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## Abstract

This paper investigates the determinants of regional disparities in road traffic accident (RTA) outcomes across European regions. Using panel data and negative binomial models, it examines socioeconomic, institutional, cultural and behavioural drivers on fatalities and injuries. The results reveal marked regional variation, with Southern Europe exhibiting higher casualty rates. Education, perceptions of road safety, rule of law, informal economy and GDP per capita significantly affect RTA outcomes. Marginal effects confirm that tertiary education substantially reduces both fatalities and injuries. The empirical evidence highlights the importance of locational and institutional factors for designing targeted, region-specific road safety policies.

**Keywords:** Road traffic accidents; European regions; Cultural factors; Behavioural patterns

***JEL classification*:** I19; R10; R41

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# (Why) Do Europeans Drive Differently?

## 1. Introduction

Road safety has long been a critical global issue, with road traffic accidents (RTAs) historically ranked among the leading causes of injury and death. Every year, approximately 1.19 million lives are lost, and 20 to 50 million people suffer non-fatal injuries due to RTAs (World Health Organization, 2025), highlighting the urgent need for effective interventions and policies. Despite significant progress in the European Union (EU) and broader Europe in recent decades, regional disparities in road safety outcomes persist. While some regions have successfully reduced traffic casualties, others continue to face higher accident rates, prompting critical questions about the underlying causes of these differences.

These disparities raise important questions about the relationship between socioeconomic variables, behavioural patterns, and road safety. Examining these factors is important, as road safety is not only a public health concern, but also influences economic growth, transportation efficiency, and regional development (Nikolaou and Dimitriou, 2018). This study addresses two key questions: Why do road safety outcomes differ between European regions? And through which regional mechanisms do differences in traffic safety outcomes arise across Europe? By exploring these questions, the study offers a new perspective, shifting the focus from the technical environment, which has been extensively studied, to the nexus of economic, cultural, behavioural and institutional factors.

Previous research has demonstrated a correlation between economic development and road safety (Kopits and Cropper, 2005), noting that higher-income countries often benefit from stricter traffic law enforcement and advanced vehicle standards (Albalate et al., 2013; Hakkert and Gitelman, 2014). However, economic growth alone does not fully explain the observed disparities, particularly in Europe's diverse NUTS 2 regions. Empirical evidence suggests that in developing or transitioning economies, rapid motorisation often leads to an initial increase in traffic accidents, as safety regulations and infrastructure development lag behind (Kopits and Cropper, 2005). This regional diversity, often manifested along the North-South or West-East axis, provides a unique opportunity to explore how economic conditions, cultural attitudes, and regulatory frameworks intersect to shape road safety. A key novelty of this study lies in its focus on cultural factors, such as perceptions of road safety, adherence to rules, and the prioritisation of safety measures. In addition, the inclusion of the informal economy, which is not explored in the existing literature, adds an important dimension to the analysis.

Although infrastructure, including well-designed roads and modern transport networks, undeniably contributes to safer mobility (Albalate et al., 2013), this study draws attention to less tangible factors. While regional variations in road quality — often associated with economic disparities— are acknowledged, they are not treated as the primary drivers. Instead, the focus is on how differences in driver behaviour, shaped by cultural norms and enforcement practices, contribute to divergent safety outcomes. For example, wealthier regions often benefit from robust enforcement and public education campaigns, while less affluent areas may face challenges with weaker regulatory oversight and outdated vehicle fleets (Török, 2020). These factors amplify regional differences and suggest that road safety reflects broader systemic and cultural dynamics.

Economic growth and technological advancements significantly influence both the implementation and effectiveness of road safety measures. In the wealthier NUTS-2 regions, strong traffic law enforcement, advanced vehicle technologies, and effective public education campaigns have helped significantly reduce accident rates. In contrast, less affluent regions often face higher crash rates due to outdated vehicles, poorly maintained roads, and weaker enforcement (Urie et al., 2016). Beyond these material factors, cultural differences, such as attitudes toward risk, adherence to rules, and prioritisation of safety measures, further complicate the picture, contributing to the North-South divide. These dynamics indicate that road safety is not a stand-alone issue, but a reflection of deeper systemic inequalities, which requires a holistic approach to uncover its causes and solutions.

This study aims to build on existing knowledge by closely examining road safety differences not only between Northern and Southern Europe, but also between Western and Eastern NUTS-2 regions. Significant economic and infrastructure differences exist between Western and Eastern Europe, with the former resembling the level of development of the North and the latter aligning more with the economies of Southern Europe. This research introduces a novel dimension by integrating the informal economy into the analysis, along with well-established factors such as income per capita and road accessibility, thus creating a more cohesive explanatory framework. Although previous studies have explored road safety at the country level or through broader European trends (Bergel-Hayat and Zukowska, 2015; Shen et al., 2013; Tolón -Becerra et al., 2013), to the best of our knowledge, no studies have conducted a comparative regional analysis in such depth, integrating economic and cultural factors. By filling this gap, this paper aims to shed light on how regional disparities shape road safety outcomes and offer fresh insights into targeted policies. Beyond the prevention of avoidable accidents, the ultimate goal is to promote more equitable economic development, ensuring that the benefits of improved safety are distributed more evenly across all European regions.

The remainder of this paper is organised as follows. The next section reviews the relevant literature. This is followed by a detailed explanation of the methodological approach, including descriptions of the data, variables, and the estimation strategy employed. The subsequent section presents the regression results and discusses the key findings, while the final section concludes the paper by summarising the main insights and explaining what they mean for policy and future research.

# 2. Literature Review

## *2.1 Economic and technical environment-related factors affecting road traffic accidents*

A road traffic accident is an independent or a combined result of internal factors of the multilevel sociocultural and technical environment (vehicle-related factors and road environment) of traffic (Özkan and Lajunen, 2011). Consistently, Shen et al. (2020) develope a comprehensive framework of safety performance indicators to facilitate international benchmarking of road safety performance. The framework encompasses three fundamental components of the road transport system: road user behaviour, vehicles, and infrastructure. The international literature highlights a significant relationship between the Gross Domestic Product (GDP) per capita and the frequency or severity of road traffic accidents. Akinyemi (2020), for example, finds that economic development, measured by GDP per capita, significantly influences road safety outcomes in Nigeria; While a higher GDP reduces crashes and fatalities in the long run, it unexpectedly increases injuries. Similarly, Sinha et al. (2021) observe an inverted U-shaped relationship between per capita income and fatality risk across Indian states, indicating that traffic deaths initially increase with income before eventually declining at higher development levels. In line with these findings, Sirajudeen et al. (2021) identify a reverse U-shaped link between economic growth and the ratio of road deaths to injuries, with road deaths dominating lower income levels and injuries becoming more prevalent as economies advance. Taken together, these studies suggest that economic growth may initially lead to more traffic accidents due to increased motorisation. Over time, as a country becomes wealthier, road safety tends to improve due to better infrastructure, safer vehicles, and stronger healthcare systems.

Concurrently, the presence of a substantial informal economy appears to exert a negative influence on road safety. Deléchat and Medina (2020) define the informal economy as market-valued activities that, if recorded, would boost tax revenue and GDP. Relevant studies have shown that the extent of the informal economy may serve as an indicator of weak institutions and low compliance with regulations, including those related to road traffic. In such contexts, there is a higher likelihood of inadequate vehicle inspections, unlicensed or uninsured driving, and insufficient policing (Castillo-Manzano et al., 2022), all factors that contribute to an increased probability of accidents. The informal economy, by sustaining high levels of informality in peripheral areas with poor transport infrastructure, restricts accessibility and formal job creation, thus impeding the development of infrastructure in African countries (Ningaye and Ketu, 2023). In Ghana, informal activities along major highways contribute to over 21 percent of reported accidents, alongside traffic congestion and environmental degradation (Nani et al., 2025). Particularly in Europe, where notable disparities in the size of the informal economy exist between Northern and Southern regions (Pappadà and Rogoff, 2025), this factor may explain the heterogeneity observed in the rates of road traffic accidents.

Regarding technical environment-related factors that affect traffic accidents, the relationship between highway network accessibility and road traffic accident rates is well documented, indicating that increased access point density and network connectivity generally correspond to higher crash rates due to conflict points and exposure, although the impacts vary by scale (macro, meso or micro), road type, access spacing, and land use context. At the macro level, for example, Wang et al. (2012) demonstrated that denser and more interconnected street networks, characterised by higher density and centrality of the network, were significantly associated with more crashes on local roads. Their study emphasised that grid and parallel network patterns, which offer more connectivity, were associated with higher crash risks compared to more disconnected layouts such as sparse or loop-and-lollipop patterns. Likewise, Hamzeie et al. (2019) found a clear inverse relationship between access spacing and crash rates on two-lane and multilane highways, with crash frequencies increasing as access spacing decreased. This supports the view that high access density increases conflict points and compromises safety. However, other studies suggest that increased accessibility can reduce the severity of the crash by improving infrastructure and traffic flow, although these benefits tend to vary with road function and exposure level (Kim et al., 2011). In contrast, higher connectivity near activity centres, such as commercial hubs, has been associated with increased frequency and severity of crashes (Schultz et al., 2010).

The increase in vehicle traffic, particularly passenger cars and freight trucks, has been identified as a key factor that worsens road safety, raises the number of traffic accidents, and increases the strain on the road infrastructure. Studies have shown that high traffic density is directly associated with a higher likelihood of collisions, especially under congested flow conditions and at urban intersections where drivers have limited manoeuvring space and reduced reaction time (Ceder, 1982). However, the severity of crashes tends to be lower in such conditions due to reduced speeds (Høye and Hesjevoll, 2020). Passenger cars, the main mode of transport in most urban and suburban areas, contribute significantly to traffic congestion, increasing the risk of accidents, especially during peak hours and on weekdays (Grimaldi, 2020). Moreover, the presence of large, heavy vehicles, such as trucks, increases the severity of accidents (Wang et al., 2022). The rapid growth of freight transport on road networks, driven by the expansion of ecommerce, has resulted in more trucks on the roads, complicating traffic flow and increasing the chances of accidents (Wang et al., 2022; Bonilla, 2016). This phenomenon becomes even more evident in specific regions or entire countries, such as Greece in Southern Europe or Denmark in Northern Europe, where freight rail transport is very limited (Eurostat, 2023). Researchers emphasise the need for combined strategies, such as effective coordination of public transport and logistics management, to reduce traffic congestion, improve road safety, and minimise damage to road infrastructure (e.g., El Amrani et al., 2024; Rezende Amaral et al., 2018).

Finally, the age of the vehicle fleet, particularly passenger cars which dominate road traffic, is a significant factor influencing the frequency of road accidents, despite limited research on the topic. Fleet age is indirectly related to a region's (or country's) economic prosperity and the quality of its infrastructure. In wealthier regions, higher incomes enable more frequent vehicle replacement, resulting in newer fleets compared to poorer areas where purchasing new vehicles is more challenging. Additionally, regions with modern infrastructure, such as electric vehicle charging stations, promote the adoption of newer, more advanced vehicles. Empirical studies, such as Santolino et al. (2022), indicate that older vehicles increase the likelihood of passenger injuries, with the greatest impact observed in cars aged 18 years or older. Similarly, Török (2020) finds that vehicle age significantly affects accident rates, with older vehicles more frequently involved due to the absence of advanced safety systems.

## *2.2 Cultural, institutional and regional characteristics associated with road traffic accidents*

The analysis of traffic accidents is influenced not only by economic and technical data but also by cultural and governance quality factors (Arslan and Özkan, 2024), such as educational level, societal attitudes toward road safety and adherence to the rule of law. In addition, factors such as climatic conditions, tourist arrivals and population density may significantly affect the frequency of accidents across different regions. First, a growing body of research highlights the profound influence of cultural and institutional context on road safety perceptions and behaviours. Özkan et al. (2006) conducted a cross-cultural study across six countries, demonstrating that national cultural dimensions, such as power distance and uncertainty avoidance, significantly shape driver attitudes. For example, Turkey and Greece exhibited higher rates of aggressive violations and errors, whereas Finland and the Netherlands displayed more safetyconscious behaviours, reflecting the impact of cultural norms. Expanding on the influence of culture, Üzümcüoğlu et al. (2018) found that cultural factors, grounded in the Hofstede and Schwartz frameworks, predict non-speeding violations (e.g., horn use, phone use and aggressive behaviours), which correlate with road traffic fatality rates. Specifically, societies with higher individualism and long-term orientation report fewer violations, suggesting that values that place emphasis on individual responsibility and future-oriented planning foster safer driving. In contrast, cultures that emphasise group belonging tend to show more traffic violations, as individuals follow social norms rather than official traffic rules. These findings highlight how cultural dimensions shape compliance with traffic regulations and affect road safety outcomes through behavioural patterns.

Second, education can play a key role in reducing traffic accidents (Sami et al., 2013), by promoting responsible driving behaviour and improving understanding of road risks. People with higher education tend to show greater compliance with traffic rules and better understanding of the risks associated with careless or aggressive driving. However, empirical studies present conflicting findings on the impact of education on driving behaviour and road accident reduction. Although Castillo-Manzano et al. (2014) find no significant association between educational background and road fatality rates, Caranci et al. (2020) in their longitudinal study of Emilia-Romagna confirm a relationship between lower education levels and increased premature mortality, including traffic accidents, particularly among men in urban areas. These findings highlight the need for targeted educational interventions to strengthen traffic awareness, especially among vulnerable groups.

Third, the relationship between the rule of law and road traffic accidents has been increasingly explored in recent literature, with a focus on how legal and governance structures influence road safety outcomes. Research such as that by Elvik (2021) and Law (2015) highlight that greater levels of democracy and political stability, as key components of a strong rule of law, are associated with lower rates of non-fatal road injuries. This suggests that strong legal frameworks, supported by democratic governance and consistent enforcement, promote safer driving behaviours and reduce accident rates. Similarly, Prakash Giri et al. (2024) underscore the importance of effective legal frameworks in developing countries such as Nepal, concluding that stricter enforcement of traffic regulations and harsher penalties for violations such as drunk driving, speeding and use of mobile phones are critical to reducing road traffic accidents. The above studies confirm the pivotal role of a strong rule of law in reducing road traffic accidents, highlighting the need for continuous research to refine and adapt legal strategies at the global and/or national level.

Last but not least, the literature highlights several important contextual factors that significantly influence the risk of road traffic accidents. Among these, specific regional characteristics, such as climate conditions (e.g. frost, rainfall, temperature) (Amin et al., 2014; Bergel-Hayat et al., 2013), population density (Nieminen et al., 2002), and intensity of tourism (Psarras et al., 2024; Xie et al., 2025) have been consistently identified as key contributors. These factors not only shape traffic patterns and road usage but also interact with infrastructural and behavioural variables, increasing or reducing accident risks in various ways.

# 3. Methodology

## *3.1 Data and Variables*

The study utilises annual data derived from sources at the NUTS-2 (2021 version) level. In some cases where data were not available at the NUTS-2[1] level, NUTS-0 (national) data were used as an alternative. Two data sets are used. The first consists of panel data from 237 regions within the EU-27, together with 52 regions from Switzerland, Norway, and the United Kingdom (UK), covering the period 2000–2022. The second dataset includes the same regions for the period 2003–2022 and introduces an additional variable: the size of the informal (or shadow) economy. Note that the five French overseas regions and three Scottish regions (UKM7, UKM8, and UKM9) in the

[1] NUTS 2 is the intermediate level of the Nomenclature of Territorial Units for Statistics (NUTS) classification defined by Eurostat, located between the broader NUTS 1 regions, which cover the main socio-economic areas and the smaller NUTS-3 regions, and is typically used for regional economic analysis.

United Kingdom[2] were excluded from both datasets due to insufficient data for most of the variables examined.

To investigate regional differences in road traffic accidents between European NUTS-2 regions, the analysis focuses mainly on locational, economic, technical, and cultural factors, while also controlling for additional regional characteristics that can affect accident rates. Hence, the initial equation is as follows:

$$Y_{it} = \alpha_0 + \text{Location}_{\iota}\beta_1 + \text{Economic \& Technical Environment Factors}_{it}\beta_2 + \text{Perceptions of road safety}_{\iota}\beta_3 + \text{Institutional Factors}_{\iota t}\beta_4 + \text{Control}_{\iota t}\beta_5 + \varepsilon_{\iota t} \quad (1)$$

where $Y_{it}$ is the dependent variable, $\alpha_0$ is a constant, and $\text{Location}_{\iota}$ is a time-invariant variable representing the geographic location of region $\iota$. The Economic & Technical environment factors, denoted by a vector for region $\iota$ at time $t$, may influence road accidents. $\text{Perceptions of road safety}_{\iota}$ represent time-invariant cultural (behavioural) characteristics, while $\text{Institutional factors}_{\iota t}$ capture time-varying institutional effects. Finally, $\text{Control}_{\iota t}$ refers to a set of control variables applied to region $\iota$ at time $t$. The coefficients $\beta_1$ through $\beta_5$ represent the effects of the respective explanatory variables and $\varepsilon_{\iota t}$ represents the error term.

The analysis employs two dependent variables, both derived from the Eurostat database: a) *RTA fatalities*, which captures the annual number of fatalities resulting from road traffic accidents per NUTS-2 region, and is expressed as the number of fatalities per million inhabitants to allow for comparability across regions of differing population sizes, and b) *RTA injuries*, which reflects the annual number of non-fatal injuries sustained in road accidents. As with fatalities, injury rates are normalised per

[2] The five French overseas regions are: Guadeloupe, Martinique, Guyane, La Réunion, and Mayotte; and the three Scottish are: Eastern Scotland, West Central Scotland, and Southern Scotland.

million inhabitants. Both variables capture different aspects of road safety. Fatalities show the most serious outcomes, while injuries reflect how often accidents occur and their wider impact. Together, they help to better understand the differences in road safety between regions.[3]

As a first step in defining the independent variables, the regions under study were categorised according to their geographical location. A categorical variable, referred to as the *Location* variable, was therefore introduced, which is divided into four categories: Northern, Western, Central and Eastern, and Southern (see Appendix I). This classification is based on Eurovoc, a thesaurus provided by the Publications Office of the European Union, which standardises terminology across EU documents and databases. This approach allows the analysis to explore whether the frequency of road traffic accidents differs depending on the position of a region/country on the map of Europe.

The analysis then incorporates several economic and technical environment-related explanatory variables. Gross Domestic Product per capita *(GDP per capita)*, expressed in Purchasing Power Standards (PPS), reflects the level of economic development of each region and was obtained from the ARDECO Annual Regional Database of the European Commission (JRC / REGIO). Due to the non-normal distribution of regional GDP values, the data were log-transformed. The second economic variable included in the analysis is the size of *Informal economy*. We use the index provided by Schneider and Asllani (2022). Although this index is only available at the national (NUTS-0) level and not at the regional level, it is still included as an economic variable. It reflects important structural and institutional factors that can influence road safety, such as

[3] According to Eurostat metadata, **RTA fatalities** refer to persons who were killed immediately or died within 30 days of a road accident as a result of an injury accident, excluding suicides, while **RTA injuries** refer to persons who, as a result of an injury accident, were not killed immediately or within 30 days, but sustained an injury that normally required medical treatment. Minor wounds, such as cuts and bruises, are generally not recorded as injuries. *'Eurostat's road safety statistics and databases do not record damage-only accidents; they focus on accidents resulting in fatalities or injuries because the definition of injuries is not harmonised across member states, making injury data unreliable for a comprehensive EU-wide comparison.'* (Eurostat, 2025)

weak regulation, limited institutional capacity, and informal transport. *Motorway density* refers to the concentration of motorways in a region. It is calculated by dividing the total length of motorways (in kilometers) by the total area (in square kilometers) of each NUTS-2 region. This variable serves as a proxy for the availability of the road infrastructure and was sourced from Eurostat. The *Passenger cars* variable, defined as the number of passenger cars per thousand inhabitants at the NUTS-2 level, also comes from Eurostat and serves as a proxy for motorisation level or vehicle exposure in a region. The last technical environment-related variable is *Road freight* transport, which was derived from Eurostat at the NUTS-3 level and aggregated at the NUTS-2 level. *Road freight* data was logarithmically transformed to reduce skewness and compress the range of values. *Fleet age*, which relates to both the economic and technical environment of a region or a whole country, is included at the country level due to the lack of NUTS-2 data and reflects the average age of passenger cars. It was calculated using data derived from the UNECE Statistical Database and was enriched with data sourced from ACEA for Greece and Slovakia, while no data are available for Bulgaria. It was calculated by applying the mean age of each age class of vehicles (e.g. 1 year for vehicles under 2 years, 7.5 years for those aged 5-10, etc.), following the assumptions (European Environment Agency, 2025) and computing a weighted average based on the number of vehicles in each category. Although not region-specific, this variable provides important contextual information. It serves as a proxy for vehicle safety standards and maintenance conditions, with older fleets generally associated with higher accident risks (Høye, 2019).

To capture factors related to the cultural and institutional characteristics of European regions, we included three variables. The first is *perceptions of road safety* - a time-invariant variable based on the second question from the Flash Eurobarometer 301 (*Road Safety in Europe*) (Europäische Kommission, 2011), conducted by the European Commission in 2010. The dataset includes individual responses, each assigned to NUTS-1, NUTS-2, or NUTS-3 regions for 26 of the 27 EU member states (excluding Croatia). Among the three non-EU countries surveyed, data are available only for the

United Kingdom. To construct this composite indicator, which includes all five sub-questions of question 2 (Q2) (see Appendix II), the responses were first assigned numerical values: "Not a problem" was given a value of 0, "Minor problem" a value of 2, and "Major problem" a value of 4. This re-scaling, which differs from the original Eurobarometer coding, was applied to enhance the variability and sensitivity of the index across regions and make differences in perceived road safety problems and risky driving behaviours clearer. Then, for each NUTS-2 region, a weighted average for question Q2 was calculated using the formula:

$$A_i = \frac{\sum_j (x_j \times w_j)}{\sum_j w_j}, \tag{2}$$

where $x_j$ is the coded response value (0, 2, or 4) for respondent *j*, and $w_j$ is the weighting factor for respondent *j*, based on the sample's representation of the region's actual population. The denominator $\sum_j w_j$ ensures that the weights are normalised.

The weighting factor for region *i* is calculated as:

$$W_i = \frac{P_i}{N_i}, \tag{3}$$

where $P_i$ is the total population of the region *i*, derived from Eurostat data, and $N_i$ is the number of respondents in region *i*. The final weighted result for each region is computed as:

$$A_{\text{weighted}i} = A_i \times W_i. \tag{4}$$

This ensures that the response to question Q2 reflects the actual population distribution of the region.

The second culture and institution-related variable, included as a proxy of educational attainment, is *tertiary education*, which indicates the percentage of the population aged 25 to 64 — who represent the main segment of the population driving on European roads — with a tertiary-level qualification. The data are derived from the Eurostat database. Lastly, to investigate the effect of institutional quality and societal trust, the *Rule of law*[4] variable is used, derived from the World Bank's Worldwide Governance Indicators (2024), expressed as a percentile rank from 0 to 100. Rule of law data are provided by international organisations at the national level and are not available at the regional (NUTS-2 or NUTS-3) level. This is reasonable, as the rule of law typically reflects national legal frameworks, institutional integrity, and governance patterns, which are generally uniform and consistent across all regions of a country.

Three variables are introduced as controls. The first is the annual *Mean temperature*, used as a proxy for the climate conditions Linsenmeier (2023). Data were derived from the World Bank's Climate Change Knowledge Portal [5]. The other two control variables are *Population density* and *Foreign tourist arrivals*. The latter are derived from the Eurostat database and are log-transformed. Appendix III summarises the variables discussed above, along with their units of measurement and sources. Summary statistics for all variables examined are presented in Table 1, while Figure 1 illustrates the key variables in the study.

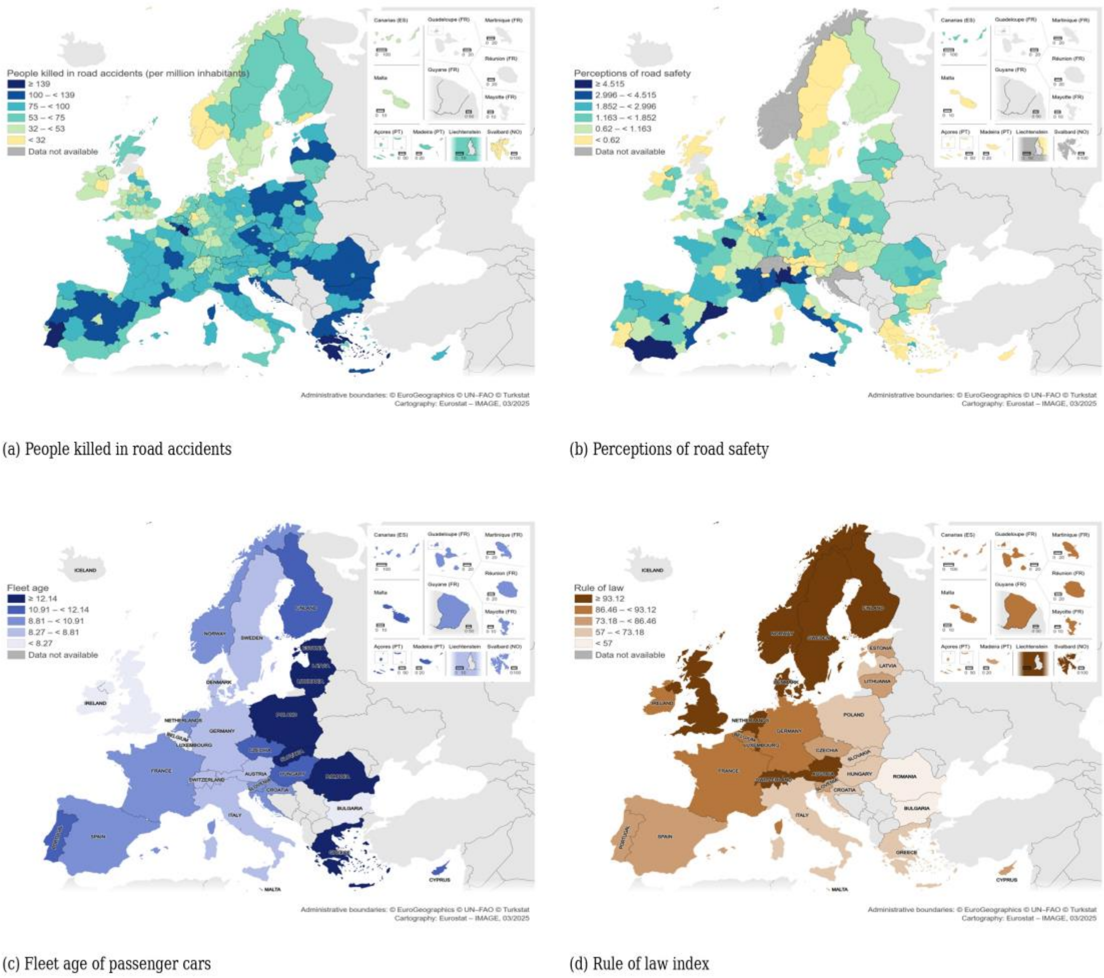
[4] Projections only for the year 2001 have been derived through interpolation.

[5] NUTS-2 regional data for Bulgaria, Croatia, Cyprus, Hungary, Ireland, Lithuania, Norway, Romania, Slovenia, Slovakia, and Sweden have been calculated by averaging the values of the corresponding NUTS-3 regions, after assigning each NUTS-3 region to its respective NUTS-2 region. In the case of the United Kingdom, each NUTS-2 region was assigned the value of its corresponding NUTS-1 region.

Table 1: Summary Statistics

| Variables | N | Mean or Percent | Std. Dev. | Min | Max |
|---|---|---|---|---|---|
| People Killed in road accidents | 5,850 | 74.029 | 44.719 | 0 | 383 |
| People Injured in road accidents | 5,693 | 3144.018 | 1924.502 | 40 | 14590 |
| Location: *Northern* | 667 | 10.040 | | | |
| Location: *Western* | 3,243 | 48.790 | | | |
| Location: *Central & Eastern* | 1,311 | 19.720 | | | |
| Location: *Southern* | 1,426 | 21.450 | | | |
| GDP per capita | 6,629 | 25,769 | 13,326.1 | 3,400 | 227,245 |
| Informal economy | 5,780 | 16.379 | 6.563 | 5.5 | 35.9 |
| Motorway density | 4,838 | 28.976 | 28.968 | 0 | 205 |
| Passenger cars | 5,828 | 491.760 | 127.095 | 81 | 2339 |
| Road freight | 5,771 | 35,752.14 | 41,364.44 | 3 | 381,437 |
| Fleet age | 5,817 | 9.398 | 2.252 | 2.99 | 17.92 |
| Perceptions of road safety | 6,187 | 1.194 | 1.012 | 0.054 | 7.854 |
| Tertiary education | 6,269 | 26.883 | 10.340 | 3.6 | 74.7 |
| Rule of law | 6,647 | 83.704 | 13.874 | 44.28 | 100 |
| Mean Temperature | 6,417 | 10.558 | 3.504 | −9.5 | 20.34 |
| Population density | 6,209 | 432.35 | 1106.11 | 3.3 | 11,509.1 |
| Tourist arrivals | 5,818 | 1,082,624 | 1,934,845 | 7,911 | 19,200,000 |

Figure 1: Mapping key variables associated with road traffic accidents in Europe.




(a) People killed in road accidents

(b) Perceptions of road safety

(c) Fleet age of passenger cars

(d) Rule of law index

To further illustrate the structure of the data, Appendix IV Figures (a) and (b) present the evolution of average road traffic fatalities and injuries at the country level over time, calculated as the mean across NUTS-2 regions. The figures reveal significant within-country temporal variation alongside persistent differences between countries, thus supporting the identification strategy adopted in the empirical analysis. Overall, road traffic fatalities and injuries exhibit a declining trend across countries, while marked cross-country differences and notable withincountry fluctuations remain throughout the period.

## 3.2 Institutional, behavioural and cultural dimensions of variables

Institutional and cultural dynamics influence the informal economy. From an institutional perspective, the magnitude of the informal sector is highly responsive to the quality and enforcement of formal regulations (Williams and Horodnic, 2019). Culturally, elements like generalised trust, tax morale, and community-based norms are pivotal. Torgler and Schneider (2009) reveal that cultural norms related to honesty, reciprocity, and civic duty are substantial predictors of tax compliance, influencing the extent of informal economic activities.

The geographical location of a country, although inherently spatial, has significant institutional and cultural implications. Geopolitical characteristics, such as terrain, climate, and access to trade routes, impact state capacity and institutional development. Acemoglu et al. (2001) contend that colonial and geographic factors shaped the development of extractive versus inclusive institutions, which, in turn, impact long-term economic and political stability. Cultural traits reveal regional patterns, as documented by Ronald and Welzel (2005), which demonstrate that values cluster geographically. Thus, location is not only a physical attribute, but also a determinant of social systems and cultural evolution.

Behaviourally, perceptions of road safety are directly related to individuals' attitudes towards risk, compliance, and attention. Studies conducted in multiple countries indicate that these perceptions strongly correlate with self-reported driving behaviours (Lund and Rundmo, 2009). Culturally, national norms influence how people assess road risk. Nordfjærn et al. (2014) find that cultural dimensions such as collectivism and uncertainty avoidance predict variations in safety perceptions for traffic management.

Tertiary education is a multidimensional concept that includes institutional, cultural, and behavioural aspects. Institutionally, it is shaped by policy design, public funding, and regulatory oversight (Marginson, 2016). National strategies for higher education significantly determine access to and quality of education. Culturally, the value placed on education varies by society. Hofstede (2001) presents cultural dimensions, such as power distance and long-term orientation, as influential in shaping attitudes toward education. Behaviourally, individual decisions about enrolment, persistence, and study fields reflect both personal aspirations and systemic constraints.

The rule of law is fundamentally conditioned by institutional and cultural factors. Institutionally, it refers to the robustness of legal frameworks, enforcement capabilities, and transparency in governance (Kaufmann et al., 2000). It is a foundational element of sustainable development and democratic governance. Culturally, societal values such as trust, individualism, and civic responsibility strengthen adherence to legal norms. (Tabellini, 2010) empirically demonstrates that regions with strong civic cultures tend to have higher institutional quality and more consistent enforcement of the rule of law.

GDP per capita is best understood as a composite outcome influenced by institutional, cultural, and behavioural factors. Institutionally, nations with transparent legal systems, efficient bureaucracies, and stable property rights tend to exhibit a higher GDP per capita (Acemoglu et al., 2001). Culturally, traits such as long-term orientation, trust, and work ethic contribute to economic performance. Tabellini (2010) finds that cultural norms significantly explain income disparities in European regions. Behaviourally, micro-level decisions regarding consumption, saving, and labour participation collectively shape macroeconomic outcomes. Thaler (1999) and Banerjee and Duflo (2013) highlight the importance of individual behaviour in understanding poverty and wealth generation.

## *3.3 Estimation strategy*

To assess potential multicollinearity among the explanatory variables, an Ordinary Least Squares (OLS) regression was initially performed. The results indicated no evidence of multicollinearity, as all Variance Inflation Factor (VIF) values were below the conventional threshold of 5. However, OLS is unsuitable for modelling count data due to its limitations. Diagnostic tests further identified heteroskedasticity and autocorrelation in the residuals, indicating the need for alternative approaches. Given the count nature of the dependent variables (i.e., RTA fatalities and injuries), Poisson and Negative Binomial models were considered as the most appropriate Chen et al. (2023). The Negative Binomial regression model was selected as the final choice for its ability to handle count data with overdispersion, unlike the Poisson model, which assumes the variance equals the mean, i.e., $\text{Var}(Y) = \text{E}(Y)$. In contrast, the Negative Binomial model assumes $\text{Var}(Y) > \text{E}(Y)$.[6]

The dependent variables *RTA Fatalities* and *RTA Injuries* exhibit severe overdispersion, with dispersion ratios of 46.37 and 253.84, respectively (see Appendix V), far exceeding the Poisson assumption of variance matching the mean (ratio = 1). The absence of excess zeros confirms that overdispersion is driven by high variance rather than zero-inflation, necessitating models like Negative Binomial regression. The Negative Binomial model's dispersion parameter, $\theta$, accounts for this excess variability, providing a more robust framework for analysing variables such as *RTA fatalities*.

The response variable $Y_{ij}$, representing the count outcome (e.g., *RTA fatalities*) for observation $j$ in region $i$, follows a Negative Binomial distribution with mean $\mu_{ij}$ and variance given by:

$$\text{Var}(Yij) = \mu ij + \theta\mu 2ij \tag{5}$$

The expected count $\mu_{ij}$ is modelled using a logarithmic link function:

$$\log(\mu ij) = Xij\beta + Zijbi \tag{6}$$

Here, $X_{ij}$ represents the fixed effects covariates (e.g., *Location*, *GDP per capita*), $\beta$ denotes the fixed effects coefficients, $Z_{ij}$ represents the random effects covariates, and $b_i$ are the random effects for region $i$, assumed to follow a multivariate normal distribution, $b_i \sim$

[6] The Negative Binomial model was chosen to capture substantial overdispersion in RTA fatality and injury counts. Although NBR coefficients can be scale-dependent, this issue typically arises in continuous trade flow models rather than in discrete count data such as ours.

$N(0,\Sigma)$. This formulation accounts for overdispersion and regional heterogeneity, improving model fitness.

Additionally, Moran's I diagnostic test revealed strong spatial autocorrelation across almost all independent variables. To address this spatial dependency and prevent biased estimates, spatial lags based on contiguity were calculated using NUTS-2 region boundaries from Eurostat shapefiles. These spatial lags were defined as weighted averages of the values from neighbouring regions, based on Queen Contiguity (first-order) adjacency matrices. The resulting spatially lagged variables were then tested for multicollinearity with their non-lagged counterparts. All spatial lags, except for the spatial lag of *Rule of Law* showed acceptable correlation levels, indicating that they could be safely included in the model. However, the spatial lag of *Rule of Law* showed a high degree of correlation with its original variable, suggesting potential multicollinearity. Therefore, it was excluded from the final specification (see Appendix VI).

To address heteroskedasticity and autocorrelation in the residuals, bootstrap standard errors were applied (MacKinnon, 2006), enhancing the statistical reliability of the estimates. The final model chosen is a mixed-effects Negative Binomial regression with spatial lags, which effectively accounts for overdispersion, regional heterogeneity, and spatial dependencies in the data. This model combines fixed and random effects, making it suitable for analysing data that include time-invariant, time-series, and categorical variables. For instance, the variable *Location* is treated as a fixed effect to assess its impact on outcomes like *RTA fatalities*, while time-invariant variables, such as *Perceptions of Road Safety*, are also fixed effects due to their assumed stability over time. Time-series variables, such as *GDP per capita*, capture temporal dynamics.

Therefore, the final form of the model, encompassing the embedded variables, is derived from the expansion of Equation (1) and is as follows:

$$
\begin{aligned}
\log(\mathrm{E}[Y_{it}]) = \beta_0 &+ \gamma_1 \text{Location}_i + \gamma_2 \text{GDP per capita}_{it} + \gamma_3 \text{Informal economy}_{c(i)t} \\
&+ \gamma_4 \text{Motorway density}_{it} + \gamma_5 \text{Passenger cars}_{it} + \gamma_6 \text{Road freight}_{it} \\
&+ \gamma_7 \text{Fleet age}_{c(i)t} + \gamma_8 \text{Perceptions of road safety}_i \\
&+ \gamma_9 \text{Tertiary Education}_{it} + \gamma_{10} \text{Rule of law}_{c(i)t} \\
&+ \gamma_{11} \text{Mean temperature}_{it} + \gamma_{12} \text{Population density}_{it} \\
&+ \gamma_{13} \text{Tourist arrivals}_{it} + \gamma_{14} \text{lag GDP per capita}_{it} \\
&+ \gamma_{15} \text{lag Informal economy}_{c(i)t} + \gamma_{16} \text{lag Motorway density}_{it} \\
&+ \gamma_{17} \text{lag Passenger cars}_{it} + \gamma_{18} \text{lag Road freight}_{it} + \\
&\gamma_{19} \text{lag Fleet age}_{c(i)t} + \gamma_{20} \text{lag Perceptions of road safety}_i \\
&+ \gamma_{21} \text{lag Tertiary Education}_{it} + \gamma_{22} \text{lag Mean temperature}_{it} \\
&+ \gamma_{23} \text{lag Population density}_{it} + \gamma_{24} \text{lag Tourist arrivals}_{it} + u_{it} \qquad (7)
\end{aligned}
$$

where the expected value of the dependent variable $Y_{it}$, with $i$ denoting regions and $t$ denoting time, is modelled in logarithmic form using a Negative Binomial regression. $\beta_0$ is the intercept. Coefficients $\gamma_1, \gamma_2, \ldots, \gamma_{24}$ capture the effects of regional and country-level explanatory variables and their spatial lags. Variables indexed by $c(i)t$ represent country-level factors, and those indexed by $it$ or $i$ represent regional-level variables. The prefix *lag* denotes the spatial lags of the respective variables, while $u_{it}$ captures unobserved heterogeneity across regions and time, addressing overdispersion not explained by the observed covariates.

Overall, this model accommodates the multilevel structure of the data, accounting for heterogeneity across European regions and temporal variations. Only complete cases are included in the regressions, with rows containing missing data in predictor variables excluded. However, if a missing value appears only in the dependent variable, the row is not used for model fitting, but a predicted value is still generated and reported. The use of bootstrapped standard errors ensures robust inference by addressing residual autocorrelation (Appendix VII) and heteroskedasticity, particularly when observations are grouped by region or over time. This approach enhances the precision of estimates and effectively handles the complexity of the data, making the mixed-effects Negative Binomial regression with spatial lags the optimal choice for analysing RTA fatalities and injuries across European regions.

As a final step, we aim to compare the impact of time-varying predictors on RTA fatalities and injuries across European countries (NUTS 0) over the period 2000–2022. Prior to analysis, we reversed the log-transformation applied to certain independent variables to restore them to their original scale. To achieve this, we employed a negative binomial regression with fixed effects, incorporating dummy variables to account for country-specific effects, using aggregated data from the European countries studied. Time-invariant variables, such as *Location* and *Perceptions of road safety*, were omitted from the model, as well as indicators that change slowly over time (i.e., informal economy, rule of law). To estimate the average percentage effect on the dependent variables for a 1 percent increase in each independent variable, we calculate the marginal effect as the mean of the dependent variable multiplied by the product of the regression coefficient ($\beta$) and 0.01, or

$$\text{Marginal effect of X on Y} = \bar{Y} \times (\beta \times 0.01) \quad (8)$$

# 4. Regression results and discussion

## *4.1 Main results*

The analysis, based on mixed-effects negative binomial regression models with spatial lags, examines the determinants of road traffic accident (RTA) fatalities and injuries across European regions. Tables 2 and 3 present the regression results for RTA fatalities and injuries, respectively. Regression (1) in each Table includes only regional variables, excluding national factors such as rule of law and fleet age, while regression (2) in both Tables includes all the independent variables.

The influence of geographic location emerged as significant across all regressions. Southern regions consistently exhibit the highest rates of both fatalities and injuries compared to Northern regions (the reference group). In regression (1) of Table 2, Southern regions have an 85% higher relative risk of fatalities (IRR = 1.85, see Appendix VIII), which moderates to 31%

Table 2: Regression results for road traffic accidents fatalities

| **Dep. Var. is RTA fatalities** | **(1)** | | **(2)** | |
|---|---|---|---|---|
| | **Coef.** | **IRR** | **Coef.** | **IRR** |
| *Location* | | | | |
| • Northern | base | | base | |
| • Western | 0.605*** (0.048) | 1.83 | 0.6241*** (0.069) | 2.060 |
| • Central & Eastern | 0.227*** (0.043) | 1.25 | 0.2843*** (0.077) | 1.330 |
| • Southern | 0.614*** (0.067) | 1.85 | 0.2667** (0.108) | 1.310 |
| GDP per capita | −0.491*** (0.054) | 0.61 | 0.0808 (0.076) | 1.080 |
| Informal economy | – | – | 0.0758*** (0.004) | 1.080 |
| Motorway density | −0.0078*** (0.001) | 0.99 | −0.0054*** (0.001) | 0.995 |
| Passenger cars | −0.0002 (0.002) | 1.00 | −0.0003 (0.001) | 1.000 |
| Road Freight | 0.0049* (0.003) | 1.00 | 0.00551 (0.004) | 1.010 |
| Fleet age | – | – | −0.0198*** (0.007) | 0.980 |
| Perceptions of road safety | 0.0011 (0.011) | 1.00 | −0.0528** (0.021) | 0.949 |
| Tertiary education | −0.0332*** (0.001) | 0.97 | −0.0219*** (0.002) | 0.978 |
| Rule of law | – | – | 0.0096*** (0.002) | 1.010 |
| Mean temperature | −0.0746*** (0.009) | 0.93 | 0.00521 (0.008) | 1.010 |
| Population density | −0.0937*** (0.022) | 0.91 | −0.1500*** (0.035) | 0.861 |
| Tourist arrivals | −0.0060 (0.004) | 0.99 | 0.0863*** (0.015) | 1.090 |
| *Variables with spatial lags* | | | | |
| lag_GDP per capita | −0.0099* | 0.99 | −0.0162*** (0.006) | 0.984 |
| lag_Informal economy | – | – | 0.0144*** (0.004) | 1.010 |
| lag_Motorway density | 0.0006 (0.001) | 1.00 | −0.0019*** (0.001) | 0.998 |
| lag_Passenger cars | −0.0001 (0.001) | 1.00 | −0.0001 (0.001) | 1.000 |
| lag_Road freight | −0.0056*** (0.002) | 0.99 | −0.00331 (0.002) | 0.997 |
| lag_Fleet age | – | – | 0.0044* (0.002) | 1.000 |
| lag_Perceptions of road safety | −0.0137 (0.017) | 0.99 | −0.0489 (0.038) | 0.952 |
| lag_Tertiary education | −0.0064*** (0.001) | 0.99 | −0.0041*** (0.001) | 0.996 |

| | | | | |
|---|---|---|---|---|
| lag_Mean temperature | 0.0040 (0.003) | 1.00 | 0.0002 (0.006) | 1.000 |
| lag_Population density | 0.0145*** (0.006) | 1.01 | 0.0105 (0.007) | 1.010 |
| lag_Tourist arrivals | 0.0042*** (0.001) | 1.00 | 0.0007 (0.002) | 1.000 |
| Intercept | 10.700*** (0.478) | | 1.520** (0.737) | |
| Log pseudolikelihood | | −15,100 | | −12,100 |
| p−value | | 0.0000 | | 0.0000 |
| Obs. | | 3,612 | | 3,012 |
| Nr. of regions | | 197 | | 190 |

*Notes: *p<0.10, **p<0.05, ***p<0.01. Bootstrap standard errors in parentheses*

regression (2) (IRR = 1.31), where all the variables are included. For injuries (Table 3), Southern regions show a 273% higher injury rate in regression (1) (IRR = 3.73), reduced to 179% in regression (2). Western regions also display elevated risks, with fatality risks 83% and 106% higher in regressions (1) and (2), respectively, and injury risks 112% and 111% higher. Central and Eastern regions show smaller but significant increases in fatalities—25% in regression (1) and 33% in regression (2)—but their injury rates are not significantly different from Northern regions in regression (2). These findings suggest that the Southern and Western regions face greater challenges in the RTA, influenced by cultural and institutional factors beyond socioeconomic conditions, as noted in studies by Kopits and Cropper (2005) and Albalate et al. (2013).

Table 3: Regression results for road traffic accidents injuries

| **Dep. Var. is RTA injuries** | **(1)** | | **(2)** | |
|---|---|---|---|---|
| | **Coef.** | **IRR** | **Coef.** | **IRR** |
| *Location* | | | | |
| • Northern | base | | Base | |
| • Western | 0.7520*** (0.061) | 2.120 | 0.7460*** (0.102) | 2.110 |
| • Central & Eastern | 0.2160*** (0.058) | 1.240 | 0.0993 (0.116) | 1.100 |
| • Southern | 1.3200*** (0.088) | 3.730 | 1.0300*** (0.137) | 2.790 |
| GDP per capita | −0.1310*** (0.045) | 0.877 | −0.0172 (0.0822) | 0.983 |
| Informal economy | − | − | 0.0449*** (0.005) | 1.050 |
| Motorway density | −0.0005*(0.001) | 1.0006 | 0.0002 (0.001) | 1.000 |
| Passenger cars | 0.0001 (0.001) | 1.0000 | 0.0001 (0.001) | 1.000 |
| Road Freight | 0.00355 (0.002) | 1.000 | 0.0030 (0.003) | 1.000 |
| Fleet age | − | − | 0.0094** (0.004) | 1.010 |
| Perceptions of road safety | −0.0538*** (0.009) | 0.948 | −0.1320*** (0.047) | 0.876 |
| Tertiary education | −0.0261*** (0.001) | 0.974 | −0.0225*** (0.002) | 0.978 |
| Rule of law | − | − | 0.0056*** (0.001) | 1.010 |
| Mean temperature | −0.1010*** (0.010) | 0.904 | −0.0622*** (0.016) | 0.940 |
| Population density | −0.0046 (0.032) | 0.995 | 0.0750 (0.064) | 1.080 |

| | | | | |
|---|---|---|---|---|
| Tourist arrivals | 0.1450*** (0.010) | 1.160 | 0.1680*** (0.013) | 1.180 |
| *Variables with spatial lags* | | | | |
| lag_GDP per capita | 0.0120** (0.005) | 1.010 | 0.0118** (0.006) | 1.010 |
| lag_Informal economy | – | – | −0.0142*** (0.005) | 0.986 |
| lag_Motorway density | 0.0012*** (0.001) | 1.000 | −0.0003 (0.001) | 1.000 |
| lag_Passenger cars | 0.0001** (0.001) | 1.000 | 0.0001 (0.001) | 1.000 |
| lag_Road Freight | 0.0014 (0.001) | 1.000 | 0.0025 (0.002) | 1.000 |
| Lag_Fleet age | – | – | 0.0044** (0.002) | 1.000 |
| lag_Perceptions of road safety | −0.1010*** (0.028) | 0.904 | −0.0736 (0.094) | 0.929 |
| lag_Tertiary education | −0.0015*** (0.001) | 0.998 | −0.0004 (0.001) | 1.000 |
| lag_Mean temperature | −0.0005 (0.005) | 1.000 | 0.0109 (0.012) | 1.010 |
| lag_Population density | 0.0039 (0.003) | 1.000 | −0.00264 (0.005) | 0.997 |
| lag_Tourist arrivals | 0.0020* (0.001) | 1.000 | 0.0023* (0.001) | 1.000 |
| Intercept | 8.2400*** (0.408) | | 4.8400*** (1.240) | |
| Log pseudolikelihood | −26,300 | | −21,400 | |
| p−value | 0.0000 | | 0.0000 | |
| Obs. | 3,448 | | 2,848 | |
| Nr. of regions | 197 | | 190 | |

*Notes: *p<0.10, **p<0.05, ***p<0.01. Bootstrap standard errors in parentheses*

Research by Üzümcüoğlu et al. (2018) and Özkan et al. (2006) further highlights the influence of cultural norms and social discipline, which are often less developed in many Southern European and Middle Eastern countries, contributing to higher accident rates.

Higher *GDP per capita* is associated with fewer RTA fatalities in regression (1), consistent with literature indicating that higher economic development improves road safety through better infrastructure and vehicles (Matas et al., 2018; Sinha et al., 2021; Sirajudeen et al., 2021). However, this effect becomes insignificant in regression (2), suggesting that it is mediated by other factors, such as the *informal economy* or *fleet age*. Similarly, *GDP per capita* is negatively associated with RTA injuries in regression (1) but becomes insignificant in regression (2).

Wealthier neighbouring regions lower local fatality risks, likely due to shared infrastructure, but increase injury risks, suggesting complex regional patterns. The size of the *informal economy*, introduced in regression (2), is positively associated with both RTA fatalities and injuries. A larger informal sector, often indicative of weaker institutional capacity and low regulatory compliance (Deléchat and Medina, 2020), appears to increase road safety risks through channels such as unlicensed driving, lack of infrastructure investment, or poor vehicle maintenance. In line with this, Nani et al. (2025) report that informal economic activities along major highways in Ghana increase the risk of accidents due to proximity to traffic and poor infrastructure. Such conditions not only heighten congestion but also contribute to the likelihood of serious accidents, supporting previous findings that associate informality with fatal outcomes. Spatial lags of the informal economy are positive for fatalities (coef. = 0.0144, IRR = 1.01) and negative for injuries (coef. =- 0.0142, IRR = 0.986), suggesting cross-regional influences. These findings are particularly noteworthy, as the role of the informal economy in shaping road safety outcomes has been largely overlooked in prior empirical research. The results thus extend the literature by linking macro-institutional weaknesses (Pappadà and Rogoff, 2025; Schneider and Asllani, 2022), proxied through informal economic activity, to tangible safety risks on European roads, and suggest that addressing informality may be as critical to improving road safety as upgrading infrastructure or raising incomes.

Regarding infrastructure, higher motorway density reduces RTA fatalities, supporting studies that link high-quality infrastructure to reduced crash frequency (Hamzeie et al., 2019). The effect on injuries is marginally significant and negative in regression (1) but insignificant in regression (2). Spatial effects reduce fatalities but increase injuries in some cases, possibly due to more traffic conflict points (Wang et al., 2012), while the number of *passenger cars* has no significant effect on either fatalities or injuries across all regressions. This aligns with literature suggesting that high vehicle density in urban areas, where speeds are lower, may not increase accident frequency and severity (Høye and Hesjevoll, 2020). Spatial lags are also insignificant, indicating limited regional spillover effects. *Road freight* is associated with higher RTA fatalities in regression (1) but shows no significant effect in regression (2), suggesting that other factors, such as the *rule of law* or *fleet age*, may mediate this relationship. For injuries, *road freight* has no significant impact in either regression. These findings diverge from prior research, which often links heavy vehicles to increased crash severity due to their reduced maneuverability and contribution to traffic congestion (e.g. Wang et al. (2022)). The lack of significance in regression (2) may indicate that freight-related risks are mitigated by regional policies or infrastructure quality, which are better captured when national-level variables are included. Spatial effects suggest that higher freight activity in neighbouring regions slightly reduces local fatality risks, possibly because heavy vehicles are diverted to adjacent areas with better road networks or stricter regulations. This could reflect cross-border logistics patterns, where freight routes avoid congested or less safe local roads. However, the absence of a clear association with injuries suggests that freight-related accidents may be more fatal than injury prone, possibly due to the higher impact forces involved in crashes with heavy vehicles (Zhang et al., 2013).

*Fleet age* is negatively associated with RTA fatalities, which contrasts with expectations that older vehicles increase risks due to outdated safety features (Santolino et al., 2022; Török, 2020). This unexpected finding may stem from older vehicles being driven more cautiously, at lower speeds, or less frequently, particularly in rural or disadvantaged regions where newer cars are less common. Alternatively, it could reflect a survivor bias, where only well-maintained older vehicles remain in use. In contrast, fleet age is positively associated with RTA injuries, suggesting that older vehicles may contribute to higher injury rates, possibly due to reduced safety features or increased degradation. Spatial effects show a positive association with fatalities but a negative one with injuries, indicating that the presence of older vehicles in neighbouring regions may exacerbate fatal crashes locally, perhaps due to cross-regional travel on shared highways, while reducing injury rates through slower driving speeds.

*Perceptions of road safety* shows a negative and statistically significant correlation with traffic accidents, both in terms of fatalities (in the full model) and injuries, confirming that regions where citizens view road safety as a significant issue experience lower accident rates. This finding may reflect heightened social awareness or stricter enforcement of legislation (Özkan et al., 2006). Spatial lags are negative but insignificant for fatalities and significant for injuries in regression (1), suggesting regional spillover in safety awareness. Education (*tertiary education*) consistently shows a significant negative effect on both fatalities and injuries across all regressions. This supports the literature which links higher education with safer driving behaviour (Ashkan et al., 2013), although some studies find no effect (Castillo-Manzano et al., 2014). Spatial effects further indicate that educated populations in neighbouring regions contribute to lower local accident rates, possibly through cultural diffusion of responsible driving norms or regional policies promoting road safety education. This reinforces the importance of education as a long-term strategy to improve road safety, particularly in regions with historically high accident rates.

Stronger *rule of law* is associated with higher reported RTA fatalities and injuries, likely reflecting more accurate reporting rather than increased road danger (e.g., Gaygısız (2010)). In countries with robust governance, accidents are more likely to be documented thoroughly, inflating reported rates compared to those with weaker institutions. This finding highlights the need to account for data reliability when comparing road safety across countries and/or regions. It also aligns with global studies showing that better governance improves road safety outcomes through stricter enforcement and better infrastructure, but reporting practices can complicate observed associations (Anbarci et al., 2006).

Among control variables, higher *mean temperatures* are associated with fewer fatalities in regression (1) and fewer injuries in both regressions, likely because better weather improves driving conditions (Amin et al., 2014). Foreign *tourist arrivals* increase injury rates, particularly in popular tourist destinations, with spatial effects suggesting that tourism-related traffic spills over to neighbouring regions (Psarras et al., 2024). This may reflect unfamiliarity with local roads or increased traffic volumes during peak seasons. Higher *population density* reduces fatalities in regression (2), consistent with lower driving speeds in urban areas (Nieminen et al., 2002), though spatial effects indicate that denser populations in adjacent regions may increase local fatality risks, possibly due to commuter traffic on shared roads.

Figure 2 complements the regression results by visualising the marginal effects of non-static predictors on RTA fatalities across European countries, grouped by their broader regional classifications. It highlights that *motorway density* and *tertiary education* display the most consistently negative marginal effects, indicating their strong protective influence on road safety across nearly all countries, especially in the case of *tertiary education* in Southern countries.

This supports earlier results suggesting that educational attainment significantly reduces the risks of fatal accidents. In contrast, *road freight* activity shows a relatively strong and positive marginal effect in Western countries, such as Germany, France and the UK – highlighting its role in increasing fatality risks, consistent with regression (1). *Fleet age* and *tourist arrivals* also exhibit negative marginal effects in many cases, though their effects are smaller in magnitude and more heterogeneous across countries; notably, the latter variable shows no effect in some Western and Northern European countries. Moreover, cross-national differences often reflect regional patterns, with Western and Southern European countries showing stronger positive effects for risk factors, while Northern and some Central and Eastern countries tend to display less pronounced or negative effects. Meanwhile, *GDP per capita*, *passenger cars*, and *population density* show marginal effects that are close to zero for most countries, indicating that their impact is likely mediated through other variables or more context-specific.

Figure 3, which visualises the marginal effects of non-static predictors on RTA injuries across European countries, provides additional insights when compared to the previous regression results. It confirms a consistent negative marginal effect of tertiary education on injuries, aligning with regression findings where higher education levels significantly reduced both fatalities and injuries. *GDP per capita* shows a negative effect in most countries, supporting regression (1)'s negative effect on injuries, though this effect weakens in regression (2). In line with the regression results, tourist arrivals exhibit small positive effects, especially in Southern tourist countries (e.g., Spain, Italy), consistent with regression findings linking tourism to increased injury risks. Notably, *fleet age* displays large negative effects, suggesting a protective influence contrary to expectations, similar to the unexpected findings in the fatality regression. These results reinforce regional variations, with Southern and Western countries showing mixed effects, while Northern countries generally exhibit smaller impacts.

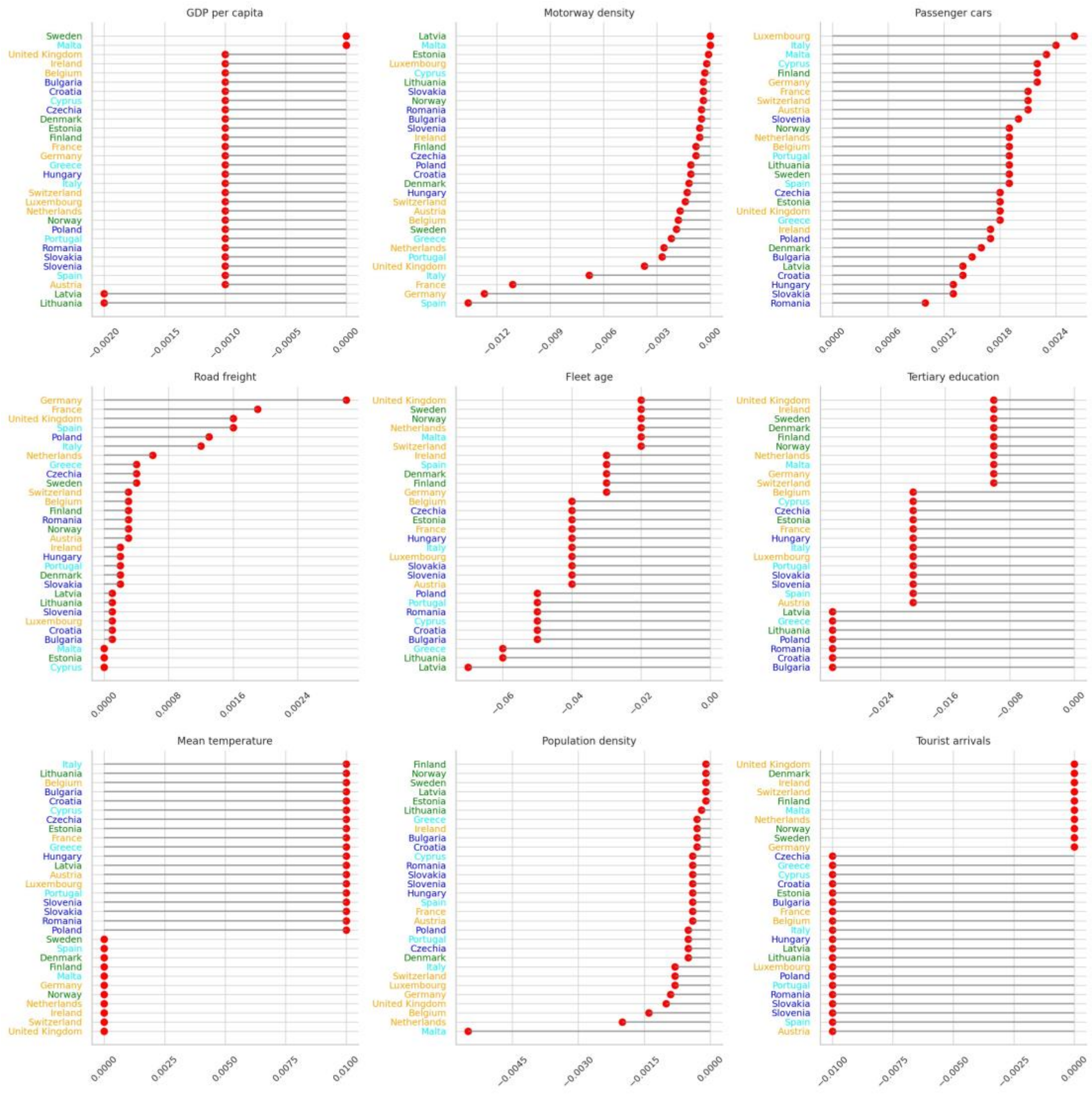



Figure 2: Marginal effects of time-varying predictors on RTA fatalities. **Note:** Northern countries in green; Western countries in orange; Central & Eastern countries in blue; Southern countries in cyan.

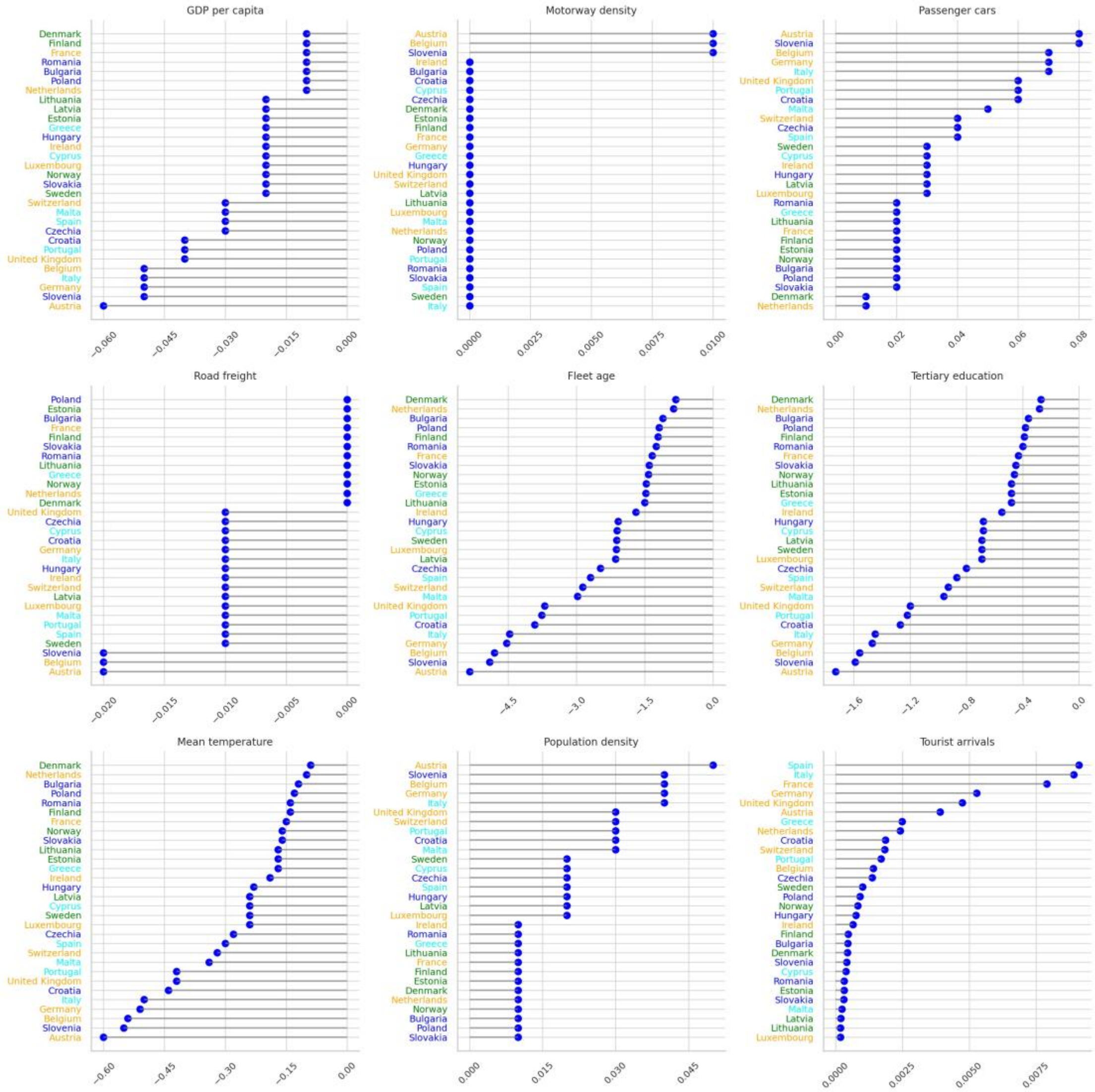



Figure 3: Marginal effects of time-varying predictors on RTA injuries. **Note:** Northern countries in green; Western countries in orange; Central & Eastern countries in blue; Southern countries in cyan.

## *4.2 Robustness checks*

An alternative assessment was carried out to assess the robustness of the results, replacing the *rule of law* variable with *traffic fines*[7] (Appendix IX). The main findings

[7] Data on traffic fines were primarily obtained from https://speedingeurope.com/, except for Cyprus, Malta, and Bulgaria, where information was collected from national or official sources.

remain largely consistent with the basic analysis. Specifically, geographical differences remain pronounced, with Southern and Western regions showing higher rates of fatal and non-fatal accidents compared to Northern regions. At the same time, variables such as the informal economy, perceived road safety, tertiary education, and tourist arrivals remain significant, affecting both fatalities and injuries in a similar way.

The inclusion of traffic fines does not substantially alter the overall picture. The positive or negative direction of the effects remains the same, which reinforces the reliability of the key findings. Moreover, the results indicate that sanctions alone are not sufficient to account for the regional differences, but rather operate in a complementary way to institutional and cultural factors, while in the case of fatal accidents they show no effect at all.

As a second robustness check, we investigated potential endogeneity in GDP per capita. To address this, we used GDP per capita from previous years (1980–1999), derived from the ARDECO database, as an instrumental variable (IV) (see Appendix X). Endogeneity may arise due to reverse causality. Higher income can enhance infrastructure, vehicle safety, and traffic regulation, thereby reducing accidents, while a reduction in accidents may increase productivity and growth, raising GDP. The first stage regression confirms that the instrument is relevant, as it has a statistically significant effect on GDP per capita. However, the control function residual from the first stage is not significant in the second stage Negative Binomial regression, indicating no evidence of endogeneity. Thus, the IV approach does not substantially alter the results, supporting the consistency of the main panel count models. [8] Finally, to address concerns related to the use of regional data and the potential misallocation of RTAs across neighbouring regions, particularly in the presence of interregional travel, we conducted an additional robustness check excluding major capital regions, namely Rome, Vienna, Berlin, Paris, and Madrid. The estimated coefficients and their

8 We also tested for endogeneity using the length of Roman roads as an instrumental variable. However, this instrument was not valid for our panel dataset structure.

statistical significance remain very similar to those reported in the baseline specification. This suggests that the main results are not driven by potential spatial reporting biases associated with capital regions.

# 5. Conclusion

This study examines the disparities in road traffic accident (RTA) casualties between European countries by exploring their underlying causes and mechanisms. To this end, it employs a range of variables related to economic, technical, institutional, and regional characteristics to elucidate the factors that contribute to the divergent outcomes in road safety between European countries. The findings reveal variation among them, with Southern countries experiencing the highest rates of RTA casualties (including fatalities and injuries), followed by Western, Central and Eastern, and Northern regions. The results suggest that road safety issues may not be effectively addressed through purely rational technical approaches (e.g., infrastructure and vehicle technology), as the causes of RTA are multifaceted and involve behavioural, institutional, and cultural dimensions. Key determinants such as the size of informal economy, perceptions of road safety, tertiary education, and rule of law are instrumental in explaining these differences and mechanisms. Moreover, the marginal effects of non-static predictors confirm the regression results, highlighting that tertiary education has a significant negative effect on both RTA fatalities and injuries across European countries.

The study reveals that a combination of diverse interventions should be tailored for each country or even between regions within the same country. Governments can adapt their policies to meet specific needs. For example, in areas with low road safety awareness and tertiary education, there is a need to improve educational initiatives on road safety in schools. In regions with lower GDP per capita, it is necessary to reassess safety issues concerning technical aspects, prioritising infrastructure maintenance and the expansion of the motorway network to ensure safety. The implementation of educational campaigns which both advocate following safety measures during driving and warn about the risks of unsafe driving serves as a crucial factor for safety improvement. However, altering behavioural patterns and cultural norms presents significant challenges, often requiring more time to yield equitable results.

Changes in culture are associated with people's mindsets and values. Fostering personal accountability, prioritising safety, integrating safety into education, and rewarding consistent attention to road safety can cultivate a culture of safety and responsibility. To encourage behaviours that minimise road traffic risks, it is essential to adhere consistently to rules and regulations, such as traffic laws and the use of seatbelts and helmets. Traffic police and law enforcement play a crucial role in this effort; they must be structured and implemented in a way that discourages people from engaging in dangerous driving. Similarly, distractions such as mobile phones or multitasking while driving should be avoided habitually. Hofstede's dimensions and Schwartz's cultural values may offer additional insights into cultural perceptions. Their availability was limited to specific years and countries, which precluded their inclusion in the analysis. More research is needed in each country, particularly in the Southern group, to examine cultural, behavioural, and institutional perspectives. This will aid in effectively managing and weighting interventions. Future studies could also develop time series indicators for concepts such as perceptions of road safety to better capture the variation over time.

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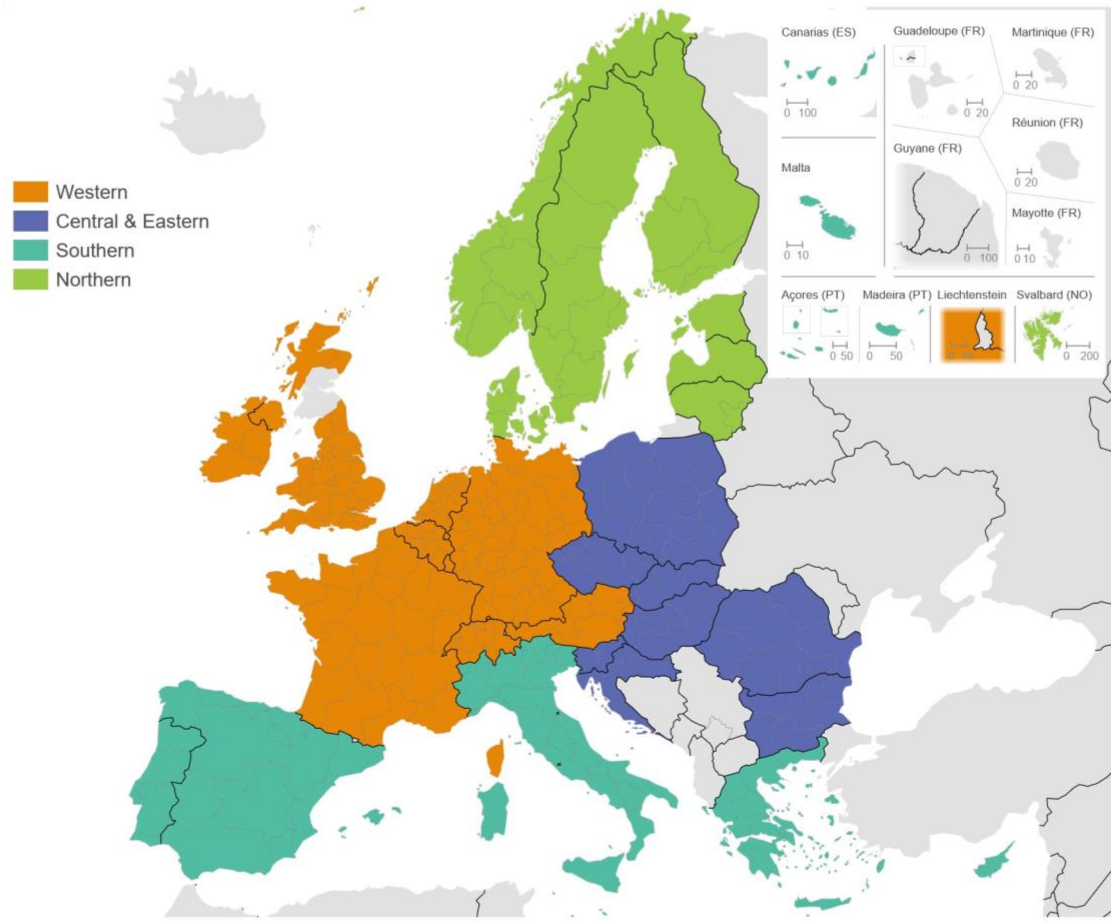
# 7. Appendices

## 7.1 *Appendix I. Location categories according to Eurovoc*




Administrative boundaries: © EuroGeographics © UN–FAO © Turkstat
Cartography: Eurostat – IMAGE, 06/2025

## 7.2 Appendix II: Eurobarometer Survey Questions

In terms of road safety, do you feel the following constitute a major safety problem, a minor safety problem, or is not a problem **[IN OUR COUNTRY]**?

A. Drivers/passengers not wearing seatbelts
B. People driving under the influence of alcohol
C. Drivers exceeding the speed limits
D. People driving while talking on a mobile phone without a hands-free kit
E. People driving while talking on a hands-free mobile phone

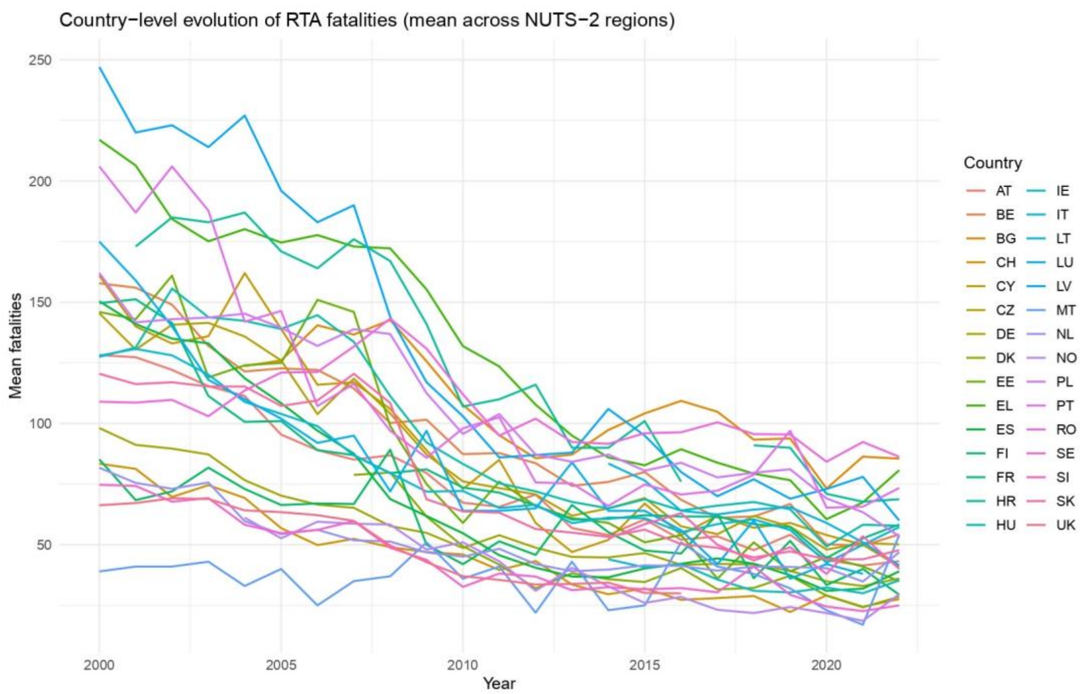
## 7.3 Appendix III: Description of the dataset

| **Variable** | **Source** |
| --- | --- |
| RTA fatalities (per million people) | Eurostat |
| RTA injuries (per million people) | Eurostat |
| Location | Eurovoc, Publications Office of the EU |
| GDP per capita in PPS | ARDECO (JRC/REGIO) |
| Informal economy | Schneider and Asllani (2022) |
| Motorway density = Total motorway (km) /area (km$^2$) | Eurostat |
| Passenger cars (per thousand inhabitants) | Eurostat |
| Road freight transport = Total transported goods in thousand tonnes | Eurostat |
| Fleet age | UNECE Statistical Database; ACEA |
| Perceptions of road safety | Flash Eurobarometer 301 (European Commission, 2010) |
| Tertiary education (% from 25 to 64 years) | Eurostat |
| Rule of Law (Percentile rank) | World Bank's Worldwide Governance Indicators |
| Mean temperature (°C) | World Bank's Climate Change Knowledge Portal |

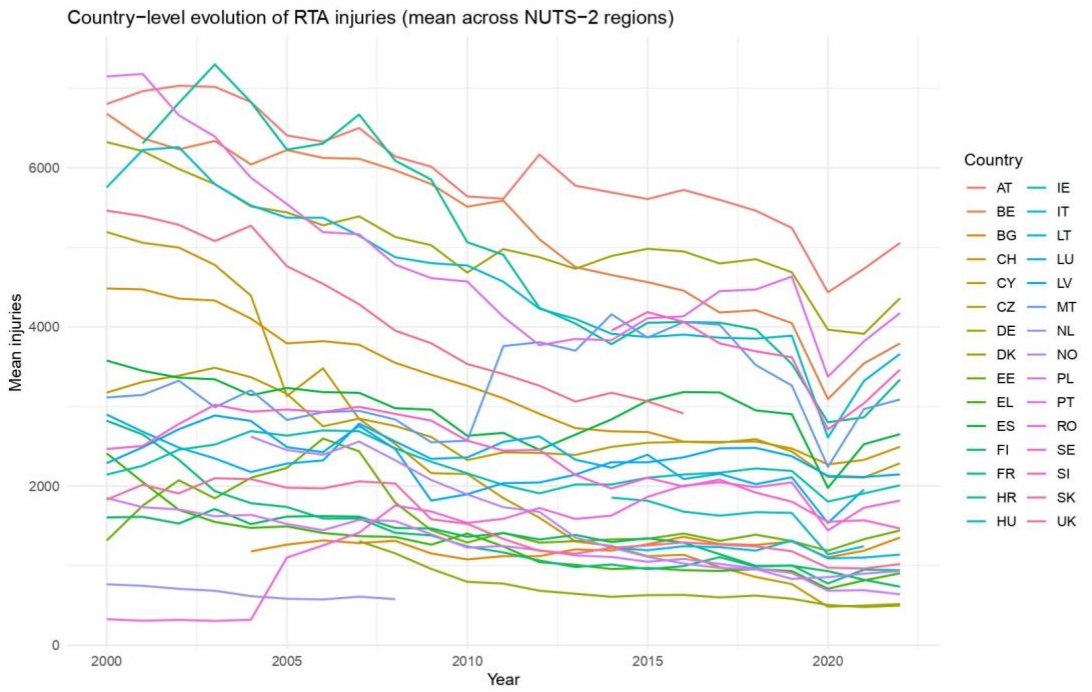
| | |
|---|---|
| Population density = Total population/land area (km²) | Eurostat |
| (Foreign) tourist arrivals | Eurostat |

## 7.4 Appendix IV: Road traffic fatalities and injuries over time

a) Fatalities




b) Injuries




## 7.5 Appendix V: Elements indicating overdispersion for the dependent Variables

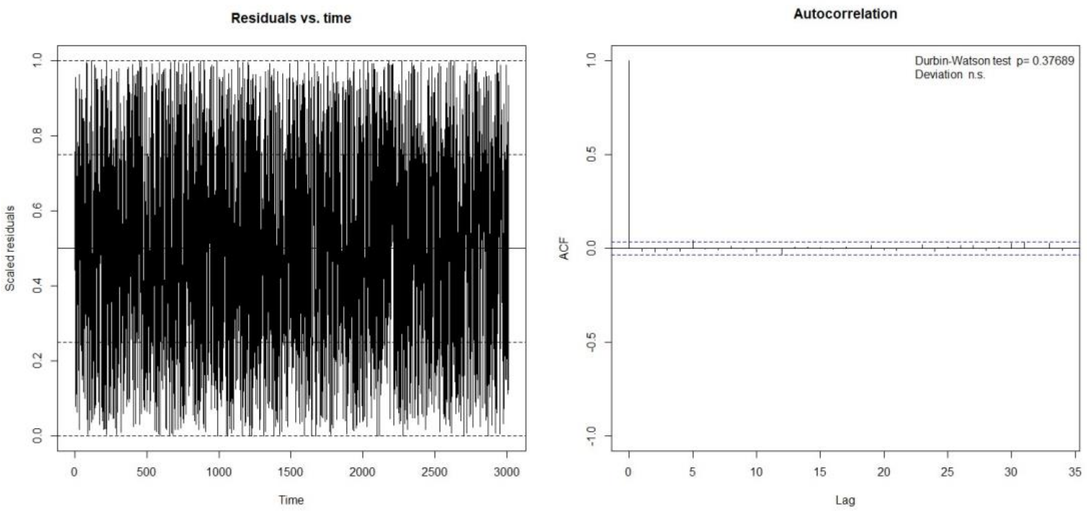
| Variable | Disper. Ratio | Zeros (%) | Exp. Zeros (%) | Overdispersion Indication |
|---|---|---|---|---|
| FATALITIES | 46.37 | 0.00 | ~0.00 | Severe overdispersion (ratio 46.37 >1) |
| INJURIES | 253.84 | 0.00 | ~0.00 | Extreme overdispersion (ratio 253.84 >1) |

## 7.6 Appendix VI: VIF, Tolerance of the model with spatial lags

| Variable | VIF | VIF 95% CI | adj. VIF | Tolerance |
|---|---|---|---|---|
| Location | 4.62 | [4.34, 4.93] | 1.29 | 0.25 |
| GDP per capita | 3.68 | [3.47, 3.92] | 1.92 | 0.27 |
| Informal economy | 3.36 | [3.16, 3.57] | 1.83 | 0.30 |
| Motorway density | 2.08 | [1.97, 2.19] | 1.44 | 0.48 |
| Passenger cars | 2.03 | [1.93, 2.15] | 1.43 | 0.49 |

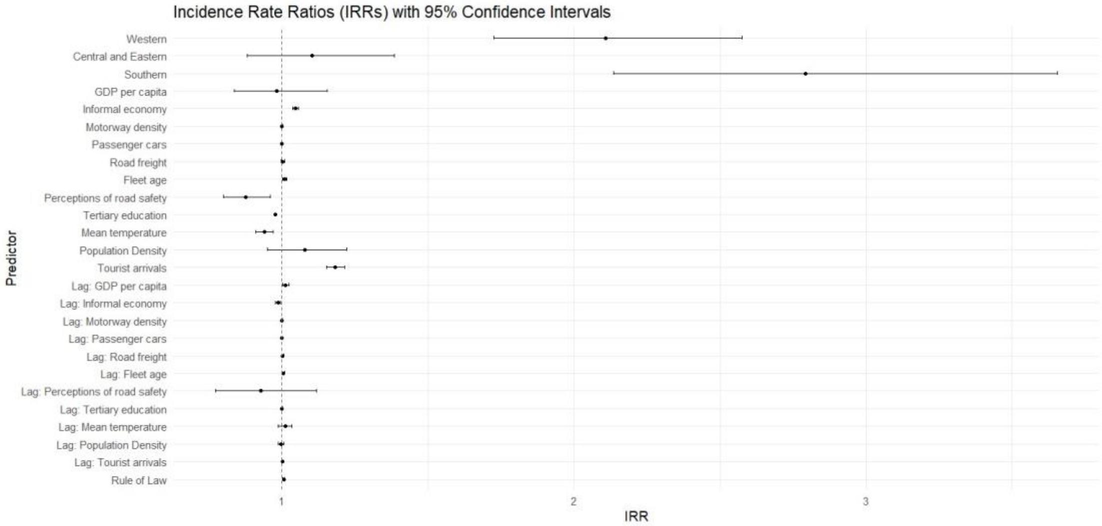
| | | | | |
|---|---|---|---|---|
| Road freight | 1.02 | [1.00, 1.13] | 1.01 | 0.98 |
| Fleet age | 1.99 | [1.89, 2.10] | 1.41 | 0.50 |
| Perceptions of road safety | 1.28 | [1.23, 1.34] | 1.13 | 0.78 |
| Tertiary education | 2.85 | [2.69, 3.03] | 1.69 | 0.35 |
| Rule of law | 1.59 | [1.52, 1.68] | 1.26 | 0.63 |
| Mean temperature | 2.14 | [2.03, 2.26] | 1.46 | 0.47 |
| Population density | 2.00 | [1.90, 2.11] | 1.41 | 0.50 |
| Tourist arrivals | 1.33 | [1.28, 1.39] | 1.15 | 0.50 |
| lag_GDP per capita | 2.59 | [2.45, 2.74] | 1.61 | 0.75 |
| lag_Informal economy | 3.32 | [3.13, 3.53] | 1.82 | 0.39 |
| lag_Motorway density | 1.08 | [1.05, 1.13] | 1.04 | 0.30 |
| lag_Passenger cars | 1.45 | [1.39, 1.52] | 1.20 | 0.93 |
| lag_Road freight | 1.33 | [1.27, 1.39] | 1.15 | 0.69 |
| lag_Fleet age | 1.41 | [1.35, 1.47] | 1.19 | 0.75 |
| lag_Perceptions of road safety | 2.35 | [2.23, 2.49] | 1.53 | 0.71 |
| lag_Tertiary education | 2.04 | [1.93, 2.15] | 1.43 | 0.42 |
| lag_Mean temperature | 2.55 | [2.41, 2.70] | 1.60 | 0.49 |
| lag_Population density | 2.02 | [1.92, 2.13] | 1.42 | 0.39 |
| lag_Tourist arrivals | 1.23 | [1.18, 1.29] | 1.11 | 0.50 |
| lag_Rule of law | 5.55 | [5.21, 5.92] | 2.36 | 0.18 |

## 7.7 Appendix VII: Autocorrelation tests of residuals




Residuals vs. Time and ACF plot with Durbin-Watson p-value

## 7.8 Appendix VIII: Incidence Rate Rations




## 7.9 Appendix IX: Robustness check with traffic fines instead of Rule of law

| Dependent Variable: **RTA fatalities** | | |
|---|---|---|
| Variable | Coef. (SE) | IRR |
| *Location* | | |
| • Northern | base | |
| • Western | 0.749*** (0.102) | 2.115 |
| • Central & Eastern | 0.159 (0.116) | 1.172 |
| • Southern | 0.194 ** (0.113) | 1.215 |
| GDP per capita | −0.009 (0.079) | 0.991 |
| Informal economy | 0.0654*** (0.004) | 1.068 |
| Motorway density | −0.006*** (0.001) | 0.994 |
| Passenger cars | 0.001 (0.001) | 1.000 |
| Road freight | 0.007*** (0.003) | 1.007 |
| Fleet age | −0.028*** (0.007) | 0.972 |
| Perceptions of road safety | −0.049*** (0.017) | 0.953 |
| Tertiary education | −0.021*** (0.002) | 0.979 |
| Mean temperature | −0.021*** (0.007) | 0.979 |
| Population density | −0.177*** (0.026) | 0.838 |
| Tourist arrivals | 0.099*** (0.016) | 1.104 |
| Traffic fines | 0.001 (0.001) | 1.000 |
| *Variables with spatial lags* | | |
| lag_GDP per capita | 0.001 (0.005) | 1,000 |
| lag_Informal economy | 0.014*** (0.004) | 1.014 |
| lag_Motorway density | −0.001* (0.001) | 0.999 |
| lag_Passenger cars | −0.001** (0.001) | 1.000 |

| | | |
|---|---|---|
| lag_Road freight | −0.003 (0.002) | 0.997 |
| lag_Fleet age | 0.005*** (0.002) | 1.005 |
| lag_Perceptions of road safety | −0.060 (0.039) | 0.942 |
| lag_Tertiary education | −0.005*** (0.001) | 0.995 |
| lag_Mean temperature | −0.008* (0.001) | 0.992 |
| lag_Population density | 0.015** (0.007) | 1.015 |
| lag_Tourist arrivals | 0.001 (0.001) | 1.000 |
| Intercept | 3.557*** (0.810) | |
| Observations | 3,012 | |
| Log pseudolikelihood | −11,595 | |
| p−value | 0.000 | |
| Nr. of regions | 190 | |
| AIC | 23,247 | |

*Bootstrap standard errors in parentheses * p < 0.10, ** p < 0.05, *** p < 0.01*

| Dependent Variable: **RTA injuries** | | |
|---|---|---|
| **Variable** | **Coef. (SE)** | **IRR** |
| *Location* | | |
| • Northern | base | |
| • Western | −0.242 (0.361) | 0.785 |
| • Central & Eastern | −1.119** (0.460) | 0.327 |
| • Southern | 0.038** (0.329) | 1.039 |
| GDP per capita | −0.086 (0.083) | 0.917 |
| Informal economy | 0.042*** (0.006) | 1.043 |
| Motorway density | 0.001* (0.001) | 1.001 |
| Passenger cars | −0.001 (0.001) | 1.000 |
| Road freight | 0.003 (0.003) | 1.003 |
| Fleet age | −0.001 (0.005) | 0.999 |
| Perceptions of road safety | −0.133*** (0.033) | 0.875 |
| Tertiary education | −0.021*** (0.002) | 0.979 |
| Mean temperature | −0.059*** (0.013) | 0.943 |
| Population density | 0.115* (0.061) | 1.122 |
| Tourist arrivals | 0.162*** (0.011) | 1.176 |
| Traffic fines | −0.005** (0.002) | 0.995 |
| *Variables with spatial lags* | | |
| lag_ GDP per capita | 0.014** (0.006) | 1.014 |
| lag_Informal economy | −0.015*** (0.005) | 0.986 |
| lag_Motorway density | −0.001 (0.001) | 1.000 |
| lag_Passenger cars | 0.0001 (0.001) | 1.000 |
| lag_Passenger cars | 0.002 (0.002) | 1.002 |
| lag_Fleet age | 0.005** (0.002) | 1.005 |

| | | |
|---|---|---|
| lag_Perceptions of road safety | −0.078 (0.070) | 0.925 |
| lag_Tertiary education | −0.001 (0.001) | 0.999 |
| lag_Mean temperature | 0.013 (0.013) | 1.014 |
| lag_Population density | −0.001 (0.005) | 1.000 |
| lag_Tourist arrivals | 0.002* (0.001) | 1.002 |
| Intercept | 7.338*** (1.544) | |
| Observations | 2,848 | |
| Log pseudolikelihood | −20,626 | |
| p−value | 0.000 | |
| Nr. of regions | 190 | |
| AIC | 41,310 | |

*Bootstrap standard errors in parentheses * p < 0.10, ** p < 0.05, *** p < 0.01*

## *7.10 Appendix X: Two-Stage IV Negative Binomial Regression Results (Endogeneity check)*

| **Variable** | **First Stage: GDP per capita** | **Second Stage: RTA fatalities (2SRI with vhat)** |
|---|---|---|
| GDP per capita 1980–1999 | 0.001*** (0.0005) | |
| GDP per capita | | 0.028 (0.164) |
| Informal economy | 0.002** (0.002) | 0.045*** (0.005) |
| Motorway density | 0.036*** (0.003) | 0.007** (0.009) |
| Passenger cars | −0.0004 (0.0003) | −0.001 (0.0003) |
| Fleet age | 0.018*** (0.002) | 0.012* (0.006) |
| Road freight | 0.024*** (0.004) | 0.013** (0.006) |
| Perceptions of road safety | 0.002 (0.002) | 0.017 (0.019) |
| Tertiary education | −0.004*** (0.001) | −0.023*** (0.003) |
| Rule of law | 0.008*** (0.001) | 0.018*** (0.002) |
| Mean temperature | 0.009*** (0.003) | 0.014* (0.008) |
| Population density | −0.205*** (0.023) | −0.295*** (0.025) |
| Tourist arrivals | 0.027*** (0.002) | 0.014** (0.020) |
| Residual (vhat) | | 0.103 (0.187) |
| Constant | 1.261 (1.754) | 1.190 (0.807) |
| $R^2$ / Pseudo $R^2$ | 0.744 | 0.10 |

| | | |
|---|---|---|
| Chi–square | 5874.20 | 1098.72 |
| Obs. | 2423 | 2423 |

*Robust standard errors in parentheses. * p<0.10, **p<0.05, ***p<0.01*

## 7.11 Appendix XI: Robustness checks excluding major European capital regions

| Dep.Var.is RTA fatalities | (1) | (2) |
|---|---|---|
| Variable | **Coef.** | **Coef** |
| *Location* | | |
| Northern | base | base |
| Western | 0.6050*** (0.060) | 0.7240*** (0.062) |
| Central and Eastern | 0.1960*** (0.058) | 0.2840*** (0.061) |
| Southern | 0.6102*** (0.088) | 0.2660*** (0.089) |
| GDP per capita | −0.4910*** (0.053) | 0.0808 (0.063) |
| Informal economy | – | 0.0758*** (0.004) |
| Motorway density | −0.0073*** (0.001) | −0.0054*** (0.001) |
| Passenger cars | −0.0002 (0.001) | −0.0003 (0.001) |
| Road freight | 0.0048** (0.002) | 0.0055 (0.004) |
| Fleet age | – | −0.0198*** (0.006) |
| Perceptions of road safety | 0.0011 (0.011) | −0.0528*** (0.020) |
| Tertiary education | −0.0332*** (0.001) | −0.0219*** (0.002) |
| Rule of law | – | 0.0096*** (0.001) |
| Mean temperature | −0.0747*** (0.010) | 0.0052 (0.007) |
| Population density | −0.0867*** (0.024) | −0.1500 (0.034) |
| Tourist arrivals | −0.0067 (0.005) | 0.0863*** (0.013) |
| *Variables with spatial lags* | | |
| lag_GDP per capita | −0.0096* (0.005) | −0.0162*** (0.005) |
| lag_Informal economy | – | 0.0144*** (0.004) |
| lag_Motorway density | 0.0002 (0.001) | −0.0019*** (0.001) |
| lag_Passenger cars | −0.0001 (0.001) | −0.0001 (0.001) |

| | | |
|---|---|---|
| lag_Road freight | −0.0054*** (0.001) | −0.0033 (0.002) |
| lag_Fleet age | − | 0.0044*** (0.002) |
| lag_Perceptions of road safety | −0.0237 (0.018) | −0.0489 (0.031) |
| lag_Tertiary education | −0.0064*** (0.001) | −0.0041*** (0.001) |
| lag_Mean temperature | 0.0041 (0.005) | 0.0002 (0.005) |
| lag_Population density | 0.0149*** (0.003) | 0.0105 (0.007) |
| lag_Tourist arrivals | 0.0036*** (0.001) | 0.0007 (0.001) |
| Intercept | 10.6800*** (0.408) | 1.5200** (0.655) |
| Log pseudolikelihood | −15,100 | −12,100 |
| Obs | 3,497 | 2,912 |
| p−value | 0.0000 | 0.0000 |
| Nr. of Regions | 192 | 185 |

*Bootstrap standard errors in parentheses. * p < 0.1, ** p < 0.05, *** p < 0.*

| Dep.Var.is RTA injuries | **(1)** | **(2)** |
|---|---|---|
| **Variable** | **Coef.** | **Coef** |
| *Location* | | |
| Northern | base | base |
| Western | 0.7520*** (0.060) | 0.7460*** (0.102) |
| Central and Eastern | 0.2160*** (0.058) | 0.0993 (0.116) |
| Southern | 1.3200*** (0.088) | 1.0300*** (0.137) |
| GDP per capita | −0.1310*** (0.045) | −0.0172 (0.082) |
| Informal economy | − | 0.0449*** (0.005) |
| Motorway density | −0.0005 (0.001) | 0.0002 (0.001) |
| Passenger cars | 0.0001 (0.001) | 0.0001 (0.001) |
| Road freight | 0.0036 (0.002) | 0.0031 (0.003) |
| Fleet age | − | 0.0094** (0.004) |
| Perceptions of road safety | −0.0538*** (0.009) | −0.1320*** (0.047) |
| Tertiary education | −0.0261*** (0.001) | −0.0225*** (0.002) |
| Rule of law | − | 0.0056*** (0.001) |
| Mean temperature | −0.1010*** (0.011) | −0.0622*** (0.016) |
| Population density | −0.0046 (0.032) | 0.0750 (0.064) |
| Tourist arrivals | 0.1450*** (0.010) | 0.1680** (0.013) |
| *Variables with spatial lags* | | |
| lag_GDP per capita | 0.0120** (0.005) | 0.0118** (0.006) |
| lag_Informal economy | − | −0.0142*** (0.005) |
| lag_Motorway density | 0.0012*** (0.001) | −0.0003 (0.001) |
| lag_Passenger cars | 0.0001** (0.001) | 0.0001 (0.001) |
| lag_Road freight | 0.0014 (0.001) | 0.0025 (0.002) |
| lag_Fleet age | − | 0.0044** (0.002) |
| lag_Perceptions of road safety | −0.1010*** (0.028) | −0.0736 (0.094) |

| | | |
|---|---|---|
| lag_Tertiary education | −0.0015*** (0.001) | −0.0004 (0.001) |
| lag_Mean temperature | −0.0005 (0.005) | 0.0109 (0.012) |
| lag_Population density | 0.0039 (0.003) | −0.0026 (0.005) |
| lag_Tourist arrivals | 0.0020* (0.001) | 0.0023* (0.001) |
| Intercept | 8.2400*** (0.408) | 4.8400 (1.240) |
| Log pseudolikelihood | −26,300 | −21400 |
| Obs | 3.333 | 2748 |
| p−value | 0.0000 | 0.0000 |
| Nr. of Regions | 192 | 185 |

*Bootstrap standard errors in parentheses. * p < 0.1, ** p < 0.05, *** p < 0.01*

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