



# **Traffic Safety in South Korea:**

## Understanding the Vulnerability of Elderly Pedestrians



**TRAFFIC SAFETY IN SOUTH KOREA:  
UNDERSTANDING THE VULNERABILITY OF ELDERLY PEDESTRIANS**

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**Abstract**

Pedestrians are vulnerable in traffic with frequently reported injuries and fatalities. These risks are believed to be correlated with socio-economic attributes such as age, income or education levels. For South Korea, we show that elderly pedestrians have a higher mortality risk than other road participants. On a municipal level, risk factors are high car ownership, an aging population and low population density, factors associated with rural areas. Risks can be mitigated through municipal financial self-sufficiency, a proxy for the ability to implement road safety measures. This suggests that road safety can be increased through municipal cooperation with the national government.

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## 1. Introduction

Traffic is dangerous. Approximately 1.25 million people die on roads annually and almost half of these deaths claim the most vulnerable: pedestrians and (motor-)cyclist (WHO, 2015).<sup>4</sup> Currently, the merits and perils of road traffic might be unbalanced between individuals. The most immediate perils – death and injury from roadside accidents – are highly correlated with socio-economic characteristics of the individuals involved in the accident. Like other policy-relevant issues, the most vulnerable groups in society such as the elderly and the economically less well-off appear at risk. We aim to show the vulnerability and the socio-economic determinants of elderly pedestrians and vehicle occupants in South Korea.

South Korea's rapid economic development over the past decades has been accompanied by rapid road expansion, motorisation and increase in traffic. Consequently, roadside injuries and fatalities are relatively high in comparison to other countries. Among the OECD member countries, South Korea has exhibited one of the highest per capita traffic fatality rates (OECD, 2016). In specific, pedestrian and the elderly are believed to be at higher risk than in other countries.<sup>5</sup> The recent status as member of the developed world in combination with higher than usual traffic fatalities makes South Korea particularly interesting for research.

In the last decade, due to improvements in car safety and policy, Korean traffic accidents have declined steadily by about one-quarter and in the year 2014 roughly 220,000 accidents occurred with approximately 5 000 fatalities (KoROAD, 2015). Almost half of the fatalities (45%) were pedestrians, a substantially larger share than in the rest of the OECD (20%). Next to pedestrians, also at risk in Korea are the elderly, with fatality rates up to three times those of other OECD countries. However, fatalities of the elderly occur mostly as pedestrians and much less in vehicle collisions.<sup>6</sup> The vulnerability of elderly and pedestrians make us investigate the determinants of elderly pedestrian accidents in comparison to vehicle (collision) accidents.

We estimate the effect of socio-economic characteristics on the probability of accidents and on accident severity on a municipal level. We are particularly interested in the effect of transport variables, economic and socio-demographic determinants such as car ownership, income, the financial situation and urbanisation. Next to aggregate accident information, we use accident reports to also estimate separate binary and ordinal outcome models to determine the risk odds for elderly and pedestrians in accident circumstances.

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4. In Asia, one in five deaths is traffic related (Grimm and Treibich, 2010). Next to the tragic personal loss, the World health organization estimates that road accidents reduce GDP by 2% even for highly-motorized nations (WHO, 2004). Often accident studies focus on the direct cost in terms of life lost and tend to ignore the substantial additional indirect cost from road congestion that can amount to an additional 1% loss in GDP. Severe accidents with injuries and fatalities increase road congestion, see, e.g. Garrison and Mannering (1990) and Adler et al. (2013).

<sup>5</sup> It is necessary to make the distinction between the total number of accidents and the number of accidents per vehicle. For developed nations, the former is usually relatively high and the latter low, in comparison, the opposite holds for developing countries. Most developed countries have seen an increase in road safety due to sound traffic policy and increased vehicle safety. For countries with rapid economic growth and associated road expansion it is perhaps helpful to take a closer look at South Korea.

<sup>6</sup> The elderly fatality rate for vehicle collisions is lower in all but three other OECD countries (OECD, 2016). The low number of elderly driver fatalities are speculated to be a result from low car ownership among that age group.

Four aspects distinguish our research from other literature. First, we focus on elderly pedestrians, an otherwise often neglected group and compare the results to elderly drivers. Second, we identify policy-relevant factors such as the municipal financial self-sufficiency on a detailed geographical level. Third, we use both aggregate municipal and disaggregate accident data in combination. This helps us identify both, accident specific and external socio-economic determinants in the same analysis. Fourth, we use data for highways and urban roads over a seven-year period. These last two aspects, makes the conclusions generally applicable to road traffic in South Korea.

We substantiate the claim that elderly pedestrians are at risk and that factors affecting this risk are similar but not identical with those of elderly drivers. A policy relevant finding is that municipal financial self-sufficiency can reduce accident risks for the elderly.

We proceed with a short review of the existing recent literature that fits our analysis in geographical area, research agenda and methodology. Afterward, we introduce the aggregate and accident data set and motivate our variable choice with descriptive statistics for the key variables, such as financial self-sufficiency. The methodological section is motivated from the literature and data section and contains the descriptions of the three main estimation models. In the following empirical results section, we interpret the tabulated estimates separately for the aggregate municipal and disaggregate individual accident data set. We scrutinise these results for robustness in the sensitivity analysis. At last, we conclude with possible policy implications and future research agenda. An overview of possible benefits from roundabouts for traffic safety is given in Annex 2.

## **2. Literature Review and Data**

We briefly review a selection of the relevant accident literature. In general, studies and study design can often be distinguished by their data source. Studies that are based on accident reports usually measure to at least some extent the effect of road side characteristics. For example, one of the main determinants of accident frequency and accident severity is vehicle speed and related, the speed limit. Korea has a relatively high inner city speed limit (i.e. 60 km/h) to which pedestrian fatality has been partially attributed (Park et al., 2008; OECD, 2016). This is even further exacerbated by the difference in speed limit larger than 30 km/h at intersections (Kim et al., 2014). In general, intersections and toll stations have more frequent and severer accidents than other road sections as Abdel-Ary (2003) concludes also for the US. We note that accident determinants are often similar across countries. For example, Lee et al. (2008) finds that international accident factors such as weather, road side obstacles and shoulder-width also appear significant in accident reports from 116 Korean rural intersections, see Table 1.<sup>7</sup>

Next to the aforementioned road side characteristics, choices of the accident parties are a deciding factor in accident severity. The use of legal and illegal driver ability inhibiting substances such as alcohol results in more frequent and more severe accidents. Furthermore, the use of seatbelts has a dramatic impact on the survivability of vehicle accidents (e.g., Singleton et al., 2004). Crucial to survival are also vehicle characteristics, such as type of vehicle (e.g. motorcycle, bus, truck, passenger car) and installed safety features (e.g. airbags) as argued by Kockelmann and Kweon (2002) for example. Hereby is also of concern the vehicle mass as a main determinant of accident severity and often an external cost factor, as the additional risk is not fully covered through the insurance premium (Van Ommeren et al., 2013).

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<sup>7</sup> Adverse weather reduces travel demand and accident severity but increases the probability of accidents (Vukovic et al. 2013).

The age of the accident parties is frequently found to determine the risk and injury severity of accidents.<sup>8</sup> There are several potential causal connections between age and accidents. These causal explanations range from old age inhibiting the ability to drive, the association of age with frailer bodily physique that is less resistant to impact, age as an approximation of socio economic characteristics such as wealth, to age as the probability to be a pedestrian. We later find evidence for the causal link of the elderly age group and their risks as pedestrians. The connection of other socio-economic characteristics of accident parties other than age is often somewhat more difficult to establish.

**Table 1. Accident determinants**

Publication	Location	Road type	Data source	Method	Determinants
Kim et al. (2014)	Korea, Seoul	Urban	Accident reports	OLS, SE	-Speed limit -Age -Mixed land use -Vehicle kilometres -Household income
Lee et al. (2014)	Korea	All fatalities	Death register and census	Poisson	-Elderly -Less educated
Park et al. (2012)	Korea	Highways	Accident reports	OP, OL, ML	-Night time -Median violation
Park et al. (2010)	Korea	All roads	Accident and death reports	Poisson	-Material deprivation index -Low educational level
Park et al. (2008)	Korea, Cheongju	Inner city intersections	Accident report	OP	-Intersections -Speed limit -Traffic lights
Lee et al. (2008)	Korea	116 Rural intersections	Accident reports	OP	-Weather -Obstacles -Exclusive right lane -Crosswalk -Speed differences -Land-use -Shoulder width
La Torre et al. (2007)	Italy	All road	Regional accidents	OLS	-Employment -Substance abuse
Singleton et al. (2004)	USA, Kentucky	All roads, vehicle occupants only	Hospital discharge data	OL	-Age -Female gender -Seatbelt -Substance use -Speed
Abdel-Ary (2003)	USA, Florida	Intersections and toll plazas	Accident reports	OP, ML, NL	-Intersections -Substance use -Area type
Kockelmann and Kweon (2002)	USA	All roads	Accident reports	OP	-Vehicle type -Substance use -Age

*Note: We distinguish between ordinary least squares (OLS), ordered probit (OP), ordered logit (OL), multinomial logit (ML), nested logit (NL) and spatial error models (SE).*

<sup>8</sup> Singleton et al. (2004) found that accident severity for car occupants increased in age, other factors being constant. Kockelmann and Kweon (2002) the drivers age plays a role, only look at vehicle collisions, younger and male drivers are usually injured less severe. For Seoul, Kim et al. (2014) find that that the share of younger population (below 16 years) reduces accident frequency and severity. In a survey study, Mori and Mizohata (1995) speculate that the reduced physical and mental function puts elderly Japanese pedestrian at risk.

Accident studies that examine the socio-economic characteristics usually rely on additional spatial information on said characteristics as detailed personal socio-economic information of accident victims is almost never available.<sup>9</sup> The use of socio-economic information of the location allows for the correlation between location and accident parties (e.g. mean household income as proxy for income of accident parties) as well as the location characteristics itself (e.g. public debt, policing). For example, La Torre et al. (2007) examine the associations between regional differences in traffic mortality and accident rates with socio-demographic factors such as employment, urbanisation, infrastructure and medical care in Italy. They find that unemployment increases traffic mortality, perhaps motivated by the additional risk from the vehicle kilometres travelled for economic activity. For certain neighbourhoods in Seoul, Kim et al. (2014) find that positive migration, household income and the number of nursery and primary schools is positively correlated with accidents. We find other factors are more important to elderly Koreans later in our study. Seldom is it possible to make a connection between income and accidents. However, Park et al. (2010) create a deprivation index from municipal characteristics and find a positive effect on accidents, in particular in combination with low educational achievements. Another study by Lee et al. (2014) that uses the national Korean death register and Census data finds greater accident mortality for elderly and less educated. In this study, education is directly measured but all other socio-economic characteristics are approximated from regional socio-economic data from where the death is registered. The missing detail of observation at the individual level is only one of many problems of accident data.

For accident research, data properties determine the suitable study design. For example, accident data is usually not random. In fact, data from accident reports is most aptly described as an outcome-based sample that contains the proportion of accident outcomes (i.e. severities). Outcomes in the data set are not the same as proportion of all accident outcomes. Non-random, also called conditioned samples may lead to overestimates (Yamamoto et al., 2008).<sup>10</sup> Studies such as from McCarthy and Madanat (1994) and DeYoung et al. (1997) recommend to ‘uncondition’ samples to avoid biased estimates through estimation strategies as the one of Manski and Lerman (1977) who propose weighting the estimation according to actual accident outcomes, a strategy we also follow in our analysis.

Another data problem can arise from the ordinal nature of accident data. The delineation between accident outcomes such as minor injury and major injury is to some extent arbitrary and abstracts from effects that affect both outcome categories. This can result in biased estimates, see Savolainen and Mannering (2007) and Paleti et al. (2010).<sup>11</sup> More general, omitted variable bias can be problematic for consistency when the omitted variables are correlated with variables that are included in the model (Washington et al., 2011). For example, when data does include separate observations for different injuries in the same crash but the estimation strategy does not account for this, biased parameter estimates are possible (Helai et al., 2008). Another example of omitted variable bias is provided by Anselin et al. (2005) where unobserved spatial and temporal correlation, such as accidents at the same highway location results in lower estimation precision.

To make matters worse, accident data sets are often incomplete in variables of interests and have a generally small sample size. This often directs the methodology towards more simplistic models.<sup>12</sup> For a detailed explanation on the choice of methodology given data problems frequent with accident research,

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<sup>9</sup> Lee et al. (2014) is somewhat an exception as they use the victims educational level as a proxy for socio-economic status however for further information then still have to rely on census data from the accident location.

<sup>10</sup> Hauer and Hakkert (1988) suggest that the estimate accuracy is inversely proportional to the square of the average proportion of crashes reported.

<sup>11</sup> Eluru et al. (2010) show that correlated unobserved factors affect estimates in models with ordinal outcomes.

<sup>12</sup> Ye and Lord (2014) provide some guidance on the effects of sample size on parameter estimates for various methodological approaches (ordered probit, multinomial logit, and mixed logit models) using a Monte-Carlo approach with both observed and simulated crash data.

see, e.g. Savolainen et al. (2011).<sup>13</sup> The cornucopia of data problems in accident research explains well why we find such numerous estimation strategies as in Table 1. See Park et al. (2012) for a comparison of the merits of some of these methodologies for Korean data that concludes that ordered logistics regression is a suitable estimation methodology for our accident report data.

For our analysis, we consider two data sets. One data set contains aggregate accident information on a municipal level and the other data set comprises disaggregate accident information. The aggregate *municipal data set* has information about road accident frequency, accident severity of the elderly and transport mode of the accident to which we add socio-economic information of the location. The precision of this location information is on a municipal (TL4) level which refers to cities, counties and districts (Si-Gun-Gu) with local administration. The more than 200 municipalities are parts of eight administrative (TL3 level) regions (i.e. provinces), six metropolitan cities, one ‘special’ city and one ‘special autonomous’ province.<sup>14</sup> Accident data is provided by the Korean Ministry of Transportation for the 2007 to 2013, in total seven years. We supplement the accident data with the OECD’s socio-economic data for the same time-period and pre-select variables according to a potential causal connection with traffic accidents, see Table A1 in the Appendix for a list of all available variables. We distinguish overall accidents by their severity: injury or death. From the overall accidents, we also separate injuries and deaths of both the elderly drivers and elderly pedestrians. Aggregate data lacks detailed information on accident parties such as vehicle type for which we turn to disaggregate accident data. A *disaggregate accident data set* with detailed information on the circumstance for a large number of accidents for the years 2005 to 2014 is provided by ten Korean car insurance providers. The accident data is representative for accidents at accident hotspots. Data reporting is on an accident basis and provides information on accident severity, cause of the accident, road side characteristics and the age of the accident parties.

Both data sets are clearly not random. Whereas the municipal data set contains the information on road accidents of the elderly for all of South Korea, i.e. the entire accident population, the disaggregate accident data set contains a non-random selection of specific accidents selected by the insurance companies. Note that traffic accident studies in general suffer from a selection bias as more severe accidents are more likely to be reported and thereby observed. Hence, our data sets also have a selection bias towards more severe accidents. In the *municipal dataset*, all accidents we observe involve at least an injury and most probable with a higher frequency severe injuries. Nonetheless, also the *disaggregate data set* contains a much higher proportion of severe accidents. The disadvantage hereby is that our study is less representative for minor accidents with merely property damage that are relatively frequent. Importantly, the advantage is that our study is representative for severe accidents that arguably have the highest socio-economic cost.

### 3. Descriptive statistics and research method

#### 3.1 Municipal data

The municipal data contains 1 495 observations, after removing randomly missing data 1 376 observations remain. Each observation records the outcome of traffic accidents involving the elderly for a municipality. There are approximately 10 000 elderly drivers injured and 5 000 pedestrians in a given year. An additional one-fifth in each category is fatally injured, see Figure 1 below. We distinguish between pedestrian accidents that involve a vehicle and a pedestrian and vehicle accidents that involve at least two vehicles. We find injury levels that are relatively stable. Fatalities in vehicle collisions have fallen

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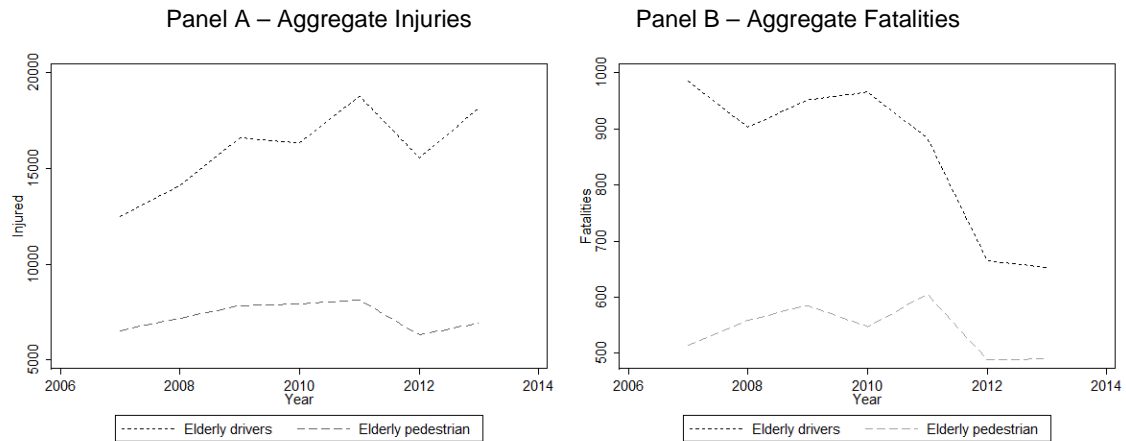
<sup>13</sup> In a meta-analysis, Elvik and Myssen (1999) find underreporting of 30% for serious injuries, up to 90% for slight injuries. The National Highway Traffic Safety Administration (2009) estimates that no-injury crashes are only reported in 50% of cases in sharp contrast to almost 100% reporting of fatal crashes (Blincoe et al., 2002).

<sup>14</sup> Due to lack of data, metropolitan autonomous city Sejong is excluded in this research.



for the elderly but fatalities remain almost constant. Apparently, the elderly are increasing likely to be involved in traffic accidents and as pedestrians fatally injured, a circumstance that underscores the importance of this study. In addition to the variation of the key dependent variables across years, there is an even larger variation between municipalities. For a better comparison between municipalities of different population size, we transform injuries and fatalities into rates per 100 000 individuals.

**Figure 1. Aggregate injuries and fatalities**



On average 58 elderly people out of a population of 100 000 persons are injured in vehicles and about 19 out of 100 000 as pedestrians. Assuming a homogenous distribution of accidents across municipalities, these are the associated annual traffic risks of the elderly for South Korea. However, injury rates for pedestrian and drivers are not homogenously distributed over population and space (see Figures in the Appendix). Municipal injury distributions are right skewed, which means a larger number of municipalities has similar injuries per 100 000 inhabitants and few have larger than the average. This approximately log-normal distribution is also reflected in the tabulated statistics in Table 2 below. The number of injuries from vehicle accidents surpasses those of pedestrian injuries more than threefold, however fatalities are similar between accident types. So, when in an accident, elderly pedestrians are more likely to die than elderly in vehicle accidents. By comparison, elderly fatalities of pedestrians and drivers are almost identical with three out of 100 000 and have an exponential distribution, meaning that the majority of municipalities have less than two fatalities in either category per year. We select 25 covariates for our analysis that can roughly be classified into four categories: four transport-related, four variables with economic context, nine socio-demographic variables and seven variables that refer to education infrastructure.<sup>15</sup> At this time, we discuss the ones that are important and for the remainder refer the reader to the Appendix.

<sup>15</sup> A list of potential covariates is in Table X in the Appendix.

**Table 2. Sub-regional accident data**

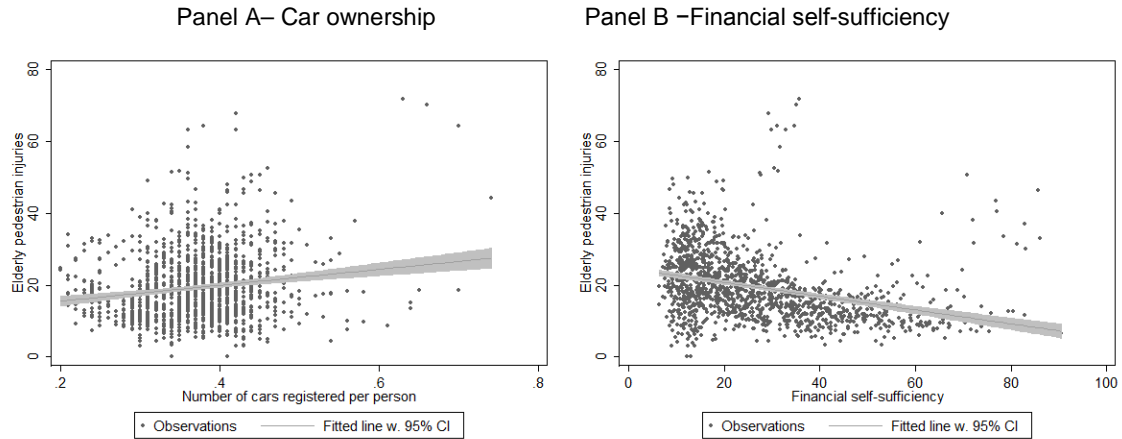
	Mean	Standard deviation	Minimum	Maximum
Elderly pedestrian injuries per 100,000	19.35	9.41	0.00	71.80
Elderly pedestrian fatalities per 100,000	3.08	2.98	0.00	26.15
Elderly driver injuries per 100,000	58.41	41.55	3.24	268.49
Elderly driver fatalities per 100,000	2.88	3.60	0.00	24.72
Cars per person	0.37	0.07	0.20	0.74
Pavement rate	83.77	13.72	46.09	100.00
Precipitation in mm	1 380.93	333.83	761.00	2 142.00
Temperature in °C	13.30	1.11	10.70	15.30
GDP	25.95	8.00	13.87	63.40
Economic participation	61.70	4.62	43.30	79.50
Financial self-sufficiency	27.32	16.30	6.40	90.50
Financial autonomy	63.00	11.04	30.80	91.70
Population density per km <sup>2</sup>	4427.83	6 734.32	19.40	29 626.47
Net migration per 100,000	-134.69	2 002.02	-1 1582.30	16 030.12
Outmigration per 100,000	14 955.29	3 466.76	6 998.53	28 411.96
Population growth	0.33	2.27	-10.33	20.08
%Population over age 65	16.03	7.66	4.39	34.62
Foreigners per 1,000	16.72	14.32	2.99	105.96
Medical doctors	2.32	2.18	0.56	22.37
Suicide per 100,000	34.58	12.18	8.10	94.40
Divorce per 1,000	2.25	0.40	1.10	4.40
Culture infrastructure	7.35	7.08	0.49	54.20
Welfare infrastructure per 1,000 elderlies	11.56	8.37	1.49	54.88
Childcare infrastructure	14.39	4.21	2.88	34.30
Kindergartens	35.37	25.73	2.00	170.00
Elementary schools	24.71	14.36	4.00	95.00
Higher education	1.54	1.82	0.00	13.00
Private institutes	1.24	0.54	0.11	4.51
<i>N</i>	1 376			

The exposure of elderly in a municipality is to a large extent captured by the percentage of elderly, people above the age 65. For Korea, the average is 16% with a municipal variation between 4% to 35%.<sup>16</sup> In general and as a result of urbanisation the elderly population is proportionally much larger in less densely populated municipalities (see Figures in Appendix). In the same context, cars ownership is correlated with population density and traffic accidents. Rapid motorisation increased car ownership fourfold over recent decades and South Korea has now an average of 0.37 cars per person. Still, car ownership is much lower than the 0.78 cars per person for the USA or 0.59 Japan but much higher than China 0.13 or Vietnam 0.02. This also demonstrates the indicative nature the study of South Korea has for other (Asian) countries with rapidly increasing motorisation. Car ownership is roughly normal distributed with substantial variation between municipalities from 0.20 to 0.74. The bivariate Figure 2 (Panel A) suggests a positive relationship between car ownership and pedestrian injuries.

Municipal financial self-sufficiency is an important policy variable relevant for traffic accidents. The self-sufficiency rate captures the capacity for public investments such as traffic safety improvements from local revenue streams and ranges from 6% up to 90%. It is also right skewed with a log-normal distribution where most municipalities have a lower self-sufficiency than the mean (27%). Panel B of Figure 2 suggests a negative relationship of financial self-sufficiency with pedestrian injuries.

<sup>16</sup> Related to the elderly population is also the number of welfare and leisure facilities per 1,000 elderlies that ranges between 1 and 55 with an average of 12.

**Figure 2. Car ownership, financial self-sufficiency and elderly pedestrian injuries**

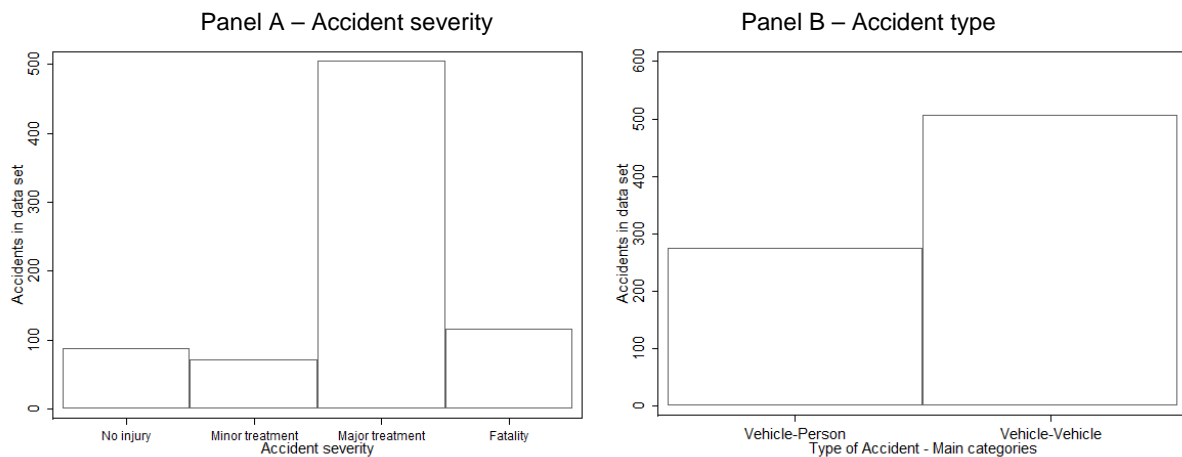


There are a few apparent outliers in the data in the migration variables. For example, net migration is the highest for the municipality of Hwaseong-si with a net change of 72 032 for a population of 450 000 in 2008. These outliers seem consistent and are unlikely measurement error and therefore we decide to retain the data. Later results are robust to exclusion of these outliers. For the 218 municipalities there are seven observations, one for each year, with an average of 6.3 observations, due to randomly missing data. We later use both *within* and *between* municipal variation for our analysis. The latter is much larger than the former (more than a factor four) for most variables.

### 3.2 Disaggregated accident data set

The disaggregated accident data set contains 5 700 observations of individuals affected in 1 799 unique accidents. We focus on 777 of these unique observations for which we have full information for all variables of interest. The majority of missing information is in accident severity, accident cause and the age of the involved parties.<sup>17</sup>

**Figure 3. Accident severity, accident type and accidents in data set**



<sup>17</sup> Missing data appears positively correlated with accident severity. We show the changes to the data through selection according to the number of victims in the accident. The source data set has a mean number of victims of 2.167 with a standard deviation of 3.413 and final data set has a mean of 1.984 with a standard deviation of 3.549. This suggest that our data selection from the source to the final data set minimizes additional non-random sample selection.

We categorise accidents by the type of accident, pedestrian or vehicle and accident severity. In accidents, vehicle accidents, more than one person is sometimes injured.<sup>18</sup> From the victims in any accident, we focus on the most severe outcome. So, that if there is one fatality and one minor injury we treat the accident as a fatal accident. Accident severity is an ordinal variable ranging from no injury over minor injury, defined as a hospital stay of a maximum of three weeks in comparison to major injuries with hospital stays longer than three weeks to fatality. Two-thirds of observations are major injuries and the remaining third is almost equally split among the other categories, see Figure 3 (Panel A) above. This distribution is suggestive of the selection bias toward more severe accidents that can be compared to the approximate ‘actual’ frequency in Table 3 below that are used as weights in the estimation section.

**Table 3. Accident severity in South Korea**

Accident Severity	Frequency in data	Actual frequency
No injury	88	220 000
Minor injury	71	30 000
Major injury	502	12 000
Fatality	116	5 000

*Note: Actual frequency is based on OECD (2016) and WHO (2004).*

As earlier, we distinguish between pedestrian accidents and vehicle accidents.<sup>19</sup> Vehicle accidents are more frequently observed, see Figure 3 (Panel B) above. As we are interested in determinants of the accident severity by accident type we obtain categories with relatively small sample size. For both accident types, we know the vehicle of the party with at least half of the accident responsibility.<sup>20</sup> The vehicle that ‘caused’ the accident is in 57% a private vehicle, 31% a bus, 7% a motorcycle and 5% a truck. This appears to reflect the distribution of vehicles types in the country.

**Table 4. Disaggregate accident data – descriptive statistics**

	Mean	Standard deviation	Minimum	Maximum
Injury & fatalities	0.89	0.32	0.00	1.00
Fatalities	0.15	0.36	0.00	1.00
No. of victims	1.98	3.54	1.00	49.00
Adverse weather	0.01	0.09	0.00	1.00
Substance abuse	0.02	0.13	0.00	1.00
Unsafe driving	0.56	0.50	0.00	1.00
Signal violation	0.31	0.47	0.00	1.00
Outside road	0.10	0.29	0.00	1.00
Private vehicle	0.57	0.50	0.00	1.00
Bus	0.31	0.46	0.00	1.00
Truck	0.05	0.21	0.00	1.00
Motorcycle	0.07	0.26	0.00	1.00
Road size*	3.06	1.18	1.00	5.00
<i>N</i>	777			

*Note: \*Road size is missing for 148 observations and so we exclude it from the main analysis.*

<sup>18</sup> The average number of victims in pedestrian accidents is 1.2 whereas the average is 2.4 victims in vehicle accidents.

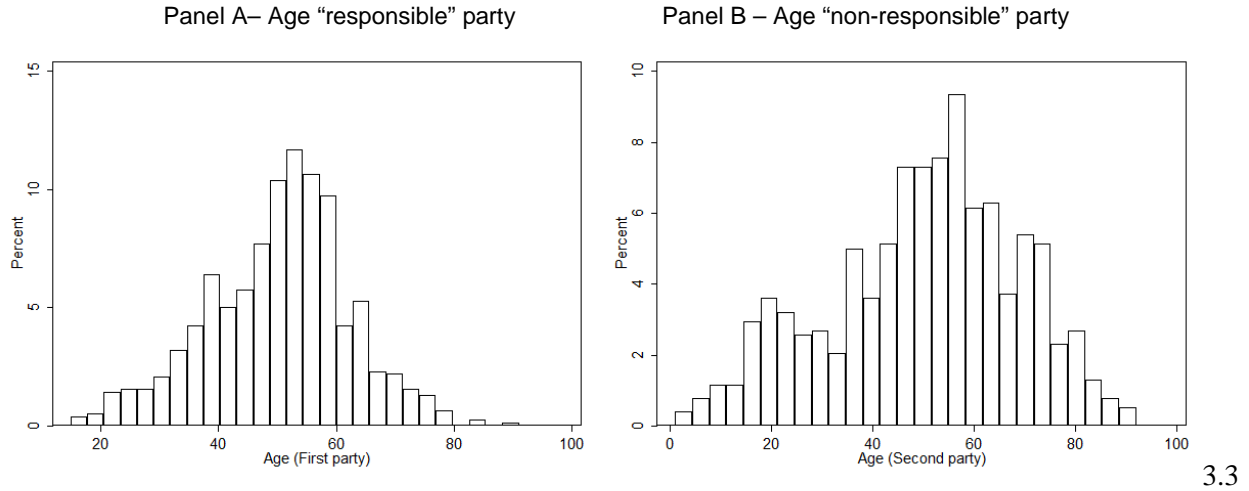
<sup>19</sup> We omit single vehicle accidents because of small sample size.

<sup>20</sup> Accident responsibility is recorded from the police and ranges from 50% to 100% for the responsible first party and between 50% to zero % for the second ‘less responsible’ party. See Figures in the Appendix.

We separate the (suspected) main cause of the accident into five exclusive categories. The most frequent is unsafe driving with 56% of observations which is representative for all forms of intentional or unintentional deviation from the codes of traffic conduct. We further identify the violation of traffic signals such as ignoring traffic lights and priority orders as well as vehicles outside the designated road markings, for example, crossing the road median and outer road marking, 31% and 10% of observations respectively. Substance abuse of alcohol and drugs and adverse weather conditions make up the remaining 3%.

The age of the accident participants is highly relevant in our analysis. We show that the age of the first ‘responsible’ accident party and second ‘non-responsible’ accident party in Figure 4. Both histograms can be considered almost normal distributed. Note that the lowest age in the first party is close to 18 because almost all drivers have to be eligible for driving a vehicle, even though three persons are slightly younger than the required 18 years for a driver’s license. The second party has larger tails with younger and older individuals. Both accident parties have the same mean age of 50 years. Later on, we split the age groups into relatively equal sized groups: below 30, between age 30 and 45, between age 45 and 65, and the elderly above 65.

**Figure 4. Age distribution of accident parties**



3.3

### 3.3 Research Method

We estimate a variety of econometric models suitable for the two data sets. With the municipal data, we use linear estimation models where the number of injuries and the number of fatalities  $Y_{i,t}$  in municipality  $i$  at time  $t$  depends on

$$Y_{i,t} = \beta' T_{i,t} + \gamma' E_{i,t} + \theta' S_{i,t} + \mu' I_{i,t} + \varepsilon_{i,t} \quad (1)$$

four transport variables  $T_{i,t}$ , the same number of economic variables  $E_{i,t}$ , nine social-demographic variables  $S_{i,t}$ , as well as eight infrastructure variable  $I_{i,t}$  plus an error term  $\varepsilon_{i,t}$ . The coefficients  $\beta'$ ,  $\gamma'$ ,  $\theta'$  and  $\mu'$  measure the corresponding effect of the variables. We estimate the above model separately for pedestrian accidents and vehicle accidents. All estimations are weighted according to municipal population size to give larger regions more importance. In a sensitivity analysis we control for sensitivity to heteroscedasticity.

For the disaggregate accident data set, we can characterise the outcome (i.e. no injury, or injury/fatality) as a binary dependent variable where we use ordinary least squares estimation.<sup>21</sup> For the binary response, we construct the dependent variable for each crash, so:

$$\begin{aligned}
Y_{i,t,injury} &= 0 \text{ if no injury} \\
Y_{i,t,injury} &= 1 \text{ if injury (and fatality)} \\
&\text{or} \\
Y_{i,t,infatality} &= 0 \text{ if no fatality} \\
Y_{i,t,infatality} &= 1 \text{ if fatality.}
\end{aligned}$$

Through this specification we then can estimate the probability of an injury or a fatality. We assume these probabilities

$$P(Y_{i,t} = 1) = \pi' A_{i,t,p} + \rho' C_{i,t} + \tau V_{i,t} + \lambda_i + \psi_t + v_{i,t} \quad (2)$$

depend on the effect  $\pi'$  of the age categories  $A_{i,t,p}$  of each of the two accident-parties  $p$ , five dummies with the accident cause  $C_{i,t}$  captured by  $\rho'$ , four vehicle types  $V_{i,t}$ , regional fixed effects  $\lambda_i$ , time-of-day dummies  $\psi_t$ , and an error term  $v_{i,t}$ . Our main focus is on the age categories  $A_{i,t,p}$  to which the reference category is individual's younger than 30 years. In particular, the age category that refers to individuals above 65 years that is involved as a pedestrian in a pedestrian accident is of interest. We weight the estimation according to frequencies specified in Table 3 to account for the sample selection bias (see, e.g. Manski and Lerman, 1977).

The ordinal nature of the dependent variable (e.g. no injury, injury and fatality) is also suitable to the use of ordered logistics.<sup>22</sup> Hereby, we specify four outcomes states

$$Y_{i,t} = \begin{cases} 0 & \text{if no injury} \\ 1 & \text{if minor injury} \\ 2 & \text{if major injury} \\ 3 & \text{if fatality} \end{cases}$$

where the reduced form specification is a bivariate relationship between the response variable and the logistic function  $G()$ , so that

$$P(Y_{i,t}) = G(\pi' A_{i,t,p}) \quad (3)$$

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<sup>21</sup> For binary outcome, OLS is similar to logistics and probit (Wooldridge, 2015). We choose model flexibility given small sample size and ease of interpretation over potentially better fitted probabilities and non-linear partial effects

<sup>22</sup> We use ordered logistics because we assume that the error term follows a standard logistic distribution. For the possibility that the error term follows a normal distribution see the ordered probit estimation results in the appendix.

Hereby we also use frequency weights to adjust for the sampling bias. However, this comes at the cost of reducing the covariates because of the small sample size. We also estimate an ordered logistics model with control variables instead of weights according to

$$P(Y_{i,t}) = G(\pi' A_{i,t,p} + \rho' C_{i,t} + \tau V_{i,t} + \lambda_i + \psi_t + v_{i,t}) \quad (4)$$

using the same covariate as in equation 2 in the sensitivity analysis. Ordered logistics regression assumes an exponential distribution of the error term. Further, we check the sensitivity of the pedestrian accident estimation to variable specification and use of an ordered probit specification. The ordered probit assumes an error with the mean zero and a normal distribution. In all models, year fixed effects control for year specific unobservables such as economic developments and the number of public holidays.

## 4. Empirical results

### 4.1 Municipal data set

Using the municipal data set, we first consider the linear estimations for elderly pedestrians and elderly drivers separately by accident outcome: injury and fatality. Pedestrian injuries are our first concern, see column one in Table 5. The transport variables car ownership per person and temperature are significantly different from zero. An increase of cars per person by 0.10 increases pedestrian injuries by one person per 100 000 population. Note that this is still short of the 0.22 car ownership increase necessary to gap the distance to Japan for example. Also mean annual temperature has a positive relationship with pedestrian injuries. A 1°C higher mean temperature is associated with a 1.10 larger number of pedestrian injuries. Usually, temperature is a good proxy for leisure outdoor activities and therefore contributes to pedestrian exposure to risk which is a probable explanation.

From the economic variables, gross domestic product has a positive effect on accidents. Usually gross domestic product is a good proxy for vehicle-kilometres-travelled. Similarly, the divorce rate might also capture to a certain extent vehicle-kilometres-travelled by commuters. Previously it has been shown that there is a positive correlation between commuting length and divorce (Sandow, 2013). It is noteworthy that financial self-sufficiency, a measure to what extent a municipality is able to rely on its revenue, reduces pedestrian injuries. An increase of self-sufficiency by its standard deviation (16.30) would reduce pedestrian injuries by 1.8 (11%). Perhaps this relates to the ability to implement road safety measures such as suitable road design and effective traffic law enforcement (see, also OECD, 2016).

Demographic variables are mostly rendered insignificant by the use of population adjusted outcome metrics. We find a small positive effect of population density perhaps an indication that more dense neighbourhoods have a larger pedestrian modal share and therefore elevated risk. The overall registered population has a negative effect, potentially reflecting the increase of pedestrian safety in larger municipalities.<sup>23</sup> The effect of the elderly population in percent measures the additional risk exposure. A 1% increase in elderly increases the number of injuries by 0.89, an elasticity of 4.6. Consequently, variables correlated with urbanisation, such as lower car ownership, population size and lower share of elderly reduce elderly pedestrian injury risk. By comparison, rural areas have attributes that lead to higher elderly pedestrian injuries rates.

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<sup>23</sup> The safety of pedestrians from other pedestrians has been compared to the additional protection of fish gained in fish swarms (Shiwakoti et al., 2010).

**Table 5. Elderly injuries and fatalities**

	(1) Pedestrian injuries	(2) Pedestrian fatalities	(3) Vehicle injuries	(4) Vehicle fatalities
Cars per person	10.80** (4.107)	4.123** (1.540)	161.2*** (15.86)	8.227*** (1.595)
Pavement rate	-0.0273 (0.0209)	0.0116 (0.00784)	0.145 (0.0807)	-0.000846 (0.00812)
Precipitation in mm	-0.000251 (0.000826)	0.0000642 (0.000310)	-0.00850** (0.00319)	-0.000297 (0.000321)
Temperature in °C	1.105*** (0.230)	-0.181* (0.0864)	0.869 (0.889)	0.0743 (0.0895)
GDP	0.0567* (0.0285)	0.0159 (0.0107)	0.213 (0.110)	0.0351** (0.0111)
Economic participation	-0.198*** (0.0546)	0.0393 (0.0205)	-0.437* (0.211)	0.0172 (0.0212)
Financial self-sufficiency	-0.109*** (0.0305)	-0.0218 (0.0114)	-0.740*** (0.118)	-0.0324** (0.0119)
Financial autonomy	0.0460 (0.0307)	0.000385 (0.0115)	0.725*** (0.119)	0.0222 (0.0119)
Population density	0.000268*** (0.0000597)	-0.00000563 (0.0000224)	-0.00000160 (0.0000230)	-0.0000231 (0.0000232)
Registered population in 100,000	-1.364*** (0.354)	-0.284* (0.133)	1.434 (1.368)	0.249 (0.138)
Net migration per 100,000	0.000429 (0.000474)	-0.000112 (0.000178)	-0.000640 (0.00183)	0.0000273 (0.000184)
Outmigration per 100,000	-0.0000186 (0.0000884)	-0.0000418 (0.0000331)	0.000215 (0.000341)	-0.000000945 (0.0000343)
Population growth	-0.511 (0.447)	0.102 (0.168)	-0.0706 (1.728)	0.00701 (0.174)
% of population over age 65	0.894*** (0.0798)	0.144*** (0.0299)	3.333*** (0.308)	0.255*** (0.0310)
Foreigners per 1,000	0.0226 (0.0180)	0.00837 (0.00676)	0.267*** (0.0697)	0.0104 (0.00701)
Medical doctors	1.566*** (0.124)	0.0268 (0.0465)	2.542*** (0.479)	-0.0782 (0.0481)
Suicide per 100,000	0.0351 (0.0218)	-0.000177 (0.00818)	-0.0213 (0.0842)	-0.00599 (0.00847)
Divorce per 1,000	2.886*** (0.611)	-0.0597 (0.229)	2.623 (2.358)	0.0926 (0.237)
Culture infrastructure	-0.0565 (0.0376)	0.00159 (0.0141)	-0.130 (0.145)	0.0209 (0.0146)
Elderly welfare infrastructure	-0.359*** (0.0476)	0.0179 (0.0178)	-0.0992 (0.184)	0.00713 (0.0185)
Childcare infrastructure	0.0350 (0.0541)	-0.00141 (0.0203)	-0.157 (0.209)	0.00176 (0.0210)
Kindergartens	0.0543 (0.0304)	0.00604 (0.0114)	0.127 (0.117)	0.00366 (0.0118)
Elementary schools	0.0332 (0.0469)	0.0222 (0.0176)	-0.275 (0.181)	-0.0195 (0.0182)
Higher education	0.417** (0.131)	0.0974* (0.0492)	0.551 (0.506)	-0.00995 (0.0510)
Private institutes	2.200*** (0.554)	0.268 (0.208)	2.869 (2.138)	0.0196 (0.215)
<i>N</i>	1376	1376	1376	1376
<i>R</i> <sup>2</sup>	0.528	0.336	0.639	0.512

The dependent variable is the number of accidents per 100,000 inhabitants on the municipal level. Year fixed-effects included. Standard errors in parentheses.

\*  $p < 0.05$ , \*\*  $p < 0.01$ , \*\*\*  $p < 0.001$



The quantity of medical doctors is positively related to pedestrian injuries. This might seem counterintuitive at first, but consider that this might reflect the detection probability of injuries that might otherwise be underreported. From the infrastructure variables, the most noteworthy is the number of leisure and welfare facilities for the elderly. We estimate that an increase by three facilities per 1 000 elderly reduces accidents injuries by one per 100 000 population. That higher education and private institutes have a positive effect on accident frequency might be a result motivated by younger drivers' lack of driving experience but could also be spurious as it does not translate to vehicle accidents or pedestrian fatalities.

Pedestrian fatalities appear to have similar determinants as pedestrian injuries. However, we find a somewhat reduced effect of most variables, noteworthy car ownership and financial self-sufficiency. Note that pedestrian fatalities are less than one-sixth of (severe) injuries. Therefore, despite lower coefficients, elasticities are similar to those of pedestrian injuries. For example, the coefficient for the population over 65 years of age is 0.144, so that a 1% increase in that stratum raises the risk of fatalities by an elasticity of 4.6.

The factors affecting elderly driver injuries and fatalities are similar to those of elderly pedestrian, albeit a few differences. For example, the number of cars per person has a substantially larger effect on driver injuries. An increase of cars per person to the Japanese level, everything else constant, would lead to an increase of 35 elderly driver injuries per 100 000 inhabitants annually. Again, we find a positive effect from the percentage of elderly in the municipality. Due to the consistent findings of these two determinants across elderly accidents we can summarise these as the effect of risk exposure.<sup>24</sup>

GDP continues to have a positive effect on driver accidents whereas financial self-sufficiency reduces the frequency. We continue to speculate that the latter is a proxy for the financial means to implement traffic safety. In contrast, financial autonomy, the self-determination where to attribute funds reduces driver safety, perhaps because of prioritisation to other areas than road safety. Note, these opposing effects are almost of similar magnitude. An increase of financial self-sufficiency reduces vehicle accidents by 0.74 whereas the same increase in financial autonomy decreases vehicle accidents by 0.72. We find a negative effect of precipitation on vehicle injuries. This is not surprising as precipitation reduces leisure activities and travel demand. For example, Vukovic et al. (2013) show for Dutch highways that precipitation increases the accident risk per vehicle but reduces travel demand and speed which in turn reduces accident severity.

Socio-economic factors such as income and education level are correlated with accident frequency. For a smaller data set that is based on Census data, we estimate the effect of income and income of elderly on accident frequency and severity.<sup>25</sup> At first, we find a negative effect of income on pedestrian and vehicle accident severity and frequency, see Table 6.<sup>2627</sup> However, this effect disappears when we include other control variables such as education levels and controls from Table 5. This suggests that socio-economic status likely translates into mobility behavior captured by variables in Table 5 that in the end determine the associated traffic risks of the elderlies.

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<sup>24</sup> Foreigner population have a positive effect on vehicle accident risk but are not determinants of fatalities or pedestrian accidents. Slower driving in a foreign country coupled with inexperience of local traffic customs might explain this finding.

<sup>25</sup> Census data is available for the years 2008, 2010 and 2012.

<sup>26</sup> Neither elderly income inequality nor income inequality is not found to be a significant determinant of elderly injuries or fatalities.

<sup>27</sup> Interestingly, the correlation is mainly with average income levels and not particularly the income levels of the elderly. This could reflect the fact that in many cases, elderly are living with and are financially supported by their children.

**Table 6. Income and elderly injuries and fatalities**

	(1) Pedestrian injuries	(2) Pedestrian deaths	(3) Vehicle injuries	(4) Vehicle fatalities
Income	-0.0298*** (0.00634)	-0.00508* (0.00205)	-0.132*** (0.0251)	-0.0123*** (0.00230)
Income elderly	0.000539 (0.00963)	-0.000513 (0.00312)	-0.0406 (0.0381)	-0.00166 (0.00350)
<i>N</i>	472	472	472	472
<i>R</i> <sup>2</sup>	0.271	0.276	0.446	0.407

The dependent variable is the number of accidents per 100,000 inhabitants on the municipal level. Year and region fixed-effects included. Standard errors in parentheses.

\*  $p < 0.05$ , \*\*  $p < 0.01$ , \*\*\*  $p < 0.001$

The choice in methodology and variable specification of Table 5 results in a good model-fit with higher  $R^2$  for all four models.<sup>28</sup> However, aggregate accident data estimations are suitable to capture the effect of aggregate factors but lack the possibility to identify the effect of accident specific characteristics, such as the direct cause of the accident, age of all the accident parties and type of vehicle. These are factors we estimate hereafter.

#### 4.2 Disaggregate data set

We separate four linear models for the binary responses *no injury* in comparison with *any injury* (including a fatality) and *any injury* outcome (including no injury) in comparison to a *fatality* for the two accident types (i.e. pedestrian and vehicle) separately, see Table 7.

**Table 7. Disaggregated accident data estimations**

	(1) OLS Pedestrian Injuries & Fatalities	(2) OLS Pedestrian Fatalities	(3) OLS Vehicle Injuries & Fatalities	(4) OLS Vehicle Fatalities
Age below 30	0 (.)	0 (.)	0 (.)	0 (.)
Age 30 to 45	-0.0306 (0.0739)	-0.680*** (0.125)	-0.0241 (0.0603)	-0.0107 (0.00858)
Age 45 to 65	0.212** (0.0774)	-0.575*** (0.126)	0.0398 (0.0504)	0.00165 (0.00773)
Age above 65	0.138 (0.0710)	-0.721*** (0.148)	0.0358 (0.0654)	-0.00470 (0.00997)
Age below 30	0 (.)	0 (.)	0 (.)	0 (.)
Age 30 to 45	-0.0752 (0.0653)	0.00975 (0.120)	-0.126 (0.0941)	0.0128 (0.0132)
Age 45 to 65	-0.161* (0.0630)	-0.0877 (0.105)	-0.0955 (0.0892)	0.0222 (0.0126)
Age above 65	-0.0396 (0.0720)	-0.0387 (0.102)	-0.0189 (0.0973)	0.0509** (0.0182)
Substance abuse	0.833*** (0.153)	0.0412 (0.236)	0.0604 (0.158)	0.0101 (0.0220)
Adverse weather	0.434* (0.171)	-0.171 (0.263)	-0.241 (0.128)	0.0159 (0.0447)
Unsafe driving	0.591*** (0.143)	0.0863 (0.198)	0.106 (0.0779)	-0.00340 (0.0102)
Signal violation	0.593*** (0.167)	0.353 (0.252)	0.0642 (0.0742)	-0.00872 (0.00903)

<sup>28</sup> Unexplained variation is possibly in road side characteristics, enforcement and distance to emergency care.

	(1) OLS Pedestrian Injuries & Fatalities	(2) OLS Pedestrian Fatalities	(3) OLS Vehicle Injuries & Fatalities	(4) OLS Vehicle Fatalities
Outside road	0 (.)	0 (.)	0 (.)	0 (.)
Bus	-0.000922 (0.0515)	-0.0469 (0.0884)	0.626*** (0.0724)	0.0780** (0.0284)
Truck	0.236** (0.0905)	-0.0692 (0.153)	0.0120 (0.120)	-0.00309 (0.00969)
Motorcycle	0.290* (0.137)	-0.879*** (0.222)	-0.275*** (0.0511)	-0.0214** (0.00698)
Morning Ref. cat.	0 (.)	0 (.)	0 (.)	0 (.)
Lunch time	0.0685 (0.0557)	-0.0468 (0.127)	-0.0157 (0.0762)	-0.00677 (0.0105)
Afternoon	0.0721 (0.0662)	-0.210* (0.104)	0.0435 (0.0592)	-0.00754 (0.0104)
Evening	-0.0459 (0.0579)	-0.140 (0.126)	-0.00770 (0.0547)	-0.0114 (0.00829)
Night	-0.0807 (0.0564)	-0.112 (0.114)	0.0582 (0.0661)	-0.00872 (0.00918)
<i>N</i>	274	274	503	503
<i>R</i> <sup>2</sup>	0.895	0.290	0.525	0.138

Province fixed effects included. Frequency weights adjust for reporting bias.

\*  $p < 0.05$ , \*\*  $p < 0.01$ , \*\*\*  $p < 0.001$

For pedestrian injuries, the age of the vehicle driver and the pedestrian appear to play minor role, see Column 1. There is weak evidence that drivers at the age from 45 to 65 years might be 20% more likely to cause a pedestrian accident with an injury than the reference group of 30 years of age and below, but this is little surprising when we recall Figure 7. All other age categories are not significant at the 5% significance level. Substance abuse, unsafe driving and signal violation increase the injury probability by between 59% to 83% in comparison to the reference category of the car driving outside the designated road markings. We also note that the involvement of trucks in comparison to passenger vehicles increases the chance of injuries by 23%, most likely due to high impact mass.

Fatalities in pedestrian accidents (column two) appear to be affected from the age of the driver, where younger drivers below 30 years (reference category) are 57% less likely to cause pedestrian fatalities than all other age categories. We can speculate this might be due to lower car ownership among younger urban people as suggested by the descriptive statistics. The vehicle seems to matter, as motorcycle drivers have an 87% lower probability to cause a pedestrian fatality in comparison to passenger vehicles.<sup>29</sup>

Age is not important as a covariate of vehicle accident injuries in Column 3. We find only the vehicle type as a determinant. Once more motorcycles reduce the probability but buses increase the probability with 63% in comparison to the reference group. Both is of little surprise. Higher impact mass increases the chances of injuries.<sup>30</sup> We find similar results for probability of fatalities in vehicle accidents in Column 4. This also the only specification where elderly accident participants are mildly (5%) more likely to parish than the youngest age group.

For a better grasp on the effect of age, we now turn to the ordinal outcome models where we use the information contained in the severity order of accidents. Yet again, we consider pedestrian accidents

<sup>29</sup> Adverse weather usually has drivers decrease speed and decreases pedestrians, however we find no significant effect on the probability of a pedestrian fatality contrary to other studies as such of Khattak et al. (1998).

<sup>30</sup> The discussion on the effect of public transportation on traffic accidents is still ongoing (see, e.g., Adler and Van Ommeren, 2016).

first in Table 8. As we choose to report odds ratios (i.e. the exponent of the coefficient), values below state a reduction in the risk and values above one an increase. We see that for drivers in the age groups older than 30 years, there is an 90% chance to cause a lower accident severity (e.g. minor injury instead of major injury) than for their younger counterparts. This effect is however only significant at the 10% for ages above 45 years.<sup>31</sup> Important for pedestrian accidents, elderly pedestrians are almost five times as likely to be injured in an accident than the reference group - below 30 years of age. Note, the chance to be injured or to be more severely injured, up to fatally injured, are by assumption all larger in this case.<sup>32</sup> The odds appear to be larger for all older groups, but standard errors are large, given the small sample size, and therefore caution is advised in the interpretation. We follow previous studies in our speculation that at older age, bodily physique can cope less with (severe) traumata from accidents.

**Table 8. Disaggregated accident data reduced from estimations**

	(1) Ordered logistics Pedestrian	(2) Ordered logistics Vehicle
Severity		
Age below 30	1 (.)	1 (.)
Age 30 to 45	0.00565*** (0.00723)	1.935 (1.120)
Age 45 to 65	0.102* (0.115)	4.994** (2.556)
Age above 65	0.0396* (0.0505)	0.721 (0.469)
Age below 30	1 (.)	1 (.)
Age 30 to 45	5.061 (4.687)	0.227** (0.124)
Age 45 to 65	1.782 (1.433)	0.181*** (0.0880)
Age above 65	4.631* (3.142)	0.715 (0.401)
<i>N</i>	274	506
pseudo <i>R</i> <sup>2</sup>	0.222	0.113

Region fixed effects included. Frequency weights adjust for reporting bias. Odds ratio reported.

\*  $p < 0.05$ , \*\*  $p < 0.01$ , \*\*\*  $p < 0.001$

We find almost the opposite probabilities for vehicle accidents. In these accidents, both parties are inside a vehicle either as driver or as passengers. Older drivers contribute to the injury severity for the party responsible for the accident. The other party has a slightly lower risk of moving up injury categories for ages between 30 to 65 years, but risks are similar between the below 30 years of age and the above 65. This reconfirms descriptive evidence of the OECD (2016) report that older age is especially relevant for pedestrian accidents and should be separately treated from vehicle accidents.

<sup>31</sup> These models assume that the increase in probability is equal across severity levels. In the ordered logistic case, it is the ratio, given a one-unit increase in the covariate, of the odds of being in a higher rather than a lower category. For fatalities with a low mean (probability) it is possible to interpret the odds as relative probabilities or risks, as these are almost identical. This is not the case for the combination of injuries and fatalities into one group, see the Appendix.

<sup>32</sup> We re-estimated the models excluding minor unspecified injuries due to possible measurement error. We find quantitatively similar results.

### 4.3 Sensitivity Analysis

We check the sensitivity of our results. For the municipal data set, we run estimations that use weights for the population size of the municipality, thereby increasing the importance of municipalities with larger population. Further, we use heteroscedasticity robust standard errors.<sup>33</sup> This is a suitable combination since observation from larger cities are now more important but also less frequent (i.e. Zipf's law) and so heteroscedasticity should increase.

We find similar results for key variables. Noteworthy is now that kindergartens have a positive effect on pedestrian injuries, a similar result to Kim et al. (2014) that only considered accidents in the capital Seoul. Apparently, in larger municipalities where children rely on their grandparents for transportation to the kindergarten, pedestrian injuries and fatalities are more frequent. One additional kindergarten increases the elderly pedestrian accident chance by 0.3% for all injury types. In other words, pedestrian accident frequency and severity are both larger with kindergartens in proximity. Policy makers that are focused on reducing pedestrian accidents in urban areas might be more inclined to rely on the statistics in Table 8.<sup>34</sup> However, since results are robust to weights and robust standard errors, both estimations have similar policy implications.

Up to this point we have relied on within and between municipal variation for our analysis. In a panel data setup, we can separately identify the effect of within municipality variation (i.e. yearly variation within a municipality) and report the outcome in Table A2 in the Appendix. The reader should hereby recall, within municipal variation is substantially smaller than the between variation and thus it is not surprising that results are less pronounced. Again, a larger presence of elderly has a positive effect on pedestrian accidents whereas in this estimation, population growth reduces these. This points once more to rural areas as more dangerous zones for pedestrians relative to urban areas.

The results for pedestrian accidents of the disaggregate accident data set in Table 8 are to a certain degree more sensitive to specification as we show in Table 10. Due to small sample size it is not possible to include frequency weights and we report column 1 with the same specification (but without weights) as in Table 8, Column 1. We find similar but less pronounced results with larger relative standard errors and lower model-fit. We then turn to the step-wise inclusion of additional control variables in Column 2 and 3 with similar results as earlier but standard errors appear less reliable.

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<sup>33</sup> We also estimated robust models for the base model in Table 5 without weights but found no noteworthy differences and so choose not to report these in detail.

<sup>34</sup> Population weights in this form make reporting more relevant for areas where the absolute number of elderly accidents is largest.

**Table 9. Elderly injuries and fatalities**

	(1) Pedestrian injuries	(2) Pedestrian fatalities	(3) Vehicle injuries	(4) Vehicle fatalities
Cars per person	14.28* (5.566)	3.883** (0.952)	141.6*** (12.73)	6.001*** (0.784)
Pavement rate	-0.0627*** (0.0167)	-0.000822 (0.00402)	0.0479 (0.0481)	-0.00116 (0.00329)
Precipitation in mm	0.0000239 (0.000701)	-0.0000457 (0.000137)	-0.00436* (0.00188)	-0.000129 (0.000127)
Temperature in °C	1.206*** (0.206)	-0.0732 (0.0484)	1.816** (0.663)	-0.00262 (0.0434)
GDP	0.0116 (0.0194)	0.0123* (0.00498)	0.0324 (0.0656)	0.0170*** (0.00478)
Economic participation	-0.153* (0.0545)	0.00652 (0.0147)	-0.194 (0.196)	0.0233 (0.0164)
Financial self-sufficiency	-0.174*** (0.0218)	-0.0107* (0.00498)	-0.556*** (0.0674)	-0.00824 (0.00439)
Financial autonomy	0.103*** (0.0227)	-0.00164 (0.00554)	0.574** (0.0733)	0.00204 (0.00500)
Population density	0.000144*** (0.0000350)	-0.00000286 (0.00000715)	0.000160 (0.0000997)	0.00000344 (0.00000539)
Registered population in 100,000	-1.105*** (0.202)	-0.157** (0.0476)	0.0932 (0.619)	0.136*** (0.0396)
Net migration per 100,000	0.000228 (0.000277)	-0.0000270 (0.0000574)	0.000207 (0.000837)	-0.0000287 (0.0000527)
Outmigration per 100,000	0.000104 (0.0000703)	-0.00000236 (0.0000194)	0.000925*** (0.000223)	-0.0000144 (0.0000196)
Pop. growth	-0.264 (0.252)	-0.00154 (0.0517)	-0.489 (0.755)	0.0457 (0.0477)
%Population over age 65	0.925*** (0.0663)	0.162*** (0.0183)	3.206*** (0.210)	0.240*** (0.0181)
Foreigners per 1,000	0.0252* (0.0121)	0.00255 (0.00232)	0.103** (0.0350)	0.00305 (0.00211)
Medical doctors	1.295*** (0.124)	0.00846 (0.0258)	2.197*** (0.352)	-0.0559* (0.0221)
Suicide per 100,000	0.00811 (0.0247)	-0.00495 (0.00740)	-0.0821 (0.0835)	-0.00357 (0.00703)
Divorce per 1,000	2.329*** (0.468)	0.0944 (0.105)	-0.269 (1.285)	-0.0208 (0.0948)
Culture infrastructure	-0.0226 (0.0502)	0.0104 (0.0145)	0.359* (0.175)	0.00385 (0.0126)
Elderly welfare infrastructure	-0.546*** (0.0548)	0.0336* (0.0157)	-0.00452 (0.183)	0.0723*** (0.0158)
Childcare infrastructure	-0.0880* (0.0366)	-0.00340 (0.0105)	-0.0669 (0.121)	0.0157 (0.00829)
Kindergartens	0.0634** (0.0204)	0.0107** (0.00361)	0.0946* (0.0461)	0.00388 (0.00257)
Elementary schools	0.0202 (0.0358)	-0.000934 (0.00719)	-0.134 (0.0827)	-0.0151** (0.00586)
Higher education	0.210** (0.0809)	0.0472** (0.0172)	-0.214 (0.250)	-0.00453 (0.0142)
Private institutes	0.607 (0.434)	0.170 (0.0918)	-0.499 (1.273)	0.0104 (0.0740)
<i>N</i>	1376	1376	1376	1376
<i>R</i> <sup>2</sup>	0.635	0.488	0.715	0.621

The dependent variable is the number of accidents per 100,000 inhabitants on the municipal level. Year fixed-effects included. Weights account for municipal population size. Robust standard errors in parentheses.

\*  $p < 0.05$ , \*\*  $p < 0.01$ , \*\*\*  $p < 0.001$

We include province fixed effects in Column 3. These additional controls for variation in characteristics between provinces appear to be either too small to change the size of effect of the covariates or sample size is too low to reduce standard errors to a meaningful level.

**Table 10. Disaggregated accident data**

	(1) Ordered logistics Pedestrian	(2) Ordered logistics Pedestrian	(3) Ordered logistics Pedestrian	(4) Ordered probit Pedestrian	(5) Ordered logistics Pedestrian
Severity					
Age below 30	1 (.)	1 (.)	1 (.)	1 (.)	1 (.)
Age 30 to 45	0.139 (0.168)	1.26e-08*** (1.50e-08)	1.32e-08*** (1.42e-08)	0.00104 (.)	4.52e-09*** (3.84e-09)
Age 45 to 65	0.150 (0.177)	1.14e-08*** (1.49e-08)	1.09e-08*** (1.30e-08)	0.00310 (.)	3.41e-09*** (3.38e-09)
Age above 65	0.141 (0.182)	1.15e-08*** (1.61e-08)	1.21e-08*** (1.56e-08)	0.00117 (.)	3.21e-09*** (3.63e-09)
Age below 30	1 (.)	1 (.)	1 (.)	1 (.)	1 (.)
Age 30 to 45	1.447 (0.816)	0.880 (0.502)	0.934 (0.528)	0.677 (0.296)	0.771 (0.612)
Age 45 to 65	1.085 (0.490)	0.883 (0.377)	0.921 (0.392)	0.667 (0.255)	0.811 (0.523)
Age above 65	1.591 (0.725)	1.301 (0.586)	1.344 (0.598)	0.985 (0.337)	1.215 (0.788)
Bus		1.885 (0.626)	1.870 (0.631)	0.707 (0.203)	1.661 (0.572)
Truck		0.900 (0.398)	0.870 (0.379)	1.911 (0.756)	0.963 (0.446)
Motorcycle		9.17e-09*** (1.21e-08)	3.44e-09*** (4.49e-09)	0.00183 (.)	1.59e-09*** (1.90e-09)
Morning Ref. cat.		1 (.)	1 (.)	1 (.)	1 (.)
Lunch time		0.387 (0.214)	0.369 (0.207)	1.627 (0.584)	0.274* (0.167)
Afternoon		0.221** (0.116)	0.220** (0.115)	0.737 (0.244)	0.152** (0.0945)
Evening		0.335* (0.171)	0.324* (0.168)	0.854 (0.330)	0.162** (0.0991)
Night		0.734 (0.339)	0.690 (0.322)	0.751 (0.237)	0.584 (0.301)
Substance abuse			0.147 (0.253)	67.80*** (74.77)	0.741 (2.231)
Adverse weather			0.356 (0.592)	6.430 (6.876)	1.808 (5.198)
Unsafe driving			0.633 (1.010)	12.35** (12.02)	4.893 (14.06)
Signal violation			1.735 (2.824)	25.28** (27.42)	13.02 (37.44)
Outside road			1 (.)	1 (.)	1 (.)
N	274	274	274	274	274
pseudo R <sup>2</sup>	0.011	0.076	0.087	0.455	0.300

Odds ratio reported. Column 3 has province fixed effects.

\*  $p < 0.05$ , \*\*  $p < 0.01$ , \*\*\*  $p < 0.001$

Columns 4 and 5 compare probit and logit estimation with each other. We find the results to be robust to model type. The sensitivity analysis documents that the trade-off between covariates and weights supports the use of reporting weights as in Table 7. We estimated separate models where we include dummy variables for all weekdays in the disaggregate data set, but this does not improve the estimation results, has no clear advantage from a causal perspective and yields no significant coefficients. All models are robust to log transformation of dependent variables.<sup>35</sup>

## 5. Conclusion

This research report examines the accident risks of elderly from traffic in South Korea. In particular, elderly pedestrians are at higher risks and consequently, we estimate determinants of their risk and those of elderly drivers. A number of socio-economic and transport-related variables are clear determinants of elderly pedestrian injuries and fatalities at the municipal level.

Car ownership and car use (approximated by gross domestic product) increase the risk. As does a larger share of the elderly population. This combination of higher car ownership and larger share of elderly population predominantly exists in rural areas where consequently the elderly are at a higher relative risk.

We show that the municipal financial self-sufficiency plays an important role for pedestrian safety and speculate that this might reflect the municipality's possibilities in implementing pedestrian safety measures. An increase of self-sufficiency by its standard deviation (16.3%) would reduce pedestrian injuries by 1.8 elderly in 100 000 individuals (11%). Financial autonomy in comparison does not appear to contribute to traffic safety and we even find some evidence that it might increase vehicle accidents.

Policy implications from these findings fit well into the established literature. Traffic safety of the pedestrians can be strengthened by recognising their vulnerability. Usually, improving the legal status of pedestrians, public awareness, better traffic rule enforcement and lower speed limits at shared infrastructure are key for pedestrian accident prevention. Improvements in public transport can also substantially reduce traffic accidents (Litman, 2016).<sup>36</sup>

Elderly are in special need of this protection as we find that when involved in an accident as pedestrian they are almost five times as likely to be severely injured or even killed than their younger counterparts. We do not find evidence for the same relationship in vehicle accidents. In general, socio-economic and accident determinants suggest that separate analysis of vehicle and pedestrian accidents might improve precision of future research estimates.

Elderly pedestrian fatalities in South Korea exemplify the danger of pedestrians of all ages and in most countries promoting private motorisation. Therefore, it is important to protect pedestrians from an accident perspective but also for other health and economic reasons.

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<sup>35</sup> In a separate estimation, we treat the information where severity is missing as no injury but find identical results.

<sup>36</sup> Improvements in public transit that increase ridership reduce traffic accidents frequency substantially, even more so in combination with campaigns reducing higher risk driving.



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## ANNEX 1

**Table A1 – Variables in municipal data set**

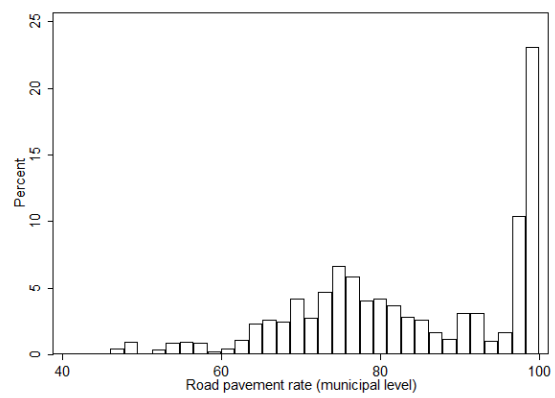
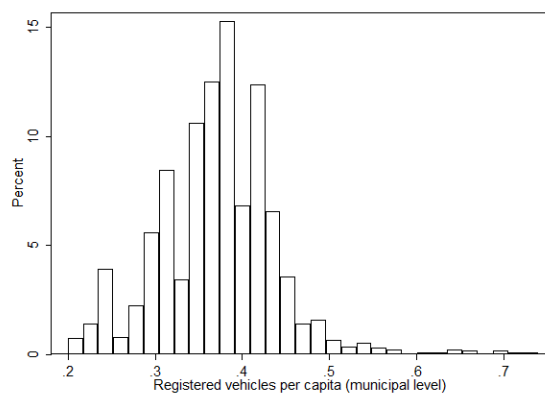
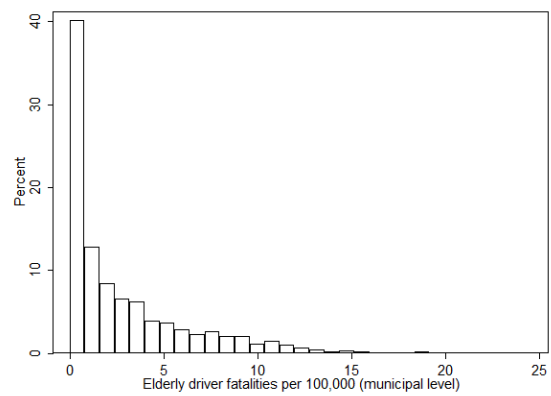
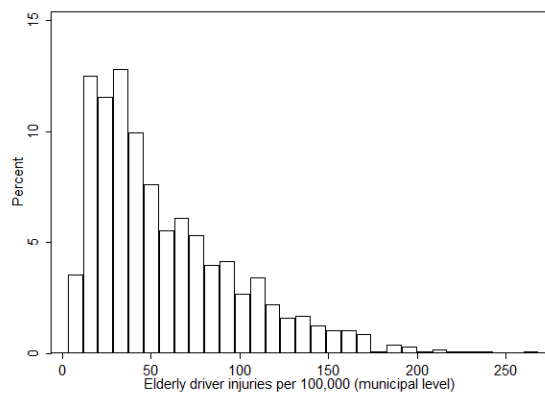
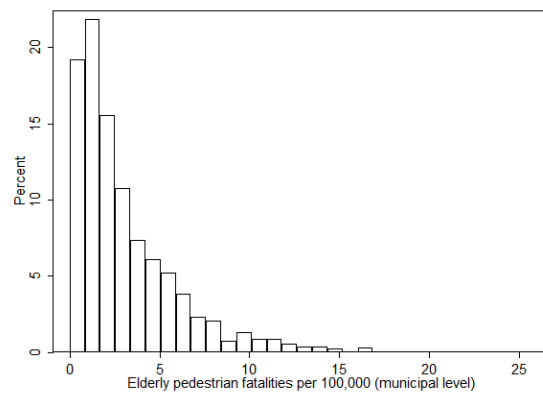
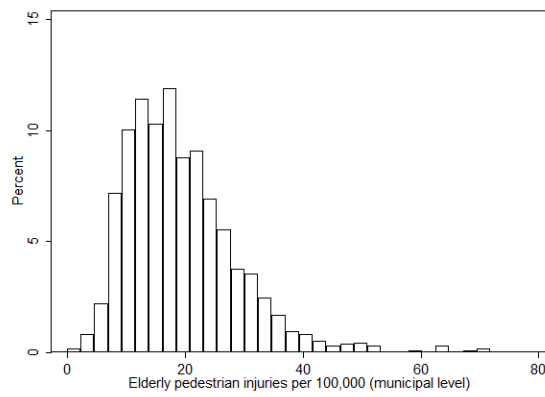
Variable name	Description	TL4	Estimation
Fatalities	Number of fatalities	Yes	Dep. Var
Injuries	Number of injured	Yes	Dep. Var
Accidents	Number accidents	Yes	Dep. Var
Elderly driver fatalities	Number of elderly driver fatalities	Yes	Dep. Var
Elderly driver injuries	Number of elderly driver injuries	Yes	Dep. Var
Elderly driver accidents	Number of elderly driver accidents	Yes	Dep. Var
Elderly pedestrian fatalities	Number of elderly pedestrian fatalities	Yes	Dep. Var
Elderly pedestrian injuries	Number of elderly pedestrian injuries	Yes	Dep. Var
Elderly pedestrian accidents	Number of elderly pedestrian accidents	Yes	Dep. Var
Regional code	TL3 level regional code	Yes	Included
Regional code	TL4 level regional code	Yes	Not Incl.
Year		Yes	Included
Population growth	Population growth rate	Yes	Included
Elderly population	Percentage of over 65 years in population	Yes	Included
Birth rate	Birth rate per woman	Yes	Not incl.
Births	Number of Births	Yes	Not incl.
Registered population	Registered population	Yes	Included
Net migration	Net movement of population	Yes	Included
Out migration	Population moving out	Yes	Included
Pavement rate	Road pavement rate	*	Included
Registered cars	Registered cars per person	Yes	Included
GPD per capita	Gross regional domestic product per capita	No	Included
Economic participation rate	Economic activities participation rate	*	Included
Employment rate	Employment rate	No	Not incl.
Opening rate	Opening to application rate	No	Not incl.
Unemployment rate		No	Not incl.
Electronics companies	Number of companies in electronic processing industry	Yes	Not incl.
Electronics employees	Number of employees in electronic processing industry per 1000 population	Yes	Not incl.
Consumer price inflation	Consumer price inflation rate	No	Not incl.
Housing price inflation	Housing price inflation rate	No	Not incl.
Financial autonomy rate	Financial autonomy	Yes	Included
Public officials	Public officials per 1000 population for local government	Yes	Included

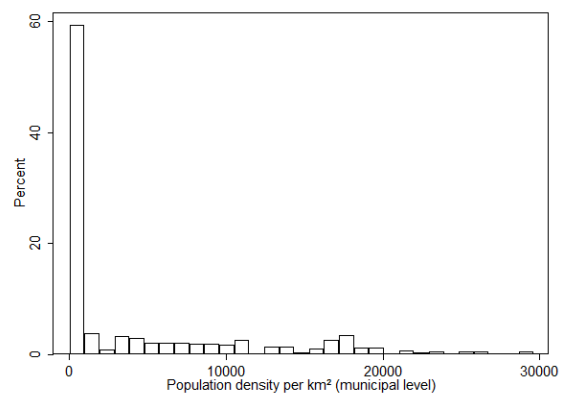
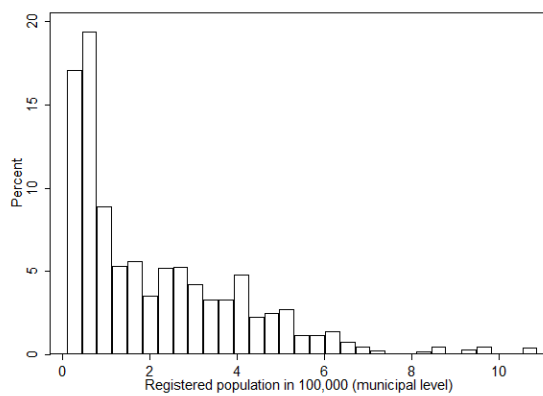
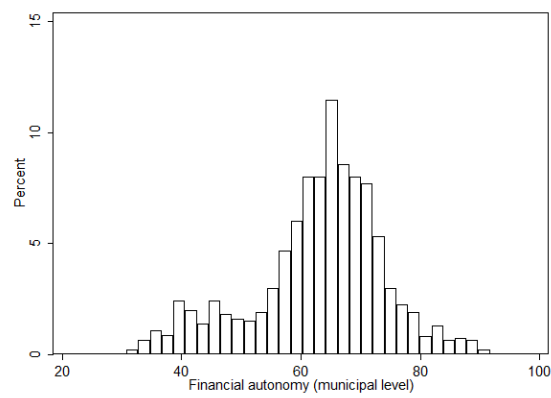
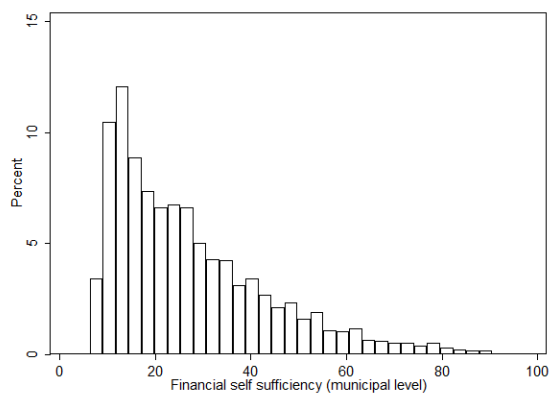
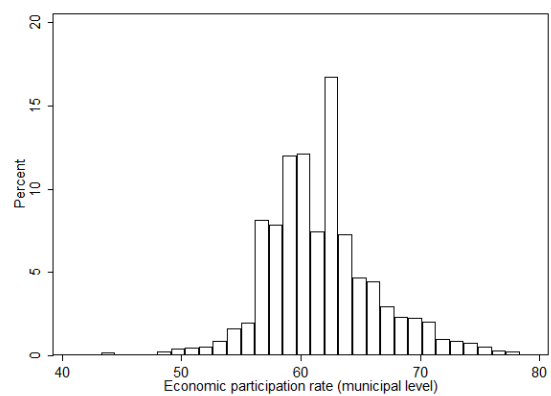
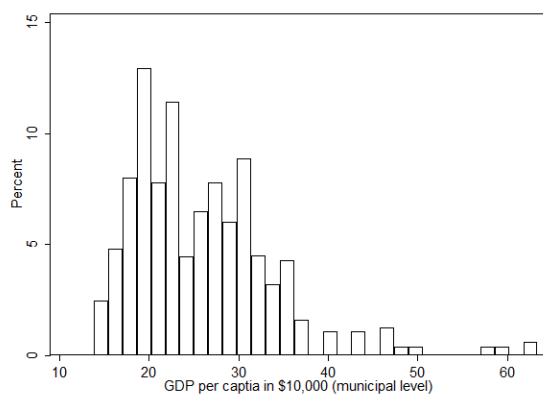
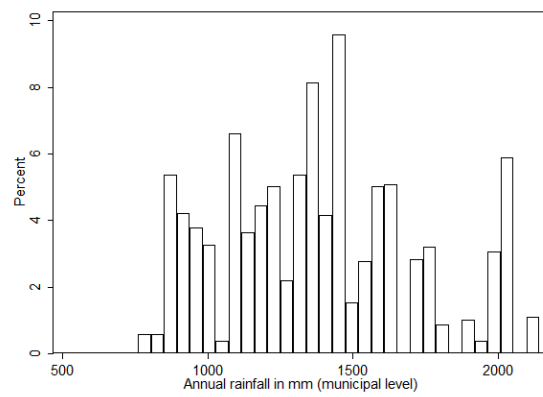
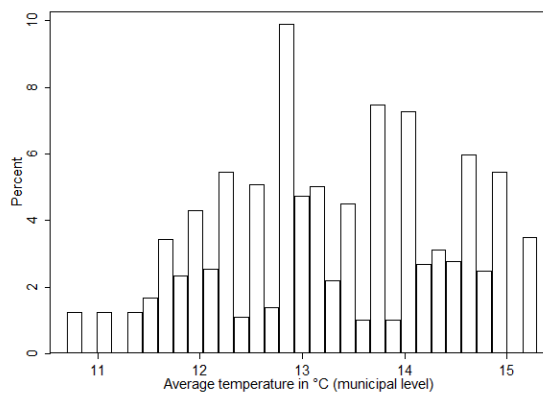
**Table AX continued – Variables in regional data-set**

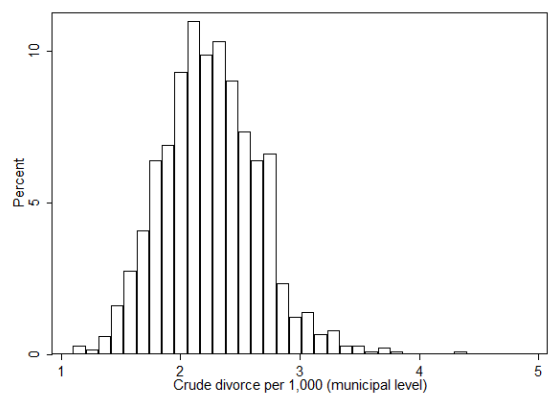
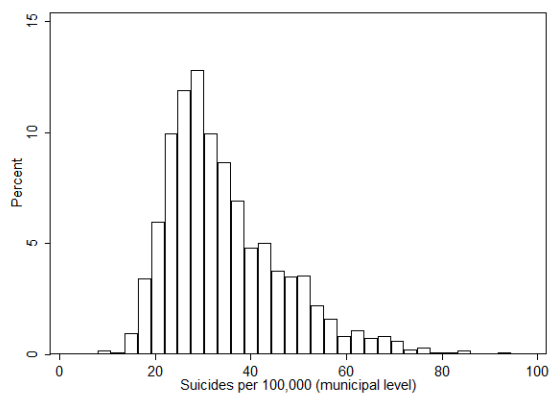
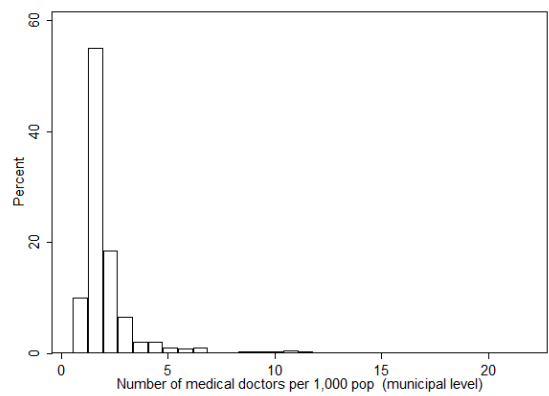
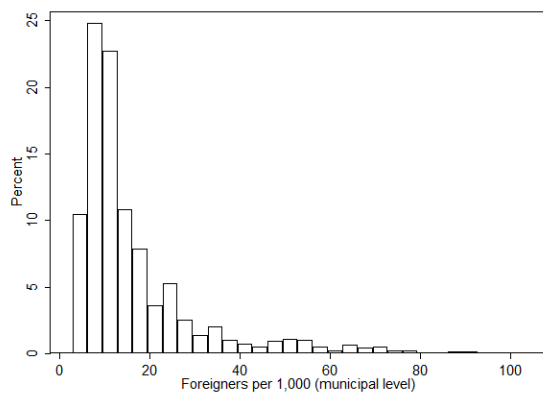
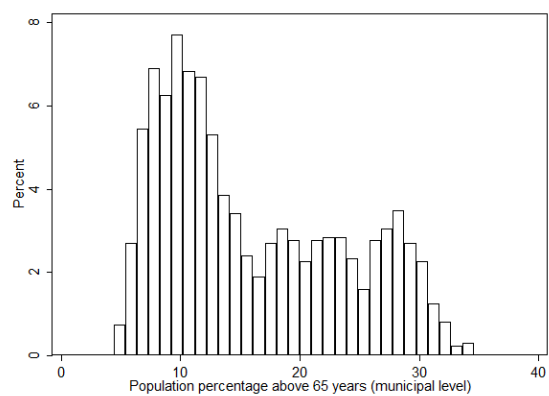
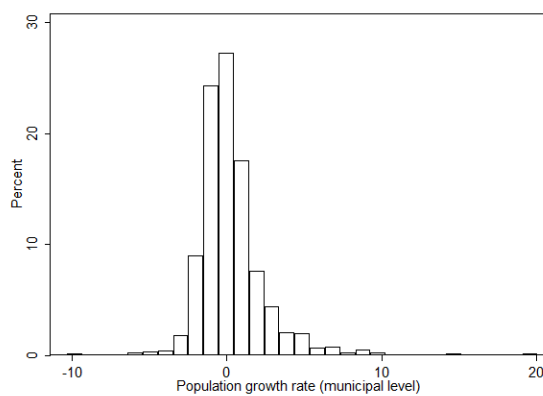
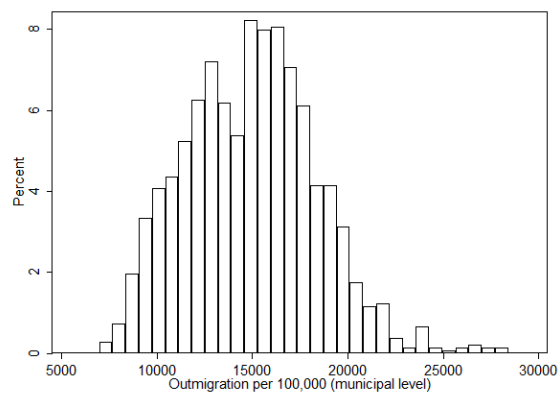
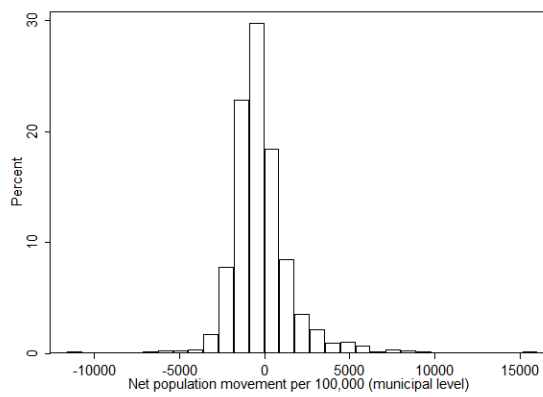
Variable name	Description	TL4	Estimation
Childcare facilities	Number of childcare facilities per 1000 children aged 0~4	Yes	Included
Leisure & welfare facilities	Number of leisure & welfare facilities for the elderly per 1000 aged 60 or more	Yes	Included
Doctors	Number of doctors at medical institutions per 1000 population [proxy medical availability]	Yes	Included
Crime	Crimes committed per 1000 population	No	Not incl.
Traffic accidents	Number of traffic accidents per 1000 vehicles	Yes	Not incl.
Fire accidents	Number of fire accidents	No	Not incl.
Suicide	Suicide rate per 100,000 population	Yes	Included
Divorce rate	Divorce rate per 1000 population (crude divorce rate)	Yes	Included
Universities	Number of vocational colleges and universities	Yes	Not incl.
Private institutes	Number of private institutes per 1000 population	Yes	Not incl.
Foreigners	Number of foreigners	Yes	Included
Foreigner density	Number of foreigners per 1000 population	Yes	Included
Urban parks	Land area of urban parks per 1000 population	No	Not incl.
Construction	Surface area of construction work underway	No	Not incl.
Land traded	Area of land traded	Yes	Not incl.
	Financial self-sufficiency	Yes	Included
	Drinking rate	Yes	Not incl.
	Smoking rate	Yes	Not incl.
Area	Land area in km <sup>2</sup>	Yes	Used for density
Temperature		No	Included
Rainfall		No	Included
Kindergartens	Number of kindergarten	Yes	Included
	Number of elementary school students	Yes	Included
	Number of farming population	No	Not incl.
	Area of agricultural land	No	Not incl.

Note: \*use of TL3 level data for missing TL4 level for the year 2007 and Seoul.

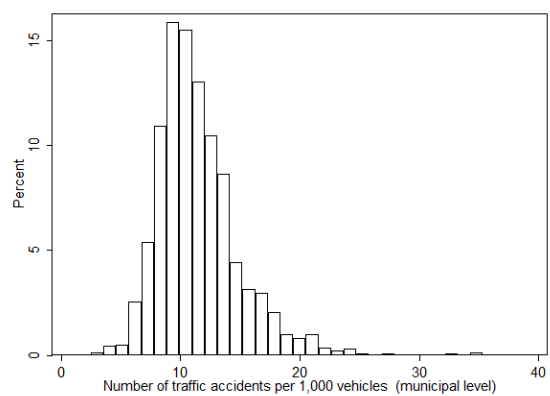
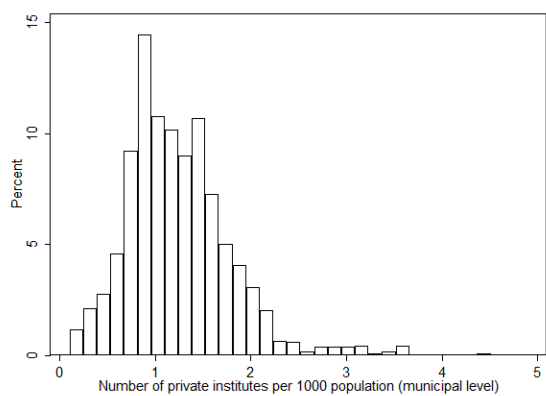
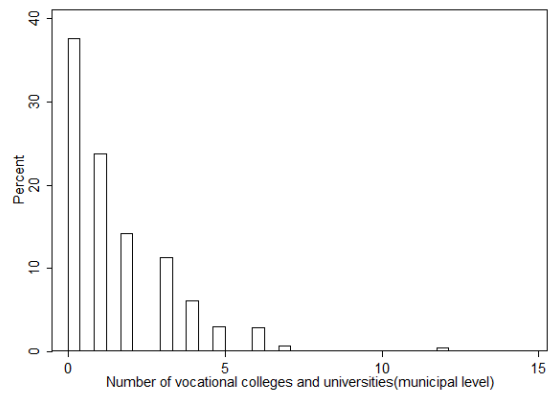
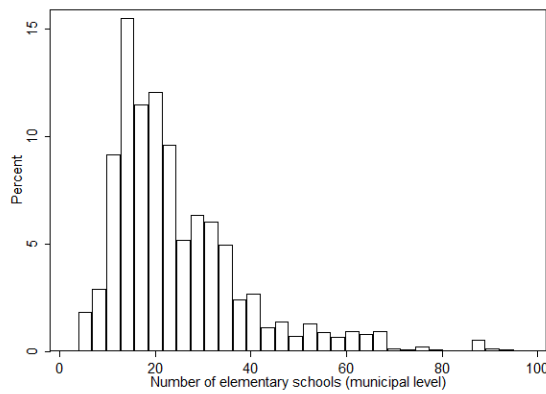
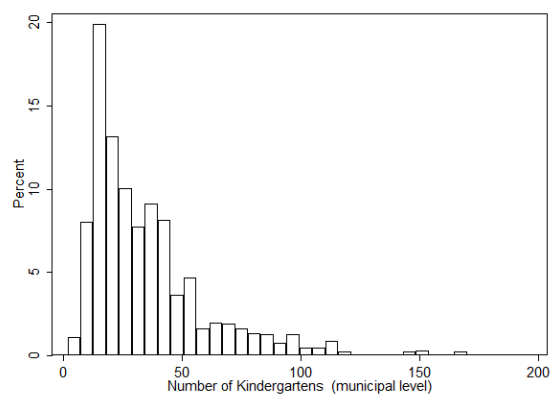
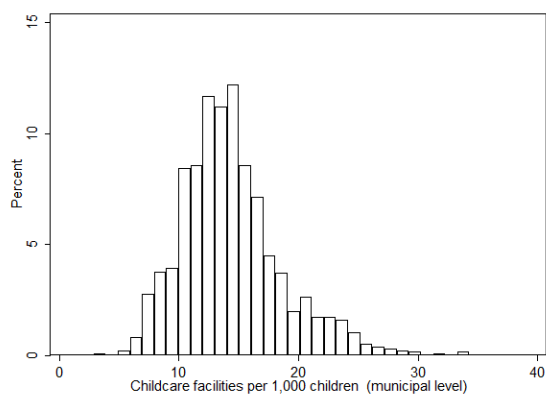
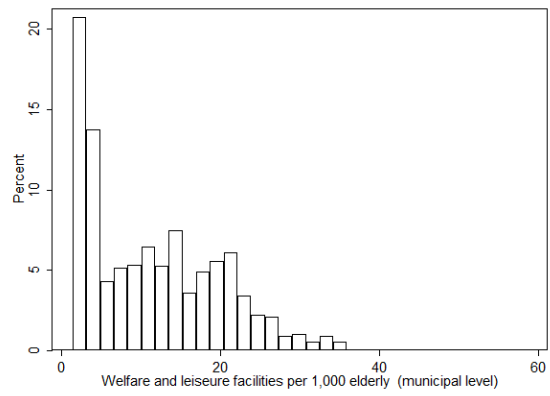
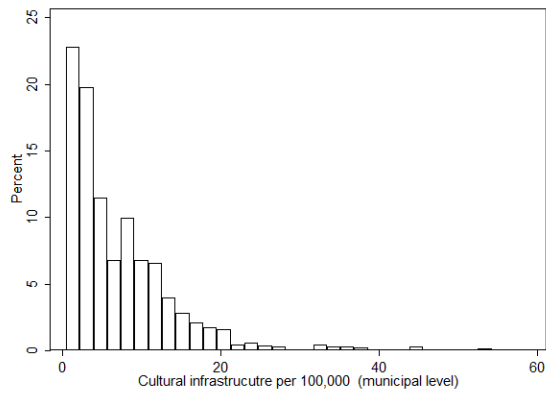
## Municipal data set

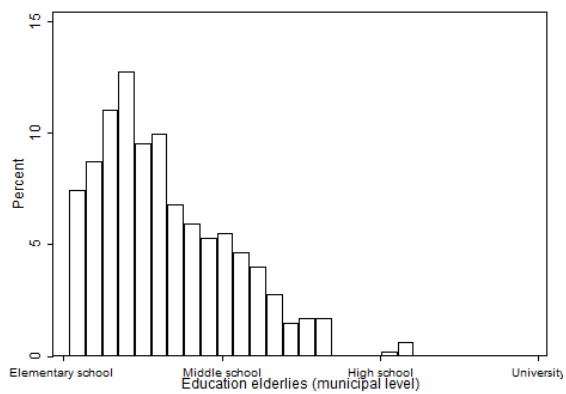
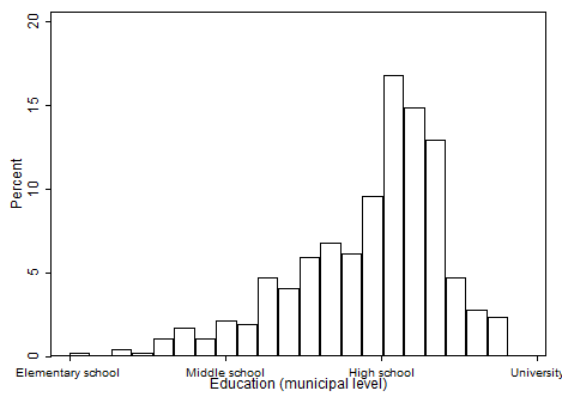
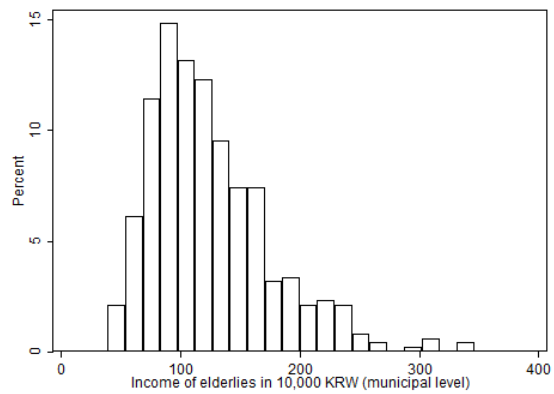
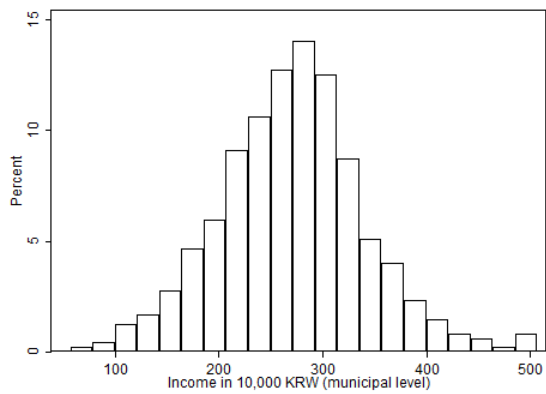
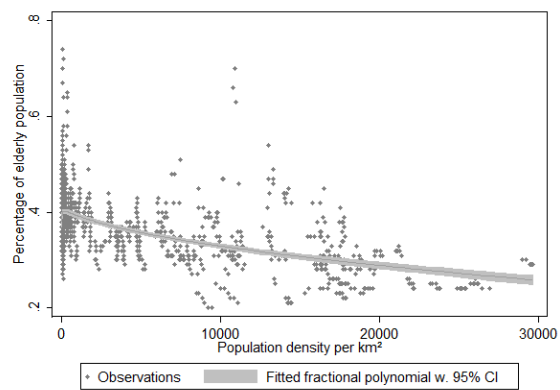
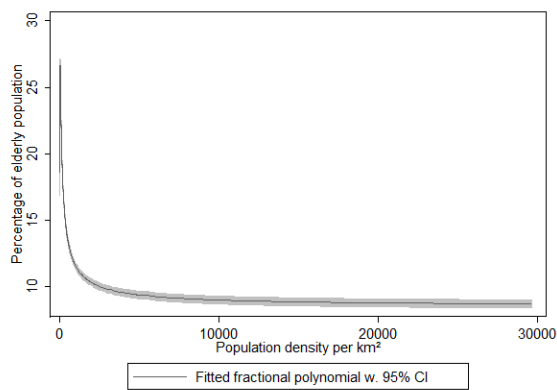
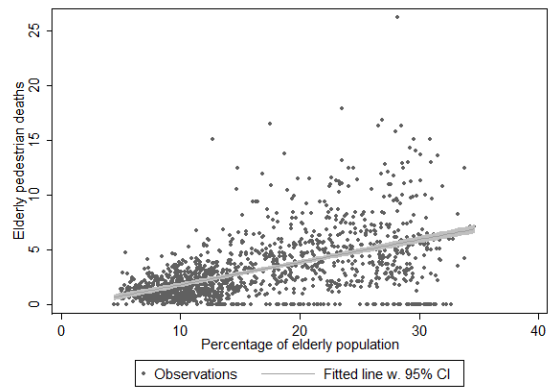
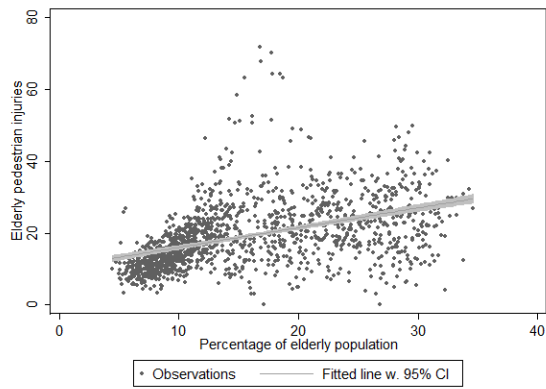




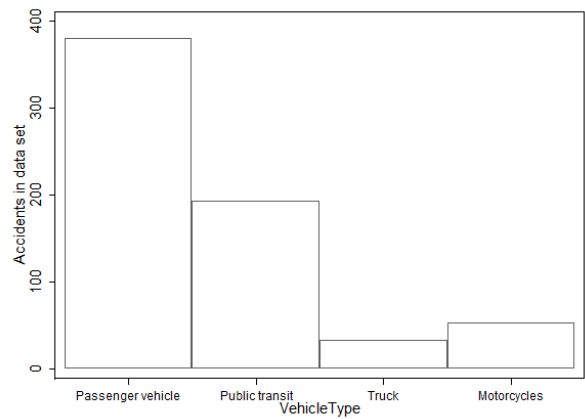
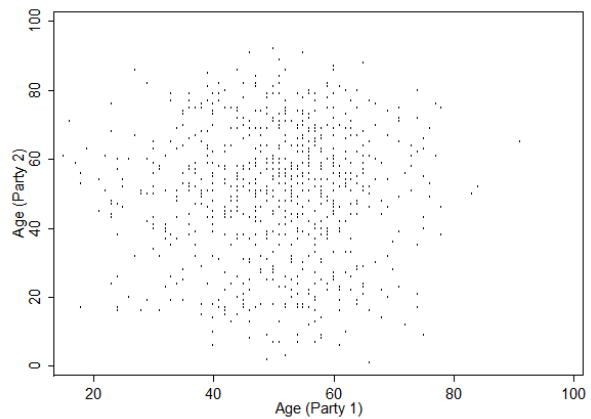
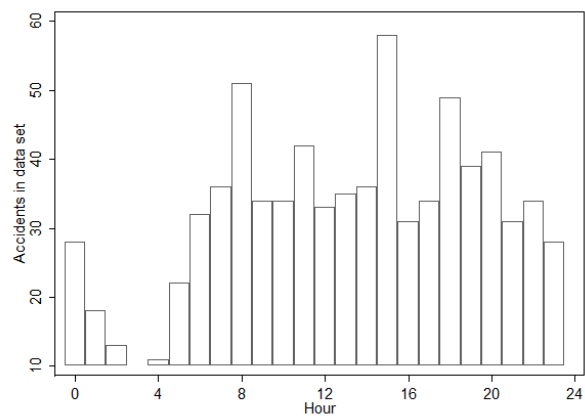
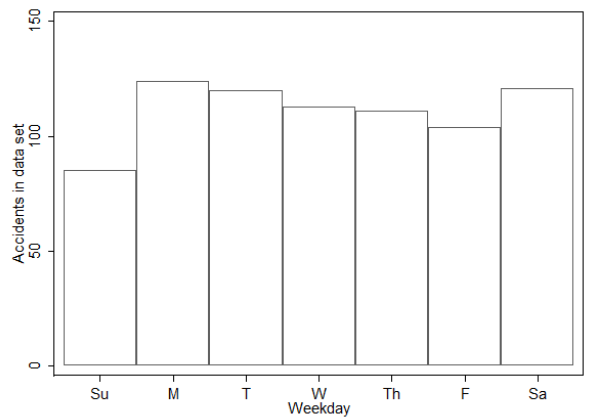
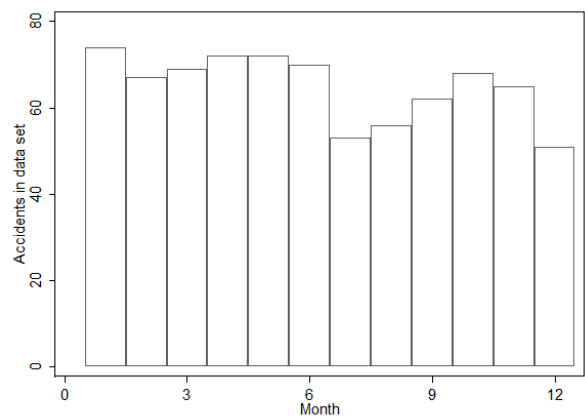
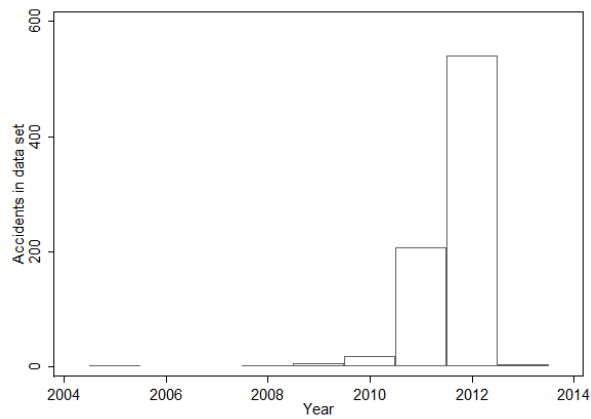


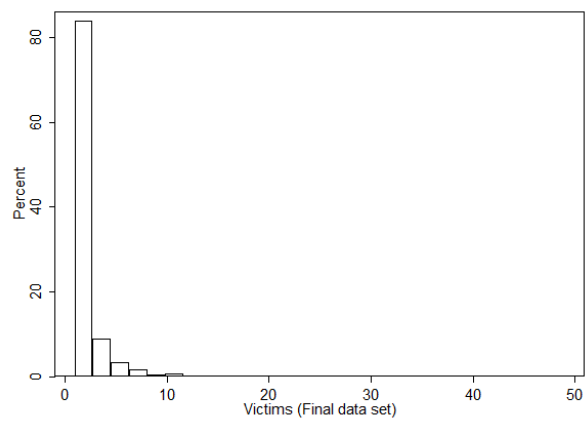
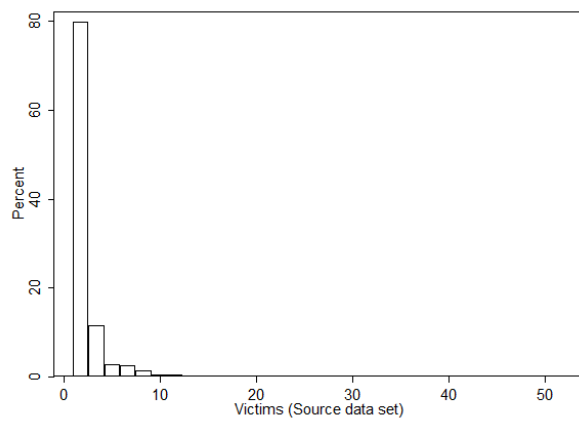
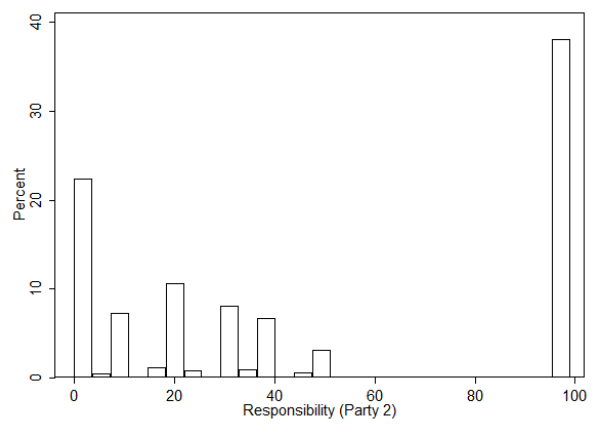
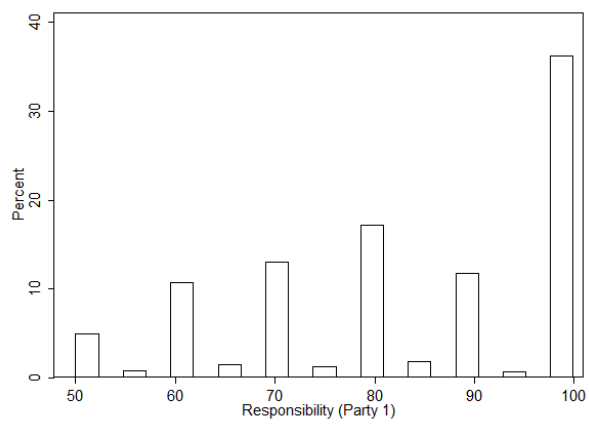
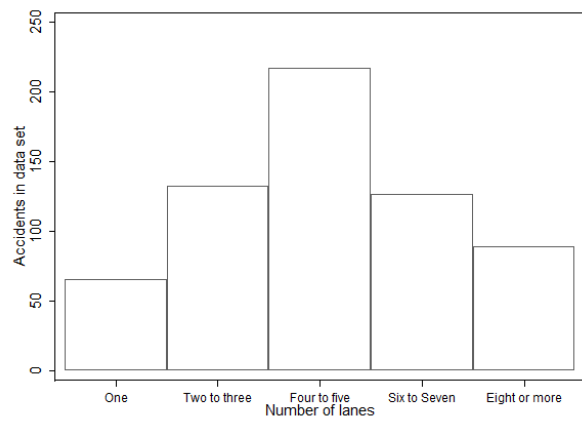
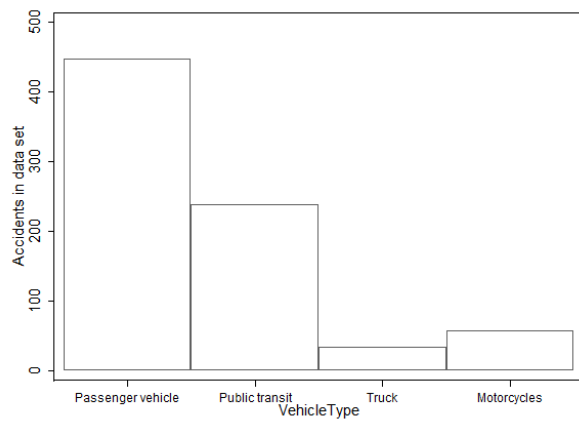


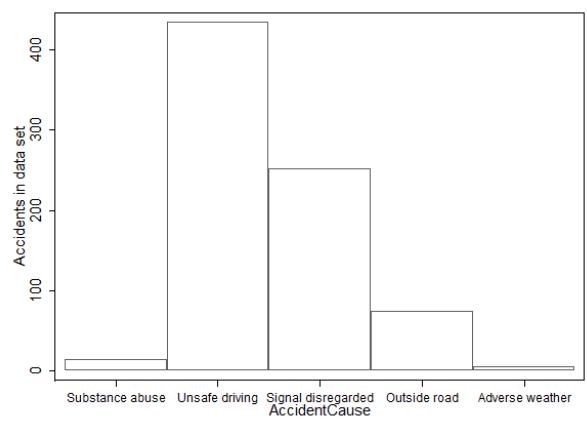
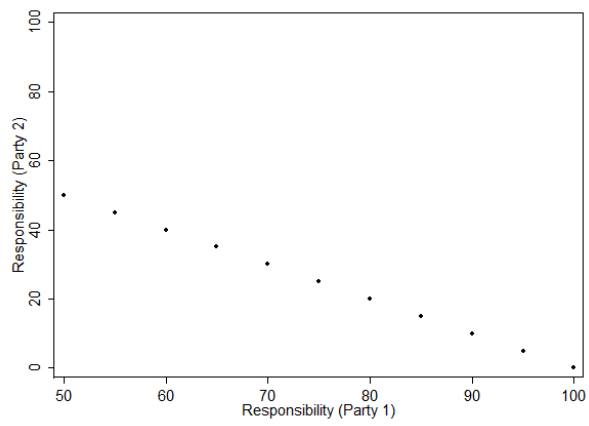




## Disaggregate data set







**Table A2 - Panel estimation, elderly injuries and fatalities**

	(1) Pedestrian injuries	(2) Pedestrian fatalities	(3) Vehicle injuries	(4) Vehicle fatalities
Cars per person	-1.584 (6.440)	-1.001 (1.965)	53.18 (28.20)	4.485* (1.879)
Pavement rate	-0.0199 (0.0498)	0.0105 (0.0143)	0.114 (0.124)	-0.00938 (0.0131)
Precipitation in mm	0.000922* (0.000456)	0.000169 (0.000161)	0.000142 (0.00130)	0.0000342 (0.000146)
Temperature in °C	0.356 (0.493)	0.319 (0.175)	2.481 (1.825)	-0.0970 (0.161)
GDP	-0.211** (0.0757)	0.0136 (0.0254)	0.141 (0.301)	0.00782 (0.0286)
Economic participation	-0.0849 (0.0544)	-0.00230 (0.0208)	0.0890 (0.177)	-0.0119 (0.0218)
Financial self-sufficiency	-0.0436 (0.0284)	-0.00570 (0.00976)	-0.211* (0.0956)	0.00333 (0.00755)
Financial autonomy	0.0210 (0.0405)	0.00840 (0.0135)	0.190 (0.108)	0.00924 (0.0104)
Population density	-0.000479 (0.000482)	0.000244* (0.000123)	0.00147 (0.00165)	0.000295** (0.0000935)
Registered population in 100,000	-1.503 (1.549)	-0.314 (0.446)	1.592 (5.563)	-0.530 (0.364)
Net migration per 100,000	0.000688** (0.000240)	0.0000151 (0.0000540)	0.000156 (0.000598)	0.0000302 (0.0000581)
Outmigration per 100,000	0.000120 (0.0000888)	-0.0000328 (0.0000287)	0.000428 (0.000290)	0.0000149 (0.0000327)
Pop. Growth	-0.563* (0.223)	-0.0287 (0.0475)	-0.295 (0.545)	-0.00558 (0.0518)
% of population over age 65	1.591*** (0.411)	0.199 (0.119)	3.895** (1.472)	0.155 (0.108)
Foreigners per 1,000	0.0874* (0.0389)	-0.00704 (0.0133)	0.137 (0.164)	0.0216 (0.0129)
Medical doctors	0.707 (0.562)	0.0416 (0.108)	2.676 (1.917)	-0.0539 (0.104)
Suicide per 100,000	-0.0142 (0.0234)	-0.0126 (0.00917)	-0.0806 (0.0850)	-0.0126 (0.00937)
Divorce per 1,000	0.0552 (0.717)	0.197 (0.279)	3.714 (2.159)	0.104 (0.236)
Culture infrastructure	-0.00250 (0.132)	0.0345 (0.0437)	1.337* (0.643)	-0.0396 (0.0505)
Elderly welfare infrastructure	-0.103 (0.181)	-0.0225 (0.0795)	0.843 (0.532)	0.0919 (0.0644)
Childcare infrastructure	-0.117 (0.0782)	0.0252 (0.0241)	-0.627* (0.301)	-0.00935 (0.0233)
Kindergartens	-0.0796 (0.0426)	-0.0215* (0.0107)	-0.132 (0.164)	-0.0163 (0.00929)
Elementary schools	0.0537 (0.130)	0.0407 (0.0403)	-0.796 (0.451)	0.0293 (0.0336)
Higher education	0.0550 (0.537)	-0.0491 (0.107)	1.339 (2.079)	0.0271 (0.0955)
Private institutes	1.395** (0.456)	0.130 (0.153)	1.303 (1.194)	0.0133 (0.104)
<i>N</i>	1376	1376	1376	1376
<i>R</i> <sup>2</sup>	0.298	0.020	0.420	0.041

The dependent variable is the number of accidents per 100,000 inhabitants on the municipal level. Panel variable is municipality. Weights account for municipal size. Year fixed-effects included. Robust standard errors in parentheses.

\*  $p < 0.05$ , \*\*  $p < 0.01$ , \*\*\*  $p < 0.001$

## ANNEX 2

### An overview on the benefits of roundabouts

Roundabouts refer to an intersection structure by which the vehicles are induced to drive rotating counter-clockwise, along a round traffic island located at the centre of the intersection. It was developed in the 1960s to overcome the shortcomings of traditional traffic circles like rotaries, which failed to efficiently handle increasing traffic flows and thus kept causing bottleneck and safety problems. Whilst inside vehicles are obliged to give way to the entering traffic in rotaries, roundabouts operate in the opposite way. The core principle of roundabouts is that the traffic is not controlled by traffic signals but by a predetermined right-to-way rule, according to which the entering traffic should yield to the traffic circulating inside. This naturally helps lower the speed of the entering vehicles and reduce the probability of fatal accidents.

Since its invention in 1960s in Britain, roundabouts soon began gaining attention from transport policymakers, as a means to facilitate efficient traffic management at intersections. In many European countries, including Britain, France, Germany and Spain, it is now a predominant form of intersection, whilst the US is progressively redesigning intersections into a roundabout format from 1990. As for Korea, it was relatively recent in 2009 when the roundabout was first introduced but the positive outcomes are already visible, with accidents decreasing by 48% and casualties by 45.2%, according to the research conducted on 96 roundabouts (MPSS, 2016). The Korean government has put forward the Implementation Plan for Promotion of Roundabouts (2013-2022), aiming at building 1 323 roundabouts over the decade from 2013 and 2022.

An attempt to quantify the benefits of roundabouts is made by the Korea Transport Institute (KOTI) (Cho et al., 2014), with the long-term objective to establish optimal roundabout models in Korean contexts by building on and expanding international experiences. The study measures the efficiency gains, broken into several categories of traffic capacity, safety, environmental impacts, vehicle economies and construction costs, through ex-ante and ex-post analysis at nine intersections (Table below).

#### Efficiency gains following the introduction of roundabouts

	Change in traffic management efficiency (%)		Annual gains in economic efficiency (1000 USD)					
	Travel time	Travel speed	From travel time reduction	From vehicle operating costs reduction	From pollution reduction	From accident reduction	From signal installation costs reduction	Total benefits
Choobu	-45.8	68.6	485.0	72.1	23.2	25.2	73.4	678.9
Changsun	-36.8	59.2	175.1	31.5	10.5	25.2	73.4	315.7
Gwanjung	-18.7	22.9	45.9	9.0	3.1	25.2	73.4	156.6
Hanjoo	-42.8	74.6	329.7	30.3	18.9	25.2	73.4	477.5
Hojeu	20.1	-16.8	-37.9	-8.2	-2.2	25.2	73.4	50.3
Ice rink	-32.0	47.0	219.6	27.8	14.3	25.2	73.4	360.3
Average	-31.3	33.3	202.9	27.1	11.3	25.2	73.4	339.9
Byungsa	-23.7	31.3	25.8	5.1	1.7	25.2	-	57.8
Museum	-17.9	21.6	277.9	53.1	18.7	25.2	-	374.9
Hyoji	-11.6	13.0	20.8	4.3	1.3	25.2	-	51.6
Average	-17.6	21.5	108.2	20.8	7.2	25.2	-	161.4

Note: 1) Travel time and speed is measured within the 150m radius from the intersection with a helicopter camera; 2) Gains from accident costs reduction are identical, as the average number of accidents is applied in calculating the costs.

Source: Cho, H.S. et al. (2014), *Research on roundabout models adapted to Korean contexts*, KOTI's general project 2014-02-01, Korea Transport Institute, Sejong special autonomous city, Korea.

First of all, the study shows the improvement in traffic management efficiency after the introduction of roundabouts. The average travel time in the sample areas decreased by 25.7% from 24.1 to 17.9 seconds, whilst the average travel speed increased by 27.2% from 22.2 to 29.6km/h. These benefits of smoother traffic flows were more noticeable at intersections previously controlled by signals than those non-signalised or flash-signalised. This is because, whilst signals can be superior in controlling high traffic volumes during peak hours, they also tend to cause unnecessary traffic delay during off-peak hours (Akçelik, 2008).

Secondly, economic gains are quantified as USD 250 700 per year for each intersection on average. The travel time reduction contributed the greatest share (USD 155 500), followed by signal installation costs reduction (USD 36 700), accident costs reduction (USD 25 200), vehicle operating costs reduction (USD 24 000) and air pollution costs reduction (USD 9 300). Despite the overall improvement of economic efficiency at the aggregated level, a wide variance of magnitude is observed across the sample areas. For example, at Hojeu intersection, both the average transit time and speed deteriorated on the contrary. This suggests that the best-fitting intersection model may be different depending on local-specific factors and needs.

Another representative advantage of roundabouts is safety enhancement. Savings in road crash costs amount to USD 25 200 per year per unit. It has also been reported that Korea saw 42% reduction in accident fatalities by replacing 192 traditional intersections with roundabouts, which was a pilot project conducted by the (then) Ministry of Security and Public Administration from 2010 and 2012 (OECD, 2016). Similar results were obtained in Australia, where casualties rate reduced by 74% after roundabouts were installed, accompanied by 32% reduction in crashes involving property damages (Austroads, 1993). Roundabouts help reduce the probability of road accidents as well as the degree of fatality, because their unique geometric design allows only eight conflict points – spots on the intersection area where the driving paths may collide –, compared to 32 at four-leg intersections (MOLIT, 2010). The structure of roundabouts also helps to improve driver's performance, as the number of decision-making points is fewer and the slower speed enables better brake-reaction (Flannery and Elefteriadou, 1999).

Whilst a wide range of benefits are reported across countries, roundabouts can be an optimal choice only under certain circumstances. According to MOLIT's Roundabout Guide (MOLIT, 2010), roundabouts are preferred, when signals unnecessarily delay traffic flows; when a large proportion of traffic is of left-turning vehicles; when the right-of-way at the intersection is ambiguous; or when fatal accidents are frequently reported. On the other hand, roundabouts are generally not recommendable in congested urban cores where explicit signal control is required to organise heavily entangled traffic, as well as in areas with substantial pedestrian volumes or in protection zones for the elderly, the disabled and children (Akçelik, 2008). The findings of KOTI's research agree to such arguments. KOTI simulated 360 scenarios with different combinations of key variables, such as number of entry lanes, traffic volume and proportion of left-turning traffic. Even though different results might be drawn depending on the variation of those variables, overall tendency suggest that a signal system grows more competitive as traffic volume increases, whilst roundabouts show greater advantages in proportion to the volume of left-turning vehicles.

Additionally, KOTI points out that public awareness on the functions and rules of roundabouts plays an important role in maximising the benefits of roundabouts. The users with higher awareness on roundabouts tend to better acknowledge the benefits and comply with the priority and slow-speed rules. Also, the capacity of a roundabout tends increase over time as drivers become more familiar with the new rules (NCHRP, 2010).

In conclusion, the central and local governments in Korea have been making efforts to better understand the effects of roundabouts in Korean context and fully harness its benefits. Not only have roundabouts been found to have substantially positive effects on traffic capacity and safety, they also produces economic



gains. Further researches are required to verify the functioning of interacting elements, such as the number and width of circulating lanes and entry lanes, signal timing and lane configurations. Traffic policymakers should bear in mind different types of intersections present different challenges for each road users, and particular attention should be paid to the vulnerable groups, including the elderly, children and cyclists. Efforts are also called for to build flexibility into the initial planning, as traffic patterns change over time and intersection patterns will have to adjust accordingly.

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