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Geographical Patterns in Road Safety: Literature Review and a Case Study from Germany

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This paper aims to geographically differentiate the road accident costs associated with living at a certain place of residence. Official accident data in Germany record the place the accident occurred, but not the casualties' places of residence. Among those involved in an accident at a certain place there may obviously be some non-residents. Hence spatial analysis based on place of accident may not be suitable for drawing conclusions about specific cost (or risk) figures for people living in certain places. People's risk of encountering an accident in areas other than that where they live may vary with their mobility.
We provide an extensive literature review of geographical accident analysis both for place of accident-based and place of residence-based approaches, including the question to what extent accident related analyses can be used to estimate residential related risks. Subsequently we report on a residence-based case study for the German state of North Rhine-Westphalia where we study per capita accident cost figures on the district level. We also examine impact factors of accident cost levels using structural equation modelling. The results show that the cost figures are considerably lower for urban residents than for suburban and rural dwellers. For children the picture is more mixed.

Keywords: Road safety, Traffic accidents, Accident costs, Residential location, Built environment.

1. Introduction

Many social and environmental factors have been identified as drivers of household suburbanisation, and the provision of a safe environment for their children is clearly a major concern of parents in this context (Hillman, Adams and Whitelegg, 1990; Kim, Horner and Marans, 2005). Cities are known to be characterised by perilous traffic, and indeed research has found higher accident risks in urban than in rural areas, particularly for children (Neumann-Opitz, Bartz and Leipnitz, 2008; Petch and Henson, 2000). This may, however, be a reflection of the conjoint study of all casualties, no matter whether fatalities, serious or slight injuries. Such figures may be relatively high in cities but they may also be strongly dominated by a large number of minor injuries. On the other hand, rural areas may be most at risk when it comes to

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more serious accidents, as "traffic safety researchers have long known that the majority of fatal crashes occur on rural roads" (Blatt and Furman, 1998, p. 705).

Accident rates are measured by number of casualties in an area per 100,000 inhabitants. This indicator, however, does not show whether living in the city is safer or less safe than living elsewhere. Not all those involved in a crash at a certain place are necessarily resident there, in-commuters and transients may be involved (Cummings, Koepsell and Mueller, 1995). As Blatt and Furman (1998) put it, "it has never been clarified as to whether rural crashes involve people who live in rural areas or residents of urban areas traveling on rural roads" (p. 705).

This paper makes use of structural equation modelling (SEM) to study the spatial distribution of per capita macro-economic road accident costs for populations living at certain places of residence. Building on an extensive literature review, we report on a case study for the German Federal State of North-Rhine Westphalia. We seek to disentangle impact factors on accident cost by using SEM. A related paper focussing on injury risks is available elsewhere, using a different approach based on regression analysis (Scheiner and Holz-Rau, 2011). For comparison, we also include some basic figures on injuries and fatalities here. To the best of our knowledge, this is the first study of this type for Germany.

The research question addressed is which spatial context contributes most to minimising road accident risk (measured here in terms of accident cost) and, hence, is conducive to sustainability from a road safety perspective.

2. State of the research

Two decades ago, Joly, Foggin and Pless (1991) noted that "there has been little published on the geography of traffic accidents" (p. 765, references for early exceptions are also provided there). This clearly has changed over the last two decades. In the following we review studies on the geographical distribution of accident rates and accident risks. We are not aware of studies focussing specifically on the geographical distribution of accident costs. The difference between 'rate' and 'risk' is that "accident rates should refer to locations or areas, whereas accident risks should apply only to individuals or groups of road users in relation to some measure of exposure" (Abdalla, Raeside, Barker and McGuigan, 1997, p. 587). In other words, accident rates refer to places where accidents occur, while accident risks refer to people, i.e. to populations who may be characterised by their behaviour, skills, lifestyles, or places of residence. These relatively narrow definitions serve well the purpose of this paper, but it should be noted that some authors use the terms accident rate and accident risk synonymously (Elvik et al., 2009, p. 35-36, see also the discussion provided by Haight, 1986).

The difference between these two spatial approaches to road safety – place of accident (POA) v. place of residence (POR) – has long been recognised (Blatt and Furman, 1998; Cummings et al., 1995; Gooder and Charny, 1993). Lu, Chou and Lee (2000) intensely discuss data issues and possible deviations between POR, POA, and place of death (in case of fatal accidents).

We start with a brief overview of impact factors for accident risk including the role of the environment, followed by a review of studies based on POA, studies based on POR, and studies of the proximity of or distance separating the two, a factor which might determine whether POA may be a proxy for POR.

2.1 Impact factors for accident risk

In general, the impact factors for accident risks and, thus, reasons for variations, may involve three interdependent realms: (1) risk exposure, (2) environment, (3) social and psychological factors. For instance, Thomson, Tolmie and Mamoon (2001) model risk as a function of exposure multiplied by hazard divided by traffic skill. Exposure, in their understanding, is mainly captured by time spent on the street, as their model refers to children. The degree of hazard is supposed to be determined by the local traffic environment. Traffic skills are individual and household factors that affect a person's ability to deal appropriately with the hazard.

While this model provides a useful start, one may well extend its details. Risk exposure is mainly an outcome of transport mode use, travel distances and traffic mix (Elvik et al., 2009, p. 35-37). E.g., large proportions of cyclists may be associated with low risk levels, possibly because car users drive more carefully in regions where many people cycle (Vandenbulcke, Thomas, de Geus, Degraeuwe, Torfs, Meeusen and Int Panis 2009).

In terms of severity of accident, driving speeds are of major importance as well. Environmental factors include the condition of the road network, road type and design, spatial context (e.g. density and land-use; plantation etc.), temporal context (e.g., darkness) and transport context (traffic density, speed and behaviour of other transport users). Social and psychological factors include sociodemographic and socio-economic structures, risk attitudes, lifestyles and 'mobility styles' (Schulze, 1999) and associated behaviour. For instance, in a questionnaire survey in Norway of 900 young adults Eiksund (2004) found that risk acceptance and risk-seeking were more common in rural than in urban areas. Many status and other social variables are also associated with the socio-spatial attributes of the neighbourhoods where people live (for examples see Thomson et al., 2001, p. 10).

Various authors differ in focus and degree of detail with respect to the impact factors of accident risk. Differences refer to type of road, operational speed, traffic mix, road user mix, mode used, site etc. However, as the focus of this paper is on relatively large-scale spatial categories (urban v. rural) each involving specific requirements for their residents' travel concerning the mix of road types and modes used, distances travelled, operational speeds etc., we stay on this somewhat rough level here. Readers are refered to the comprehensive discussion in Elvik et al. (2009) for a more detailed discussion.

2.2 POA-based approaches

Many studies examine attributes of places where accidents are more likely to occur than elsewhere. These studies are typically based either on accident counts and control for area and/or population size of the areas under study, or on accident rates, using population as the denominator. Overall, results have tended to claim that high density and urbanity are associated with lower rates of severe injuries. When accident rates including all injuries are considered, the results are less conclusive.

Ewing, Schieber and Zegeer (2003) found a negative association between density and fatalities per inhabitant in a study of 448 counties in the USA. This applied to all casualties considered together as well as to pedestrian casualties. Amount of pedestrian travel (acting as a proxy for pedestrian risk exposure) was controlled.

Dumbaugh and Rae (2009) studied accident counts for San Antonio, USA, on the neighbourhood level. They controlled for size, population density, socio-demographics, and traffic infrastructure attributes of the neighbourhoods, and found that large-scale retail outlets were associated with increased risk of accident and injury, while the opposite was true for traditional designs with high density, walkability and small-scale neighbourhood shops. They interpreted these findings as resulting from higher speed levels on arterials and less driving in traditional neighbourhoods.

Noland and Quddus (2004) studied 8,414 wards in England and found urban areas with higher densities associated with a lower absolute number of casualties and particularly fatalities, but a higher number of casualties in areas with higher workplace densities (similarly: Levine, Kim and

Nitz, 1995, for Honolulu). This study controlled for area size and population size, demographic structure, urban structure and transport infrastructure.

Kim, Pant and Yamashita (2010) studied accident counts in Honolulu, Hawaii on a micro-scale grid cell level. They found that the odds of a crash (versus no crash) were high in business, commercial mixed land use, and high-density residential areas. This was true for injury crashes, and when all crashes were considered. The odds of a fatal crash were also high in business and commercial mixed land use areas, while fatalities showed no significant association with residential density.

In Germany Apel, Kolleck and Lehmbrock (1988) studied accidents in 80 cities with over 60,000 inhabitants. They found that compact, dense cities were associated with lower accident rates and ascribed this to lower per capita travel volume, i.e. to risk exposure. They also found that accident rates increased with the extension of road networks (road length divided by population plus in-commuters), car ownership, and car use. Meewes (1984) reported similar results for towns and municipalities with less than 80,000 inhabitants. Neither of the studies allowed comparisons to be made between large cities and more rural municipalities.

Many a study focuses on children. Neumann-Opitz et al. (2008) found higher accident rates for children aged 14 or under in German cities than in rural or suburban districts. The direction of the association varied between transport modes. Pedestrian accident rates increased with municipality size, while the opposite was true for vehicle occupants. This suggests compensatory mechanisms based on variations in mode choice and, thus, exposure. Accident severity was not considered and the large number of slight injuries thus dominated the overall picture.

Dissanayake, Aryaija and Wedagama (2009) studied child injuries in Newcastle, UK, on the intra-urban level. They found land use density to be negatively associated with the number of children injured. The authors traced this back to traffic calming systems prevalent in such areas. Again, injury severity was not considered.

In contrast, the findings of Petch and Henson (2000) for Salford, UK, suggested higher rates of child pedestrian/cyclist casualties in inner-city areas. The findings included positive relationships between casualty rates and over-crowding (persons per household), traffic volume and the proportion of no-car households. The latter relationship may suggest that children in areas with low levels of car ownership walk and bike more than average. Similarly, Joly et al. (1991) reported for Montreal that child pedestrian and cyclist injury rates tended to be concentrated in inner-city, low-income areas.

All studies reviewed so far referred to POA and did not consider the casualties' POR. It was therefore impossible to draw conclusions about the geographically specific accident risks of different residential populations, even though some studies implicitly used POA as a proxy for POR.

2.3 POR-based approaches

POR-based approaches may capture the risk of injury for a population better than studies based on POA.

Blatt and Furman (1998) studied the involvement of drivers in fatal accidents in the USA. They found above average risk figures for rural and small town populations. This held true for all drivers taken together, for male drivers, young drivers, and drivers in crashes involving child fatalities. The risk figures for rural areas were generally about twice the size one would expect, if the risks were evenly distributed. As per-capita miles driven did not differ that much, exposure could not account for the large differences.

Scheiner and Holz-Rau (2011) reported case studies for two German regions. They distinguished by severity of injury and age, but not by travel mode. They also found the highest risk figures for rural and suburban areas, and lower risk figures for city dwellers. This was true for all age groups.

Baker, O'Neill and Ginsburg (1992) reported road accident fatality risks for the USA and found the risk figures for motor vehicle occupants to be highest in remote rural areas, whereas risk figures for pedestrians and motorcyclists reached a maximum in central cities, again suggesting spatial compensatory mechanisms based on mode choice.

In the UK there is a strong focus on the accident risks of disadvantaged population groups, using variables such as income, social status, or ethnic background. Related studies consistently showed that risk figures are positively related to social deprivation (see Abdalla et al., 1997; Edwards, Green, Roberts, Grundy and Lachowycz, 2006; for child injury risk see Petch and Henson, 2000; Thomson et al., 2001). Baker et al. (1992, p. 224ff) reported similar results for the USA; their analysis was based on income. Edwards et al. (2006) provided a comprehensive study in this area. Referring to a small-scale level of 4,765 census areas in London, they distinguished between age groups, severity of injury, and transport mode. They found the pedestrians injury rate in the most deprived areas to be almost three times higher than in the least deprived areas. The same applied to injured child pedestrians. The findings for cyclists were similar, while the association between area deprivation and car occupants' injuries was less clear.

In these studies there is strong overlap between area and social inequality, which makes it difficult to judge on the 'true' role played by either geographical or social differences. Most studies that focus on social inequality do not explicitly take urban form into account, nor do they distinguish by categories such as urban and rural. An exception is Hewson (2004), who studied the links between deprivation and child injury risk in Devon County, UK on the ward level. He made an explicit distinction between an POA-based and a POR-based approach. The results consistently showed that deprivation as well as level of urbanity were positively associated with risk levels. However, how urbanity was measured was not explained in more detail. Also, no distinction was made between levels of injury severity.

2.4 Does using POR or POA make a difference?

Numerous studies aim to determine the distance between a POA and the casualties' POR, or the proportions of casualties who reside in a defined area where the accident occurred. If most accidents occur very close to where the casualties live, the distinction between the two approaches reviewed above would make little sense. The results concerning distance depend on travel mode, sociodemographics (namely age), and measurement accurateness (e.g., size of the areas).

Edwards et al. (2006) computed distances between POA and casualties' POR on a small-scale level in London, resulting in a median distance of 2.75 km. For the middle age group, the value was slightly higher. The median value for car occupants was 2.92 km, which seems surprisingly low (perhaps because the data were limited to London, thus excluding long-distance trips). The values for pedestrians and cyclists were 1.06 km and 2.14 km, respectively. Similarly, Abdalla et al. (1997) reported a median value of 2.4 km for all casualties (pedestrians < 1 km) for Scotland (calculated on the postcode level).

For children the distances between POA and home are generally relatively short. Petch and Henson (2000) reported for children under 17 years of age that the proportion of casualties who were involved in an accident less than 500 m from their residence was 62% for pedestrians, 56% for cyclists, and 18% for motor vehicle occupants, which well matched values for New Zealand (Roberts, Norton, Dunn, Hassall and Lee-Joe, 1994), and for Devon County, UK, where the median is less than 500 m (calculated from Hewson's (2004) Figure 3; similarly: Edwards et al., 2006; Joly et al., 1991).

To sum up, POA may be used as an approximate measure of POR-based risk figures for children (and perhaps for other population groups with low mobility levels), for non-motorised modes, and generally when the spatial resolution of the analysis is clearly beyond the municipality level (e.g. when districts or countries are compared).

2.5 Conclusions

Generally, POA analysis allows detection of the effects of the environment (e.g., road network, traffic volume, traffic speed, land use) on safety, but does not allow correct estimations of risk figures for a certain population. POR-based analysis is about people's risks rather than risky sites. Hence, it permits estimation of risk figures for a population, but gives no information on the safety or unsafety of particular sites. To a certain extent POA may serve as a proxy for POR, depending on the population group and the mode under study, and the spatial resolution of the analysis.

Some methodological conclusions may be drawn from the overall picture provided by the literature.

- Many studies are limited to pedestrians, non-motorised modes, drivers or car occupants. While such a focus is helpful for many research questions, it gives no information about the total risk figures faced by a population. Risk figures for different modes may offset each other, as exposure depends on mode use, which has consistently been shown to differ widely between urban, suburban and rural areas, as well as within cities (Scheiner and Holz-Rau, 2007; Ewing and Cervero, 2010).
- The focus is often on children. While this is a group that clearly deserves particular attention, we are interested in an overall valuation of different spatial structures.
- The strong overlap of social variables and area characteristics due to residential segregation often makes it difficult to draw conclusions on the 'really' decisive variables affecting safety.
- Many studies do not distinguish by severity of injuries. They thus treat all injuries as equal, no matter whether a broken arm or a fatality results. Urban areas may score relatively high in total injury figures, while severe injuries and fatalities tend to be more prevalent in rural areas. Analysis should either be categorised by, or weighted by severity, e.g. by using macro-economic cost. To the best of our knowledge, we are not aware of any study that aims to determine road accident cost geographically with a focus on spatial context.
- The majority of studies that employ POR-based approaches focus on social disadvantage rather than area characteristics in terms of urban form, city size, density and the like.
- Exposure is generally recognised to be a key impact factor of injury risk. However, exposure differs systematically between area types due to spatially specific travel behaviour. Hence, controlling for exposure may result in underestimating geographical effects, as exposure itself is to some extent determined by area type.

In a prior study we examined POR-based accident risk in the same study area (Scheiner and Holz-Rau, 2011). However, as that study was based on regression analysis using composite factor scores as explanatory variables, we could not isolate the impact of real-world variables. In this paper we use SEM to do exactly this.

3. Methodology

Official German accident data do not record casualties' POR. This paper uses data suitable for consideration of POR. POA is not considered in our empirical study. The study area and data are briefly introduced in the following.

3.1 Study area

Our study area is North-Rhine Westphalia (NRW), which is located in north-west Germany (Figure 1). NRW is divided into 54 districts and cities with a mean area of 631 km². Cities are for practical purposes 'urban districts' but they are actually known as 'district-free cities' (*kreisfreie Städte*) and typically include agglomeration cores, i.e. cities with about 100,000 inhabitants or more. Districts (*Landkreis*) include suburban and rural areas. We use the terms 'district' and 'district level' to include 'district-free cities'.

NRW is strongly urbanised with the highest population density of all German federal states (528 inh/km²) except for the city states of Berlin, Bremen and Hamburg (Table 1). In terms of population NRW is the largest German state with almost 18 million inhabitants. The Rhine-Ruhr region, a cluster of cities at the centre of NRW, is the largest population agglomeration in Germany. Only 13 percent of NRW municipalities have fewer than 10,000 inhabitants, compared to 87 percent in the whole of Germany.

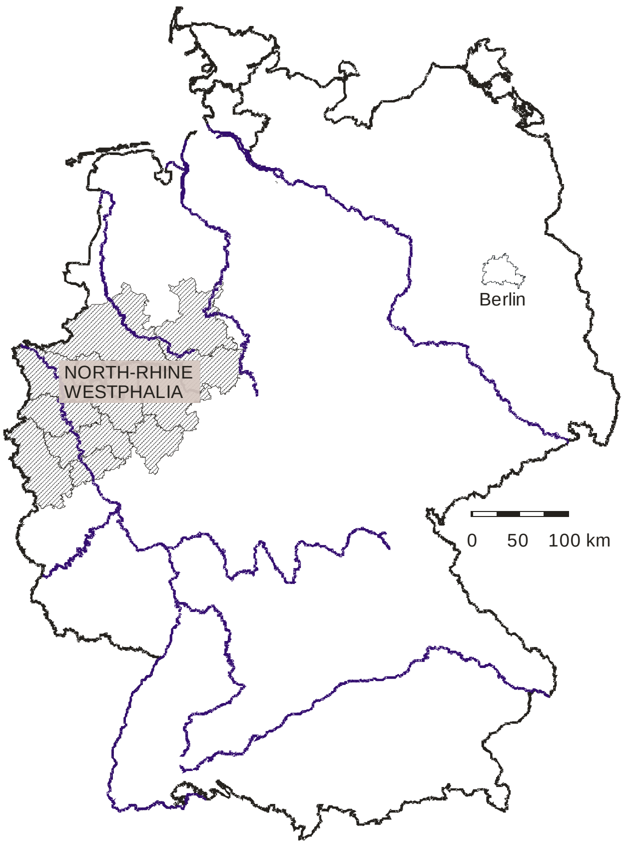

Figure 1. Location of the study area in Germany

Table 1. The study area: basic figures (2007)

	NRW	Germany
Area (1,000 km²)	34.086	357.104
Population (millions)	17.997	82.219
Density (inhabitants/km²)	528	230
Cities > 250,000 inh (no.)	13	27

Source: Destatis (Federal Statistical Office).

3.2 Data

Casualties' POR are not recorded in official German statistics. We therefore used vehicle license numbers, which indicate the district where the vehicle is registered, as a proxy. This provided a relatively rough spatial resolution based on the 54 NRW districts. As the district of Aachen and the city of Aachen have the same number plate, they were treated as one district. 53 spatial units were thus used in the analysis. Using number plates means data may be slightly biased, because vehicles may not be registered at the occupants' POR, casualties may be passengers, or the vehicle in question may be rented or a company car.

The data were provided by the Statistical Office NRW. Such data are not regularly published but are available upon request. The data included all casualties on any road type from 1998 to 2008. They were classified by age groups (0-5, 6-14, 15-17, 18-20, 21-24, 25-64, 65+) and severity of injury. Roughly 707,200 cases (about 7,400 fatalities, 122,000 severe injuries, 576,900 slight injuries) with an identifiable vehicle license number are included in the data. Six percent are out-of-state plates.

We geographically classified injured pedestrians and bicyclists by POA, as they do not have number plates. This is a sufficient proxy for the POR in these cases (see Section 2.4), given the large district sizes[3].

In addition to the accident data, structural attributes of the districts were used to see whether they may help explain accident risks and improve understanding of spatial differences. Attribute selection was based on the literature (see Section 2), but also on data available in the regional data base of the NRW Statistical Office. Mean values of the years 1998 to 2008 were used except where noted.

- Compactness: share of settlement plus transport areas in total district area (the numerator in this fraction refers basically to built-up area plus land area used for transport infrastructure, see BBSR 2010 for details)
- Extension of road network: share of road space in total district area
- Population density: 1,000 inhabitants per km²
- Car ownership level: passenger cars per 1,000 inhabitants
- Workplace centrality: ratio of work places (subject to social insurance contribution) to residential population
- Demographic structure: shares of age groups among the population
- Socio-political climate: share of Green voters at the 2005 federal election.

[3] The data did not include accidents involving NRW inhabitants outside the state borders. The real risk figures are therefore higher than those calculated in this study. Municipality level data for Lower Saxony showed that this underestimation is limited to a narrow belt of not more than 5 km along the state border (see Scheiner and Holz-Rau, 2011). On the district level this is hardly relevant, so we refrained from any correction.

The latter attribute requires explanation. It seems likely that dominant attitudes towards (transport) policy in an area may play an important role in road safety. This is a factor that is difficult to reflect in standardised data. The Green party is the only one of the sizeable German political parties that advocates a specific transport policy that differs from that of other parties. Kahn and Morris (2009) found that share of Green voters significantly affected travel behaviour in a municipality. However, we are not aware of any studies using share of Green voters in the context of road safety.

Concerning demographic structure, we focus on two age groups for parsimony: those aged 18-24 and the elderly (65+ years of age). The former is known to be the main risk age group and the latter represents a vulnerable group of relatively slow drivers. We do not expect the reduction in complexity achieved by excluding some age groups to substantially affect our results, as the population age composition is well reflected in the indicators finally used.

Unfortunately, regional transport demand data that could adequately reflect risk exposure was not available. Car ownership level was thus used as a proxy. Car ownership rate is the crucial factor determining geographical differences in exposure (particularly on the aggregate level), as the vehicle kilometres driven by those who have a car available is relatively similar between urban and rural areas in Germany (Motzkus, 2001). Car ownership is closely connected to car use even on the individual level (Scheiner and Holz-Rau, 2007), although individually or in certain population subgroups this association may vary. Data on operational speed levels was also unavailable. The general speed limit in Germany is 50 km/h within and 100 km/h outside built-up areas. It thus seems likely that mean operational speed levels are extremely closely and negatively correlated with compactness and that introducing a measure of operational speed levels would not substantially change the structure and results of the analysis. There is no general speed limit on German motorways. Many motorways, however, have local speed limits, particularly in metropolitan areas with high traffic densities. This may also contribute to urban-rural differences in accident risks. However, driving on country roads is likely to play a more important role in this respect, as the number of injuries per vehicle kilometre driven on motorways is only a quarter of that of all roads taken together (the corresponding figure for fatalities is about one third) (BMVBS 2012). Table 2 shows descriptive statistics of the explanatory variables finally used for modelling (see results section).

Table 2. Descriptives of explanatory variables used in SEM

	min	max	mean	standard deviation
Green voters (%)	0.039	0.152	0.074	0.023
Workplace centrality	0.200	0.589	0.306	0.072
Compactness	0.108	0.752	0.365	0.181
Population density	0.128	3.349	1.093	0.911
Car ownership level	0.446	0.608	0.532	0.041
Aged 18-24 years (proportion)	0.066	0.094	0.078	0.005
Aged 65+ years (proportion)	0.151	0.218	0.183	0.015
Accident cost (m € per 100,000 inhabitants)				
all age groups	9.809	23.774	15.658	3.913
0-14 years	6.278	11.961	9.091	1.309
18-24 years	17.846	64.844	37.389	14.916
65+ years	8.163	24.631	13.870	4.019

3.3 Analysis

Our approach was fairly straightforward. We estimated population-based risk figures for fatalities, severe injuries and slight injuries per 100,000 inhabitants. We computed annual mean values over the observation periods in order to level out random variance. We did not consider road category or accident site. We calculated per capita accident costs from the risk figures. This conforms to the sum of fatalities and injuries, weighted by severity. It should be noted that the most basic meaning of 'risk' is the probability that an event occurs. Empirically this may be expressed in relative frequencies (in our case: relative to population size). However, treating all accidents, from slight injuries to fatalities, as equal is not reasonable. There are two solutions. Either one may study various severity categories separately, or one may weight by severity. The first option may, however, produce much redundant information, and it does not answer the question concerning impact factors on overall damage. Hence, we opt for weighting. To improve accessibility for readers, we also provide some figures on injuries for comparison.

We used the standard unit costs used in cost benefit analysis in German transport planning (BASt, 2010), which are based on a human capital approach (1,035 m € for fatalities, 110,506 € for severe injuries, 4,403 € for slight injuries). They include direct and indirect reproduction costs (costs for medical and vocational rehabilitation of casualties) and costs for the loss of human resources in terms of their economic value, including non-marketed value (domestic work and hidden economy). We excluded vehicle damage. Our calculations therefore tend to slightly underestimate geographical differences, because vehicle damage tends to be more expensive in serious accidents.

Our analysis starts with descriptive spatial comparisons between district types (Table 3). We also map accident costs. Subsequently, we use SEM to ask which spatial attributes of the districts and municipalities help explain accident costs for the total population and for three selected age groups. We also estimated SEMs for fatality risk (fatalities per 100,000 inhabitants) which are available upon request from the authors due to lack of space.

Our modelling approach is based on various causal assumptions (Figure 2). First, in line with studies on segregation and residential choice we assume that the demographic composition of the population is exogenous to spatial context, i.e. that different population groups are not equally distributed in space. Second, in line with transport studies we assume that spatial context is exogenous to car ownership as car ownership decisions are typically based on longer-term residential decisions (Scheiner and Holz-Rau, 2007; Van Acker and Witlox, 2010). Third, we assume that spatial context, sociodemographics and car ownership level are exogenous to accident cost (or injury risk, respectively).

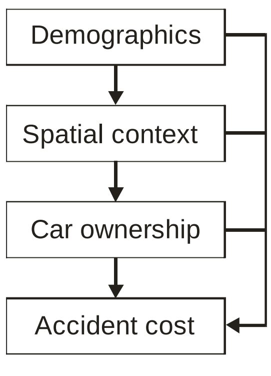

Figure 2. Modelling approach

It should be noted that these premises do not fully meet the complexities of reality. For instance, car ownership may affect residential choice rather than vice versa. However, the causal chain of sociodemographics affecting spatial context, which in turn affects car ownership is based on extensive travel behaviour modelling efforts that showed these causal assumptions to be superior to or at least equal as good as any reversed causality between either two (Scheiner and Holz-Rau, 2007).

We did not expect to encounter spatial autocorrelation due to the size of the districts, as autocorrelation was seen to be weak even on the municipality level in another case study (Scheiner and Holz-Rau, 2011). As our data include only 53 cases, significant effects are rare. We conventionally report significance levels, but focus our interpretation on effect magnitudes, as our sample is not random but covers the whole universe of accident reports in NRW.

Table 3. District types in the study area

District type	criteria	no. of districts	inh (m)	inh (%)
Agglomeration cores ('core cities')	'urban district', > 100,000 inh	22	7.2	39.9
High-density suburban districts	> 300 inh/km²	16	6.6	36.8
Medium-density suburban districts	> 150 inh/km²	12	3.6	20.0
Rural districts	< 150 inh/km²	3	0.6	3.5
All		53	18.0	100.0

Based on the BBSR district typology (see www.bbsr.bund.de), simplified.

SEM is a powerful tool that allows the investigation of multi-stage interrelations between variables. Unlike regression analysis or discriminant analysis, SEM can deal with several endogenous variables with interdependent relations with each other, as well as the inclusion of intervening variables. It h as become popular in transport studies since the 1990s (Golob, 2003), and it is an established instrument in road accident studies (Wong, Chung and Huang, 2010).

We have to cope with two data limitations: first, the small sample size, and second, the non-normality of some of our variables (as established by Shapiro-Wilk's W test). Browne (1984) developed an asymptotically distribution-free (ADF) estimation procedure that can be applied to binary or ordinal-level variables. However, for non-normal continuous variables (as the ones we examine) the maximum likelihood (ML) approach is regarded as superior to the ADF procedure (Schermelleh-Engel, Moosbrugger and Müller, 2003, p. 27). According to Hoogland and Boomsma (1998) the ADF procedure performs better in the estimation of standard errors as long as the average kurtosis of the observed variables exceeds three, and n>400. In our case, Fisher kurtosis values (K, centered at zero) are smaller than one for all variables used except for Green voters (K=2.8) and workplace centrality (K=4.1). The multivariate kurtosis values range between 9.91 and 10.96.

Concerning necessary sample sizes, Hoogland and Boomsma suggest n>20*df for ADF estimation, and n>5*df for ML estimation, as otherwise ML tends to reject the model too often. For an average kurtosis >5.0 and ML estimation, the sample size should be n>10*df.

Given these considerations, we believe that the ML approach appropriately fits our data despite non-normality. Our sample is small, but clearly exceeds the necessary size (df=1, n=53). Anyway, as noted above, we are more interested in effect magnitudes than in significance and, hence, standard errors. The analyses were undertaken using the software AMOS 7.0.

From the multiple relations we tested in initial model versions ('full models') we excluded the effects of demographic structure (share of 18-24 years old and share of 65+ years old) on Green voters and population density, as the standardised effects were generally smaller than 0.03, and significance levels were p>0.5. What is more, we simplified the models by assuming unidirectional rather than bi-directional relationships between workplace centrality and Green voters, and between compactness and density, respectively. Setting bi-directional effects free resulted in negative variance estimates for Green voters and compactness. Eliminating the two reverse effects (from population density to compactness and from Green voters to workplace centrality) had little effect on the coefficient estimates or explained variance of accident cost. We also tested for reverse unidirectional relationships separately, respectively, without finding much difference in coefficient estimates. These simplifications resulted in the 'reduced form models' presented here.

4. Results

4.1 Descriptive analysis

Table 4 shows that per capita accident costs were considerably lower for urban dwellers than for the suburban and rural population. This was particularly the case for car occupants and thus was likely to be associated with spatial variation in per capita vehicle miles travelled and/or operational speed. Accordingly, these cost differences are perhaps compensated by above-average accident costs for urban bicyclists and pedestrians.

However, accident costs for bicyclists were – contrary to this 'compensation hypothesis' – below average in agglomeration cores and highest in medium-density suburban districts. For pedestrians, agglomeration cores performed clearly worse than other district types, supporting the compensation hypothesis. Considering cyclists and pedestrians together resulted in accident costs being highest in medium-density suburban districts, and lowest in high-density suburban districts. Thus, spatial variation seemed not to be particularly systematic. Please note that the transport mode-specific figures in Table 4 may be summed up as they refer to the total population of the area types considered. This is because every inhabitant may be a bicyclist, a pedestrian and a vehicle occupant at various points in time.

The right half of Table 4 shows corresponding risk figures for being injured or killed. These suggest that the high costs in rural areas are mainly due to fatalities. The risk of a fatal accident is twofold higher for rural dwellers than for those living in agglomeration cores. The risk of a severe injury is also highest in rural areas, while the figures for slight injuries are highest in agglomeration cores, although the spatial differences are less marked in relative terms. When all casualties are summed up, regardless of accident severity, spatial differences almost completely level out. Hence, the risk of having an accident is almost equally distributed over the spatial categories defined here, but accidents are far more severe for those living in suburban or rural districts, resulting in higher cost figures. Injury figures categorised by mode and age group are available from the authors upon request.

Table 4. Accident costs, fatality and injury risk by district type in NRW

	Accident costs (m € per 100,000 inhabitants)				**Fatality and injury risk (occurrences per 100,000 inhabitants)**			
	Bicycl-ists	**Ped-estrians**	**Motor vehicle occupants**	**Sum**	**Fatalit-ies**	**Severe injuries**	**Slight injuries**	**All casual-ties**
Agglomeration cores	2.4	3.2	7.0	12.6	3.2	70	360	434
High-density suburban districts	2.7	2.3	10.4	15.4	4.5	83	353	440
Medium-density suburban districts	3.7	2.5	13.4	19.6	6.8	101	330	438
Rural districts	2.3	2.7	15.9	20.9	6.9	112	315	434
Overall	2.8	2.7	9.8	15.3	4.5	82	350	437

Table 5. Accident costs by district type in NRW – age groups (m € per 100,000 inhabitants in the respective age group)

	Age group							
	0-5	**6-14**	**15-17**	**18-20**	**21-24**	**25-64**	**65+**	**overall**
Agglomeration cores	5.6	11.4	13.4	25.3	22.5	12.2	11.8	12.6
High-density suburban districts	5.1	10.6	21.7	44.6	32.3	14.4	13.4	15.4
Medium-density suburban districts	4.7	11.4	26.5	60.7	44.3	18.2	18.1	19.6
Rural districts	6.4	12.2	31.2	77.4	49.0	19.7	14.4	20.9
Overall	5.2	11.1	19.8	41.3	31.4	14.5	13.7	15.3

In total, per capita accident costs for rural dwellers were 60 to 70 percent higher (20.9 v. 12.6) than for city dwellers. These spatial differences would change little even if we were able to code pedestrians and bicyclists correctly according to POR, because total costs are dominated by motor vehicle occupants for whom the spatial differences are most striking.

Comparing age groups (Table 5) showed the well-known concentration of high costs among young adults: the costs virtually exploded at driving age and decreased again in the middle age group. The spatial distribution suggested that this short-term 'cost summit' – although existent in all spatial environments – was far less pronounced in cities than in suburbia and the countryside. While the costs increased from the age group 6-14 to the age group 18-20 by factor 2.2 in agglomeration cores (25.3 / 11.4=2.2), it increased by factor 6.3 in rural districts (77.4 / 12.2=6.3). Accident costs in the age group 18-20 were therefore threefold higher in rural areas than in agglomeration cores. For adolescents, the middle-aged and the elderly, the costs were also higher in suburban and rural areas than in cities, reaching more than factor two for adolescents.

Geographical patterns are shown in Figures 3 to 6. The categories are based on quintiles. The picture for the total population corresponded strikingly with the NRW urbanisation pattern (Figure 3). The Ruhr area, the Rhine chain with Düsseldorf, Cologne and Bonn, and the urban triangle of Wuppertal, Solingen and Remscheid showed the lowest costs. Districts with medium cost figures gathered in the high-density suburban districts of the greater Rhine-Ruhr region as well as in and around the cities of Bielefeld, Siegen and Aachen. High cost figures appeared in the rural areas.

For children the picture was more mixed (Figure 4). Low cost figures for children were found in many agglomeration cores as well as in some suburban and rural areas. Other agglomeration cores, such as Düsseldorf, Duisburg, Hagen (south of Dortmund) and Hamm (north east of Dortmund), displayed high costs, but the same was also true for many suburban and rural areas.
In the early years of driving (18-20) the urban-rural differences were found to be particularly blatant (Figure 5). Rural areas displayed cost figures two to four times higher than those of the Rhine-Ruhr agglomeration. Just one of the smaller agglomeration cores (Hamm) fell into the second highest category. The cost values among young adults were dominated by motor vehicle occupants even more than in other age groups. Nine of ten fatalities in this group were motor vehicle occupants.

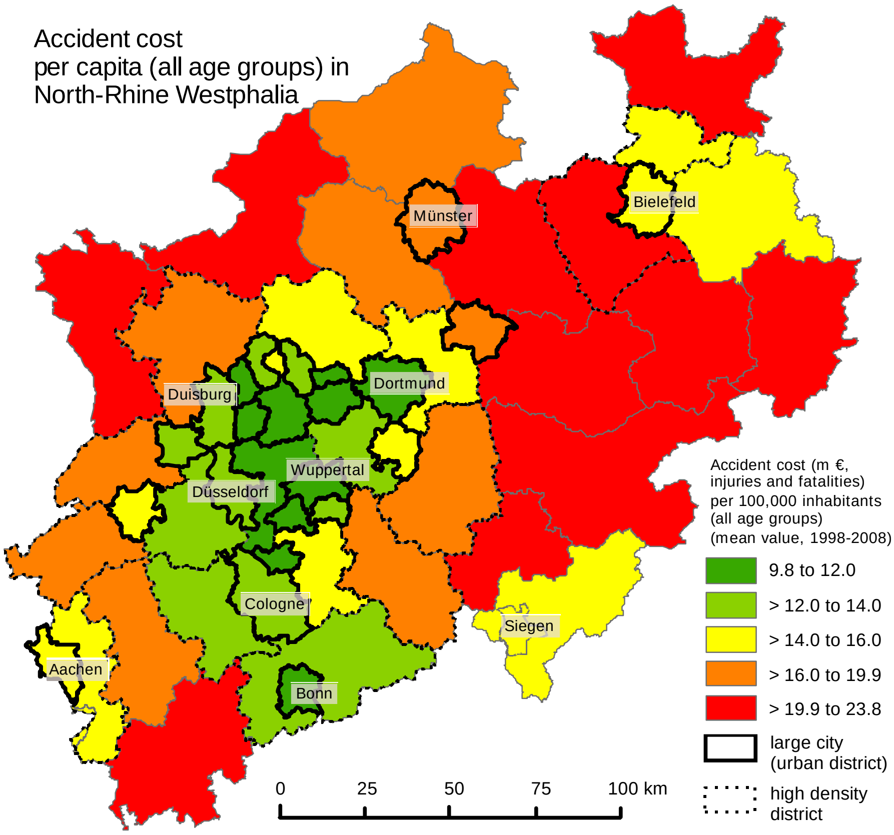

Figure 3. Accident costs in NRW (all age groups)

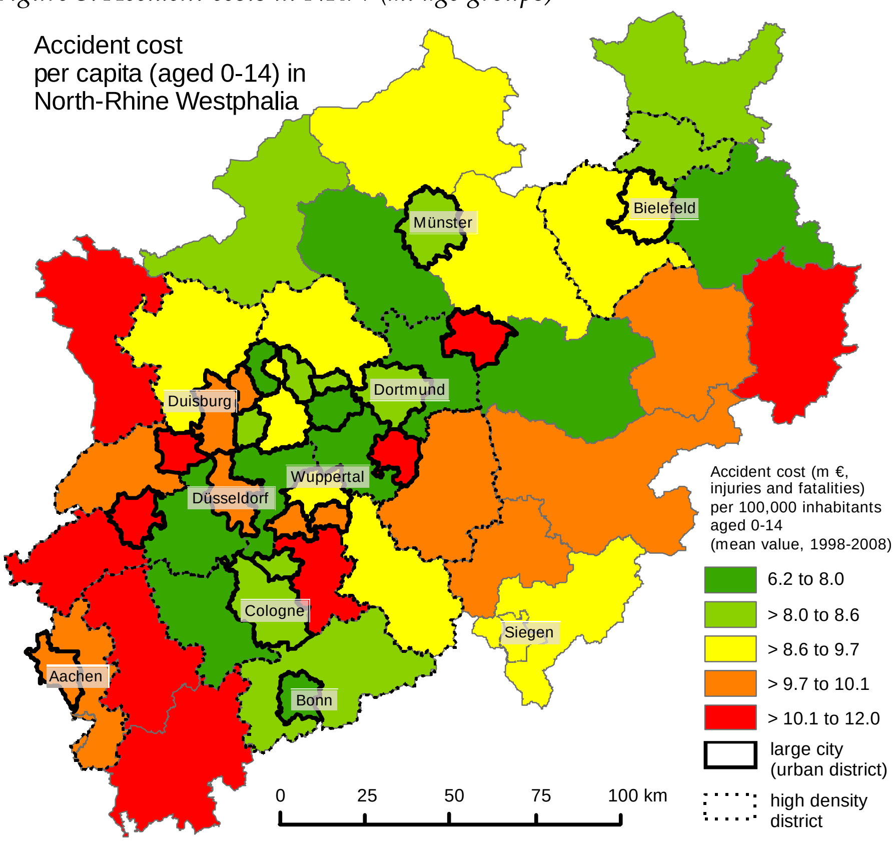

Figure 4. Accident costs in NRW (aged 0-14)

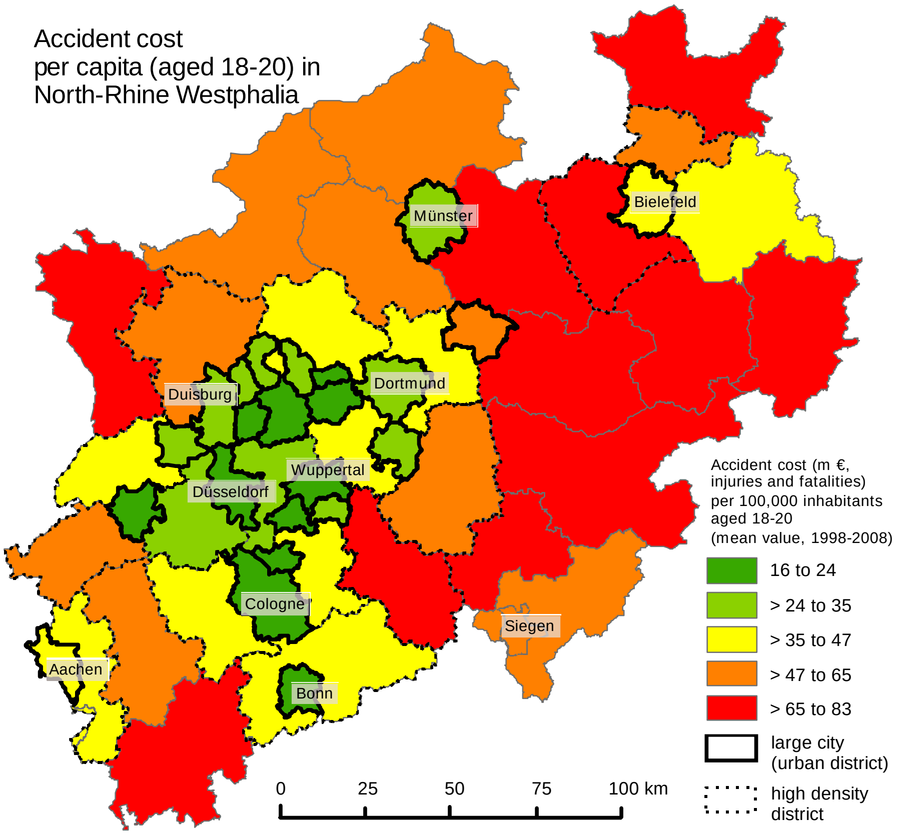

Figure 5. Accident costs in NRW (aged 18-20)

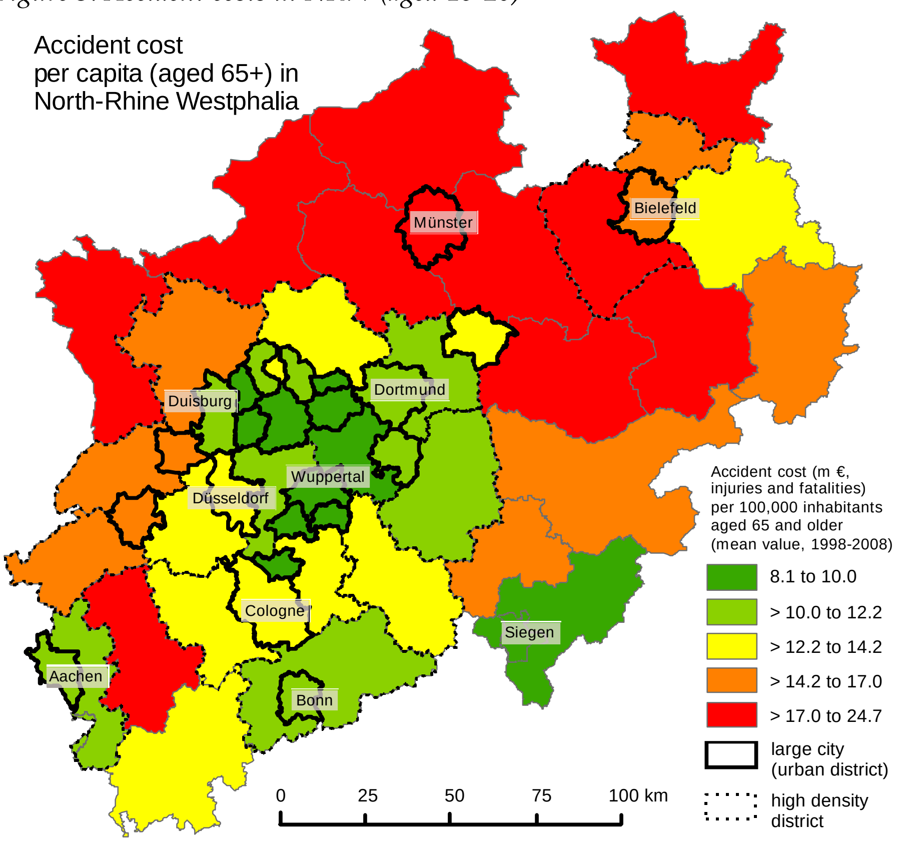

Figure 6. Accident costs in NRW (aged 65 and older)

For the elderly the picture is similar, yet slightly different (Figure 6). It should be noted that the risk in the age group 65+ was not focused on a certain transport mode. Only three of ten fatalities in this age group were motor vehicle occupants, four of ten were bicyclists, and three of ten were pedestrians. As for other age groups, the cost figures for the elderly were lower in agglomeration cores than in the countryside. However, some of the agglomeration cores exhibited high costs, namely Münster, which was in the highest cost quintile, Bielefeld, Krefeld and Mönchengladbach (the latter two are located west of Düsseldorf).

4.2 Modelling

There are a number of heuristic indicators with which to assess the goodness-of-fit of SEMs. For most such indicators decision rules that have been tested in methodological studies are available. Three of these indicators, along with the corresponding decision rule, are given in Table 6 for our models. According to the indicators, the model fit is generally close, even in the simplified 'reduced form' models shown in the figures. In order to achieve a good fit we set free error covariances between the error variables associated with workplace centrality, Green voters, compactness and population density step by step. We checked the parameter estimates during the fitting process after each step. There were no noteworthy changes which makes us confident that our estimates are relatively robust.

The model for all age groups taken together suggests that compactness, density and the share of Green voters are closely associated with lower accident costs (Figure 7). The direct effect of density is most pronounced, but as density is endogenous to compactness in our model, the total effect of compactness clearly exceeds that of density (Table 7)[4]. Car ownership is negatively associated with accident costs, but the effect is relatively weak. Workplace centrality is associated with higher accident costs, perhaps due to in-commuters, but considering the positive association between workplace centrality and Green voters, the total effect of workplace centrality is close to zero.

In demographic terms, the share of those aged 65 or more reduces accident cost, while those aged 18 to 24 years tend to increase cost. Taking indirect effects into account, the effect of the elderly has about the same strong magnitude as that of compactness.

Turning to the model for child accident costs (Figure 8), it should be noted that the level of variance explanation is relatively low. In other words, the variables used explain child accident risks to a lesser extent than accident risks in general, reflecting the scattered picture on the map with the less clear-cut urban-rural divide.

Table 6. The models' goodness-of-fit

	RMSEA	**PCLOSE significance**	**Hoelter (p=0,05)**
		decision rule	
	<0,05 good >0,1 n.a.	**n.s. (> 0,05) good**	**≥ 200 good**
Full models	0.000	0.898	10,571
Reduced form models (as shown in figures)	0.000	0.989	885

n.a.: not acceptable
n.s.: not significant
The values for all models presented are identical.
RMSEA (Root Mean Square Error of Approximation) measures discrepancy between the model implied and the true universe covariance matrix, in relation to degrees of freedom. This ratio is related to sample size. In cases of

[4] The total effect a variable has on another variable is calculated as the sum of direct and indirect effects. Consider the total population model as an example (Figure 7). The total effect of population density on accident cost equals -0.34 + -0.97*-0.07 = -0.27.

close fit, RMSEA approaches zero. PCLOSE is the probability for testing the 'null hypothesis of close fit' which claims that the universe RMSEA value is no greater than 0.05. The Hoelter statistics specifies the required sample size (critical n) to reject the model at a given significance level. The larger the value, the better the fit.

Table 7. Standardised total effects of various variables on accident cost

Accident cost for...	Workplace centrality	Green voters	Compact-ness	Population density	Car ownership	18-24 yr old	65+yr old
...all age groups	-0.011	-0.245	-0.547	-0.271	-0.070	0.224	-0.524
...0-14 yr old	-0.085	-0.353	0.060	0.558	-0.471	0.088	0.050
...18-24 yr old	-0.142	-0.325	-0.604	0.082	0.137	0.188	-0.440
...65+ yr old	0.124	-0.182	-0.248	-0.730	-0.108	0.103	-0.649

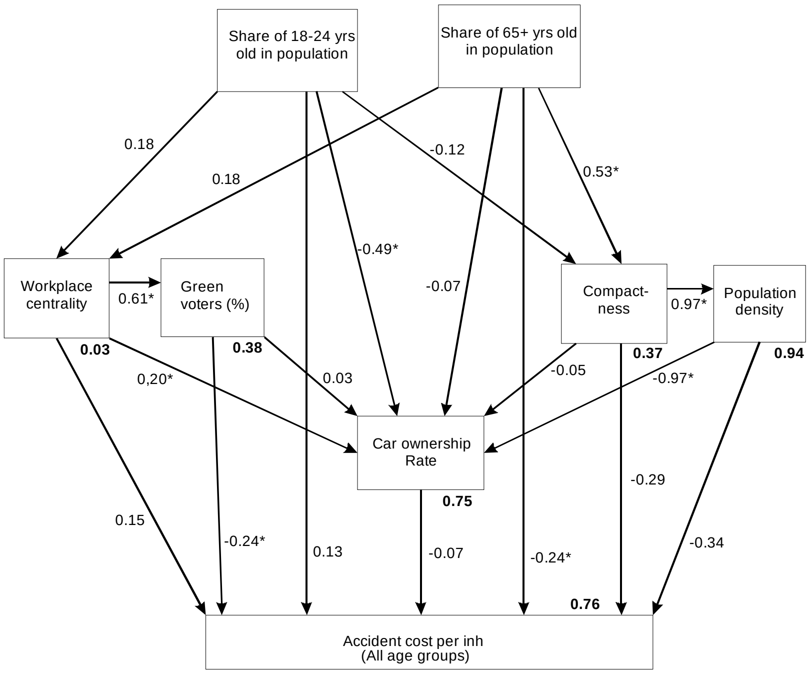

Figure 7. Accident cost model (all age groups)

This and the following figures show standardised coefficients and shares of explained variance (bold) for the endogenous variables. Coefficients marked with an asterisk are significant (p=0.05).

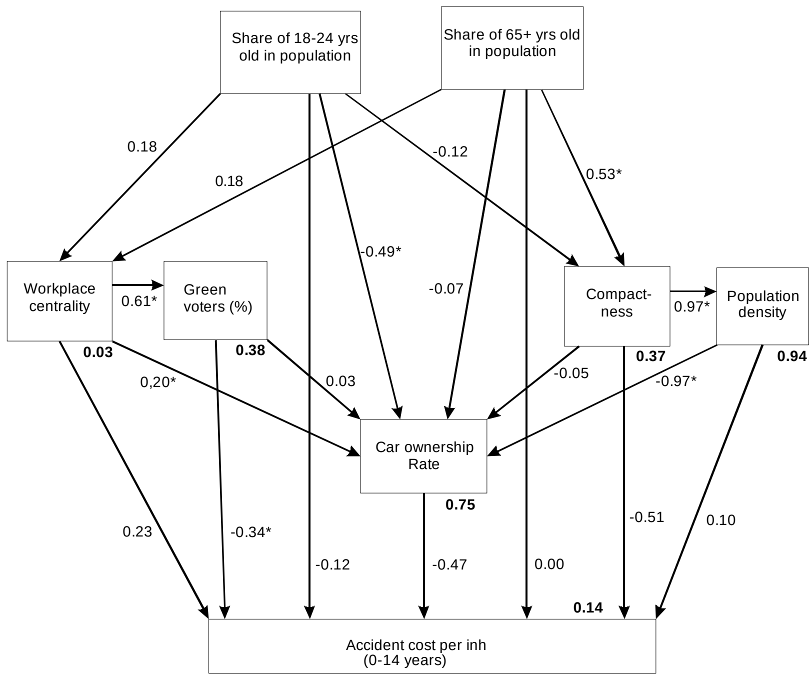

Figure 8. Accident cost model (aged 0-14)

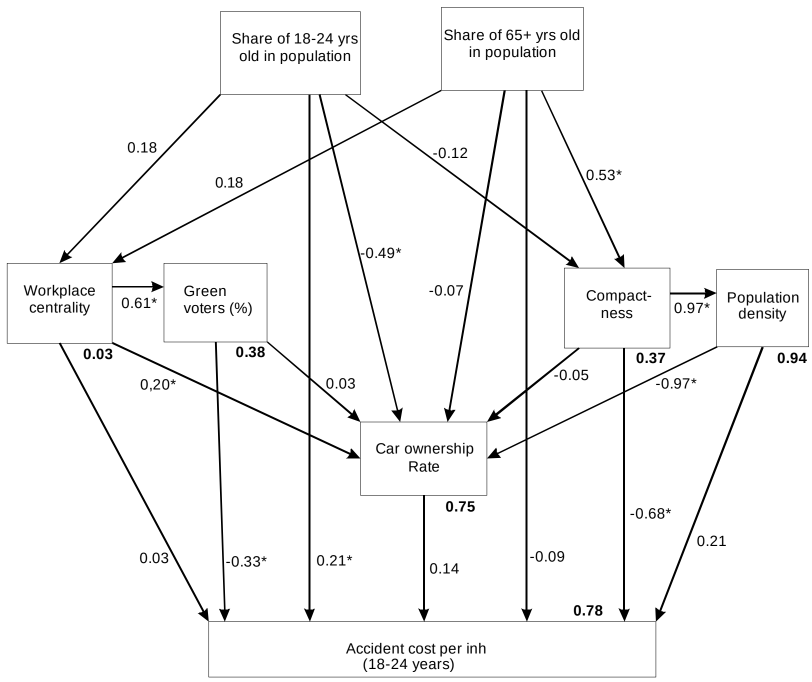

Figure 9. Accident cost model (aged 18-24)

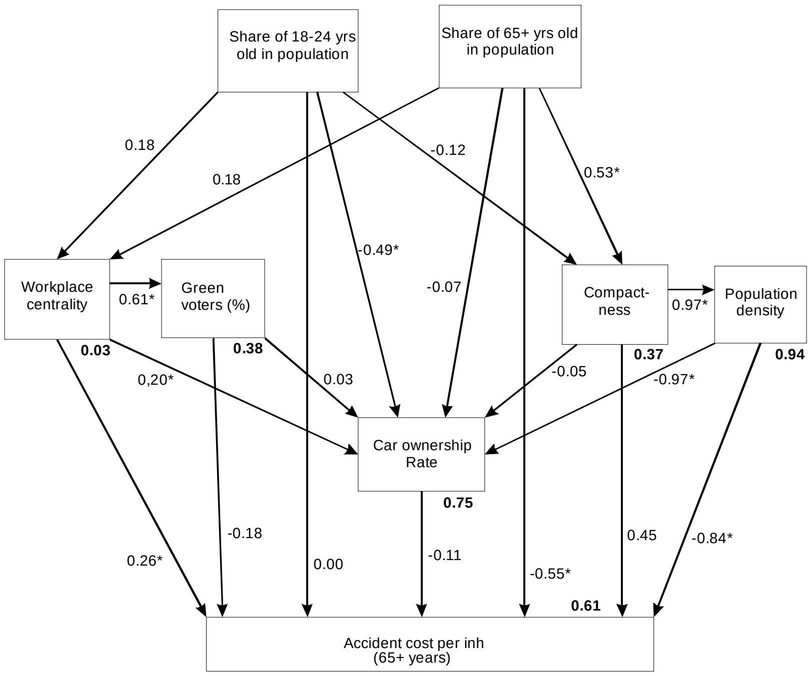

Figure 10. Accident cost (aged 65 and older)

Another characteristic of the child accident model is the, albeit moderate, positive effect of density on accident cost. The total effect is even stronger, as it includes a strong positive component mediated by car ownership level. By contrast, the negative direct effect of compactness is counterbalanced by positive indirect effects. Hence, the total effect of compactness is close to zero. These findings suggest that increasing density could impose more risk for children, and this association is not counterbalanced by a noteworthy effect of compactness.

The model for young adults aged 18-24 years is again somewhat different (Figure 9). Compactness is strongly associated with lower accident costs here. The effect of density goes the opposite way, but the total effect is very weak due to positive indirect effects. The impact of workplace centrality is negative, a finding which is mainly due to the indirect negative effect mediated by Green voters. Car ownership level has a moderate positive effect on accident cost in this age group.

Turning to the model for the elderly shows some variations again (Figure 10). The impact of density is negative, as in the total population model, but the direct effect of compactness is positive here for the first time. However, the total effect of compactness is negative as well, albeit considerably weaker in magnitude than that of density. In demographic terms, the impact of the share of the elderly is strongly negative, while a large share of adolescents tends to increase accident cost moderately.

We also estimated separate models for fatalities, severe injuries and slight injuries, categorised by the same age groups. These models are not discussed in detail here due to lack of space but are available from the authors upon request. Generally speaking, the models for fatalities and severe injuries point in the same direction as those presented here. In some cases a coefficient in a fatality model is considerably weaker than the respective coefficient in the cost model for the same age group. In these cases the respective association is stronger in the severe injury model. Hence, the composite effect on costs is a mix of a relatively low fatality risk and a high risk of severe injury.

The models for slight injuries differ considerably more from the results presented here. For instance, compactness is associated with more risk of slight injury (all age groups taken together), while the reverse is true for serious injuries and fatalities, and these associations taken together lead to the negative association between compactness and cost discussed above. The same is true for the share of those aged 65 or more in the population. These differences in sign generally reflect the finding that various spatial and socio-spatial settings may be associated with more severe but fewer slight accidents (rural areas), or vice versa, as shown in the descriptive results above. For an overall evaluation of geographical patterns in safety, a weighting approach is thus a valuable option.

To sum up, the overall picture from the cost models with respect to effect signs is relatively clear, but the picture concerning their magnitudes is more mixed.

Compactness of urban form has a negative and strong effect on accident cost, except for child accidents, which are hardly affected by compactness. Density delivers a less clear picture: its impact on the elderly's accidents is strongly negative, while its impact on child accidents goes the opposite way. All age groups taken together, density is associated with lower accident costs, albeit to a lesser extent than compactness. Remarkably, the magnitude of the compactness effect is weak in exactly those models where the density effect is strong, and vice versa. This suggests that density and compactness are correlated so strongly that their effects superimpose each other to a certain extent.

Level of car ownership is negatively associated with child accident costs, while the effects for other age groups are more modest and have varying signs. As a consequence, car ownership has only a very weak effect on accident costs when all age groups are taken together. The impact of workplace centrality is moderate as well, and its impact on different age groups varies in sign. The proportion of Green voters is consistently negative and relatively strong for all separate age groups and for the population as a whole.

With respect to demography, a large proportion of the 'risk age group' of young adults in the population increases accident cost moderately, while a large proportion of the elderly strongly decreases accident cost for the population as a whole, as well as for all age groups separately except for children.

5. Conclusions

This paper presented geographical analyses of road accident costs based on a case study for North-Rhine Westphalia. We categorised casualties among car occupants by their POR and, hence, estimated residential population-based accident costs in different built environments. Per capita accident costs reflect accident risk levels weighted by severity of accident. The validity of our data was limited to a certain extent, as we had to spatially assign pedestrians and bicyclists to crash locations. However, our results confirmed earlier findings from another Germany case study based on valid information on POR for all casualties (Scheiner and Holz-Rau, 2011), and a literature review suggests that the risk of false coding in the case of non-motorised traffic is limited, particularly on the rough spatial scale we used.

The main finding was that the cliché of risky urban life is wrong. The road accident cost levels were considerably lower in urban settings than in suburban or rural areas. Differences in driving speeds are likely to play an important role here, although we did not have direct information on operational speed. Better public transport opportunities (e.g. in cases of foreseeable alcohol consumption) and lower levels of exposure (less driving) of city dwellers may also contribute to this finding. Descriptive analysis showed that this general pattern was true for all age groups studied except for children, for whom geographical differences were minor and patterns were more mixed. Descriptive statistics showed that child accident costs were slightly above average in cities, but highest in rural districts. However, SEM revealed that more density was associated with higher child accident costs. The negative effect of car ownership on child accident cost could suggest that in suburban and rural areas, where car ownership levels are high, children are escorted more frequently and their mobility is less self-reliant, which may explain the lower accident cost level.

Our SEM exercises attempted to disentangle the relationships between various factors affecting accident cost level. These models suggested that compactness strongly reduces accident costs, although the effect on child accidents was close to zero. Compactness was closely related to population density and, hence, these two variables superimposed each other to a certain extent.

Interestingly, car ownership, which worked as a proxy for exposure here, had only moderate effects, except for its negative effect on child accidents just discussed. This suggests that exposure (in terms of level of driving) may be less relevant than driving speed which is closely related to urbanity. The relatively moderate effects of this 'transport variable', as compared to the urban form variables density and compactness, was supported by the moderate impact of workplace centrality, which determines the necessary level of commuting.

A car-critical socio-political climate (Green voters) also consistently reduced accident costs. This is most likely not an effect of strong Green political power, as the Green party holds a maximum of 15.2 percent (city of Cologne). We rather suggest this variable be a reflection of socio-political climate – the relative dominance of an alternative, largely academic social milieu that is critical of risky driving and of the notion of the car being a status symbol giving certain privileges to its driver.

We also found marked demographic effects. An ageing population was associated to lower accident costs, perhaps due to more careful driving, less night-driving, lower speeds and/or shorter distances driven. Conversely, a large share of young adults in the population increased accident costs (even among other age groups), albeit more moderately.

The main practical implication of our findings is that urbanity contributes to more safety and, hence, sustainability. Dense urban structures with mixed land-use are therefore valuable goals for transport planning from a safety perspective. Creating awareness in terms of a car-critical socio-political climate may also support safety goals.

Further research is required firstly in terms of other case studies in various spatial contexts and on more finely grained spatial scales. For urban regions an internal classification would be of particular interest in order to assess cost or risk levels for central v. peripheral neighbourhoods, as there are typically sharp differences in terms of social and demographic structures, travel mode use, and the built environment.

Secondly, further social stratification of cost or risk figures could contribute to better understand risk involvement, e.g. by gender, ethnic and social status, car availability, and individual travel mode use. Individuals with low levels of driving in rural districts could be less at risk than frequent-driving city dwellers. One has to keep in mind the aggregate nature of our analysis and the associated risk of ecological fallacy.

Thirdly, the completeness of impact factors and the causal structures connecting them both deserve clearly more attention. For instance, as we focused on geographical patterns on an aggregate level we did not consider attitudes such as risk-seeking or male status-seeking, nor behavioural aspects such as alcohol consumption or aggressive driving. The direction of causal flows between attitudes, behaviour, space-time context, and any outcome variable also has been a long-standing issue in transport studies, but still we often rely on plausible assumptions rather than trusted knowledge in this respect.

Last, but not least, the conclusions drawn from our research were much in favour of urban environments. This calls for research on safety aspects in rural areas, including the role of mode choice, different road types, operational speed levels, and differences in land use and settlement structures within rural areas.

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