Influence of road investment and maintenance expenses on injured traffic crashes in European roads

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Abstract

This study analyses the influence of economic resources invested in road infrastructures, both in construction and maintenance, upon injured traffic crashes. Furthermore, a set of control variables related to diverse factors was added: infrastructure, socioeconomics, meteorology and legislation. Consistent with this, a panel data model for the interurban network of twenty European countries was built, thus contributing to the literature with a study covering different countries and taking into account the possible effect of traffic regulation changes and alcohol consumption. As significant results, an inverse relationship with the injured traffic crashes has been obtained for the variables of maintenance expenditure, unemployment rate, per capita income and demerit point system, and a direct relationship for investment in construction and alcohol consumption. All things considered, allocating economic resources to road maintenance may be an effective tool to develop of a more sustainable and safer road transport system.

Keywords: investment in roads; road maintenance expenditure; road safety; traffic safety; sustainable transportation

1. Background

The main problem with road transport is the high number of crashes and their associated victims. Thus, this issue is needed to eliminate as soon as possible in order to achieve a more sustainable transport system. Despite Europe´s comparatively low rate of highway deaths (9.3 per 100,000 inhabitants), according to the World Health Organization (2018), the European Union has reaffirmed its ambitious objective to reduce the number of highway mortalities to zero by the year 2050. Bearing in mind that one of the main factors affecting traffic crashes are road conditions (layout, number of lanes, road surface, signalling, etc.), the achievement of this objective may be compromised if we take into account that the past decade has been marked by economic crises seriously affecting budgeted resources for highways, which directly influences the quality and safety of roads. Indeed, the European Investment Bank affirms that, in 2016, the joint EU budget for infrastructures was still 20% below the levels previous to the economic crisis of 2008-2014 (European Investment Bank, 2018). Meanwhile, the reduction in the number of highway deaths has been slower than anticipated: just 20% from 2010 to 2017, when, according to the *European road safety policy orientations,* a 50% reduction in victims was put forth as the objective for 2020 (European Commission, 2018, 2010). To better contextualize this, a comparison of certain European countries is shown in Table 1. In addition to traffic crashes, this table highlights the simultaneous increase in traffic and the reduction of the general budget allocated to road infrastructure. Even though the 26% reduction in the number of injured traffic crashes between 1998 and 2016 represents a good side of several road safety policies pursued in recent years, there is still room for improvement.

[t]Table 1 near here [/t]

For this reason, it is of vital interest to analyse the factors involved in road crashes, one of the most relevant ones regarding the state of our highway network (layout, capacity, surface, signals, etc.). One indirect means of considering the state of a roadway network in a road safety study is taking into account the economic resources invested in highways (investment in construction and expense in maintenance). Accordingly, in theory, a greater investment in construction, together with a greater expense in maintenance, would help ensure a safer highway network, which would necessarily bear an influence on the frequency of crashes. In the Table 2 showed below, we look at nationwide studies that include some variables related with the economic resources invested in highways, along with others, in their road safety models.

[t]Table 2 near here [/t]

As it can be seen in the references above, the relationship between the economic resources allocated to road construction and maintenance may vary depending on the country under consideration. Thus, a macro study using data from different countries can provide further evidence on the general relationship of the above investment variables upong road safety. In this sense, Antoniou et al. (2016) underlined that the main interest of a macro-panel model, using data from different countries and including economic variables, is the result of more robust estimations than those obtained with data from a single country, enhancing simplicity by obtaining a single model, instead of a model for each country.

At an international level and from a macro panel perspective, below we offer some references covering the international realm to evoke possible variables that might be taken into account.

Kopits and Cropper (2005) analysed the effects of per capital income for a total of 32 countries on mortality rates, including demographic and social variables, plus variables of motorization and the length of the infrastructure. The results did not show a significant influence for per capita income. However, the consumption of alcohol, the improvement of medical services, and a lesser proportion of young drives did have an effect on the mortality rates. Bishai et al. (2006) analysed the relationship between economic development and crashes, using data from 41 countries. These authors found a different relationship depending on the per capita income of the country: an increase in per capita income in low-income countries showed an increase in the crashes rate, whereas countries with a greater per capita income at the onset traced the opposite trend. They also found that greater consumption of fuel and of alcohol were related with greater mortality in wealthy countries. Within Europe, Antoniou et al. (2016) analysed the time series of traffic deaths and the GDP in 30 countries. The authors identified great heterogeneity in the elasticities obtained in the long term for the different countries, finding a significant relationship with positive values in 10 of them. In turn, Calvo-Poyo et al. (2020) carried out a study within the European context of the influence on traffic mortality of the economic resources invested. They included a series of variables to control factors regarding transport, socioeconomic and meteorological. The results obtained indicate a direct relationship for the investment in construction, and an inverse one for the expense in maintenance, both variables being representative only in the year just following the execution of expenditure. In a broader study –both geographically and conceptually speaking– Elvik (2021) used a series of democratic and governability indicators together with other explicative variables (consumption of alcohol and motorization rate) to study their influence upon the traffic fatality rates of 148 countries. The results point to a statistically significant relationship that is inverse to the level of democracy of a country, to the efficiency of government, to the motorization rate and to the consumption of alcohol per capita with respect to road mortality.

To sum up, bearing in mind the scarcity of international studies using macro-panel models to analyse the influence of economic resources invested in roadways upon injured traffic crashes, the present study is intended to fill this important gap. Additionally, the present study takes into account, along with other factors, variables related with alcohol consumption and traffic regulations, not included before in the previous studies, the aim being to find a more reliable and complete explanation for the problem. The aim of the study is to analyse the influence of economic resources invested in roads upon traffic safety. The practical application of the results of this study would provide evidence on how to allocate financial resources to road infrastructure in a more efficient way to tackle a major transport problem: road traffic injuries. Therefore, the results of this research may be quite relevant for policymakers in their decisions on road transport, public health and investment strategies.

2. Methodology

2.1. Empirical approach

In striving to maximize the number of countries as well as the period of study, we opted to formulate a panel model -covering 20 countries and a 19-year time span- to explain the crashes entailing injury that occurred on their respective national roadways. This type of model is widely used in literature on road safety at a macro level (Antoniou et al., 2016; Bishai et al., 2006; Castillo-Manzano et al., 2014; Kopits and Cropper, 2005, 2008; Noland, 2003; Traynor, 2009; van Beeck et al., 2000), yet they have particular aspects that should be taken into account in order to ensure robust estimators. To this end, certain tests were performed in order to check potential issues that could compromise the estimates. As a consequence of the results obtained on these tests –

shown in Table 3– the panel was deemed to afford groupwise heteroscedasticity, first-order autocorrelation and contemporaneous correlation.

[t]Table 3 near here[/t]

Therefore, to resolve these problems and derive a better inference from the linear model estimated from the time series data, a method of panel corrected standard error (PCSE) put forth by Beck and Katz (1995) was used, with a first-order country-specific autocorrelation. The data panel model thus adopted the following form:

$$y_{it} = \beta_0 + \beta_1 X_{1it} + \beta_2 X_{2it} + \ldots + \beta_K X_{Kit} + \mu_{it} \quad (1)$$

where y_{it} represents the dependent variable, with subindexes *i* for each country and *t* for each year. X_{Kit} are the independent variables, β_K are the estimable coefficients, and μ_{it} the error term:

$$\mu_{it} = \rho_i \mu_{it-1} + e_{it} \quad (2)$$

ρ_i being the autocorrelation parameter specific to each country and e_{it} corresponds to the independent and identically distributed errors. The software used to estimate the model is STATA version 12.1, in which a Prais-Winsten regression was applied to estimate the parameters.

With regards to variable selection criteria in traffic crash models, Hakkert and Braimaister (2002) recommend using a ratio according to the level of exposures as the dependent variable. Furthermore, along these lines and in order to establish comparisons across countries, several authors have assessed the suitability of taking diverse risk indicators, given the availability of data for Europe (Farchi et al., 2006; Papadimitriou et al., 2013). Among the indicators recommended to measure exposition, the number of passengers per km is the only one presenting enough data for all the countries and years of study. Therefore, following the recommendations present in the literature, this study adopts a traffic crash ratio as a dependent variable, defined as the number of crashes on inter-urban roads (resulting in at least one injured or killed person) per one billion passengers-km. In this way, it is possible to control in the dependent variable for the factor that contributes most to the occurrence of crashes, exposure (Fridstrøm et al., 1995).

With regard to the independent variables, investment in road construction and expenses in maintenance are considered as the main variables of study, together with another series of control variables included in articles related with the subject of study. Thus, these independent variables pretend to control some of the numerous factors that influence road crashes, which are generally grouped into three categories: attributed to the human factor, related with the vehicle, or tied to the road itself and its setting (Haddon, 1980; Elvik, 2009). Accordingly, one way to consider the conditioning factors of the road in an approximate, overall form, can be through the economic resources invested in the roadway infrastructure.

As for two variables of economic expenditure for highways, in order to work with quantities comparable among countries, they are expressed in the form of units per kms of roadway. This means of evaluating economic resources can be found in previous studies (Aparicio Izquierdo et al., 2013; Calvo-Poyo et al., 2020; Fridstrøm and Ingebrigtsen, 1991; Sánchez-González et al., 2021; Sánchez González et al., 2020, 2018).

Approximately accounting for the characteristics of the roadway infrastructure in each country, the proportion of high-capacity roads is used. The extension of the high-capacity network has been found to have a significant influence on reducing traffic mortality in Europe (Albalate and Bel, 2012), and reducing crashes on national roads (Albalate et al., 2013; Aparicio Izquierdo et al., 2013; Sánchez González et al., 2018).

Continuing with the socioeconomic factors, included in the model are the variables: motorization rate, unemployment rate, per capita income, and consumption of alcohol per capita. The inclusion these socioeconomic variables may serve as a proxy to explain certain mechanisms that are linked to the accident rate outcome, such as: traffic composition, road user behaviour or renewal of car fleet (Wijnen, 2015). The motorization rate has been widely used in the literature as an indicator of the level of prosperity (Albalate, 2008; Albalate et al., 2013; Aparicio Izquierdo et al., 2013; Calvo-Poyo et al., 2020; Castillo-Manzano et al., 2015; Elvik, 2021; Nguyen-Hoang and Yeung, 2014; Sánchez-González et al., 2021; Sánchez González et al., 2020, 2018). The rate of unemployment is used, in turn, to control for economic cycles (Albalate, 2008; Albalate et al., 2013; Antoniou et al., 2016; Calvo-Poyo et al., 2020; Elvik, 2015; Hakim et al., 1991; He, 2016; Nguyen-Hoang and Yeung, 2014; Sánchez-González et al., 2021; Sánchez González et al., 2020, 2018; Wegman et al., 2017). As a means of assessing the level of development of a country, the per capita income is widely used (Bishai et al., 2006; Castillo-Manzano et al., 2015; Elvik, 2015; Nguyen-Hoang and Yeung, 2014; Sánchez González et al., 2020; Yannis et al., 2014). Finally, previous studies have linked the consumption of alcohol, through different indicators, to an increase of road crashes (Albalate, 2008; Bishai et al., 2006; Castillo-Manzano et al., 2017; Elvik, 2021; Fridstrøm and Ingebrigtsen, 1991; Traynor, 2009), for which reason the consumption of alcohol per capita is added for the purpose of controlling this phenomenon. This variable includes the total amount of beer, wine, spirits, and any other spirits that the population older than 15 years intake in a year.

In terms of meteorology, precipitation is the parameter most often considered in the literature, whether by means of annual, monthly or daily data (Aparicio Izquierdo et al., 2013; Bergel-Hayat et al., 2013; Calvo-Poyo et al., 2020; Eisenberg, 2004; Fridstrøm et al., 1995; Fridstrøm and Ingebrigtsen, 1991; Nguyen-Hoang and Yeung, 2014; Sánchez-González et al., 2021; Sánchez González et al., 2020, 2018; Theofilatos and Yannis, 2014). Therefore, in view of the consistent presence of precipitation effects on road safety studies, this variable was included to control for possible meteorological factors that may affect the road environment.

Finally, as a control for legislative factors that pretend to influence the driver behavior, it was deemed best to account for the onset of using a Demerit Point System (DPS). Despite numerous legislative changes affecting road safety during the study period, the introduction of a DPS stands out for both its effectiveness and similarity of purpose in the countries studied. A common characteristic of this type of system is that, once a certain level of points has been reached, the driver´s license is revoked. The effectiveness of this system has been evaluated in a number of studies (Abay, 2018; Albalate, 2008; Castillo-Manzano et al., 2015; Izquierdo et al., 2011; Lee et al., 2018; Zambon et al., 2007). On the other hand, it was not found enough homogeneous information on other legislative changes to adequately include them in the study. The impact of such measures at a macro-panel country level would deserve a specific analysis.

Table 4 sums up the variables selected for inclusion in the model, along with their definition and the main descriptive statistics.

[t]Table 4 near here[/t]

Regarding this series of variables to be used as regressors, no problems of multi-collinearity were detected. To confirm this, both the pair-wise correlations among variables and the Variance Inflation Factor (VIF) were verified. As shown in Table 5, only the variables that represent a one year delay (referring to construction investment or maintenance expense) give coefficients over 0.8, which is very reasonable. At the same time, the overall VIF (5.373) does not surpass a value of 10, the figure generally considered as indicative of this “problem” (Gujarati, 2003).

[t]Table 5 near here[/t]

Meanwhile, to ensure the stationarity of the different time series, we proceeded to check the existence of unitary roots in the panels. For this purpose, and given the existence of contemporaneous correlation, the Breitung test (Breitung and Das, 2005) was applied, which assumes the existence of unitary roots in the null hypothesis and the stationarity of the panel in the alternative hypothesis. The results of the test strongly support the null hypothesis for the variables of proportion of high capacity roads (*lambda: 1.9026, p-value: 0.9715*) and for the motorization rate (*lambda: 1.5233, p-value: 0.9362*), and to a lesser extent, the variable consumption of alcohol was accepted (*lambda: -1.2979, p-value: 0.0972*). In order to achieve the stationarity of these three variables, then, they were differentiated (Greene, 2003), the model thereby accounting for their annual variations.

Finally, to verify the behaviour of the estimations and detect, as far as possible, the presence of *omitted variable bias*, the regression was carried out using the *stepwise* algorithm (Elvik, 2021), in which the independent variables are added one by one.

2.2. Data sources

We gathered data from 1998 up to 2016 on the following countries: Austria, Belgium, Croatia, Czechia, Denmark, Estonia, Finland, France, Germany, Ireland, Italy, Latvia, Lithuania, Luxemburg, Malta, Netherlands, Norway, Poland, Portugal, Slovakia, Slovenia, Spain, Sweden and United Kingdom. Just two of these countries do not belong to the European Union at present: Norway and the UK. We attempted to include the rest of the countries of the EU (Bulgaria, Cyprus, Greece, Hungary and Rumania), but sufficiently disaggregated data were not available either for the number of injured crashes on inter-urban roads, or about the economic resources invested in the road network.

Crash data were obtained from the United Nations Economic Commission for Europe (UNECE), which offer a sufficient level of disaggregation between crashes occurring inside versus outside built-up areas. We also consulted the Road Safety Authority (RSA) of Ireland to complete the data series for that country. Then, owing to a lack of data or breaks in the time series of records, Lithuania, Luxemburg, Malta and Norway were eliminated from the dataset, leaving a total of 20 countries of study.

With reference to the data on economic resources invested in roadways, deserving mention –given its extensive coverage—is the database of the Organisation for Economic Cooperation and Development (OECD), managed by the International Transport Forum (ITF), which collects data on investment in the construction of roads and expenditure on their maintenance, following the definitions of the United Nations System of National Accounts (2008 SNA). Despite some data gaps, overall the time series present consistency from one country to the next. Moreover, to confirm the consistency and complete missing data, we resorted to diverse additional sources, mainly the national Transport Ministries of the respective lands. All the monetary values were converted to constant prices in 2015 using the OECD price index.

Table 6 shows the sources used to gather data about all the variables considered in the study.

[t]Table 6 near here[/t]

3. Results and discussion

Table 7 presents the results of the regressions of the six models developed by means of the *stepwise* algorithm. In this way, in a first model only the main study independent variables were included: investment in construction and expense in maintenance, both for the present year and for one year later, and in the following models the rest of the control variables were successively added, making it possible to note potential changes in the sign or level of significance of the variables. With regard to the country-specific autocorrelation parameters of the model, those corresponding to model (6) are reported in Figure 1, while those of the remaining models can be found in Appendix A.

[t]Table 7 near here[/t]

[f]Figure 1 near here[/f]

In the first place, as mentioned above, **model (1)** includes only the variables corresponding to the economic resources invested in the roadways, as well as the respective one-year lags. Both variables obtained significant results for the one-year lagged alone, and they show different signs: positive for construction, and negative for maintenance. The results of these variables remain quite constant for the rest of the models (2-6). This behaviour for the investment in road construction, with a positive sign, has been previously documented in the literature (Calvo-Poyo et al., 2020; Fridstrøm and Ingebrigtsen, 1991; Sánchez-González et al., 2021; Sánchez González et al., 2020, 2018). According to Fridstrøm and Ingebrigtsen (1991), the unexpected effect of this variable could be related with the fact that, most of the investment in construction was spent in a few high-cost operations (tunnels, bridges, or stretches of mountain roads). Moreover, there exists the possibility of producing the so-called "Peltzman effect" (Peltzman, 1975), by virtue of which drivers would tend to assume a greater risk at the Wheel when they perceive that the factors affecting the roadway are improved. This effect of risk compensation may lead to more crashes in certain road-inherent situations, for example when the driver perceives good pavement condition (Chen et al., 2017), or linked to the confidence deriving from passive security devices of the vehicle, such as the airbag (Winston et al., 2006) or the seat belt (Lv et al., 2015). In the case of newly built or highly improved roads, indirectly as a consequence of better quality, this undesired effect on road safety could be produced.

Expense in maintenance show an inverse relation with the injured traffic crashes rate. This finding is also reported previously in the literature, and reflects the beneficial effect of investment upon road safety in national studies (Albalate et al., 2013; Fridstrøm and Ingebrigtsen, 1991; Nguyen-Hoang and Yeung, 2014; Sánchez-González et al., 2021; Sánchez González et al., 2020, 2018), and international ones (Calvo-Poyo et al., 2020). The result reported here evidences the beneficial influence that road maintenance expenditure has on the main external cost of roadways, namely, on traffic crashes and the associated victims.

Then, in **model (2)**, the mean annual precipitation is added, although in itself it does not give significant results and is strongly rejected. Its inclusion does not make any change in the sign of the previous variables, but it does slightly modify the level of significance of the maintenance expenditure effect with one year of delay. The effects of precipitation on road safety have been shown to be significant in several studies, though most use data with a monthly or daily aggregation (Theofilatos and Yannis, 2014). Furthermore, its effect may differ, depending on the level of aggregation of the data considered, being inverse when monthly precipitation is used, and direct when daily precipitation is taken into account (Eisenberg, 2004). Fridstrøm et al. (1995), in a study of Nordic countries, found a direct relationship between precipitation and number of crashes. Bergel-Hayat et al. (2013) arrived at contradictory results when studying central European countries (France and The Netherlands) as opposed to Mediterranean ones (Greece). Like in the previous article, the incorporation of numerous countries with very diverse climates may be the reason why precipitation is not significant in the present study. Because it does not give significant results in any of the models here, it is discarded.

When it comes to **model (3)**, the annual variation in the proportion of high-capacity roadway and the annual variation of the motorization rate are incorporated. These variables do not prove significant in the models. According to the literature, high-capacity roads might be expected to play a beneficial role in terms of road safety, as a consequence of better design parameters and stricter quality standards (Elvik et al., 2009). Albalate and Bel (2012), in a study within the European context, found that the extension of the network of high capacity roads had a beneficial effect on decreased mortality, but this effect was only seen if those roadways were free. Otherwise, according to their study, an inefficient price system may lead to re-routing, which can make the occurrence of crashes on alternative routes rise, so that crashes in the network as a whole rose. The present study considers countries that may have different systems of financing (high-capacity toll roads, free ones, or both), a mixture that could have had an influence of the non-significant results obtained.

The rate of motorization, according to the literature, can show different behavior depending on the level of development of a country: up to a certain level of economic development, the motorization rate is related with rises in traffic crashes (Page, 2001), but after that point, the trend reverses, and the increased motorization rate is linked to a beneficial effect in terms of road safety (Yannis et al., 2011). In the eight EU countries analysed by Yannis et al. (2011), this change in tendency was seen, in general, for a motorization rate between 150 and 300. In the present study, due to the fact that, for certain periods, countries such as Latvia, Croatia, Slovak Republic, Poland and Estonia would pertain to the former group, while the fact that the series was differentiated to eliminate trend effects may have influenced our yield of non-significant results for this variable.

In turn, **model (4)** takes in the variables unemployment rate and per capita income. These variables do not affect the level of significance of the variables included in the previous model, but the sign changes for motorization rate. Both the unemployment rate and the per capita income obtain significant results with a negative sign, along the lines of previously published results (Albalate et al., 2013; Albalate and Bel, 2012; Aparicio Izquierdo et al., 2013; Calvo-Poyo et al., 2020; Elvik, 2015; Hakim et al., 1991; He, 2016; Sánchez-González et al., 2021; Sánchez González et al., 2020, 2018). According to Elvik (2015), the unemployment rate can be tied to fewer crashes in one of three ways: by reducing traffic (as a consequence of lesser economic activity), by influencing the behavior of users (especially reducing high-risk behavior such as *speeding* or *drinking and driving*), or by having an effect of the composition of the traffic (mainly in terms of lesser participation by high-risk groups such as young drivers). The first of these possibilities can be discarded in the context of our study, as the level of exposure is controlled within the dependent variable. The second effect is difficult to contrast, as user behavior lies beyond the realm of the study; notwithstanding, a later model includes the consumption of alcohol as an approximation to this type of risk. The third effect may indeed be produced in the present study, as the group of greater risk —youth— is also most affected by periods of adverse economics, which entail high unemployment (Dietrich and Möller, 2016). Meanwhile, the inverse relationship between per capita income and the injured traffic crashes rate seen in the model would agree with previous studies at a macro level linking favourable economic conditions to greater traffic safety, and especially to a decrease in mortality (Bishai et al., 2006; Gaygisiz, 2009).

Continuing to add variables, **model (5)** incorporates the annual variation in alcohol consumption and the introduction of a penalty point system, both these variables resulting significant and having opposite signs. A direct relation between alcohol consumption with road crashes is very much present in the bibliography consulted. Accordingly, 25% road mortalities are alcohol-related, despite the fact that just 1.6% of all the kilometres travelled are covered by drivers with over 0.5 g/l of alcohol in blood (European Commission, 2015). This negative effect of alcohol consumption in traffic safety has been observed in previous macro studies as well (Albalate, 2008; Albalate and Bel, 2012; Bishai et al., 2006; Castillo-Manzano et al., 2017; Page, 2001). The introduction of some sort of penalty point system showed itself to bear a beneficial influence on road safety, as reported elsewhere (Abay, 2018; Albalate, 2008; Izquierdo et al., 2011; Lee et al., 2018; Zambon et al., 2007). This beneficial effect derives from a change in driver behavior, which entails better adherence to traffic regulations, as reported by Abay (2018), who noted that, as demerit points accumulate, individuals make a greater effort to drive safely; and depending on the number of demerit points, a reduction of 9% to 34% can be seen for speed-related offenses, meaning improved road safety.

Finally, to obtain a simpler model, the non-significant variables of **model (5)** — proportion of high-capacity roads, and motorization rate— were removed in **model (6)**. Discarding these variables did not condition the level of significance of the rest of the variables included in the previous model, while the estimations maintained very similar values and kept the same sign. Furthermore, the country-specific autocorrelation parameters show high values, ranging from the 0.527 of Latvia to the 0.957 of France. For these reasons, we can state that the exclusion of these variables does not introduce an omitted variable bias.

4. Conclusions

The present study analyses the influence of economic resources invested in road infrastructures upon injured traffic crashes at a European level. To this end, a macro panel data model was created, with twenty countries, and for the period between 1998 and 2016. Due to the fact that the occurrence of road crashes is a complex problem, a set of control variables related to diverse factors was added: infrastructure, socioeconomics, meteorology and legislation.

As for the target variables of the present study —investment in construction and expense in maintenance—, both showed significant effects one year after their execution. This finding is consistent with the bibliography consulted. In particular, and as a practical application of the study results, a beneficial effect in reducing road crashes of the expenditure on road maintenance has been found. Therefore, expending resources in road infrastructure maintenance may be an effective tool for reducing traffic crashes on European roads.

Moreover, four of the control variables gave significant results. Accordingly, the rate of unemployment rate, the per capita income, and the Demerit Point System showed a beneficial influence on reduction of the injured traffic crashes rate. Therefore, and from a practical point of view, the implementation of a demerit point system in several European countries has proven to be a useful evidence-based policy to improve traffic safety. In turn, annual variation in the consumption of alcohol per capita had a direct relationship with the injured traffic crashes rate, showing the harmful repercussion that alcohol consumption might bring to road safety. Hence, policies aimed at reducing alcohol consumption can have a positive impact on decreasing road traffic accidents.

In turn, this study found some limitations regarding the access to data which constrained the scope of the study. Notwithstanding the difficulties of data homogenisation between countries, additional efforts are needed to increase the number of categories into which road investments are classified or the grouping of road crashes information. For instance, the availability of serious injuries data could provide future macro-panel models with more valuable insights into the EU objective of a 50% reduction in serious injuries by 2030.

Finally, some other lines of research can be derived from this study. As more disaggregation of road investment data by type of road (e.g. two-lane highway, motorway) becomes available, future research would be needed to analyse the different effects that may exist depending on the type of road in which the economic resources are invested. Moreover, the unexpected relationship between investment in construction and crashes —which has appeared in this research and in other references consulted— should be studied in more depth. Also, due to the diverse outcomes seen in nationwide studies, considering countries inequalities could lead to a further understanding of the issue. This knowledge would help to allocate economic resources in the most efficient way according to a specific objective.

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6. Disclosure statement

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

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8. Appendix A

Country-specific autocorrelation parameters (ρ_i) for model (1): **Austria:** 0.946 **Belgium**: 0.922 **Croatia**: 0.846 **Czechia**: 0.875 **Denmark**: 0.939 **Estonia**: 0.859 **Finland**: 0.942 **France**: 0.952 **Germany**: 0.852 **Ireland**: 0.922 **Italy**: 0.818 **Latvia**: 0.811 **Netherlands**: 0.914 **Poland**: 0.911 **Portugal**: 0.648 **Slovakia**: 0.790 **Slovenia**: 0.933 **Spain**: 0.879 **Sweden**: 0.918 **United Kingdom**: 0.854

Country-specific autocorrelation parameters (ρ_i) for model (2): **Austria:** 0.951 **Belgium**: 0.922 **Croatia**: 0.716 **Czech Republic**: 0.875 **Denmark**: 0.935 **Estonia**: 0.813 **Finland**: 0.936 **France**: 0.945 **Germany**: 0.826 **Ireland**: 0.928 **Italy**: 0.681 **Latvia**: 0.846 **Netherlands**: 0.914 **Poland**: 0.871 **Portugal**: 0.516 **Slovak Republic**: 0.628 **Slovenia**: 0.819 **Spain**: 0.910 **Sweden**: 0.910 **United Kingdom**: 0.844

Country-specific autocorrelation parameters (ρ_i) for model (3): **Austria:** 0.946 **Belgium**: 0.921 **Croatia**: 0.806 **Czech Republic**: 0.879 **Denmark**: 0.939 **Estonia**: 0.857 **Finland**: 0.943 **France**: 0.952 **Germany**: 0.842 **Ireland**: 0.924 **Italy**: 0.752

Latvia: 0.796 **Netherlands**: 0.912 **Poland**: 0.907 **Portugal**: 0.584 **Slovak Republic**: 0.685 **Slovenia**: 0.928 **Spain**: 0.859 **Sweden**: 0.912 **United Kingdom**: 0.857

Country-specific autocorrelation parameters (ρ_i) for model (4): **Austria:** 0.946 **Belgium**: 0.921 **Croatia**: 0.741 **Czech Republic**: 0.659 **Denmark**: 0.940 **Estonia**: 0.859 **Finland**: 0.945 **France**: 0.955 **Germany**: 0.800 **Ireland**: 0.905 **Italy**: 0.579 **Latvia**: 0.631 **Netherlands**: 0.908 **Poland**: 0.894 **Portugal**: 0.518 **Slovak Republic**: 0.645 **Slovenia**: 0.907 **Spain**: 0.894 **Sweden**: 0.887 **United Kingdom**: 0.790

Country-specific autocorrelation parameters (ρ_i) for model (5): **Austria:** 0.952 **Belgium**: 0.916 **Croatia**: 0.772 **Czech Republic**: 0.313 **Denmark**: 0.922 **Estonia**: 0.895 **Finland**: 0.944 **France**: 0.955 **Germany**: 0.843 **Ireland**: 0.783 **Italy**: 0.295 **Latvia**: 0.362 **Netherlands**: 0.867 **Poland**: 0.885 **Portugal**: 0.571 **Slovak Republic**: 0.783 **Slovenia**: 0.927 **Spain**: 0.875 **Sweden**: 0.922 **United Kingdom**: 0.650

Country-specific autocorrelation parameters (ρ_i) for model (6): **Austria:** 0.953 **Belgium:** 0.918 **Croatia:** 0.864 **Czechia:** 0.564 **Denmark:** 0.923 **Estonia:** 0.901 **Finland:** 0.945 **France:** 0.957 **Germany:** 0.891 **Ireland:** 0.805 **Italy:** 0.568 **Latvia:** 0.527 **Netherlands:** 0.874 **Poland:** 0.896 **Portugal:** 0.741 **Slovakia:** 0.892 **Slovenia:** 0.929 **Spain:** 0.899 **Sweden:** 0.924 **United Kingdom:** 0.619

	YEAR 1998			YEAR 2016		
Country	Traffic (Billions of passenger-km)	Road investment (% of the GDP)	Crashes (number on interurban roads)	Traffic (Billions of passenger-km)	Road investment (% of the GDP)	Crashes (number on interurban roads)
Austria	64.86	0.47%	15,733	80.44	0.32%	13,540
Belgium	100.15	0.08%	31,272	106.14	0.31%	24,972
Croatia	17.50	1.79%	2,030	26.18	0.93%	1,791
Czechia	59.73	0.88%	9,735	72.26	0.92%	8,382
Denmark	50.33	0.57%	3,101	59.09	0.72%	1,181
Estonia	6.19	0.79%	785	12.84	0.89%	557
Finland	53.30	0.79%	2,967	57.01	0.79%	2,309
France	672.21	0.76%	41,402	742.50	0.52%	20,291
Germany	828.07	0.24%	137,049	946.80	0.30%	96,459
Ireland	35.76	0.74%	3,500	55.03	0.26%	2,195
Italy	662.55	1.02%	62,352	704.54	0.21%	56,517
Latvia	10.00	0.69%	1,443	13.90	1.46%	1,251
Netherlands	137.10	0.45%	13,681	140.80	0.30%	5,208
Poland	141.10	0.25%	17,576	203.78	0.82%	9,795
Portugal	64.00	1.61%	16,216	90.46	0.31%	7,214
Slovakia	19.30	1.26%	3,261	27.84	1.20%	2,088
Slovenia	18.98	1.72%	2,721	26.48	0.59%	2,237
Spain	276.17	0.76%	44,388	329.88	0.32%	36,721
Sweden	88.81	0.71%	6,635	114.50	0.69%	7,008
United Kingdom	635.68	0.57%	65,254	667.53	0.46%	54,378
Total	**3,941.77**	**0.81%**	**481,101**	**4,478.00**	**0.62%**	**354,094**

Table 1. Comparison of traffic, road investment and crashes between 1998 and 2016. Source: DG Move, OECD-ITF, Eurostat, UNECE and national transport ministries

Reference	Country	Years	Methodology	Dependent variable	Road infrastructure investment variables (*Sign of relationship in parenthesis)*		Other independent variables
Fridstrøm and Ingebrigtsen (1991)	Norway	1974-1986	GLM: Poisson panel data	Injured traffic crashes, fatal crashes, road users injured, road users killed, car occupants injured, pedestrian and bicyclist injured	Relative increase in road capital per km (+/-)	Maintenance expenditure per km (-)	Gasoline sales, kms driven in scheduled transport, snowfall, rainfall, daylight, length of road network, accident reporting routines, vehicle technical controls, convictions, registered vehicles, novice drivers, seat belt usage, alcohol sales
Aparicio et al. (2013)	Spain	1999-2004	DRAG method, based on Box-Cox transformation	Accidents with injured, fatal accidents		Maintenance expenditure per km (+/-)	Vehicle kilometres, proportion of heavy vehicles, proportion of motorways, foggy days, snowy days, precipitation, temperature, percentage of learner drivers, unemployment, non-working days, old vehicles, vehicles with ABS, random alcohol checks, driving licence suspensions, traffic regulations reform act, alcohol reduction act
Albalate et al. (2013)	Spain	1990-2010	GLM: Negative binomial panel data	Fatalities, all casualties	Investment in construction per inhabitants (·)	Maintenance expenditure per inhabitants (-)	Proportion of motorways, proportion of roads by width, motorization, unemployment rate, old people, medical doctors per capita, general traffic rules, vehicle renewal, European program 97, European program 03, traffic law reform
Nguyen-Hoang and Yeung (2014)	USA	1980-2010	GLM: Negative binomial panel data	Fatalities	Capital stock per capita (-), total highway expenditures per capita (-)		Vehicle miles travelled, lane mileage, licensed drivers per capita, ratio of heavy vehicles, motorization rate, seat belt law, speed limit in rural/urban areas, child restraint law, minimum age to purchase beer, gas price, precipitation,

							temperature, GPD per capita, unemployment rate, population density
Sánchez et al. (2018)	Spain	1999-2015	LM: Panel corrected standard errors with autoregressive structure	Fatalities/Serious injuries/Slight injuries per vehicle-kilometre	Investment in construction per kilometre (+)	Investment in replacement per km (-)	DPS, traffic volume, motorization rate, annual variation in population density, unemployment rate, precipitation, proportion of motorways
Sánchez et al. (2020)	Spain	1999-2020	LM: Panel corrected standard errors with autoregressive structure	Fatalities/Serious injuries/Slight injuries per vehicle-kilometre	Investment in construction per kilometre (+/-)	Investment in replacement per km (+/-)	GPD per capita, DPS, traffic volume, motorization rate, annual variation in population density, unemployment rate, precipitation, proportion of motorways, foreign tourist, old vehicle, annual variation of young people, old people, education
Sánchez-González et al. (2021)	Chile	2000-2017	LM: Panel corrected standard errors with autoregressive structure	Fatalities/Serious injuries/Less serious injuries/Slight injuries per vehicle, and per inhabitant	Investment in construction per kilometre (+)	Investment in replacement per km (-)	Traffic law, Zero Tolerance Law, annual variation of motorization, annual change in population density, unemployment rate, precipitation, annual change in the proportion of non-paved roads, proportion of motorways

Acronyms used in Methodology: GLM (Generalized Linear Model), DRAG (Demande Routière, Accidents et Gravitè – Gaudry (1984)), and LM (Linear Model)

0 **Table 2. Summary of references considering road infrastructure investment variables**

Hypothesis	Test	Results
Homoscedasticity across cross-sections	Levene test (Levene, 1960)	W0 = 15.306*** W50 = 9.287*** W10 = 14.394***
Inexistence of first-order autocorrelation	Wooldridge test (Wooldridge, 2007)	F = 74.793***
Independence of the cross-sections	Pesaran test (Pesaran, 2020)	13.465***, with absolute mean value of the residual correlation = 0.395

**** p<.01*

Table 3. Tests performed to the panel dataset

Variable	Unit	Mean	Std. Dev.	Min	Max
Crash	Crashes per billion pkm	106.866	59.63	14.252	312.265
Invest	Thousand euros per km (2015 prices)	20.255	35.519	0.033	279.89
Maintain	Thousand euros per km (2015 prices)	8.151	11.14	0.247	83.758
Precipit	Average depth of rain water during a year (mm)	913.802	282.736	445.697	2266.78
Motorways	Proportion of high capacity roads over the total road network (%)	2.57	4.108	0	21.419
Motor	Cars per 1000 inhabitants	435.293	89.504	199.385	625.17
Unemploy	Unemployment rate (%)	9.097	4.073	3.1	26.1
GDP Cap	Thousand euros per inhabitant (2015 prices)	27.014	12.898	5.239	57.399
Alcohol	Litres per capita (Age > 15)	10.929	2.108	6.2	17.75
DPS	Dummy (0, 1)	.624	.485	0	1

Note: 380 observations for each variable

Table 4. Description of the variables

Variables	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)
(1) Invest	1.00										
(2) L1.Invest	0.96	1.00									
(3) Maintain	0.36	0.348	1.00								
(4) L1.Maintain	0.37	0.375	0.94	1.00							
(5) Precipit	-0.05	-0.04	0.03	0.03	1.00						
(6) Motorways	0.72	0.75	0.26	0.26	-0.08	1.00					
(7) Motor	-0.03	-0.02	0.35	0.36	0.26	0.07	1.00				
(8) Unemploy	-0.05	-0.02	-0.03	-0.03	-0.23	0.20	-0.39	1.00			
(9) GDP Cap	-0.11	-0.12	0.11	0.11	0.19	-0.13	0.49	-0.55	1.00		
(10) Alcohol	0.16	0.15	-0.27	-0.28	0.05	0.08	-0.15	-0.17	-0.22	1.00	
(11) DPS	-0.18	-0.18	0.07	0.06	0.25	-0.17	0.28	-0.02	0.14	-0.08	1.00

Table 5. Correlation matrix

DATA	**SOURCE**
Number of Crashes	UNECE; RSA
Road investment / Road maintenance expenditure	OECD/ITF; *Ministerstvo dopravy*, Czech Republic; *Bundesministerium für Verkehr und digitale Infrastruktur*, Germany; *Ministerie van Infrastructuur en Waterstaat*, Netherlands; *National Statistics Office*, Malta; *Ministério da Economia e Transição Digital*, Portugal; *Ministerio de Fomento*, Spain; and *Trafikverket,* Sweden.
Passenger-km / Length of road network / Stock of vehicles	Directorate-General for Mobility and Transport (DG MOVE); *Ministère de l'environnement de l'énergie et de la mer*, France; *Ministero delle Infrastrutture e dei Trasporti*, Italy; *Statistisk sentralbyrå*, Norway; *Instituto Nacional de Estatística*, Portugal.
Gross Domestic Product	The World Bank
Unemployment rate	Eurostat; The World Bank
Population	Eurostat
Alcohol consumption	World Health Organization (WHO)
Precipitation	European Climatic Energy Mixes (ECEM) of the Copernicus Climate Change
Demerit Point Systems	European Transport Safety Council (ETSC), EU BestPoint-Project

Table 6. Sources of data

Crash	(1)	(2)	(3)	(4)	(5)	(6)
Invest	.111	.127	.117	.08	.048	.054
	(.078)	(.092)	(.084)	(.084)	(.076)	(.063)
L1. Invest	.198***	.194**	.19**	.168**	.139*	.156***
	(.073)	(.085)	(.082)	(.084)	(.077)	(.06)
Maintain	-.139	-.13	-.138	-.054	.006	-.036
	(.104)	(.114)	(.106)	(.112)	(.11)	(.095)
L1. Maintain	-.228**	-.219*	-.209*	-.204*	-.196*	-.174*
	(.105)	(.115)	(.111)	(.119)	(.117)	(.095)
Precipit		0				
		(.006)				
D. Motorways			1.427	.801	-.676	
			(4.772)	(4.737)	(4.597)	
D. Motor			.009	-.034	-.03	
			(.054)	(.058)	(.061)	
Unemploy				-1.89***	-2.256***	-1.768***
				(.58)	(.492)	(.522)
GDP cap				-.985***	-1.355***	-1.238***
				(.214)	(.158)	(.175)
D. Alcohol					2.153*	2.13*
					(1.216)	(1.155)
DPS					-13.469***	-12.04***
					(3.178)	(3.369)
_cons	100.859***	97.845***	99.343***	142.173***	164.786***	156.462***
	(7.939)	(9.267)	(7.355)	(11.595)	(7.603)	(9.071)
Observations	360	360	360	360	360	360
R-squared	.575	.66	.624	.713	.82	.724

Standard errors are in parentheses. "L1" means lag 1 and "D" means that the series are differentiated.
**** p<.01, ** p<.05, * p<.1*

Table 7. Results of the models

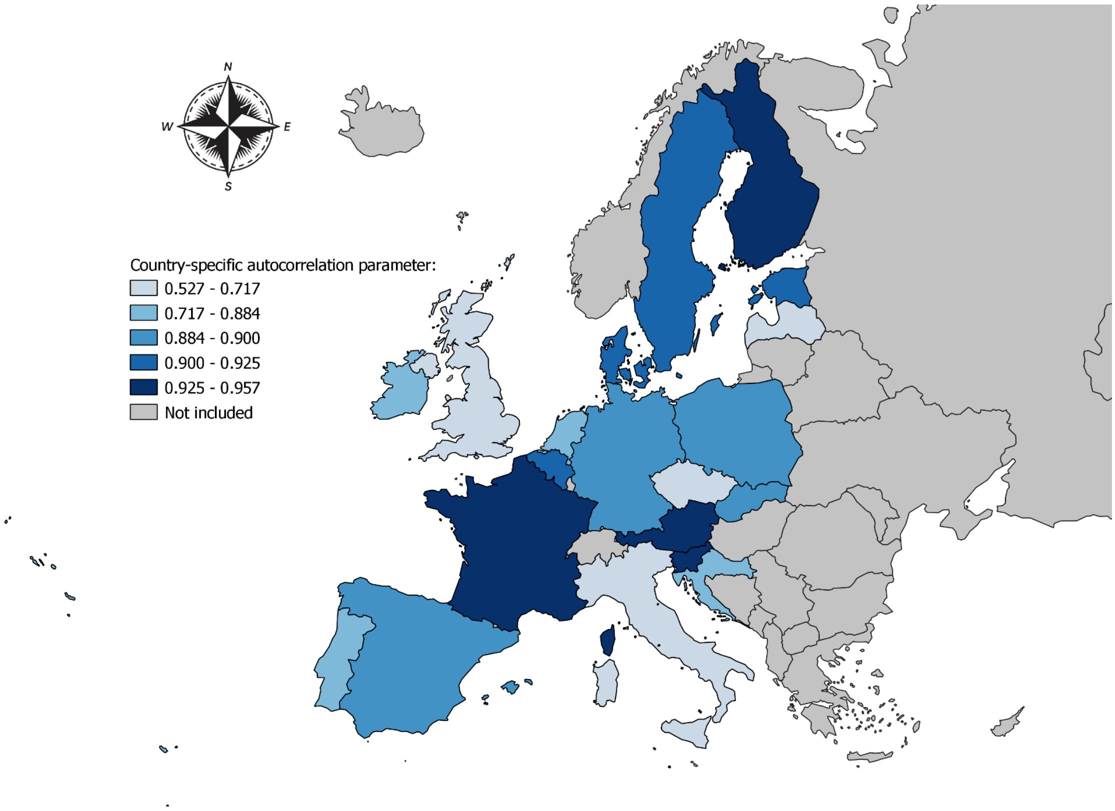

Figure 1. Country-specific autocorrelation parameter for model (6)