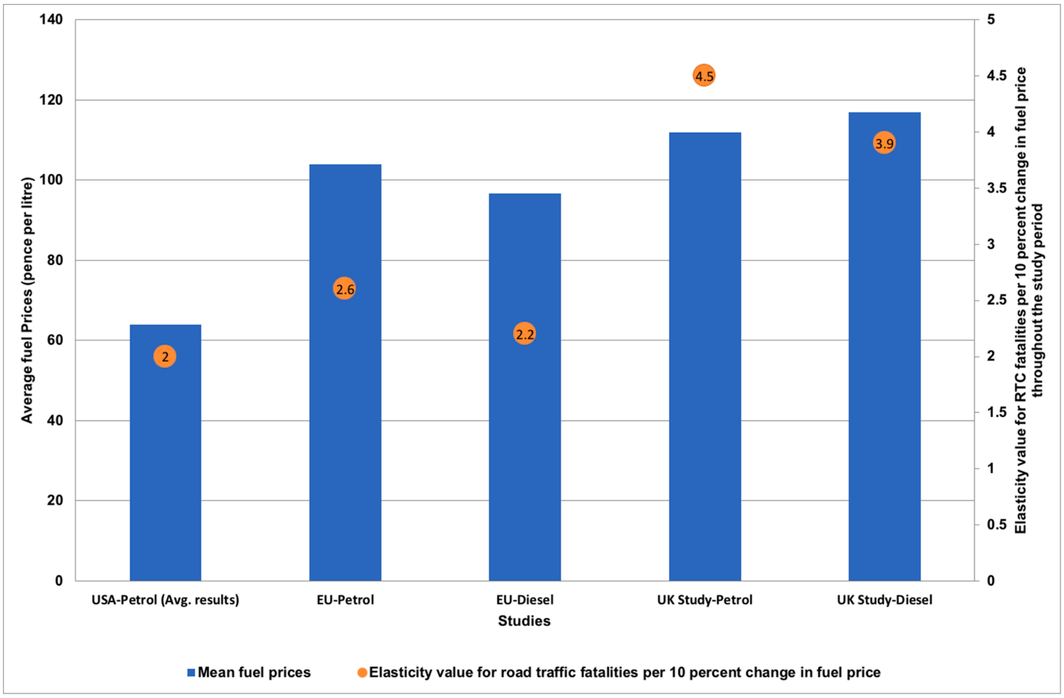

Fig. 5. Average fuel prices and elasticity value for road traffic fatalities per 10 percent change in fuel price throughout the study period: a comparison of low and high fuel price regions.

EU study is pulled from the UK published paper and data collected for this research, while for the American studies the average fuel price of USA for the study duration (1998 to 2018) was calculated manually.[2] The comparison does support the findings of this research that the effect of fuel prices is less significant on reducing road deaths in the low fuel price regions like USA compared to the high fuel price regions like the UK and the EU. Further comparison revealed that there is more fatality reduction in the UK compared to the EU where average fuel prices were higher than the EU.

Thus, this comparison further strengthens the negative relationship of fuel prices and road traffic collisions suggesting that regions with higher fuel price could gain more road safety benefits compared to low fuel price region. The overall evidence of fuel price effectiveness against traffic collisions could provide road safety planners a clear picture of the future road safety implications, guiding them towards a better solution through and after the transition period in the absence of this fiscal measure.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data availability

Data will be made available on request.

References

Bishai, D., et al., 2006. National road casualties and economic development. Health Econ. 15 (1), 65–81. https://doi.org/10.1002/hec.1020.

Bolton, P., 2020. *Petrol and diesel prices, Briefing Paper*. Available at: https://commonslibrary.parliament.uk/research-briefings/sn04712/.

Burger, N.E., Kaffine, D.T., 2009. Gas Prices, Traffic, and Freeway Speeds in Los Angeles. Rev. Econ. Stat. 91 (3), 652–657. https://doi.org/10.1162/rest.91.3.652.

Burke, P.J., Nishitateno, S., 2015. Gasoline prices and road fatalities: international evidence. Econ. Inq. 53 (3), 1437–1450. https://doi.org/10.1111/ecin.12171.

Chao, W., 2010. The Relationship Between Traffic Congestion And Road Accidents: An Econometric Approach Using GIS. Loughborough University, Chao Wang. Available at: https://repository.lboro.ac.uk/account/articles/9455501.

Chen, S., Kuhn, M., Prettner, K., Bloom, D.E., 2019. The global macroeconomic burden of road injuries: estimates and projections for 166 countries. Lancet Planet. Health 3 (9), e390–e398.

Chi, G., et al., 2015. Safer roads owing to higher gasoline prices: How long it takes. Am. J. Public Health 105 (8), 119–125. https://doi.org/10.2105/AJPH.2015.302579.

Chi, G., Boydstun, J., 2017. Are gasoline prices a factor in residential relocation decisions? Preliminary findings from the American housing survey, 1996–2008. J. Plann. Educat. Res. 37 (3), 334–346, 10.1177%2F0739456X16657159.

Chi, G., Cosby, A.G., Quddus, M.A., Gilbert, P.A., Levinson, D., 2010. Gasoline prices and traffic safety in Mississippi. J. Saf. Res. 41 (6), 493–500.

Chi, G.Q., McClure, T.E., Brown, D.B., 2012. Gasoline prices and traffic crashes in Alabama, 1999–2009. Traffic Inj. Prev. 13 (5), 476–484. https://doi.org/10.1080/15389588.2012.670815.

Chi, G., Zhou, X., McClure, T.E., Gilbert, P.A., Cosby, A.G., Zhang, L.i., Robertson, A.A., Levinson, D., 2011. Gasoline prices and their relationship to drunk-driving crashes. Accid. Anal. Prev. 43 (1), 194–203.

Chi, G., Quddus, M.A., Huang, A., Levinson, D., 2013. Gasoline price effects on traffic safety in urban and rural areas: Evidence from Minnesota, 1998–2007. Saf. Sci. 59, 154–162.

Chin, H.C., Quddus, M.A., 2003. Applying the random effect negative binomial model to examine traffic accident occurrence at signalized intersections. Accid. Anal. Prev. 35 (2), 253–259. https://doi.org/10.1016/s0001-4575(02)00003-9.

Cooper, J., 2020. *FuelsEurope Statistical Report 2020*. Available at: https://www.fuelseurope.eu/publications/publications/fuelseurope-statistical-report-2020.

Council of the European Union, 2003. Council Directive 2003/96/EC of 27 October 2003: restructuring the Community framework for the taxation of energy products and electricity. Off. J. Eur. Union L 283, 51–70.

Currie, G., Phung, J., 2007. Transit ridership, auto gas prices, and world events: New drivers of change? Transport. Res. Rec. J. Transport. Res. Board 1992, 3–10. https://doi.org/10.3141/1992-01.

Delsaut, M., 2014. The Effect of Fuel Price on Demands for Road and Rail Travel: An Application to the French Case. Transportation Research Procedia 1 (1), 177–187. https://doi.org/10.1016/j.trpro.2014.07.018.

Department for Business Energy and Industrial Weekly road fuel prices, 2018. Available at: https://www.gov.uk/government/statistical-data-sets/oil-and-petroleum-products-weekly-statistics.

Department for Transport (2018) *The road to zero. Next steps towards cleaner road transport and delivering our industrial strategy.*, *Department of Transport*. Available at: https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/723501/road-to-zero.PDF.

[2] US energy prices https://www.eia.gov.

Department for Transport (2020) 'Reported road casualties in Great Britain: 2019 annual report, DfT, Sep., 2020.', *Reported road casualties Great Britain, annual report: 2019*, (September), p. 36. Available at: https://www.gov.uk/government/.
European Commission (2018) *Road safety: Data show improvements in 2018 but further concrete and swift actions are needed.*
European Commission (2020b) 'Questions and Answers: Sustainable and Smart Mobility Strategy', (December). Available : here.
Goodwin, P., Dargay, J. and Hanly, M. (2004) 'Elasticities of road traffic and fuel consumption with respect to price and income : A review elasticities of road traffic and fuel consumption with respect to price and income : A review', 1647(January). https://doi.org/10.1080/0144164042000181725.
Grabowski, D.C., Morrisey, M.A., 2004. Gasoline Prices and Motor Vehicle Fatalities. J. Policy Anal. Manage. 23 (3), 575–593. https://doi.org/10.1002/pam.20028.
Haire, A., Machemehl, R., 2007. Impact of rising fuel prices on U.S. Transit ridership. Transport. Res. Rec. J. Transport. Res. Board 1992, 11–19. https://doi.org/10.3141/1992-02.
Hardin, J.W., Hilbe, J.M., 2002. Generalized Estimating Equations, Second. Generalized Estimating Equations.
Hilbe, J.M., 2011. Negative Binomial Regression, 2. Cambridge University Press.
Hilbe, J.M., 2014. Modeling Count Data. Cambridge University Press.
Hirst, D. *et al.* (2020) 'Electric Vehicles and Infrastructure Briefing Paper', *House of Commons Library* [Preprint], (March). Available at: http://www.parliament.uk/.
Hyatt, E., Griffin, R., Rue, L.W., McGwin, G., 2009. The association between price of regular-grade gasoline and injury and mortality rates among occupants involved in motorcycle- and automobile-related motor vehicle collisions. Accid. Anal. Prev. 41 (5), 1075–1079.
IISD (2019) *Increasing Taxes on Fossil Fuel Consumption Key numbers*. Available at: https://www.iisd.org.
International Transport Forum (2015) *Why Does Road Safety Improve When Economic Times Are Hard?* Available at: www.internationaltransportforum.org.
ITS (2020) *Glossary for Transport Statistics 2019 5th edition, Glossary for Transport Statistics 2019 5th edition*. https://doi.org/10.1787/505b670b-en.
Jeihani, M., Sibdari, S., 2010. The impact of gas price trends on vehicle type choice. J. Econ. Econ. Educ. Res. 11 (2), 1–11.
Jung, H., Yu, G., Kwon, K.-M., 2016. Investigating the effect of gasoline prices on transit ridership and unobserved heterogeneity. J. Public Transp. 19 (4), 56–74.
Li, H. (2014) *Impacts of Traffic Interventions on Road Safety : An Application of Causal Models 2013*. https://doi.org/10.25560/18068.
Litman, T. (2014) 'Pricing For Traffic Safety How Efficient Transport Pricing Can Reduce Roadway Crash Risk, 2318(2012), pp. 16–22. https://doi.org/10.3141/2318-03.
Marsden, G., Anable, J., Docherty, I., Brown, L., 2021. At a crossroads: Travel adaptations during Covid-19 restrictions and where next?. Centre for Research into Energy Demand Solutions, Oxford. ISBN 978-1-913299-08-8.
Memon, A.-Q. (2012) *Modelling Road Accidents From National Datasets : a Case Study of Great Britain*.
Mohammadi, M.A., Samaranayake, V.A., Bham, G.H., 2014. Crash frequency modeling using negative binomial models: An application of generalized estimating equation to longitudinal data. Anal. Methods Acc. Res. 2, 52–69. https://doi.org/10.1016/j.amar.2014.07.001.
Naqvi, N.K., Quddus, M.A., Enoch, M.P., 2020. Do higher fuel prices help reduce road tra ffi c accidents ?, 105353 Accid. Anal. Prev. 135. https://doi.org/10.1016/j.aap.2019.105353.
Noland, R.B., Karlaftis, M.G., 2005. Sensitivity of crash models to alternative specifications. Transport. Res. Part E: Log. Transport. Rev. 41 (5), 439–458. https://doi.org/10.1016/j.tre.2005.03.002.
Noland, R.B., Quddus, M.A., 2002. 'Improvements in Medical Care and Technology and Reductions in Traffic-related Fatalities in Great Britain'. Available at: https://core.ac.uk/download/pdf/7046254.pdf. https://doi.org/10.1016/S0001-4575(02)00132-X.
Noland, R.B., Quddus, M.A., 2004. Analysis of pedestrian and bicycle casualties with regional panel data. Transp. Res. Rec. 1897, 28–33. https://doi.org/10.3141/1897-04.
Nowak, W.P., Savage, I., 2013. The cross elasticity between gasoline prices and transit use: Evidence from Chicago. Transport Policy 29, 38–45. https://doi.org/10.1016/j.tranpol.2013.03.002.
Organization of Economic Co-operation and Development (OECD) 2020. Available at: https://stats.oecd.org/.
Raccuja, G. (2017) *Miles Better: A distance-based charge to replace Fuel Duty and VED, collected by insurers*.
Safaei, N., et al., 2021. Gasoline prices and their relationship to the number of fatal crashes on U.S. roads. Transport. Eng. 4 (April 2011), 100053. https://doi.org/10.1016/j.treng.2021.100053.
Santos, G., 2017. 'Road fuel taxes in Europe: Do they internalize road transport externalities?'. Transp. Policy 53, 120–134. https://doi.org/10.1016/j.tranpol.2016.09.009.
Scuffham, P.A., 2003. Economic factors and traffic crashes in New Zealand. Appl. Econ. 35 (2), 179–188. https://doi.org/10.1080/0003684022000017566.
Smith, Z., 2000. *The petrol tax debate*. The institue of Fiscal studies, July 2000, ISBN 1-903274-09-5.
Sun, H.O., 2016. *Understanding Public Transit Ridership through Gasoline Demand : Case Study in San Francisco Bay Area*. CA.
Suphanchaimat, R., Sornsrivichai, V., Limwattananon, S., Thammawijaya, P., 2019. Economic development and road traffic injuries and fatalities in Thailand: An application of spatial panel data analysis, 2012–2016. BMC Public Health 19 (1). https://doi.org/10.1186/s12889-019-7809-7.
The Guardian, 2022. 'Sky-high fuel prices push drivers to consider public transport'. Available at: https://www.theguardian.com/business/2008/jul/31/petrol.diesel.publictransport.
The Organisation for Economic Co-operation and Development (OECD), 2021. *Carbon Pricing in Times of COVID-19: Key Findings for the Russian Federation*.
Wang, T., Chen, C., 2014. Impact of fuel price on vehicle miles traveled (VMT): Do the poor respond in the same way as the rich? Transportation 41 (1), 91–105. https://doi.org/10.1007/s11116-013-9478-1.
United Nations Economic Commission for Europe (UNECE) (2020) *United Nations Economic Commission for Europe (UNECE) -Collision Data*. Available at: https://w3.unece.org/PXWeb2015/pxweb/en/STAT/STAT_40-TRTRANS_01-TRACCIDENTS/03_en_TRAccmonth_r.px/.
WHO (2010) *Global Status Report on Road Safety, WHO 2010, Renewable Energy World*. http://ra.ocls.ca/ra/login.aspx?url=http://search.ebscohost.com/login.aspx?direct=true&db=enr&AN=56097888&site=ehost-live.
Wolff, H., 2014. Value of time: Speeding behavior and gasoline prices. J. Environ. Econ. Manag. 67 (1), 71–88. https://doi.org/10.1016/j.jeem.2013.11.002.
World Economic Forum, 2022. *Bus And Bicycle Journeys Rise As UK Petrol Prices Soar*. Available at: https://www.weforum.org/videos/bus-and-bicycle-journeys-rise-as-uk-petrol-prices-soar.
World Health Organization, 2018. *WHO:Global Status Report on Road Safety 2018*. https://doi.org/10.1093/imamci/dnt037.
World Health Organization, 2022. *World Bank Data, Global Health Observatory Data, 2022*. Available at: https://data.worldbank.org/indicator/SH.STA.TRAF.P5.
Yannis, G., Papadimitriou, E., Folla, K., 2014. Effect of GDP changes on road traffic fatalities. Saf. Sci. 63, 42–49. https://doi.org/10.1016/j.ssci.2013.10.017.
Zhang, T., Burke, P.J., 2021. Fuel prices and road deaths: Motorcyclists are different. Accid. Anal. Prev. 162 (September), 106396 https://doi.org/10.1016/j.aap.2021.106396.
Zheng, B., 2000. Summarizing the goodness of fit of generalized linear models for longitudinal data. Stat. Med. 19 (10), 1265–1275. https://doi.org/10.1002/(sici)1097-0258(20000530)19:10%3C1265::aid-sim486%3E3.0.co;2-u.