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UK road accidents. Long run trends and persistence using fractional integration

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ABSTRACT

This study analyses long-term trends and persistence in road traffic accidents in the United Kingdom using fractional integration models. Although numerous interventions have been implemented to reduce accident rates, persistent effects and temporal dynamics have received little attention, especially in accidents involving pedestrians, cyclists and drivers. Traditional approaches, based on integer differentiation, do not adequately capture these prolonged dependencies, limiting understanding of the underlying processes. Fractional integration allows for the modelling of non-stationary series with mean reversion, offering a more accurate representation of the temporal structure and persistence in the data. The results show high persistence in cyclist and pedestrian deaths, indicating that temporary interventions are insufficient to achieve sustainable reductions in accident rates. These conclusions have direct implications for public policy formulation: permanent strategies are required that include investments in safe infrastructure (segregated lanes, improved pedestrian crossings), continuous enforcement of speed limits and regulations, and monitoring systems differentiated by user type. Overall, the study provides empirical evidence on the need for structural and sustained approaches to reduce accidents.

1. Introduction

Traffic accidents represent one of the major public health issues worldwide, with devastating consequences both in terms of loss of human lives and economic impact. Despite numerous efforts and policies implemented to reduce road traffic accidents, the persistence of traffic accidents remains a significant concern. This study focuses on analyzing long-term trends and the persistence of traffic accidents in the United Kingdom with annual data from 1927 to 2022 using fractional integration techniques.

Fractional integration allows data to be modelled with long-term processes, providing a more accurate understanding of the long-term dependency of traffic accidents. This study aims to identify persistence patterns that can better inform policymakers about the effectiveness of past interventions and help design more effective and sustainable policies to improve road safety. The results obtained are crucial for understanding how previous interventions have influenced current accident rates and for developing strategies that more effectively address the reduction of road traffic accidents.

In this research, fractional integration techniques are applied to model the persistence of traffic accidents over time. Different types of accidents, including those involving pedestrians, cyclists, and motorcyclists, are analyzed to determine if there are significant differences between these groups. The results provide a solid foundation for designing more effective and sustainable public policies.

The results of this research indicate a strong long-term persistence in road traffic fatality rates in the United Kingdom, especially for cyclists and pedestrians. This suggests that past interventions have had a lasting impact on accident rates but also highlights the need to continue monitoring and adjusting road safety policies for these vulnerable groups.

The rest of the paper is organized as follows. Section 2 presents a contextual setting on the historical evolution of the series under examination. Section 3 contains a brief literature review. Section 4 displays the dataset, and the methodology used, while Section 5 is devoted to the empirical results. Section 6 concludes the paper.

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2. Contextual setting

Traffic accidents are one of the main public health problems in the world and are, according to the latest *Global status report on road safety 2023* of the World Health Organization, the leading cause of death in people between 5 and 29 years of age. The global death toll in the same report records the deaths of 1.19 million people, of which two thirds were among people of working age, between 18 and 59 years of age. The report also highlights that, although only 60% of the world's vehicles are concentrated in low- and middle-income countries, these countries account for 92% of road deaths (World Health Organization, 2023).

Beyond the physical and moral damage caused by these accidents in our societies, there is also a strong economic impact. The World Health Organization estimates that the economic cost of road accidents accounts for 3% of GDP in developed countries (World Health Organization, 2023). Examining the connection between road accidents and GDP reveals that, on average, a 1% increase in road accidents leads to a 0.42% drop in real GDP (Tandrayen-Ragoobur, 2024). Technically, to the costs of suffering associated with injuries or family losses the medical costs and productivity losses associated with fatalities and injuries must also be added (Bougna et al., 2022).

In addition, the cost of accident prevention is not small. In 2012 alone, the UK estimated it to be £15,122 million, broken down into £1,955 million for lost productivity, £490 million in medical costs, £7,478 million in human costs and £4,840 million for property damage (Department for Transport, 2012).

All the data are alarming and the public health problem is amplified by these social and economic implications (Ahmed et al., 2023), which invite us to consider the problem as a whole, with a holistic approach. The figures have awakened the desire to work to reduce accident rates in the main international authorities.

Thus, in September 2020, the World Health Organization, together with the United Nations General Assembly (resolution 74/299), proclaimed the period 2021–2030 as the *Second Decade for Road Safety*, aiming to reduce by 50% the total number of deaths and injuries due to traffic crashes during that period. For its part, in 2018 the EU set itself the goal of also reducing the number of road fatalities by 50% by 2030. To achieve this, it has created the so-called Strategic Action Plan on Road Safety. The EU's wish is to achieve the goal of zero road fatalities by 2050 (Ecola et al., 2018).

One difficulty for these global strategies to improve road safety is that the number of accidents is very different in different regions of the world. Globally, the World Health Organization's *Global status report on road safety* 2023 indicates that 28% of all fatalities worldwide occurred in South East Asia, 25% in the Western Pacific, followed by 19% in Africa. The number of fatalities is significantly lower in the Americas and the Eastern Mediterranean region, where they are close to 11%, and drop to 5% in the rest of Europe. But within Europe, the differences are striking as can be seen in Table 1.

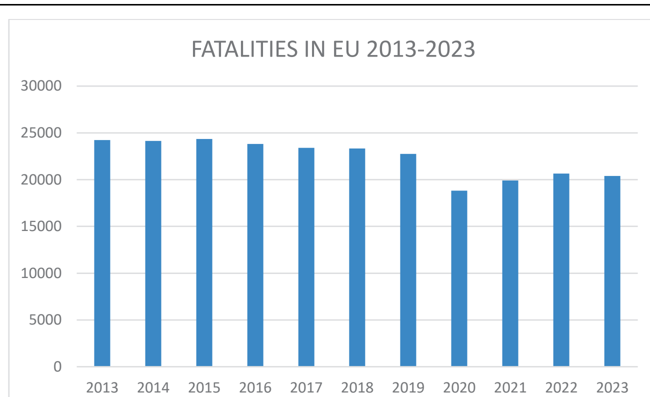
The Nordic countries (Sweden, Norway, Finland, Denmark) lead, together with Germany, the Netherlands and the UK, the ranking of European countries with the fewest accidents. In contrast, the European countries with the highest number of road accidents are Romania, Bulgaria, Croatia and the Baltic countries, with the exception of Estonia (World Health Organization (2023). It is also the case that the differences in accident reduction vary widely from one region to another.

The European Region has the largest decline in fatalities since 2010, with a 36% reduction, followed by the Western Pacific Region with a 16% decline (World Health Organization, 2023). Data in the EU, while highly stabilised at the overall level, show significant differences between countries. In the EU, the Annual statistical report on road safety in the EU 2025 indicates that, between 2013 and 2023, the number of road accidents has decreased very slightly in countries such as France, Austria, Germany, Portugal and Italy, while it has increased in Spain, the Netherlands, Estonia and Ireland (European Commission, 2025). On the other hand, Denmark, Norway, Belgium, Lithuania, and Slovenia are reducing the number of road fatalities very significantly (OECD International Traffic Forum, 2024) and are on track to meet the 50% fatality reduction target by 2030 (Zu et al., 2022). See Table 2 and Table 3. Table 4..

This is undoubtedly a complex problem as the causes of accidents coexist with many other factors. Of course, the causes of accidents are varied, but speeding, driving under the influence of alcohol or drugs, and the non-use of essential safety measures (motorbike helmets or seat belts) significantly increase the risk of death on the road (Golfiroozi et al., 2024). This is compounded by infrastructure investment factors. Eighty per-cent of roads assessed by the World Health Organization do not meet a minimum required rating for pedestrian safety. Furthermore, the aforementioned weak reduction in global mortality occurs in a context where the global vehicle fleet has doubled in the last decade, the road network is still undergoing significant expansion worldwide, and the world's population has increased by more than a billion people in the last decade.

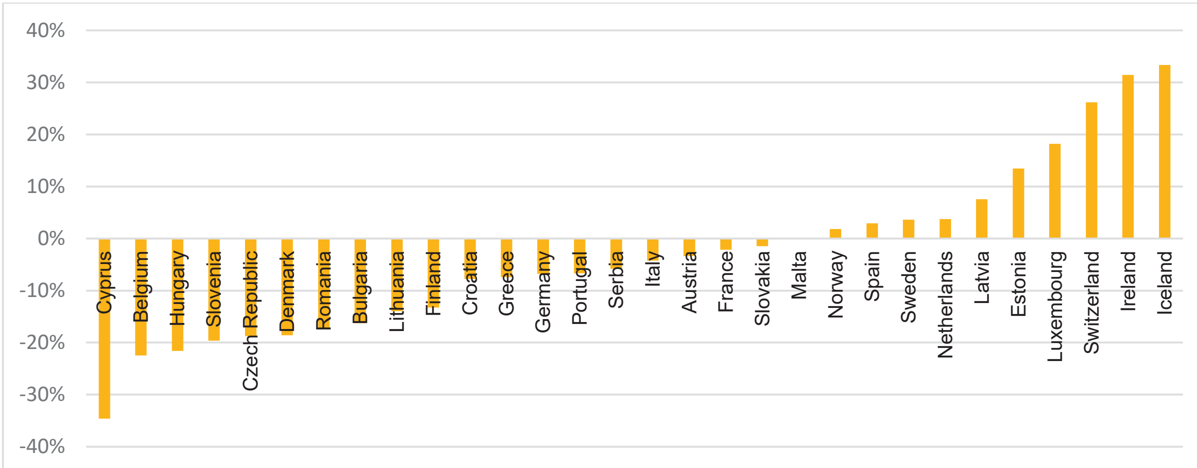
These differences in accident reduction data between neighbouring countries, which are even involved in common road safety policies, are the reason for the interest of this research. The evidence that there are countries where accident rates are not reduced, or are reduced very slowly, compared to others where road safety policies achieve better results, suggests a sophisticated study of the data (Elvik, 2010) is required to determine whether there are patterns of persistence that help

Table 1
Fatalities in EU 2013–2023.



Source: Own elaboration based on the Annual Statistical Report 2025 of the European Road Safety Observatory.

Table 2
Number of road fatalities in the EU and EFTA countries. Percentage change 2023 compared to 2019.



Source: Own elaboration based on the Annual Statistical Report 2025 of the European Road Safety Observatory.

Table 3
Number of Road fatalities per million population in the EU and EFTA countries 2013–2023.

	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023
EU-27	55	55	55	54	53	53	51	42	45	46	46
Belgium	69	67	68	59	54	53	56	43	45	46	43
Bulgaria	83	91	98	99	96	87	90	67	81	78	82
Czech R.	62	65	70	58	55	62	58	48	50	50	46
Denmark	34	32	31	37	30	30	34	28	22	26	27
Germany	41	42	43	39	39	40	37	33	31	33	34
Estonia	61	59	51	54	36	51	39	44	41	37	43
Ireland	41	41	35	39	32	29	29	30	27	31	35
Greece	80	73	73	76	68	65	64	54	58	63	61
Spain	36	36	36	39	39	39	37	29	32	37	38
France	51	53	54	54	53	50	50	39	45	50	48
Croatia	86	73	82	73	80	77	73	58	72	71	71
Italy	57	56	56	54	56	55	53	40	49	54	52
Cyprus	51	52	67	54	62	57	59	54	50	41	37
Latvia	88	106	95	80	70	77	69	73	78	60	75
Lithuania	86	91	83	66	67	62	67	63	53	43	56
Luxembourg	84	64	64	56	42	60	36	42	38	56	39
Hungary	60	63	65	62	64	65	62	47	56	55	49
Malta	40	23	25	51	41	38	32	21	17	54	30
Netherlands	28	28	31	31	31	35	34	30	29	37	34
Austria	54	51	56	50	47	46	47	39	41	41	44
Poland	88	84	77	80	75	75	77	66	59	50	52
Portugal	64	64	60	57	61	68	67	52	54	60	61
Romania	93	91	95	97	99	96	96	85	93	86	81
Slovenia	61	52	58	63	50	44	49	38	54	40	39
Slovakia	46	54	57	51	51	48	50	45	45	49	49
Finland	48	42	49	47	43	43	38	40	41	35	33
Sweden	27	28	27	27	25	32	22	20	20	22	22
Switzerland	33	30	31	26	27	27	22	26	23	28	27
Norway	37	29	24	26	20	20	20	17	15	21	20
Iceland	47	12	49	54	47	52	17	22	24	24	21
Liechtenstein	54	81	54	0	53	0	0	26	0	51	0

Source: Own elaboration based on the Annual Statistical Report 2025 of the European Road Safety Observatory.

to better delimit the type of scenario that policy-makers in each country must face when planning their policies.

The aim of this paper is to determine the persistence over time of a shock received on the time series of road accidents. Regardless of the nature of the shock and its immediate consequences, if we have information about the persistence of an impact over time on the accident rate, we can better target social and economic policy actions based on improving road safety. At the same time, this persistence would help to explain the differences in the effectiveness of the fight against road accidents in each country. The aim of this article is to offer an added-value perspective based on the study of the data, which allows us to understand the strength and intensity with which road safety policies should be implemented in order to obtain significant results in the reduction of road accidents. The study of this statistical persistence will be carried out using the fractional integration technique explained in detail below.

Regarding the UK data on which we base our study, the latest Reported road casualties Great Britain, annual report 2024, based on data

Table 4
Number of Road fatalities by groups in UK 2020–2024.

Road user type	Age group	Severity	2020	2021	2022	2023	2024
Pedestrians	All casualties	Killed	406	317	423	393	392
Pedestrians	All casualties	All casualties	18.323	14.932	19.170	19.248	19.092
Pedal cyclists	All casualties	Killed	126	116	107	87	83
Pedal cyclists	All casualties	All casualties	15.803	16.900	16.517	15.302	14.345
Motorcycle users	All casualties	Killed	291	291	351	325	319
Motorcycle users	All casualties	All casualties	14.023	14.836	17.210	17.002	16.407
Car occupants	All casualties	Killed	669	603	805	736	727
Car occupants	All casualties	All casualties	75.547	66.580	75.909	73.652	70.597
All road users	All casualties	Killed	1.563	1.406	1.798	1.632	1.607
All road users	All casualties	All casualties	131.201	120.920	137.842	134.389	128.920

Source: Department for Transport 2025: Reported Road casualties in Great Britain, provisional data.

from 2023, shows a slight decrease in the number of road accident victims, with low accident figures remaining stable, which has been the trend in recent years. Moreover, these accident figures in the UK have been among the lowest in the world for many years. In 2023, the UK had the third lowest number of road deaths per million population (Department for Transport, 2024). This stability in the number of fatalities and serious injuries suggests a detailed analysis.

It should also be noted that the value of persistence has different implications if the shock is positive, not negative. A negative shock, producing a one-off increase in the number of accidents, with a low rate of persistence over time, will have a small transitory effect. In this way, the shock will be dampened reasonably quickly, without the need to implement additional road safety policies to bring us back to pre-impact safety states. But if the persistence rates are low and the shock is positive, the benefits do not last over time and the system will quickly return to previous accident rates, and it will be necessary to reinforce the efforts of economic and social policies aimed at reducing accident rates.

Finally, it should be noted that the interest in studying the persistence of traffic accidents over time goes beyond the public health problem generated by the number of victims. As stated, these accidents have associated management, productivity, and prevention costs that must be targeted alternatively based on the degree of persistence of accidents over time in different countries. Studying this persistence with this approach allows us to assess whether the effects of interventions may be temporary or long-lasting, providing a solid basis for the design of more effective public policies. This provides a preliminary study through a careful study of the data, which can then be connected to all correlation-based research.

3. Literature review

The issue of traffic accidents has been the subject of academic research from multiple perspectives. Most analyses of accident data have traditionally focused on causal analysis, generally based on regression techniques (Basu & Saha, 2017). More recently, researchers have increasingly employed data-driven methods such as neural networks, machine learning, and decision trees (Ashraf, 2021; Shaik et al., 2021; Bokaba et al., 2022; Berhanu et al., 2023), as well as artificial intelligence frameworks (Chand et al., 2021).

Much of this literature concentrates on risk factors including sleep and fatigue (Taylor & Dorn, 2006; Scarpelli, 2021; Saleem, 2022), weather conditions (Sentić et al., 2022; Das et al., 2024), traffic speed and flow (Wang et al., 2024), distractions (Karthaus et al., 2020), and demographic variables such as age and gender (Scott-Parker, 2020; McCarty & Kim, 2024). In many cases, the analysis combines multiple causes and disaggregates them by country, region, or demographic group (Martins & Garcez, 2021; Yang et al., 2023; Liu et al., 2024).

Beyond causal studies, substantial work has been devoted to identifying spatial or temporal concentrations of accidents (Basu & Saha, 2022; Alkaabi, 2023). The increasing availability of large datasets has also supported research into accident prediction (Takale et al., 2022; Berhanu et al., 2023). A further important strand of research examines the economic costs of accidents (Elvik, 1995; Chantith et al., 2021; Bougna et al., 2022; Schoeters et al., 2022) and their links to infrastructure investment, economic development (Akinyemi, 2022), and prevention campaigns (Dyreborg et al., 2022; Berhanu et al., 2023).

From a methodological standpoint, the literature stresses the importance of selecting the appropriate analytical approach to obtain reliable results (Gutierrez-Osorio & Pedraza, 2020; Chand et al., 2021). Classical statistical models, however, often suffer from multicollinearity and omitted variable bias, which has led scholars to propose alternative frameworks, including reconstructions based on long time series (Elvik & Høye, 2022). Within this debate, only a limited number of studies have explored long-memory properties using fractional integration. While fractional integration has been applied in other fields, including transport economics (Barros et al., 2015), its application to road safety remains relatively novel.

A key contribution in this emerging area is the study by Chang, Huang, Man, Gong, and Zhou (2022), who applied an ARFIMA–GARCH model to traffic mortality rates in Florida (1975–2018). Their approach simultaneously captures temporal persistence through fractional integration and conditional volatility through the GARCH component, providing a richer representation of accident dynamics than traditional ARIMA models.

The results confirm the existence of long-memory structures, indicating that the effects of accidents do not dissipate rapidly. Importantly, they also incorporate exogenous factors –petrol prices, alcohol consumption, unemployment, and the proportion of rural versus urban roads- demonstrating that economic and structural variables significantly shape road safety outcomes. The study thus provides valuable insights for public policy. Nevertheless, the analysis does not explicitly account for structural breaks, which may bias persistence estimates in long historical datasets.

The study by Zhou and Chang (2023) advances this line of work by combining traditional statistical models with machine learning to model accident frequency. Although not centred exclusively on fractional integration, their hybrid framework highlights the value of blending predictive accuracy with interpretability, a balance that is especially relevant in policy contexts. However, the limited scope of their dataset restricts the generalisability of findings. Similarly, Xu et al. (2022) apply Bayesian models to bicycle accidents with incomplete data, illustrating how advanced statistical methods can enhance inference in data-limited settings. Their approach complements the fractional integration literature, though it does not directly address long memory.

In Europe, Duarte-Monedero et al. (2021) apply fractionally integrated models to Spanish accident data, confirming the existence of long-memory structures. Their findings reinforce the cross-national relevance of fractional models, though the study does not fully explore the interaction between structural and behavioural risk factors. By contrast, Andrade and Antunes (2019) evaluate the long-term effects of road safety policies in Brazil, showing that certain interventions have durable impacts on accident reduction. This underscores the need to consider policy as a determinant of persistence in accident series.

From a methodological standpoint, Vlahogianni and Karlaftis (2009) provide a critical comparison between fractionally integrated dual-memory models and conventional approaches such as ARIMA and GARCH. Their results demonstrate that fractional models capture temporal dynamics more effectively and avoid over-differencing, which can obscure persistence patterns. However, their analysis is based on simulated and relatively small-scale datasets, limiting direct applicability to large historical accident records.

Taken together, these contributions suggest that fractional integration offers a robust framework for capturing the long-term dynamics of traffic accidents. However, the literature on this topic is still in its infancy. Only a few empirical studies have directly applied fractional integration to road safety. For example, Duarte-Monedero et al. (2021) analyse accidents in Spain and find very low persistence, implying that policy effects dissipate quickly and require sustained interventions. Wanke et al. (2023) reach similar conclusions for Brazilian motorways, highlighting the challenges of maintaining accident rate reductions over time, given the short memory properties detected. In contrast, Gil-Alana et al. (2024), in a recent study on Great Britain (2024) broadens the approach by examining road deaths since 1926. By incorporating structural breaks and non-linear trends into fractionally integrated models, the study finds evidence of long-term persistence, offering a richer understanding of accident dynamics in a highly developed road safety context.

The present study differs from these contributions and expands on them in three key aspects. First, unlike the study Chang et al. (2022), which incorporates exogenous variables (oil prices, alcohol consumption, unemployment) into an ARFIMA-GARCH framework, our analysis focuses on the pure persistence properties of the series without confounding factors, allowing for a clearer identification of memory structures. Second, while Duarte-Monedero et al. (2020) and Wanke et al. (2023) examine relatively short time horizons (1993–2017 for Spain; 2010–2021 for Brazil), our dataset covers the period 1927–2022, providing an exceptionally long historical perspective that better captures long-term dependencies. Third, and most importantly, we disaggregate fatalities by vulnerable road user groups (pedestrians, cyclists, motorcyclists), going beyond aggregate analysis to reveal heterogeneous patterns of persistence across different user types, a dimension that has not been explored in previous fractional integration studies on road safety.

Despite this progress, there remains no systematic research on the persistence of accidents in the United Kingdom using long historical data. Previous UK studies have primarily addressed pattern identification (Sinclair & Das, 2021) or causality and risk factors (Clarke et al., 2010; Obasi & Benson, 2023), but not long-memory dynamics. According to international benchmarks, the UK has among the safest roads worldwide, with significant reductions in accident rates and relatively low mortality. Expanding the literature to cover this case is therefore crucial.

The present study contributes by extending existing analyses of Spain and Brazil to the UK, where road safety is more advanced. Specifically, it draws on a uniquely long dataset covering 1927–2022, in contrast to the shorter time horizons in previous research (1993–2017 for Spain; 2010–2021 for Brazil). Moreover, considering recent WHO reports (2023) identifying pedestrians, cyclists, and motorcyclists as the most vulnerable road users, this study disaggregates fatalities across these groups. Although car occupants account for most casualties in the UK, motorcyclists register the highest mortality rates per billion miles travelled. By differentiating between cyclist, pedestrian, and motorcyclist fatalities, this research provides new evidence on whether persistence varies across user groups.

In sum, this study extends the application of fractional integration to one of the safest road systems worldwide, combining long-term historical data with a disaggregated focus on vulnerable road users. This dual contribution both advances the methodological literature on long-memory models and deepens the empirical understanding of road safety dynamics in the UK.

4. Data and methodology

The UK government website was used to search for data on traffic accidents, vehicles, and fatalities in Great Britain. The year 2022 has been taken as the cutoff date as it is the latest confirmed, non-provisional, data in the latest available report from the European Road Safety Observatory on the number of road deaths, from October 2024, based on data from previous years. As earlier mentioned, data are annual starting at 1927. We use this long dataset to capture in a better way the long range dependencies in the data based on long memory models.

For the methodology we use fractional integration. That means that the series are fractionally differentiated to render them with a standard stationary behavior. In other words, if we suppose $\{u(t), t = 0, \pm 1, \ldots\}$ is a covariance stationary I(0) process, $\{x(t), t = 0, \pm 1, \ldots\}$ is integrated of order d or I(d) if it can be expressed as:

$$(1-B)^d x(t) = u(t), \quad t = 1, 2, 3, \cdots. \tag{1}$$

where B is the backshift operator, that is, $Bx(t) = x(t\text{-}1)$ and d may be any real value.

By using a Binomial expansion, it can be proved that the polynomial in B in the left hand side of (1) can be expressed, for any real d, as

$$\sum_{j=0}^{\infty} \binom{d}{j} (-1)^j B^j = \; 1 - dB + \frac{d(d-1)}{2} BL^2 - \cdots$$

Based on the above formula, the differencing parameter d may be taken as and indicator of the degree of persistence of the series, since x(t) can be represented as

$$x(t) \;=\; dx(t-1) - \frac{d(d-1)}{2}\, x(t-2) + \cdots + \; u(t)$$

and the higher the value of d is, the higher is the degree of dependence between the observations.

This specification based on fractional numbers allows us to consider a wide range of cases including, among others, the following ones:

i) anti-persistence, if $d < 0$,

ii) short memory, if $d = 0$.

iii) long memory, though covariance stationary processes, if $0 < d < 0.5$,

iv) 1/f noise, if $d = 0.5$,

v) nonstationary mean reverting processes, if $0.5 \le d < 1$,

vi) unit roots, if $d = 1$,

vii) explosive processes, if $d > 1$.

5. Empirical result

In the empirical application carried out in the following section, we allow for potential linear trends of the form:

$$y(t) = \alpha + \beta t + x(t), t = 1, 2, 3, \cdots. \tag{2}$$

where y(t) indicates the observed data, and α and β are unknown parameters referring to a constant and a linear time trend. Thus the model under examination is the one conformed by (1) and (2), i.e.,

$$y(t) = \alpha + \beta t + x(t), (1-L)^d x(t) = u(t), \tag{3}$$

and u(t) is supposed to be an uncorrelated process with zero mean and constant variance.

The estimation of the parameters in (3) is conducted via maximum likelihood in the frequency domain by using a simple version of a testing approach proposed in Robinson (1994) and widely used in empirical applications.

Table 5 displays the estimates of d in the equation given by (3) for each of the five series under examination in the three classical scenarios of i) no deterministic terms, ii) a constant, and iii) a constant with a linear time trend. The results are similar across the three specifications, though we have marked in bold in the table the most appropriate case for each series, this decision being made on the basis of the significancy of these deterministic terms.

The first thing we observe in Table 5 is that the time trend coefficient is statistically significant only in the case of Motorcycle Fatalities; for Pedestrian Fatalities and All Fatalities the intercept is the only significant deterministic term, while for Pedal Fatalities, neither the intercept nor the time trend are required in the specification of the model. Concerning the specific estimates of the selected models, in Table 6, we observe that the estimates of the differencing paramter widely vary from 0.57 (Motorcycle Fatalities) to 1.15 (Pedal Fatalities). More importantly, the hypothesis of a short memory pattern (i.e., $d = 0$) cannot be rejected in the case of Motorcycle killings; this hypothesis is rejected in favor of long memory ($d > 0$) in the remaining three series, with values below 1 for All Fatalities ($d = 0.74$) and Pedestrian Fatalities (0.93), but higher than 1 for Pedal Fatalities (1.15); however, the confidence intervals are so wide in the four series that the unit root null hypothesis (i.e., $d = 1$) cannot be rejected in any of them. According to these results, shocks in Motorcycle Fatalities might be transitory and to some extent in All Fatalities and Pedestrian Fatalities though in the last two series with long lasting effects; for Pedal Fatalities, however, they are expected to be permanent. The implications of these results is different depending on if the shock is positive or negative. Thus, in the event of a negative shock, increasing the number of fatalities, the strongest measures should be adopted in case of Pedal Fatalities, while in the case of Motorcycles the series might revert by itselft to its original trend; on the contrary, if the shock is postive, due for example to the implementation of appropriate measures, especial care should be adopted with Motorcycle Fatalities since the series has a tendency to return to their original level. Nevertheless, as earlier mentioned some caution should be adopted here. Thus, for example, for Motorcyle fatalities, the confidence interval is so wide that we cannot reject neither the stationarity I(0) nor the nonstationary I(1) case, though the estimate itself suggest the case of mean reversion.

Finally, we should mention that the use of alternative fractionally integrated methods such as Sowell's (1992) maximum likelihood approach in the time domain or the semiparametric log-periodogram estimates (Geweke and Porter-Hudak, GPH, 1983; Robinson, 1995) did not alter the conclusions reported in this work, showing similar evidence in terms of mean reversion for the Motorcycles Fatalities and lack of it for the remaining series though once again with wide confidence intervals.

Although this study focuses on the United Kingdom, similar fractional integration approaches have been applied elsewhere, illustrating the potential value of cross-country comparison. For example, ARFIMA-type models have been used to capture long memory in road fatality series in Florida (Chang et al., 2022), while Wanke et al. (2023) apply fractional integration techniques to Brazilian motorway accident series and Duarte-Monedero et al. (2021) analyse persistence in Spanish accident series using fractional methods. In addition, Vlahogianni and Karlaftis (2009) provide a transport-focused methodological discussion of the properties of memory and fractional integration in traffic time series. A systematic international comparison applying the same fractional integration framework to several countries would help determine whether the long-term persistence patterns identified here are specific to the UK or generalisable; however, such a comparative exercise exceeds the scope of this article and is therefore left for future work.

Table 5
Estimates of the differencing parameter.

Time series	No terms	An intercept	A linear time trend
Pedal Fatalities	**1.15 (0.92, 1.48)**	1.10 (0.53, 1.48)	1.10 (0.79, 1.44)
Pedestrian Fatalities	0.94 (0.68, 1.31)	**0.93 (0.65, 1.28)**	0.93 (0.65, 1.28)
Motorcycle Fatalities	0.67 (0.43, 1.62)	0.70 (0.48, 1.65)	**0.57 (−0.04, 1.64)**
All Fatalities	0.73 (0.49, 1.05)	**0.74 (0.50, 1.18)**	0.73 (0.48, 1.19)

Source: Own elaboration.The value in mark refer to the estimates corresponding to the selected specifications.

Table 6
Estimated coefficients of the selected models in Table 5.

Time series	No terms	An intercept	A linear time trend
Pedal Fatalities	1.15 (0.92, 1.48)	−——	−——
Pedestrian Fatalities	0.93 (0.65, 1.28)	4.7840 (6.28)	−———
Motorcycle Fatalities	0.57 (−0.04, 1.64)	−0.7098 (−0.17)	0.7424 (2–80)
All Fatalities	0.74 (0.50, 1.18)	3.3102 (5.69)	−——

Source: Own elaboration. The values in parenthesis in columns 3 and 4 are the associated t-values for the deterministic terms.

6. Conclusions

In the UK, road traffic fatalities show strong long-term persistence, especially for cyclists and pedestrians. The addition of a linear trend in the models does not significantly alter the persistence estimates in most cases, suggesting that past interventions continue to have a significant impact on crash rates. These findings underline the need to continue to monitor and adjust road safety policies, particularly for vulnerable groups such as cyclists and pedestrians.

The high persistence of accidents in the case of pedestrians and cyclists conditions the design of policies, where progress in road safety for these vulnerable groups does not depend on campaigns or temporary measures, but rather requires structural and regulatory interventions with continuity over time as the only way to improve accident rates. Awareness campaigns adapted to the protection of these vulnerable users may be complementary, but by themselves are not sufficient to modify persistent trajectories.

Therefore, improving outcomes for these groups mainly requires investment in specific infrastructure, especially through networks of segregated bicycle lanes, which have shown evidence of risk reduction (Teschke et al., 2012; Harris et al., 2013; Guirao et al, 2023). Likewise, better illuminated and clearly marked pedestrian crossings, together with urban redesigns of points with a high number of accidents, will also help. Improvements in pedestrian lighting and visibility have been associated with significant declines in the number of accidents (Beyer & Ker, 2009). In addition, in the case of pedestrians, the introduction of Leading Pedestrian Intervals (LPI), which grant a few seconds of advantage to pedestrians before vehicles can turn, significantly reduce pedestrian accidents in urban areas (Fayish & Gross, 2010).

Furthermore, enforcement policies based on sustained speed controls, compliance with pedestrian crossings and safe overtaking distance for cyclists, as well as alcohol and drug checks, are essential to prevent the positive effects of these rules from dissipating. The continued application of these measures contributes to transforming improvements into permanent safety gains (Wilson et al., 2010; WHO, 2023). Finally, instead of conducting joint monitoring of accidents, it seems desirable to establish specific monitoring systems for pedestrians and cyclists. This would allow a more agile and precise evaluation of the impact of interventions and adjust policies dynamically.

These four groups of proposals are summarized in the Table 7 with the recommended measures and their mechanisms and most relevant indicators for monitoring progress.

While these policy recommendations are empirically grounded in the

Table 7
Policy recommendations for high-persistence groups (cyclists and pedestrians).

Group of proposal	Measures	Suggested indicators
Specific infrastructure	Segregated bicycle lanes, pedestrian crossings with better lighting and signage	Kilometres of segregated infrastructure; separation of crashes by type of road; monitoring of user-specific risk rates
Enforcement and regulation	30 km/h (20 mph) limits, automated controls, compliance with pedestrian crossings and cyclist overtaking distance	Measurement of average and 85th percentile speed; compliance rates; accidents in controlled zones
Targeted campaigns as a complementary measure	Directed at drivers and vulnerable users	Awareness levels in surveys; study of variation in reported infractions
Differentiated monitoring	Creation of separate systems for monitoring pedestrian and cyclist accidents	KSI indicator by user group; response time to interventions; measures implemented on high-injury roads

Source: Own elaboration.

observed persistence patterns, their implementation presents several practical and institutional challenges that warrant consideration. First, the infrastructure investments required –including segregated cycling infrastructure and enhanced pedestrian crossing facilities- entail substantial capital expenditure and may encounter constraints related to existing urban morphology, land availability, and competing budgetary allocations across transport and planning domains. Second, the sustained enforcement measures necessitate long-term institutional commitment and adequate allocation of personnel resources, which may prove difficult to maintain given the temporal misalignment between policy cycles and the long-run nature of accident persistence identified in this study. Third, the establishment of differentiated monitoring systems requires institutional capacity, technical expertise, and inter-agency coordination mechanisms that may not be uniformly present across local and regional authorities.

However, these implementation challenges can be addressed through strategic policy design and institutional arrangements. Regarding to capital constraints, evidence suggests that phased implementation prioritising high-risk corridors can yield demonstrable improvements in safety and cost-benefit ratios that facilitate subsequent resource allocation and political support for wider roll-out. To ensure continuity of implementation beyond electoral cycles, incorporating road safety objectives into broader public health frameworks –where evidence-based interventions enjoy greater institutional stability- can serve as a buffer against short-term political fluctuations. Finally, institutional capacity requirements for differentiated monitoring can be met by leveraging existing data collection infrastructures and establishing formal coordination protocols between transport authorities, law enforcement agencies, and public health agencies, thus avoiding the creation of parallel institutional structures. These proposals are important for policy makers because they provide a view of how the proposed interventions based on the study of recorded trends can offer improvements in current and future accident rates.

The findings of this study are important for policy makers as they provide a comprehensive picture of how past interventions and trends affect current crash rates. Understanding these long-term patterns can inform more effective and sustainable policy measures to reduce road accidents. By filling the gap in the literature on long-memory processes in road safety, this research contributes to the theoretical and practical aspects of road safety analysis, offering insights into the effectiveness of past safety measures and the potential for future improvements.

A limitation of the present work is the number of observations available (96) for this application, which produces wide confidence intervals for the estimates of the differencing parameter. This is something that could be resolved by using alternative data frequency, if available. The linear nature of the deterministic structure employed in this work is another obvious limitation that could be solved by using alternative methodologies still within the context of fractional integration. Examples are the Fourier functions in time (Gil-Alana and Yaya, 2021) or neural networks as in Yaya et al. (2021). The results reported in this work for the UK data can also be extended to the analysis of potential structural breaks, and to other European and non-European countries to see if a similar pattern also holds outside the UK. Moreover, based on the long historical period examined in this work, the analysis can be extended for potential confounding variables (such as traffic volume, vehicle fleet composition, regulatory changes, or economic conditions) that may have shaped accident trends. Work in all these direction is now under progress.

CRediT authorship contribution statement

Marta Torres-Polo: Visualization, Validation, Project administration, Investigation, Data curation. **Luis Alberiko Gil-Alana:** Writing – original draft, Software, Methodology, Investigation, Funding acquisition. **Jorge Moya Velasco:** .

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Declaration of competing interest

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Declaration of the use of AI

The authors declare no use of AI technologies in this work.

Ethicsapproval

This research did not involve human participants, animals, or sensitive personal data. Therefore, approval from an Institutional Review Board (IRB) was not required.

Data availability

Data will be made available on request.

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