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Assessing School Travel Safety in Scotland: An Empirical Analysis of Injury Severities for Accidents in the School Commute

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Abstract: School travel has been a significant source of safety concerns for children, parents, and public authorities. It will continue to be a source of concerns as long as severe accidents continue to emerge during pupils' commute to school. This study provides an empirical analysis of the factors influencing the injury severities of the accidents that occurred on trips to or from school in Scotland. Using 9-year data from the STATS19 public database, random parameter binary logit models with allowances for heterogeneity in the means were estimated in order to investigate injury severities in urban and rural areas. The results suggested that factors such as the road type, lighting conditions, vehicle type, and age of the driver or casualty constitute the common determinants of injury severities in both urban and rural areas. Single carriageways and vehicles running on heavy oil engines were found to induce opposite effects in urban and rural areas, whereas the involvement of a passenger car in the accident decomposed various layers of unobserved heterogeneity for both area types. The findings of this study can inform future policy interventions with a focus on traffic calming in the proximity of schools.

Keywords: school travel; injury severities; accidents; binary logit; heterogeneity in the means; random parameters

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1. Introduction

Over the last decades, the involvement of children in road accidents with severe injury outcomes has raised major concerns for local and national road authorities as well as for the general public. In Scotland, recent evidence suggests that children are indeed involved in accidents that are associated with different levels of injury severity. In 2020, approximately 490 child casualties were reported, which accounts for about 10% of the total casualties in all road accidents. Out of these, six children suffered fatal injuries, while 176 children were reported as seriously injured [1]. Figure 1 shows the number of children (under the age of 15) who were killed annually as a result of land transport accidents in Scotland between 2008 and 2019. In 2008 and 2016, the largest numbers of deaths were recorded; whereas, since 2017, the number of child fatalities has significantly decreased, but it is still above zero. These statistics clearly show that, despite the significant advances in safety policies and crash-avoidance technologies and systems, children continue to be a particularly vulnerable group of road users.

School travel (i.e., travelling to or from school) accounts for a significant proportion of the trips in which children are regularly involved [3]. In the UK, enhancing active school travel is among the policy priorities of local authorities and public health bodies [4], as walking or cycling to school have been linked with physical and mental health benefits for children [5]. However, the trade-off between the benefits of active school travel and the accident risk exposure for children who walk or cycle to school has been a matter of continuing debate, not only among policymakers but also among the public. In fact, the perceived level of safety constitutes a key factor that influences travel mode choice in school-related trips, with parents and children perceiving it as a hindrance to active travel [6,7]. In this context, it is important to better understand the factors that contribute to the occurrence of school travel-related accidents and the consequent injury severities. This would help to shape appropriate policies so as to curb the actual or perceptual barriers to the uptake of active school travel and eliminate any child casualties emerging during the commute to school.

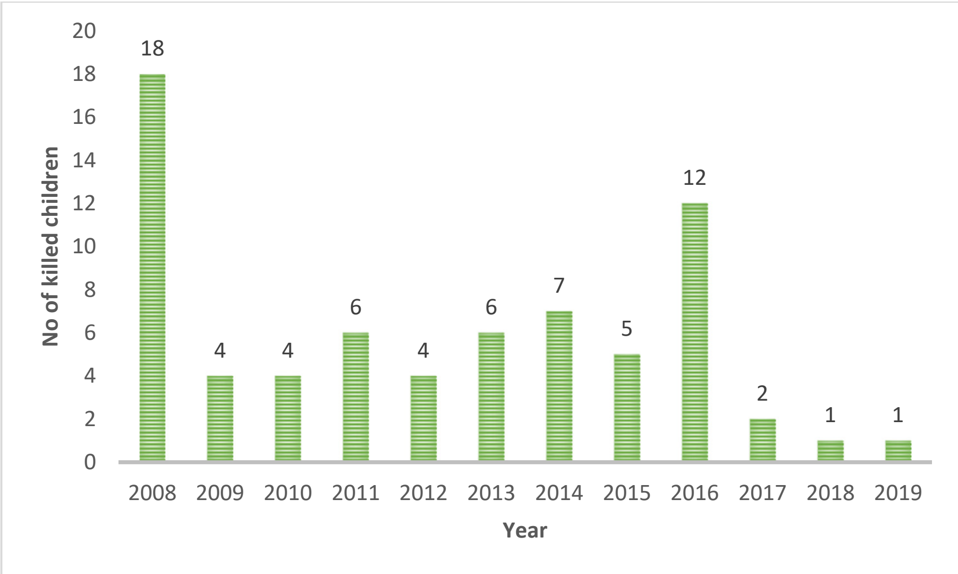

Figure 1. Annual number of children killed under the age of 15 in Scotland from 2008 to 2019 as a result of a land transport accident. Source:- Transport Scotland 2020 [2].

Drawing some lessons from previous studies, Jensen [8] examined the level of road safety among children. According to the study, the pertinent factor that enhanced the level of a child's safety was the use of seatbelts in cars, while the implementation of targeted safety measures, such as speed reduction through traffic calming and the signalisation of junctions, improved the safety around the school routes. Such safety measures can also foster a behavioural shift from car and bus use to cycling for school journeys.

Using data from Baltimore City, Maryland in the US, Clifton and Kreamer-Fults [9] utilized multivariate models in order to examine the injury severities of the pedestrian–vehicular crashes that happened within the neighbourhood of public schools. The study further examined the relationship between the physical and social characteristics of the areas near the schools and the severity of the crash injuries. They found out that the availability of a driveway or of a turning bay at the entrance of the school reduced both the crash risk and injury severity. Further results that were related to the neighbourhood's characteristics (such as transit access, commercial access, and population density) had a more heterogeneous impact on crash dimensions.

Focusing on the relationship between active travel and safety, Wilson et al. [6] identified the safety concerns for and key barriers to active school travel to elementary schools in Southwestern Ontario, Canada. The study did not examine accident severity; however, it suggested that the lack of a safe environment for walking or cycling may stand as a significant obstacle to active school travel among children. Similarly, Mehdizadeh et al. [10] showed in their study that safety-related challenges also serve as barriers to active school travel among children in Iran. Cycling to school has been also perceived as less safe by adolescents and their parents, especially compared to walking, as shown by Mandic et al. [11] using data from Dunedin, New Zeeland.

From a spatiotemporal perspective, previous research has aimed to shed further light on the potential spatial or temporal heterogeneity that is related to the determinants of school travel safety. Warsh et al. [7] deployed a GIS-based method in order to analyse the associations between school location characteristics and motor vehicle–child pedestrian collisions based on the police-reported crash data from Toronto, Canada. The study was based on the reported crashes between 2000 and 2005, which involved pedestrians under 18 years of age. The study assessed the distance of each crash location from the school using GIS techniques, thus enabling associations between school distance and the spatial (crossing locations) and temporal (school travel times) characteristics of the crashes. The findings showed that injury severities were more pronounced in the school zones and reduced as the distance from schools increased. Likewise, the frequency of crashes and severe injuries within school zones were higher at midblock locations and intersections.

Kingham et al. [12], found that accident rates did increase during the school commute in Christchurch, New Zealand; however, they did not detect evidence of accident clustering in the areas around schools. In Chile, Blazquez and Celis [13] investigated school-aged child pedestrian accidents and they identified spatial dependencies among the typical influential factors such as time of the day, intersection presence, and absence of traffic signs. In the US, McArthur et al. [14], upon performing a spatial analysis of pedestrian and bicycle accidents involving school-aged children, they found that schools on local roads were associated with a higher frequency of crashes, while school districts with larger pupil populations were also linked with higher frequencies of crashes. Most of the studies that have been devoted to measuring the spatiotemporal dependencies of school travel accidents have mainly focused on the accident frequencies or rates, whereas little evidence has been identified with regard to the dependencies of the factors that are related to accident injury severities.

In the UK, recent evidence has proven that pupils are more prone to injury accidents while travelling to school compared to other commuters [15]. However, there is a lack of evidence on the specific determinants of the injury severities of the accidents that occur while commuting to school. This study seeks to partially fill in this knowledge gap by statistically analysing the accidents that have occurred in the context of school-related travel and investigating the factors affecting their injury severities in Scotland, which is a developed nation of the UK.

Overall, the previous research has shown that the physical and built environments in the areas where the schools are located [9,16] may induce further heterogeneity in the factors that influence school travel related accidents. Therefore, the statistical analysis of accident injury severities should take into account the disparities in the physical and built environments. That is particularly important for Scotland, where a considerable number of communities are located in remote and rural areas, where transport provision and accessibility are more limited when compared to urban and well-connected areas. Such disparities are also reflected in the way that the Scottish pupils travel to school. In large urban areas, more than 50% of children walk to school, whereas in remote rural areas the corresponding proportion is less than half of that of urban areas (approximately 21.5%). On the contrary, almost three out of four children in remote rural areas travel by car, van, or school bus, whereas the respective proportion in urban areas does not exceed 36% [17].

These discrepancies in the school travel choices in combination with the differences in the transport infrastructure between urban and rural areas may have an impact on the associated level of safety. In the past, the Scottish Government has stated as a priority the improvement of safety in rural roads because the level of injury risk (due to road accidents) is higher compared to urban roads [18]. However, while the injury risk disparities are well-established between urban and rural areas, previous research has not thoroughly investigated whether and how the factors that are affecting injury severities in school travel-related accidents may vary between these two area types. In Scotland, 21% of the population resides in rural areas, even though the latter account for almost 95% of the country's land mass [19]. Hence, in this study, we carried out separate statistical analyses for the urban and rural areas in an effort to provide more granular insights into the determinants of school travel safety, which can inform more targeted interventions.

2. Materials and Methods

This section presents an overview of the data source and characteristics and a concise description of the statistical methods that were used for the analysis and modelling of the school travel-related accidents.

2.1. Data

The data for the analysis and modelling were drawn from STATS19, a UK accident database that is publicly available from the Department for Transport. This database contains information only about accidents that were reported to and recorded by the police [20]. This comprehensive database contains a range of information such as the accident's attributes (e.g., the location, time and day of the accident, number of casualties and vehicles, and injury severity), road design and operational features (e.g., the type of the road and speed limit), socio-demographic characteristics of the casualties and vehicle occupants (the gender, age, and residence location type), features of the vehicles (e.g., the type, condition, age, and engine characteristics), and observed environmental conditions (weather lighting conditions and road surface condition) when the crash occurred. The reported injury severity is defined in terms of three injury outcomes, namely slight, serious, and fatal injury. Slight injuries refer to minor injuries, which do not require medical treatment. Serious injuries refer to severe injuries that led to the hospitalization of the associated person or required serious medical treatment (e.g., concussions, fractures, or internal injuries) [21]. As noted in [22,23], the STATS19 database does not record no-injury accidents, which has been highlighted as a limitation of its reporting mechanism [24].

The present study is based on a subset of the school travel related accidents that occurred in urban and rural areas in Scotland over a period of nine years, between 2010 and 2018. This subset was derived using information about the purpose of the journey where the accident occurred, as recorded in the STATS19 dataset. In particular, the subset includes the accidents that occurred in journeys where pupils were travelling to or from school with someone else (e.g., a parent or guardian) or alone, regardless of the means of travel. This subset consists of 559 accident cases in urban areas and 235 accident cases in rural areas. In line with the previous research [24,25], the severity outcome of each accident was determined by the level of injury that was sustained by the person who was most severely affected. In rural areas, for 51.5% of the cases the most severe injury was sustained by a vehicle driver, motorcyclist, or cyclist, for 24% of the cases by a vehicle passenger, and for 24.5% of the cases by a pedestrian. In urban areas, for 46.3% of the cases the most severe injury was sustained by a vehicle driver, motorcyclist, or cyclist, for 17.2% of the cases by a vehicle passenger, and for 36.5% by a pedestrian. However, given that the involvement of bicycles is relatively low for both urban and rural accidents (7.3% and 5.5%, respectively), the vast majority of casualties concerns vehicle occupants (either drivers or passengers).

2.2. Methodological Approach

In this study, a binary logit modelling approach was deployed in order to identify the impacts of various environmental, road, vehicle, and occupant factors on the injury severities of school travel-related accidents. Given the low proportion of fatal injuries in the dataset, serious and fatal injuries were merged into a single outcome [26]. Hence, the dependent variable has two outcomes, namely slight injury (coded as "0" in the dependent variable) and serious or fatal injury (coded as "1" in the dependent variable). The binary logit is a special case of the multinomial logit (MNL) discrete outcome model, wherein the dependent variable has only two outcomes [27]. In this context, we defined A_{in} as a severity function that determines the likelihood of an observed accident n to result in an injury outcome i, as shown in Equation (1) [28]:

$$A_{in} = \boldsymbol{\beta}_n \mathbf{X}_{in} + \varepsilon_{in} \tag{1}$$

In Equation (1), $\mathbf{X}$ stands for a vector of explanatory variables, i.e., the observable characteristics that determine the injury's severity, $\boldsymbol{\beta}$ represents a vector of the estimable parameters corresponding to $\mathbf{X}$, and ε_i represents a disturbance term, which is Gumbel distributed.

In order to account for the unobserved heterogeneity (i.e., the influence of unobserved attributes on the injury severities), random parameters were considered in the model estimation procedure, hence a mixed logit model with a binary dependent variable was finally specified. According to Washington et al. [27], the incorporation of random parameters into the accident severity function enables a separate vector of coefficients $\boldsymbol{\beta}$ for each accident observation n to be estimated, as shown in Equation (2):

$$\boldsymbol{\beta}_n = \beta + \boldsymbol{\omega} \mathbf{Z}_n + \delta_n \tag{2}$$

where, the mean of the random parameter distribution is represented by β, $\mathbf{Z}_n$ indicates a vector of the exogenous factors that capture the heterogeneity in the mean of $\boldsymbol{\beta}_n$, $\boldsymbol{\omega}$ represents a vector of the estimable parameters for $\mathbf{Z}$, and δ denotes a randomly distributed term. The inclusion of the $\mathbf{Z}_n$ term allows the detection of additional variables ("heterogeneity-in-the means" factors) that can further decompose the unobserved heterogeneity, thus allowing the random parameters to vary as a function of the exogenous factors. In line with the definition of the mixed logit model, the probability of the binary dependent variable to have value equal to 1 (i.e., for the accident to result in a serious injury or fatality) is given by:

$$P_n(i|\boldsymbol{\varphi}) = \int \frac{e^{\boldsymbol{\beta}_n \mathbf{X}_{in}}}{1 + e^{\boldsymbol{\beta}_n \mathbf{X}_{in}}} q(\boldsymbol{\beta}_n|\boldsymbol{\varphi}) d\boldsymbol{\beta}_n \tag{3}$$

where, $q(\boldsymbol{\beta}_n \mid \boldsymbol{\varphi})$ is the density function of $\boldsymbol{\beta}$, typically mentioned as the mixing distribution, and $\boldsymbol{\varphi}$ denotes the vector of the parameters for the mixing distribution. All of the other terms remain as previously defined. The unrestricted formulation of the random parameters in Equation (2) allows the identification of the variables that influence the mean of the distribution of the random parameters. These variables decompose the unobserved heterogeneity that may be encapsulated in the means of the random parameters [29]. It should be noted that a normal distribution was used for fitting the random parameters in the binary logit models, in line with previous literature [27,29].

To estimate the random parameter binary logit models, the simulated maximum likelihood estimation technique was used [22,30]. Halton sequence draws [31] were deployed in order to conduct the numerical integrations that are required for model estimation [32]. The statistical models were estimated using 500 Halton draws, which were found to generate stable model coefficients.

To measure the specific impact of each explanatory variable on the probability of an accident to result in a serious or fatal injury, elasticities and pseudo-elasticities were also calculated. Elasticities provide the change in the injury severity probability due to a 1% change in the value of an explanatory variable. In cases of indicator explanatory variables, pseudo-elasticities were calculated, which show the extent to which the change of an indicator variable from 0 to 1 modifies the injury severity probability.

It should be noted that for model estimation we investigated all of the possible independent variables that can be drawn from the dataset as well as numerous combinations of these. In line with previous research [27], the statistical models that are presented in the next section yielded the best results using three fundamental criteria: statistical significance (in terms of t-stats, p-values, and likelihood ratio tests), statistical fit (in terms of improvement in the log-likelihood function), and conceptual validity.

3. Results and Discussion

This section provides the model estimation results as well as a discussion of the findings for the factors that were identified to affect school travel-related accidents in urban and rural areas of Scotland.

3.1. Model Estimation Results

3.1.1. School Travel-Related Accidents in Urban Areas

Table 1 provides the descriptive statistics of the explanatory variables that were included in the model for urban areas. Table 2 provides the estimation results and pseudo-elasticities of the random parameter binary logit model for the accidents that occurred during school-related travel in urban areas. All of the explanatory variables of the model produced statistically significant coefficients at a 95% level of confidence or greater. A positive coefficient indicates an increase in the probability of a severe outcome (i.e., serious or fatal injury), whereas a negative coefficient implies a decrease in the probability of a severe outcome and, subsequently, an increase in the probability of a slight injury.

Table 1. Descriptive statistics of the variables included in the model for urban areas.

Variable	Percentage (%) *
Accident injury severity (1 if serious or fatal injury, 0 if slight injury)	16.46%
Vehicle type indicator (1 if passenger car, 0 otherwise)	87.48%
Road type indicator (1 if the accident occurred on a single carriageway, 0 otherwise)	84.62%
Pavement surface conditions (1 if the surface was dry, 0 otherwise)	60.82%
Day of the week indicator (1 if the accident occurred on a weekend, 0 otherwise)	17.89%
Driver's age indicator (1 if at least one driver involved in the accident was older than 60 years, 0 otherwise)	4.65%
Vehicle age indicator (1 if the vehicle was older than 10 years, 0 otherwise)	13.95%
Intersection type indicator (1 if the accident occurred on a signalised intersection, 0 otherwise)	5.72%
Point of impact indicator (1 if the first point of impact during the accident was nearside, 0 otherwise)	15.56%
Lighting conditions indicator (1 if the accident occurred during dark conditions but street lights were in operation, 0 otherwise)	5.19%
Vehicle engine indicator (1 if any of the vehicles involved in the accident had an engine running on heavy oil, 0 otherwise)	29.87%
Location indicator (1 if the accident occurred within the area of Glasgow, 0 any other area)	25.58%

* This is the percentage of the accident sample for which the variable in question has a value equal to 1.

The results show that the accidents that occurred during school-related trips on single carriageways in urban areas were more likely to result in serious or fatal injuries. Single carriageways are undivided roadways typically consisting of one lane per direction and they constitute the most widely observed type of highway in the Scottish road network [33]. Even though their speed limits are restrained to 30 mph in built-up areas, more than half of drivers typically exceed the speed limit and one out of five drivers exceed the limit by more than 5 mph [34]. Such speeding patterns may bear a considerable impact on the injury severities of accidents, as suggested by previous research [35,36]. Notably, the pseudo-elasticity of the variable representing single carriageways is the largest positive, thus indicating the most pronounced effect among all of the variables that favour severe injury outcomes in urban areas. In fact, the presence of a single carriageway increased the probability of a serious or fatal injury by approximately 266.4%.

Severe injury outcomes are also linked with accidents that occurred on weekends, as the relevant variable was found to increase the probability of serious or fatal injuries by approximately 44%, as shown in Table 2. The vast majority of schools do not have classes on the weekends, however, various activities (e.g., extra-curricular activities, sport events, and preparatory classes for exams) usually take place at schools during several weekends, which may entail an additional commute throughout these days. Even though fewer school-related trips are made on weekends, speeding patterns are more evident compared to weekdays [37]. Accidents involving older vehicles (over 10 years old) are also more likely to yield a severe injury outcome. This finding corroborates with previous evidence in Scotland [23] and it may pick up either the lower safety performance of these vehicles or risk-taking patterns exhibited by drivers when using older vehicles. The type of vehicle propulsion was also found to affect injury severities, as vehicles with engines that run on heavy oil are associated with KSI (killed or seriously injured) casualties. This engine type may serve as a proxy for heavy-duty vehicles (e.g., heavy goods vehicles—HGVs, buses, and coaches). The latter vehicles are generally more prone to severe traffic incidents, due to their mass and the extent of energy that is dissipated [38], especially in collisions with smaller body vehicles.

Table 2. Estimation results of the model for school travel-related accidents in urban areas.

Variable Description	Para-Meter	Standard Error	*t*-Stat	*p*-Value	95% CI	Elasticity
Variables with fixed parameters						
Constant	−4.915	1.222	−4.02	0.000	−7.310–2.520	
Road type indicator (1 if the accident occurred on a single carriageway, 0 otherwise)	3.148	1.015	3.10	0.002	1.158–5.138	2.664
Day of the week indicator (1 if the accident occurred on a weekend, 0 otherwise)	2.465	0.710	3.47	0.001	1.072–3.857	0.441
Driver's age indicator (1 if at least one driver involved in the accident was older than 60 years, 0 otherwise)	6.199	1.435	4.32	0.000	3.387–9.011	0.288
Vehicle age indicator (1 if the vehicle was older than 10 years, 0 otherwise)	3.095	0.776	3.99	0.000	1.575–4.615	0.432
Point of impact indicator (1 if the first point of impact during the accident was nearside, 0 otherwise)	2.325	0.703	3.31	0.001	0.947–3.703	0.362
Lighting conditions indicator (1 if the accident occurred during dark conditions but street lights were in operation, 0 otherwise)	2.219	1.056	2.10	0.036	0.150–4.288	0.115
Vehicle engine indicator (1 if any of the vehicles involved in the accident had an engine running on heavy oil, 0 otherwise)	1.546	0.538	2.87	0.004	0.491–2.601	0.462
Location indicator (1 if the accident occurred within the area of Glasgow, 0 any other area)	−2.412	0.748	−3.22	0.001	−3.879–−0.946	−0.617
Variables with random parameters						
Vehicle type indicator (1 if passenger car, 0 otherwise)	−5.689	1.246	−4.56	0.000	−8.132–−3.246	−4.977
Standard deviation of parameter density function	7.912	1.426	5.55	0.000	5.118–10.706	
Pavement surface conditions (1 if the surface was dry, 0 otherwise)	−7.571	1.562	−4.85	0.000	−10.632–−4.510	−4.605
Standard deviation of parameter density function	17.237	3.154	5.47	0.000	11.056–23.418	
Intersection type (1 if signalised intersection, 0 otherwise)	−31.489	9.573	−3.29	0.001	−50.252–−12.726	−1.803
Standard deviation of parameter density function	56.020	14.727	3.80	0.000	27.156–84.883	
Number of observations			559			
Restricted log-likelihood			−249.997			
Log-likelihood at convergence			−232.221			

The involvement of elderly drivers (older than 60 years old) is also associated with more severe injuries in accidents on urban roads. The vulnerability of elderly drivers and their higher risk exposure to severe injuries have been long recorded in previous studies [39,40]; despite the low proportion of elderly drivers that is shown in Table 1, their propensity to serious or fatal outcomes is confirmed when they are involved in accidents during school-related trips. Severe injuries were also more likely to be sustained in accidents that occurred under dark ambient conditions. During night time, the reduced visibility for drivers in combination with their limited perception of roadway hazards may lead to driving errors, which can lead to severe accidents [24]. Alongside the lighting conditions, we also investigated the impact of weather conditions as well as the combined effect of weather and lighting conditions, but such trials did not produce statistically significant results in the model for urban areas. Furthermore, in the accidents where the first point of impact was on the nearside, the probability of serious or fatal injuries increased by approximately 36%. The collisions featuring nearside impacts featured a higher risk for a severe outcome, as they bore significant potential for serious pelvic, abdominal, and chest injuries [41,42].

A set of factors was also identified to reduce the probability of severe injuries and, conversely, to increase the probability of slight injuries in the model for urban areas. Among these, three factors produced statistically significant random parameters (i.e., these factors were identified to have varying effects across the accident observations): the passenger car, dry surface, and intersection type indicators. The distributional effects of the random parameters are shown in Figure 2. The distributions that are illustrated in the latter show the proportions of the accident sample, across which a specific variable, which produced a random parameter (i.e., it did have a varying effect across the accident observations), either increased the probability of a serious/fatal injury or the probability of a slight injury. These proportions have been readily derived from the means and standard deviations of each random parameter, considering also that a normal distribution was used to fit the random parameters (see also Section 2). It should be noted that none of the means of these random parameters were found to be determined by additional exogenous factors, thus heterogeneity in the means was not identified in this model specification.

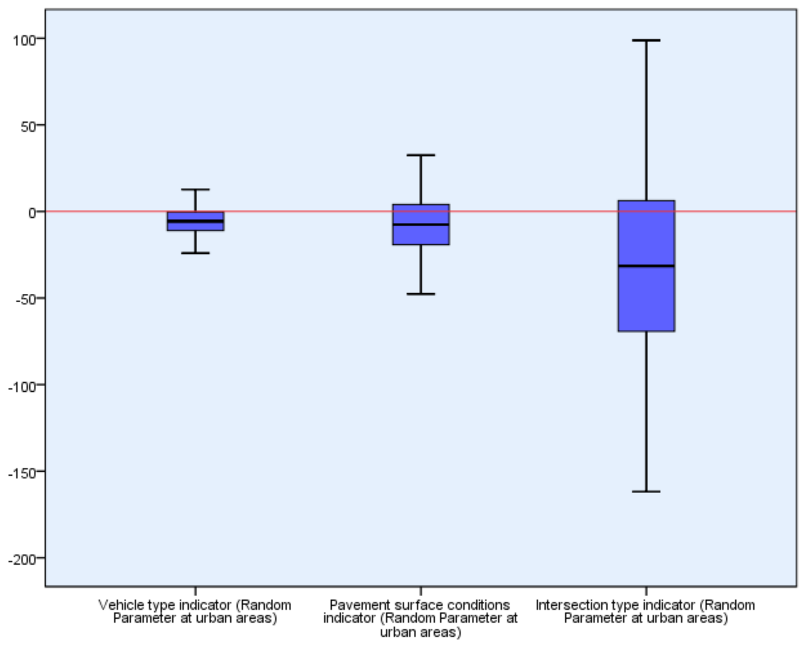

Figure 2. Boxplots illustrating the random parameters' distributions in the accident injury severity model for urban areas (the lower and upper limits of the box reflect the interquartile range, the thick line in the middle of the box represents the median, the red line indicates the zero value, and the whiskers are defined by the minimum and maximum values of the distribution).

The involvement of a passenger car was found to have a varying, yet statistically significant, effect across the observations, with the majority of these (76.4%) being associated with higher probability of a slight injury. The rest of the observations (23.6%) were more likely to result in severe outcomes (either a serious or fatal injury). The passenger car constitutes one of the most popular transport means for school-related travel in Scotland, as more than a quarter of pupils usually travel to school by car [43]. Due to this fact, the variable representing passenger cars may capture unobserved heterogeneity possibly arising from disparate sources such as the prevailing traffic characteristics or behavioural responses of drivers at the time of the accident. For example, accidents involving passenger cars in urban networks may occur under congested traffic conditions, especially during the peak hours when the school commute typically takes place. Such congested patterns are accompanied by low operating speeds, which possibly have a favourable impact on accident injury severities. In contrast, the school commute is considered as a regular trip for minors' parents or guardians (who are expected to serve as drivers) and, given their familiarity with the travel route or general traffic conditions at the time of the trip, risk-compensating behavioural patterns may emerge (i.e., the drivers adopt riskier driving habits as they feel overly confident with the particular trip). Under unfavourable accident circumstances, such risky behavioural patterns may translate into more severe injuries. It should be noted that the passenger car has the strongest impact among all of the explanatory variables in the model for urban areas, with the corresponding pseudo-elasticity indicating an increase in the probability of a slight injury by a stunning 500%.

The dry road surface has also a heterogeneous impact on accident injury severities, as it also produced a statistically significant random parameter. Based on the distribution of the latter, approximately 67% of the accidents that occurred on a dry road surface were more likely to result in slight injuries, whereas the remaining 34% of cases were linked with a higher probability for a severe outcome. Even though a dry road surface implies the immediate absence of precipitation and the likely presence of mild weather, a portion of drivers, typically those who are familiar with the school commute, may be prompted to undertake more risk-taking manoeuvres due the lack of apparent road hazards. The heterogeneity underpinning the impact of the road surface conditions on injury severities and the potential relationship with risk compensating behaviour has been also discussed in previous research [22,44].

The accidents that occurred in signalised intersections were also found to be associated with varying patterns of injury severities, with the vast majority of cases (71.3%) having a higher probability for slight injuries. Intuitively, vehicle movements in signalised intersections are segregated in time and space, hence the severity of conflicts and encounters between motorised (and non-motorised) users that could lead to hazardous incidents is lower. In light of the pseudo-elasticity for the specific variable, the probability for a severe injury in accidents at signalized intersections was reduced by 180% on average.

Finally, the accidents occurred in Glasgow were associated with a lower injury outcome, with this effect being fixed across the sample. This variable captures the location-specific effects, as Glasgow is the most populated and urbanized city in Scotland. The school travel patterns in Glasgow evidently vary from those of the rest of Scotland, as the proportions of pupils who walk or are driven by car to school are higher compared to the Scottish average figures [45]. Therefore, the safety of school trips in Glasgow warrants further investigation in the future, due to the unique school travel characteristics in that area.

3.1.2. School Travel-Related Accidents in Rural Areas

Table 3 gives a breakdown of the descriptive statistics for the explanatory variables that were included in the model for rural areas, whereas Table 4 shows the estimation results of the random parameter binary logit model for the accidents that occurred in the context of school-related travel in rural areas. Several determinants of accident injury severities in urban areas tuned out to have an observable impact on the accidents in rural areas too, namely the road type, lighting conditions, and the vehicle propulsion type.

Table 3. Descriptive statistics of the variables included in the model of accident injury severities for rural areas.

Variable	Percentage (or Mean) *	Standard Deviation
Accident injury severity (1 if serious or fatal injury, 0 if slight injury)	17.02%	-
Lighting conditions indicator (1 if the accident occurred in daylight, 0 otherwise)	93.19%	-
Weather conditions indicator (1 if the accident occurred in rainy conditions, 0 otherwise)	16.60%	-
Vehicle movement indicator (1 if the vehicle was going ahead at the moment of the accident, 0 otherwise)	65.11%	-
Road type indicator (1 if the accident occurred on a single carriageway, 0 otherwise)	87.66%	-
Vehicle propulsion indicator (1 if any of the vehicles involved in the accident had an engine running on heavy oil, 0 otherwise)	33.62%	-
Age band of the casualty [1: 0–5 years; 2: 6–10 years; 3: 11–15 years; 4: 16–20 years; 5: 21–25 years; 6: 26–35 years; 7: 36–45 years; 8: 46–55 years; 9: 56–65 years; 10: 66–75 years; 11: Over 75 years]	6.60	2.06
Vehicle type indicator (1 if passenger car, 0 otherwise)	75.32%	-

* The percentages reflect the proportions of the accident sample for which the variable in question has a value equal to 1.

With respect to the road type, the results suggest that accidents on rural single carriageways are associated with heterogeneous effects on injury severities. As opposed to urban areas, wherein the single carriageway indicator was found to strongly favour severe injuries as a fixed parameter, this road type was associated with a more balanced distribution of the impacts in rural areas, as it produced a statistically significant random parameter. As shown in Figure 3, for approximately 57% of cases, the presence of a single carriageway increased the probability of slight injuries, whereas for the rest 43% of cases, it increased the probability of serious or fatal injuries. In rural areas, single carriageways have different operational characteristics than urban areas, especially in relation to traffic volumes and speed limits. Although the speeding patterns may not be evidently different on single carriageways between urban and rural dwellers [46], the heterogeneity in the effect of this road type may be attributed to the diverse behavioural responses of drivers to external stimuli (e.g., environmental conditions, traffic patterns, and built environment) during school-related trips in rural areas. Please note that while several built environment characteristics were investigated for both urban and rural accidents, including the posted speed limit, level and type of traffic control, presence of a crosswalk or any other pedestrian facility, and many others, these resulted in statistically insignificant results.

The lighting conditions were also found to affect injury severities in rural areas, with their impact being consistent with the corresponding effect in the model for urban areas. The accidents that occurred in daylight were more likely to yield a slight injury outcome, thus highlighting the positive effect of natural illumination. The pseudo-elasticity of this specific variable underscores its relative importance (compared to the other explanatory variables of the model), as it bears the strongest—in magnitude—impact on injury severities; interestingly, daylight's presence increased the probability of a slight injury by almost 365%.

The effect of vehicle propulsion in the model for rural areas was different from that observed in urban areas. Slight injuries were more likely to be observed in accidents involving a vehicle running on a heavy oil engine; as opposed to urban trips, where severe injuries were more likely to be sustained. Given that heavy oil engines possibly imply heavy-duty vehicles, the discrepancy in that effect may be associated with the characteristics of accidents involving heavy vehicles in rural areas. For example, previous evidence from the US [47] has suggested that, in rural areas, truck-involved crashes that occurred in the early morning or until the late afternoon (up to 3 p.m.)—with both periods including usual school commute times—were more likely to result in slight injury outcomes when compared with any other time of the day. Interestingly, the presence of a vehicle running on a heavy oil engine increases the probability of a slight injury by 125.2%.

Fine weather conditions were, intuitively, found to increase the probability of a slight injury (by 45.5%, as shown by the corresponding pseudo-elasticity in Table 4). Similar to the daylight conditions, fine weather contributed to a better perception of the potential roadway hazards, so that the drivers could still undertake evasive actions in order to reduce the severity of any possible conflicts or interactions that could lead to accidents.

Table 4. Estimation model for school travel-related accidents in rural areas.

Variable Description	Parameter	Standard Error	*t*-Stat	*p*-Value	95% CI	(Pseudo-) Elasticity
Variables with fixed parameters						
Constant	−2.448	1.526	−1.60	0.109	−5.438–0.542	
Lighting conditions indicator (1 if the accident occurred in daylight, 0 otherwise)	−3.918	1.186	−3.30	0.001	−6.243–1.594	−3.651
Weather conditions indicator (1 if the accident occurred in rainy conditions, 0 otherwise)	−2.740	1.157	−2.37	0.018	−5.008–0.472	−0.455
Vehicle movement indicator (1 if the vehicle was going ahead at the moment of the accident, 0 otherwise)	2.973	0.890	3.34	0.001	1.228– 4.718	1.935
Vehicle propulsion indicator (1 if any of the vehicles involved in the accident had an engine running on heavy oil, 0 otherwise)	−3.723	1.087	−3.43	0.001	−5.854–−1.593	−1.252
Variables with random parameters						
Road type indicator (1 if the accident occurred on a single carriageway, 0 otherwise)	−1.235	1.551	−0.80	0.426	−4.275–1.805	−1.083
Standard deviation of parameter density function	6.905	1.562	4.42	0.000	3.844–9.966	
Age band of the casualty	0.143	0.198	0.72	0.470	−0.245–0.530	0.942
Standard deviation of parameter density function	0.744	0.171	4.35	0.000	0.409–1.079	
Heterogeneity-in-the means variable: Vehicle type indicator (1 if passenger car, 0 otherwise)						
Road type indicator (1 if the accident occurred on a single carriageway, 0 otherwise)	−3.076	1.70303	−1.81	0.0709	−6.414–0.262	
Age band of the casualty	0.371	0.23298	1.59	0.1116	−0.086–0.827	
Number of observations			235			
Restricted log-likelihood			−108.625			
Log-likelihood at convergence			−96.504			

Two factors were associated with a more severe outcome in the model for rural areas: the vehicle’s movement at the time of the accident and the age band of the casualty. Specifically, vehicles moving ahead were observed to prompt the highest increase of probability for a serious or fatal injury, which is equal to 193.5%. Such a vehicle direction implies that drivers were not undertaking any turning or overtaking manoeuvre—which could be cognitively demanding—at the time of the collision, hence they were more likely to indulge in risk-taking behaviour [48]. The results also unveiled the heterogeneous impact of the casualty age band, as this variable produced a statistically significant random parameter. The distribution of the latter suggests that the involvement of older casualties is associated with more severe injury outcomes for more than half (approximately 58%) of the accident observations. For the remaining 42% of the sample, slight injuries were recorded for accidents involving older casualties. The dominant effect of the casualty's age on the injury severity seems, once again, to capture the greater vulnerability of older individuals in road accidents [15,49]. In contrast, the presence of both older individuals and minors as vehicle occupants for school related travel may encourage a proportion of drivers to practice more safe and considerate driving. This behavioural nuance could potentially explain the association between older casualties and slight injuries.

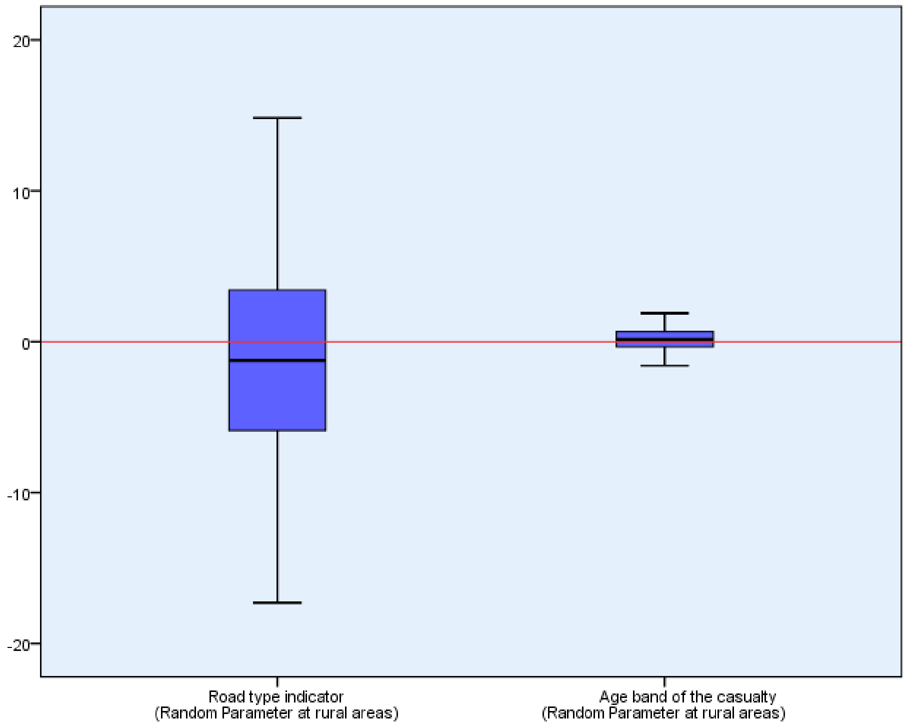

Figure 3. Boxplots illustrating the random parameters' distributions in the accident injury severity model for rural areas (the lower and upper limits of the box reflect the interquartile range, the thick line in the middle of the box represents the median, the red line indicates the zero value, and the whiskers are defined by the minimum and maximum values of the distribution).

Another common influential factor among urban and rural accidents is the vehicle type and, particularly, the passenger car. In both models, this factor decomposes the heterogeneity that is underpinning the injury severities, but via different mechanisms. Specifically, for rural areas, the passenger car does not emerge as a random parameter (as in urban areas), but as an exogenous factor that affects the means of the other two random parameters of the model, i.e., the casualty age band and the single carriageway indicator. In fact, the passenger car was found to decrease the mean of the random parameter distribution for the single carriageway indicator. Given that the mean of the specific parameter was already negative, a further decrease in its value (as posed by the passenger car) entailed a higher proportion of observations where the presence of a single carriageway was likely to result in a slight injury outcome. In other words, among the accidents that occurred on a rural single carriageway, the involvement of a passenger car further increased the probability of slight injuries. The passenger car was also observed to increase the mean of the random parameter related to the casualty age. In a similar manner, this result means that, among accidents with older casualties, the presence of a passenger car further increased the probability of a serious or fatal injury. This finding is in line with those of previous studies [50,51], which have pinpointed the propensity of older passenger car occupants to KSI outcomes.

4. Conclusions

Over the last few years, school travel safety has been a significant source of concern for parents and local communities in Scotland and abroad. This paper provides new empirical evidence on the determinants of injury severities for accidents that occurred during school travel, taking at the same time into account the variations stemming from the land use or built environment characteristics. In this context, separate accident injury severity models were estimated for urban and rural areas by employing a random parameter binary logit framework with allowances for heterogeneity in the means of the random parameters. This framework enabled the capture of the influence of unobserved heterogeneity in the accident data, which, if left unaccounted for, can induce significant bias in the outputs of the statistical analysis [52,53].

The results revealed that very few factors are common between the models for urban and rural areas. Vehicles running on heavy oil and single carriageways were identified to commonly affect accident injury severities, but with contradictory impacts among urban and rural areas. Both factors were associated with severe injuries in urban areas, but in rural areas, their impact was found to vary across the accidents, with a dominant tendency towards slight injuries. The lighting conditions were found to consistently influence injury severities for both urban and rural areas, with dark conditions favouring severe injuries and daylight being associated with slight injuries. The results also demonstrated that significant heterogeneity arises from the road surface conditions, with a dry pavement at the time of the accident resulting in slight injuries for most of the urban incidents. The presence of a signalised intersection also acted as a source of heterogeneity in urban accidents during school-related travel, but mainly favouring slight injury outcomes. Accidents including elderly vehicle occupants were more likely to result in severe injuries, especially for urban areas, whereas a proportion of such accidents in rural areas was linked with less severe injuries, which may reflect instances of risk-averse driving. The passenger car also captured various layers of heterogeneity with impact not only on the injury severity probabilities, but also on the distributional effect of the random parameters, as, in rural areas, the specific factor was found to decompose the heterogeneity in the means of random parameters.

The findings of this study can inform policy interventions with an overarching aim to enhance the safety of school-related travel. The impact of heavy-duty engines on injury severities pinpoints the need for more restrictions in the traffic of heavy vehicles, especially in urban areas and in the vicinity of schools. The observed relationship between single carriageways and severe injuries may prompt the implementation of more traffic calming measures on this road type. These can include the establishment of 20 mph zones around schools as well as the introduction of variable speed limits during the school operation hours. Future safety awareness initiatives can be targeted to elderly road users, who were found to be susceptible to severe injuries in both urban and rural areas. However, in rural areas, older users in passenger cars were even more prone to severe injuries, hence policy interventions promoting active school travel could bring significant public health benefits in a synergetic manner for different vulnerable road users such as children and the elderly. Schemes like the School Street, which has been used in the UK, can actively enhance active travel for children and their guardians through prohibiting vehicular traffic in the vicinity of schools [54]. In urban areas, the relationship between dark conditions and severe accidents can prioritise the installation of better street lighting and school zone signs with reflective sheeting in order to improve road users' visibility. Finally, given the established role of the passenger car in school travel safety for both urban and rural areas, road safety campaigns are also suggested, with a primary focus on eliminating speeding and other types of aggressive driving behaviours by parents or guardians in the proximity of schools.

This study is not without limitations. The database mainly includes information about accidents in school-related travel that involve private motorised modes of transport, whereas very little information was available for travel that was carried out by bicycle, walking, or public transport. The scarcity of this information directly stems from the low shares of cycling or bus use for school travel or the underreporting of minor accidents (especially those which included travel on foot). Future endeavours can shed more light on the safety assessment of active travel to school, as the latter constitutes a high priority of policymakers in an effort to enhance the physical activity of children and also reduce the mobility-related emissions that are caused by motorised modes of transport. In this context, future studies can further explore the factors influencing an accident injury's severities, considering even more disaggregate analyses for the children who travel to school as pedestrians, cyclists, or vehicle passengers and taking into account the patterns of temporal heterogeneity [55].

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