THE ROLE OF ROAD SAFETY IN A SUSTAINABLE URBAN MOBILITY: AN ECONOMETRIC ASSESSMENT OF THE SPANISH NUTS-3 CASE.

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ABSTRACT:

There has been a structural change in mobility in major Spanish cities in recent decades, with a switch to the pattern followed in other countries in the area. A shift has taken place from a traditional Mediterranean model to a North American city stereotype, with uncontrolled motorization and major implications for public health. This article specifically analyzes negative road safety related externalities that result from this process, given that the trend seems to show a steady decline in road safety accidents on urban roads in Spain, with major differences among NUTS-3 provinces. The objective is to evaluate the factors that empirically explain these differences for the 2003-2013 period using a panel data analysis. Results show that a key role is played by urban development variables, such as population density and improvements in health services, with advances linked to more accessible and sustainable urban transportation, such as the Smart City concept. Not only does this article close a gap in the literature, but the findings can also serve as a practical guide for the development and implementation of urban mobility and road safety plans, and reveals the special needs of the most vulnerable groups.

Keywords: Road Safety, Urban Areas, Smart City, Panel Studies, NUTS-3 provinces.

JEL Codes: C33, O18, R41.

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1. Introduction

The analysis of current and future road transport trends in large cities is a research topic of growing international importance (Archer and Vogel, 2000). High levels of traffic congestion remain one the most visible transport problems in any developed city, as a consequence of the increased number of private vehicles that come from the uncontrolled motorization (Yigitcanlar et al., 2015), which, according to a general consensus, may also be related to both the lack of an effective/attractive public transit system and opportunities for walking and cycling (Beirao & Cabral, 2007; Julsrud & Denstadli, 2017).

Factors such as the mass movement of population from rural areas to cities, high human density, urban sprawl and the consequent increase in daily commutes by private cars (Dumbaugh and Rae, 2009; Vassallo et al., 2012) have turned urban space into a scenario not only with environmental externalities (air pollution, noise) (Kersys, 2015), but also with other health negative risks such as traffic accidents (Shekari et al., 2016).

In recent decades, European cities have moved on from the traditional Mediterranean model, in which economic and leisure activities were clustered together in the city center, and journeys were predominantly made on foot or on public transport (Salvati and Gargiulo Morelli, 2014). There has been a proliferation of the North American-influenced city stereotype, characterized by uses and services being widespread and the migration of population to metropolitan residential areas, forcing citizens to invest more time in their journeys and triggering a modal change toward motorized means of transport (Dura-Guimera, 2003).

Nevertheless, despite of the relationship between urban mobility and road safety, most efforts follow an accessibility and sustainability approach that focuses on environmental issues, and the literature that has addressed urban sustainability from a safety dimension is both more recent and less abundant.

This literature shows that accidents that occur on urban roads present differentiated risk factors from interurban road accidents, with urban morphology having special repercussions (Gomes, 2013; Ma et al., 2010; Moeinaddini et al., 2014; Scott et al., 2016), especially road intersections (Ferreira and Couto, 2013). In addition, the wide variety of collectives should not be neglected: pedestrians, cyclists, young drivers, motorcycles and scooters, private cars, transportation vehicles and public transit vehicles all share a limited amount of urban space and this complicates mobility (Chang et al., 2016; Jevtić et al., 2015; Maestracci et al., 2012; Tay et al., 2011).

Researchers such as Rakauskas et al. (2009) and Zwerling et al. (2005) analyze factors that could explain accidents in urban areas. For example, on highways drivers travel longer distances, weather conditions and the state of the roads can have a greater effect on driving, speeds are higher and, above all, the speed and quality of post-accident trauma attention play a crucial role (the “golden hour”, Castillo-Manzano et al., 2014; Sánchez-Mangas et al., 2010). Other studies (Archer and Vogel, 2000; Moeinaddini et al., 2015; Vorko-Jović et al., 2006) point to factors such as traffic congestion, greater frequency of journeys (greater exposure to risk), different alcohol/drug consumption patterns that are especially acute at weekends, and drivers’ different attitudes and behaviors.

Studies by Clark (2003), Clark and Cushing (2004), Ewing et al. (2003, 2016), Suhkai and Jones (2014) and Yeo et al., (2015) are especially significant. These authors analyzed the influence of variables such as the degree of urban sprawl, with an almost exponential increase in the number of private vehicle journeys from metropolitan areas to inner cities.

This is the current article’s object of study for the specific case of urban roads in Spanish provinces (EU statistical classification NUTS-3 regions), for which to date there has been a marked lack of literature addressing the issue of urban accidents disaggregated on the territorial scale. This article seeks to fill the gap in the literature on urban traffic accidents in Spain, as the precedents that explore the problem on the regional and provincial levels (Albalate et al., 2013; Gómez-Barroso et al., 2015; Redondo-Calderón et al., 1999; Rivas-Ruiz et al., 2007; Úbeda et al., 2016; Tolón-Becerra et al., 2009; 2013) only consider the effects of accidents on inter-city roads, or address accidents in urban areas in a single province or city (De Oña et al., 2011, 2013; García-Altés and Pérez, 2007; Kanaan et al., 2009; Melchor et al., 2015; Prat et al., 2015).

The main contribution of this article is to determine the statistically significant factors that explain the different urban road safety outcomes at the provincial level in Spain, subsequently focusing on the main and most populated cities (provincial capitals). A negative binomial multivariate model is formulated and applied to original panel data for the 2003-2013 period. The results are an essential step forward in the ability to tackle the issue of traffic accidents on Spanish city roads with a greater guarantee of success.

The article is structured as follows: following this Introduction, the second section presents the database used and the methodology applied; the third section gives the results and the corresponding discussion; and lastly, a conclusions section is included and the paper is completed with the bibliography.

2. Empirical framework: data, variables and methodology

Using available official data, an original database has been constructed for urban road safety that is unprecedented in Spain. Taking into account that the aim of the current study is to assess road safety in urban settings at the provincial level in Spain, panel data were constructed *ad-hoc* for a sample made up of the 50 provinces into which Spain is politically and administratively organized (EU statistical classification NUTS-3 regions), excepting Ceuta and Melilla. The two Autonomous Cities of Ceuta and Melilla in North Africa were excluded from the analysis due to the skew that they would have introduced into the sample due to their small size and special characteristics compared to the other cities. The period of analysis spans from 2003 (when Law 57/2003 concerning Large Cities was passed) to 2013 (the most recent year for which standardized data can be found). Figures 1 and 2 show differences in urban road safety in the 50 Spanish provinces considered in the analysis to facilitate understanding of the database.

[PLEASE INSERT FIGURE 1 NEAR HERE]

[PLEASE INSERT FIGURE 2 NEAR HERE]

Table 1 describes the variables considered (same naming as in the model, below) and the sources from which they are taken. The unit of observation is the province-year pair. Variables can be split into two groups:

1. Endogenous. Accidents and fatalities within 30 days (following the Vienna Convention's international criterion) recorded on urban roads in Spanish NUTS-3 provinces.

2. Explanatory. Sample economic, social-demographic, geographic and mobility heterogeneity is captured with different categories of variables: demographic (population density and population structure by age); economic (economic activity and sectoral structure); health network (hospital density); geographic (latitude and longitude); mobility (motorization); and accessibility/sustainability conditions affecting urban transit (Smart City, alternative non-motorized public transit modes).

[PLEASE, INSERT TABLE 1 NEAR HERE]

This panel has been econometrically treated with the STATA package using an econometric model that takes province i during period t in the expression (1):

$$Y_{it} = \alpha + \beta_k X_{it} + \gamma_k Z_{it} + \nu' Year_{it} + \varepsilon_{it}, \qquad (1)$$

where Y_{it} are explained road safety variables for either the total number of urban traffic accidents or the number of urban traffic fatalities per accident (within the following 30 days, according to the Vienna Convention); X_{it} contains the vector of attributes of each province (the explanatory variables relating to demographic, economic, motorization, geographic and health characteristics); Z_{it} are dummy variables that identify the accessibility and sustainability conditions in which urban mobility takes place (regarding Smart City status and the availability of a subway and/or urban rail system). Dummies are also included for *Year* to capture the common time trend in all the provinces; and ε_{it} is the mean zero random error.

The explanatory variables considered in the two models (one for each explained variable: urban accidents and fatalities) are based on factors typically analyzed in previous road safety studies (Albalate and Bel, 2012; Castillo-Manzano et al., 2013, 2014, 2015, 2016; Dee,1999; and Tolón-Becerra et al., 2013 for Spanish NUTS-3 provinces, but in relation to accidents on intercity roads), and the few precedents that exist on urban road safety (for example, Vorko-Jović et al., 2006, and Yannis et al., 2015 for the case of the principal European cities).

With respect to their description, as can be observed in Table 1, Gross Domestic Product (GDP) per capita is used to test for any relationship between economic development and road fatalities. According to the prior literature, *a priori* it is not clear what the sign of the coefficient related to this variable should be. On the one hand, the road accident fatality rate could rise along with a country’s economic development due to greater risk exposure (Kopits and Cropper, 2005), but on the other hand, the relationship between economic development and the road accident fatality rate could reduce and the trend could even reverse once a certain income level has been reached (Bishai et al, 2006). In this article, both GDP per capita and GDP per capita squared are considered as exogenous variables.

Following prior studies (Albalate and Bel, 2012; Castillo-Manzano et al., 2013, 2015; Kopits and Cropper, 2005), Table 1 also includes a variable for the motorization rate.

However, the relationship that should be expected for this variable is not very clear, either.

On the one hand, higher motorization levels could imply greater exposure to traffic accidents but, on the other, more developed countries would benefit from better infrastructure and better vehicles, more progressive policies and more beneficial social attitudes toward road safety (Castillo-Manzano et al, 2013). It should be mentioned that the GDP per capita and motorization variables might capture similar effects, although the correlation found between the two (see Table 3, below) is not sufficiently high to consider the existence of a collinearity problem.

From the economic point of view, Table 1 also shows that variables have been considered for the relative importance that the manufacturing sector and the construction sector have on total employment in the province. Both of these variables seek to capture the approximate impact that heavy truck traffic flows due to industrial and construction activities may have on road safety in Spanish urban areas. According to earlier studies (Castillo-Manzano et al., 2015, 2016; Dablanc et al., 2013; Dong et al., 2014; Nuzzolo and Comi, 2014; Nuzzolo at al., 2016), these trucks’ special technical features and the difficulty that their maneuvering presents in urban conditions suggest that a negative outcome on road safety should be expected.

From the demographic point of view, two control variables have been considered. First, following earlier studies on urban road traffic accidents, a variable for Population Density has been included. According to what has gone before, in principle a negative sign should be expected for the influence that this has on urban road safety, in the sense that, the more concentrated the population (and, therefore, the less disperse it is throughout the metropolitan area), the more the number of fatalities caused by road accidents should decrease. Previous studies agree that this relationship can be explained by greater traffic congestion in more densely populated cities incontrovertibly contributing to a significant reduction in driving speeds and, as is well known, this is one of the basic risk factors that leads to traffic accidents (Clark, 2003; Ewing et al., 2003, 2016; Graham and Glaister, 2003; Sukhai and Jones, 2014; Yannis et al., 2015; Yeo et al., 2015). On the other hand, greater population density could also be expected to entail more traffic accidents, as there is a rise in the degree of vehicle exposure to accidents.

Also with respect to the population, a control variable is included for the mean age of the population in each province with the purpose of capturing the demonstrated greater vulnerability that certain collectives present. In this regard, according to certain authors such as Kanaan et al. (2009), Keall et al. (2004), Prat et al. (2015), Stevenson and Palamara (2001) and Williams et al. (1998), for example, the youngest drivers are a major risk collective that contribute by raising the likelihood and severity of accidents, especially in urban areas, as a result of drugs and alcohol DUI behaviors. However, the relationship between road safety outcomes and mean age is complex. In this regard, the number of fatalities as well as the number of accidents per mile driven (by car) has a “hammock” shape, with very high accident numbers per kilometer traveled for people below 25 and above 80. Despite this, motorist accidents are rare below driving age. For pedestrian crashes, it seems that the “hammock” is shifted toward younger ages, and continuously worsens for all age groups above 30, and even more so when a person reaches 80 or 85. The same is true for cyclists; accident rates rise sharply after the age of 80, although the trend starts at about 70.

Regarding the special characteristics of each of the provinces, first consideration has been given to each provincial capital’s geographic location and atmospheric conditions using variables based on their Longitude and Latitude coordinates. The purpose of these variables is not only to capture the effect of each NUTS-3 province's location on road safety (for example, whether it is more of a coast-oriented area or not), but also to approximate for each province's climate conditions, given the difficulties for completing the panel data with more specific statistics for the entire sample. In this respect, the literature seems to point to climates with higher rainfall and less sunlight having harmful effects on accident likelihood and severity (Ivan et al., 2015).

Following other authors (Castillo-Manzano et al., 2013), the effects that having a more- or less-developed health network might have on inner urban accidents have been considered. For this, a variable has been included for provincial public hospital density per square kilometer.

Lastly, one of this article's most novel contributions lies in the inclusion of two dummy variables to analyze the specific effects that the sustainability and accessibility of the different provincial urban areas' mobility has on road safety. A dummy has been included to capture whether the cities in the Spanish provinces have Smart City status or not. Despite the ongoing debate as to what a Smart City is exactly, there does nevertheless seem to be some agreement as to the need for urban transportation to play a key role in the context of "Smart Health" (Buck and While, 2015; Solanas et al., 2014; Zubizarreta et al., 2015).

Very recent studies (Agarwarl et al., 2015; Medvedev et al., 2015) note that a transportation system based around the advantages of Artificial Intelligence and the so called "Internet of Things" could greatly improve sustainable urban mobility. To be more precise, authors such as Krishnan and Balasubramanian (2016) and Zhuhadar et al. (2017) have demonstrated that traffic flows and urban congestion would be optimized by integrating information and communication technologies in a Smart City. This would enable especially vulnerable users, such as pedestrians, to be detected on the street (Guayante et al., 2014), which would help to predict and reduce the number and severity of urban traffic accidents. Considering this evidence, a negative correlation should be expected in the model.

In other regards, a second dummy variable has been included to address the presence of a subway and/or urban rail system in each of the cities in order to capture the level of development and variety of the non-motorized urban public transit network. In relation to this, earlier studies (Kersys, 2015; Redman et al., 2013; Yannis et al., 2015) demonstrate an inverse relationship with traffic accidents, in the sense that (as is logical) private vehicles not only contribute to disrupting traffic in the city, but also present worse road safety levels than public transit.

Other relevant factors that could influence safety outcomes, such as road density, speed limits, road condition (paved and unpaved) or the type of roads (highway versus surfaced streets with more stop lights) cannot be included in the analysis as they are homogeneous in all Spanish NUTS-3 provinces (e.g., speed limits; unlike the case for the US, for example), or because, unfortunately, data are unavailable at a provincial level. This is a limitation of our work that must be recognized.

Table 2 gives the variables' descriptive statistics. As in the econometric analysis below, a distinction is made between the entire sample and a subsample of provinces with capital cities of over 200,000 inhabitants.

[PLEASE INSERT TABLE 2 NEAR HERE]

3. Results and discussion

Bearing in mind the nature of sample panel data, the binomial negative method is applied by estimating equation (1). In particular, the STATA xtgee command has been used assuming negative binomial distribution. The xtgee command estimates panel data models averaged by population. It should be mentioned in this respect that count data models and a negative binomial model are regularly used to analyze road safety determinants (e.g., Abdel-Aty and Radwan, 2000; Albalate et al., 2013; Chin and Quddus, 2003; Coruh et al., 2015; Johansson, 1996; Karlaftis and Tarko, 1998; Quddus, 2008).

Estimations can present problems of heteroscedasticity and temporal autocorrelation in the error term. Specifically, the Wooldridge and Breusch-Pagan/Cook-Weisberg tests are applied to test for any serial autocorrelation and heteroscedasticity problems, respectively. In other respects, standard errors robust to heteroscedasticity are used in the estimation and an AR (1) correlation is assumed in the error term.

The unit root test (Levin et al., 2002) is also applied. This can be understood as an augmented Dicky-Fuller test with included *lags*. This test indicates that neither of the two dependent variables presents a stationarity problem. The normality of the variables has also been tested with a Doornik-Hansen test and the results show that distribution is non-normal which supports the suitability of using a negative binomial method.

Table 3 gives the correlation matrix of the variables used in the analysis. Once more a distinction is made between the entire sample and a subsample of provinces with capitals of over 200,000 inhabitants. As can be observed, there are no markedly high correlations among the considered explanatory variables, which means that they are not affected by any multicollinearity problems. If any such problems did exist, they would distort the obtained estimations and even give rise to parameters of an unusually high magnitude.

Based on the values obtained in Table 3, negative correlation is detected for both explained variables (Accidents and Fatalities) for the average population age, the provincial capital's longitude coordinate, hospital density and private vehicle motorization rate; it is positive for the GDP per capita, population density and availability of a subway and/or urban rail network variables.

On the other hand, the latitude and Smart City status explanatory variables, and also those for the relative importance of the manufacturing and construction sectors for employment as a whole, have different signs depending on whether the endogenous variable is Fatalities or Accidents.

[PLEASE INSERT TABLE 3 NEAR HERE]

Tables 4 and 5 give the results for two estimated models that consider as alternative endogenous variables the number of fatalities per traffic accident and the number of traffic accidents recorded on urban roads in Spanish NUTS-3 provinces, respectively.

[PLEASE INSERT TABLES 4 AND 5 NEAR HERE]

Both Table 4 and Table 5 provide four model specifications. The first two, (1) and (2), give results using GDP per capita and GDP per capita squared as alternative explanatory variables and both consider the entire sample of 50 Spanish NUTS-3 provinces (600 observations). Columns (3) and (4) make the same distinction between the two GDP explanatory variables but disaggregate the sample by size of the provincial capitals; these can be regarded as large cities, i.e., with populations of over 200,000 inhabitants (subsample of 18 provincial capitals with 216 observations). This disaggregation enables the identification of any differential road safety behaviors in large cities.

Evidence was found of a nonlinear relationship between road mortality and level of economic activity, corroborating the results for intercity roads obtained by authors such as Bishai et al. (2006), Castillo-Manzano et al., (2014, 2015), and Kopits and Cropper (2005). In fact, the coefficient associated with provincial GDP per capita is positive and statistically significant both for the entire sample and for the distinction by size of the provincial capitals. However, the same variable squared is negative and statistically significant.

The variable for the private car motorization rate, defined as the number of passenger cars per capita, is positive but not clearly significant for either urban traffic accidents or urban traffic fatalities. For urban traffic fatalities, it is only statistically significant when we consider the entire sample and the GDP per capita squared is not included as explanatory variable. For urban traffic accidents, it is only statistically significant when we consider the larger provincial capital subsample.

To justify this it is important to take into account that the impact that this variable has on traffic safety can be contradictory, as previously explained (see Section 2). Moreover, it is also possible that any effect of the private car motorization rate is also being captured by the GDP per capita variables.

The population mean age variable is positive and significant for fatalities and negative and significant for accidents (although this result does not hold for traffic fatalities when we consider the larger provincial capital subsample). This shows that the older the mean age, the fewer the number of accidents, but also that the accidents are more severe. This result is consistent with Constantinou et al. (2011) and Langford et al. (2006), who support the idea that a population structure in which a young population predominates leads to a higher road accident rate, but that the consequences are more serious in the case of an older population. This is all justified by the fact that younger drivers present greater exposure to risk as a result of risk-taking behaviors, more driving errors and greater consumption of alcohol/drugs while driving, whereas older populations are usually more experienced, drive less and take greater precautions, but present certain physical shortcomings which cause them to be more vulnerable (Li et al., 2003). This means that despite being involved in fewer accidents, the impact of these is greater in terms of morbidity and mortality (Koppel et al., 2011).

Additional regressions have been run in this respect that consider the proportion of young population (population between 15 and 29 years) and the proportion of old population (population above 60 years old) as regressors instead of the mean age variable. Results of these additional regressions confirm that the younger population is related to more accidents but the older population is related to more fatalities. However, the decision was taken to retain the mean age variable as the explanatory variable in the regressions, as the statistical significance of the young and old variables is modest (or null) and distorts the statistical significance of some of the other explanatory variables.

The variable that measures the importance of manufacturing over total employment is negative in the regression for fatalities and positive for accidents. However, the statistical significance of the variable is modest or null in the traffic fatalities regressions. This gives an approximate explanation of the impact that a greater amount of inner city industrial activity has on traffic safety. In line with previous articles such as Castillo-Manzano et al. (2015, 2016), it can be stated that more intense heavy vehicle traffic linked to urban industrial activity contributes to a higher accident rate (due to the limitations that result from such vehicles circulating in urban areas); however, the consequent brake that they put on the speed of inner city traffic may result in a lower road mortality rate.

With respect to cities' geographical locations, it can be observed that the variable for Latitude is positive and significant in the estimates for accidents, while it is also positive and significant for fatalities although in this latter case this result only holds for the larger capitals subsample in the fatalities regressions. This result is in line with previous studies (Golob and Recker, 2003; Ivan et al., 2015; Jaroszweski and McNamara, 2014) and might indicate that urban traffic accidents are more frequent in cities in the north of Spain, where the climate is more adverse. However, in this context it is important to note that although bad weather can be predicted to lead to worse road safety, this does not mean that there are greater numbers of traffic accidents and fatalities in all northern areas in general. In fact, international experience shows that Northern European countries such as Sweden, Finland, the United Kingdom, Norway, etc. have been implementing optimal strategies and actions for many decades, as a result of which they are now considered world leaders in road safety, and models to imitate (see Castillo-Manzano et al., 2014).

With respect to the Longitude variable, a positive and significant coefficient has been obtained in the larger provincial capitals subsample regressions (both for fatalities and accidents), which indicates that there are more accidents and fatalities on urban roads in provinces in the east of the country. Geographically-speaking, the provinces in question coincide with the main tourist areas in Spain and, in some cases, in all Europe (specifically, in the case of the Mediterranean coastal provinces of Barcelona, Alicante and Valencia, and Majorca in the Balearic Islands); these are provinces with intense visitor traffic and a great deal of leisure and night life. Earlier literature has already shown that highly concentrated tourism can be associated with an increase in traffic accidents in these particular areas of Spain, although only some specific areas have been evaluated, such as the Balearics (see e.g., Rosselló and Saenz-de-Miera, 2011; Saenz-de-Miera and Rosselló, 2012).

As a consequence of this finding, testing for a possible correlation between tourist activity and urban accidents in all Spanish NUTS-3 provinces is a line of investigation that remains to be addressed in future research.

Results for the main explanatory variables that can be more related to levels of urbanization or urban development (population density, hospital density, Smart City status, subway and/or urban rail availability) suggest that the concentration of population and services in large cities can lead to greater road safety in net terms.

To be specific, in line with earlier studies such as Castillo-Manzano et al. (2013) and Clark and Cushing (2004), the sign of the hospital density per kilometer variable is negative, but it is only statistically significant for explaining urban road mortality in general for the entire sample. This suggests that when there are more hospitals available, there is a reduction in accident severity (due to a fall in the time for post-accident medical treatment to be administered, as A&E services are in closer proximity). However, as might be expected, the relationship is not as strong with the likelihood that an accident will occur. In the case of the larger provincial cities (provincial capitals) subsample, no statistical significance is detected because of limited variability among the provinces.

With respect to the population density variable, it can be observed in Tables 4 and 5 that a positive sign and statistical significance are obtained in accident regressions, and a negative sign in the case of road mortality. The prior literature can be used to explain this: it is logical that more people are actively mobile in very dense urban areas and, therefore, there is a greater risk of accidents; however, accidents are less severe due to greater inner city traffic congestion, which limits driving speeds (see, for example, Clark and Cushing, 2004; Ewing et al., 2003, 2016; Graham and Glaister, 2003; Sukhai and Jones, 2014; Yannis et al., 2015).

In other regards, the variable representing availability of a well-developed public transit system in the form of a subway and/or urban light rail system seems to reduce the number of fatalities in traffic accidents, although statistical significance is only obtained at 10% in one of the regressions for the larger provincial capitals subsample. The number of accidents also seems to be lower for larger cities with a more developed public transit system, although the variable is not statistically significant. These results corroborate what is suggested by other authors, such as Kersys (2015), Redman et al. (2013) and Yannis et al. (2015).

The variable that captures Smart City status can be observed to maintain a negative and generally significant correlation in the fatalities regression, while it is not significant in the accidents regression. This novel result can be explained by the fact that the development of a technology-based smart urban transit system can make a clear contribution to reducing the most serious consequences of urban traffic accidents, as has also been concluded by recent research by Agarwarl et al. (2015), Guayante et al. (2014); Krishnan and Balasubramanian (2016), Medvedev et al. (2015) and Zhuhadar et al. (2017). In other respects, the lack of significance of the reduction in the number of accidents can be explained by the fact that the concept of Smart City is, broadly-speaking, still in the embryonic stage in Spain.

In short, this article’s research results for urban road safety in Spanish provinces are in the same line as earlier studies that find that higher levels of urban development and greater concentrations of activities and population result in a lower urban road traffic accident rate. However, although the findings show that integrating road safety into a smart transportation system developed within the Smart City framework enables gains to be made in urban road mortality, it does not justify abandoning more traditional accident prevention strategies, such as those that are education- or traffic supervision or control-based (see Leden et al., 2014).

4. Concluding remarks.

The inexorable growth of urban mobility in developed countries in recent decades, underpinned by the intensive use of private motorized vehicles, has resulted in increased numbers of privately owned vehicles and their excessive usage for personal journeys. This has given rise to a variety of negative externalities that compromise their environmental, social and energy sustainability, with road accidents standing out.

In this context, this paper applies econometrics to determine the factors that explain differences in urban road safety in Spanish NUTS-3 provinces. For this, unprecedented panel data were compiled for the 2003-2013 period and a differently specified negative binomial model applied for the endogenous variables of traffic accidents and fatalities in urban areas.

Novel results have been obtained that cover a gap in the literature on this issue, mainly on the level of Spain. In particular, the findings reveal a positive correlation between the level of urban development (approximated by variables for economics, industrial activity, healthcare, more advanced urban transit systems, and smart network implementation to connect the city’s functional subsystems) and improvements to urban road safety. More specifically, it seems that in the case of cities in Spanish provinces, a wider urban spread inevitably leads to more severe traffic accidents, whereas road mortality is lower in urban areas with denser populations (thus more densely concentrated).

In view of the obtained estimations, a negative correlation is found between population density and road mortality. Consequently, it can be concluded that urban dispersion seems to be a risk factor for particularly severe urban traffic accidents. As journey volume and distance (and, therefore, driving speeds) are unavoidably higher in a more widespread urban environment, urban dispersion seems to be inversely related to road mortality, which makes its management and planning a question of public health.

For all the above reasons, it can be stated that population can be considered to be a sufficiently significant predictor of urban road mortality in the Spanish provinces. Following Litman (2015), publicly subsidized transport policies in large cities, with more sustainable means of transport can, on occasion, unintentionally give rise to a perverse effect in the form of excessive city expansion toward outlying metropolitan areas.

The results obtained in this article indicate that, from the perspective of road safety, it might be more sociably desirable to give incentives to promote urban concentration rather than the suburban model that has predominated in recent decades, with the urban development of dormitory towns attached to larger Spanish cities. At the same time, following Alper et al. (2015), the firm belief exists that sub-central level road safety management can also be an efficient means of creating a safer context for all urban traffic users, and for the most vulnerable users, especially.

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TABLES AND FIGURES

TABLE 1. Variables used in empirical analysis

Variables	**Description**	**Source**
Accidents	Number of traffic accidents recorded on urban roads in Spanish NUTS-3 provinces	Directorate General of Traffic (DGT)
Fatalities	Number of urban traffic accident fatalities within 30 days of the accident in Spanish NUTS-3 provinces	Directorate General of Traffic (DGT)
GDP per capita	Gross Domestic Product per capita in thousands of Euros at market prices in Spanish NUTS-3 provinces	Spanish Regional Accounts (National Statistical Institute, INE)
Age	Mean age of population in number of years in Spanish NUTS-3 provinces	National Statistical Institute (INE)
Longitude	Latitude in coordinates of provincial capital in decimal degrees	Google Maps
Latitude	Longitude in coordinates of provincial capital in decimal degrees	Google Maps
Population Density	Number of inhabitants per km^2 in Spanish NUTS-3 provinces	Eurostat for NUTS-3
Hospital Density	Number of public hospitals per km^2 in Spanish NUTS-3 provinces	Catalog of National Hospitals. Spanish Ministry of Health, Social Policy and

		Equality
D^{Smart_city}	Dummy variable (fictitious) that takes a value of 1 if the cities in each Spanish NUTS-3 region have Smart City status and 0 otherwise	Spanish Smart City Network (RECI)
D^{subway_rail}	Dummy variable (fictitious) that takes a value of 1 if the cities in each Spanish NUTS-3 region possess a subway and/or urban light rail system and 0 otherwise	Spanish Observatory of Metropolitan Mobility
Importance of manufacturing	Importance for employment of industrial sector manufacturing activity over total provincial employment in thousands of persons	Spanish Regional Accounts (National Statistical Institute, INE)
Importance of construction	Importance for employment of construction sector over total provincial employment in thousands of persons	Spanish Regional Accounts (National Statistical Institute, INE)
Motorization	Number of private cars per 1000 inhabitants in NUTS-3 provinces	Directorate General of Traffic (DGT)

TABLE 2. Variables descriptive statistics

Variables	**Mean**		**Standard Deviation**		**Minimum**		**Maximum**	
	Entire sample	**Provincial Capitals >200,000 inhabitants**	**Entire sample**	**Provincial Capitals >200,000 inhabitants**	**Entire sample**	**Provincial Capitals >200,000 inhabitants**	**Entire sample**	**Provincial Capitals >200,000 inhabitants**
Accidents	986.57	2156.12	2412.39	3712.61	5	25	14840	14480
Fatalities	12.72	22.82	18.87	27.81	0	0	149	149
GDP per capita	20.80	21.48	4.50	5.02	12.16	12.94	38.10	38.10
Age	42.15	40.99	2.77	2.21	36.29	36.29	49.44	46.9
Longitude	4.88	6.87	6.10	9.42	0.21	0.22	41.39	41.39
Latitude	39.91	38.66	3.14	4.24	28.27	28.27	43.75	43.21
Population density	134.41	264.58	175.00	223.51	8.9	51.1	806.4	806.4
Hospital density	6.21e-06	4.97e-06	2.67e-06	1.37e-06	2.45e-06	2.45e-06	0.000018	8.18e-06
D^{Smart_city}	0.16	0.20	0.36	0.40	0	0	1	1
D^{subway_rail}	0.18	0.5	0.38	0.50	0	0	1	1
Importance of manufacturing	0.24	0.23	0.08	0.10	0.09	0.09	0.51	0.51
Importance of construction	0.17	0.16	0.05	0.05	0.07	0.08	0.3	0.3
Motorization	666.12	647.23	70.47	67.98	492	503	957	864

TABLE 3a. Correlations matrix (Entire sample)

Variables	Fatalities	Accidents	GDP	Age	Longitude	Latitude	Pop_dens	Hospitals	Smart	Subway/Rail	Manufacturing	Construction	Motorization
Fatalities	1												
Accidents	0.86	1											
GDP per capita	0.23	0.30	1										
Age	-0.26	-0.20	0.06	1									
Longitude	-0.01	-0.06	-0.09	0.03	1								
Latitude	-0.001	0.02	0.42	0.60	-0.23	1							
Population density	0.66	0.72	0.33	-0.31	0.05	-0.27	1						
Hospital density	-0.35	-0.31	0.006	0.34	-0.13	0.19	-0.43	1					
D^{Smart_city}	-0.06	0.07	0.006	0.12	0.01	0.04	0.02	-0.01	1				
D^{subway_rail}	0.47	0.52	0.25	-0.22	0.001	-0.16	-0.31	-0.31	0.12	1			
Importance manufacturing	-0.001	0.009	0.55	0.23	-0.08	0.62	-0.08	0.14	0.001	-0.04	1		
Importance construction	0.05	-0.09	-0.27	-0.18	-0.02	-0.16	-0.13	-0.03	-0.51	-0.12	-0.32	1	
Motorization	-0.09	-0.06	0.23	0.14	-0.21	-0.03	-0.08	0.19	0.05	-0.02	-0.23	-0.03	1

TABLE 3b. Correlations matrix (Provincial Capitals >200,000 inhabitants)

Variables	Fatalities	Accidents	GDP	Age	Longitude	Latitude	Pop_dens	Hospitals	Smart	Subway/Rail	Manufacturing	Construction	Motorization
Fatalities	1												
Accidents	0.86	1											
GDP per capita	0.29	0.40	1										
Age	-0.15	-0.08	0.29	1									
Longitude	-0.14	-0.18	0.02	0.10	1								
Latitude	0.17	0.20	0.46	0.66	-0.18	1							
Population density	0.60	0.70	0.37	-0.21	-0.12	-0.21	1						
Hospital density	-0.49	-0.51	-0.14	0.17	0.09	0.17	-0.6	1					
D^{Smart_city}	-0.11	0.06	-0.02	0.24	-0.02	0.08	-0.0		1				
D^{subway_rail}	0.32	0.42	0.35	-0.06	-0.20	0.05	0.40	-0.39	0.12	1			
Importance manufacturing	0.06	0.08	0.55	-0.17	0.04	0.69	-0.20	0.20	0.01	0.05	1		
Importance construction	0.05	-0.12	-0.37	0.13	-0.07	-0.19	-0.09	-0.14	0.59	-0.19	-0.09	1	
Motorization	0.03	0.06	0.02	-0.39	-0.21	-0.40	0.18	-0.01	0.03	0.23	-0.58	0.13	1

TABLE 4. Estimation results (panel data model, mean population with negative binomial distribution)

	Endogenous variable: Number of urban traffic accident fatalities			
Independent Variables	**(1) Entire sample with GDP per capita squared as explanatory variable**	**(2) Entire sample without GDP per capita squared as explanatory variable**	**(3) Provincial Capitals >200,000 inhabitants with GDP per capita squared as explanatory variable**	**(4) Provincial Capitals >200,000 inhabitants without GDP per capita squared as explanatory variable**
GDP per capita	0.21 (0.06)***	0.03 (0.01)***	0.23 (0.11)**	-0.005 (0.02)
GDP per capita^2	-0.003 (0.0012)***	-	-0.004 (0.002)**	-
Age	0.03 (0.001)**	0.03 (0.001)**	-0.09 (0.02)***	-0.08 (0.02)***
Longitude	0.001 (0.003)	0.04 (0.004)	0.009 (0.004)**	0.01 (0.004)***
Latitude	0.01 (0.02)	0.01 (0.02)	0.05 (0.01)***	0.07 (0.01)***
Population density	-0.0005 (0.0002)**	-0.0004 (0.0002)*	0.0004 (0.0003)	0.0007 (0.0004)*
Hospital density	-49311.49 (12901.44)***	-49175.93 (13383.51)***	44912.9 (38109.73)	38499.83 (43882.75)
D^{Smart_city}	-0.24 (0.15)*	-0.24 (0.14)*	-0.61 (0.26)***	-0.69 (0.27)***
D^{subway_rail}	-0.07 (0.10)	-0.09 (0.10)	-0.21 (0.14)	-0.22 (0.13)*
Importance manufacturing	-0.84 (0.52)*	-0.63 (0.59)	1.23 (1.03)	1.44 (1.31)
Importance construction	-0.34 (1.08)	-0.21 (0.14)	2.99 (2.27)	2.69 (2.18)
Motorization	0.0008 (0.0005)	0.001 (0.0005)***	0.0006 (0.0011)	0.0017 (0.001)
Intercept	-16.09 (0.93)***	-14.75 (0.78)***	-13.03 (1.33)***	-12.17 (1.38)***
Year fixed effects	YES	YES	YES	YES
Wald test (joint sign.)	425.05***	448.55***	-	-
Breusch-Pagan/Cook-Weisberg test for heterogeneity (Ho: Constant variance)	1191.10***	1165.16***	128.25***	129.18***
Wooldridge test – autocorrelation (Ho: No first order autocorrelation)	8.75***	8.76***	6.90***	6.91***
ADF test – nonstationarity (Ho: nonstationarity)	-0.60***	-0.60***	-0.53***	-0.53***
Doornik-Hansen test for multivariate normality	12237.21***	10903.34***	1878.44***	1608.89***
No. Observations	600	600	216	216
No. Provinces	50	50	18	18

Note 1: standard errors in brackets, robust to heteroscedasticity and grouped by province. Regressions specify a within-group AR(1) correlation structure for panels. Population used as exposure variable.

Note 2: Statistical significance at 1% (***), 5% (**), 10% (*), respectively. STATA does not give the Wald test in the regressions for the subsample of most highly populated provincial capitals.

TABLE 5. Estimation results (panel data model, mean population with negative binomial distribution)

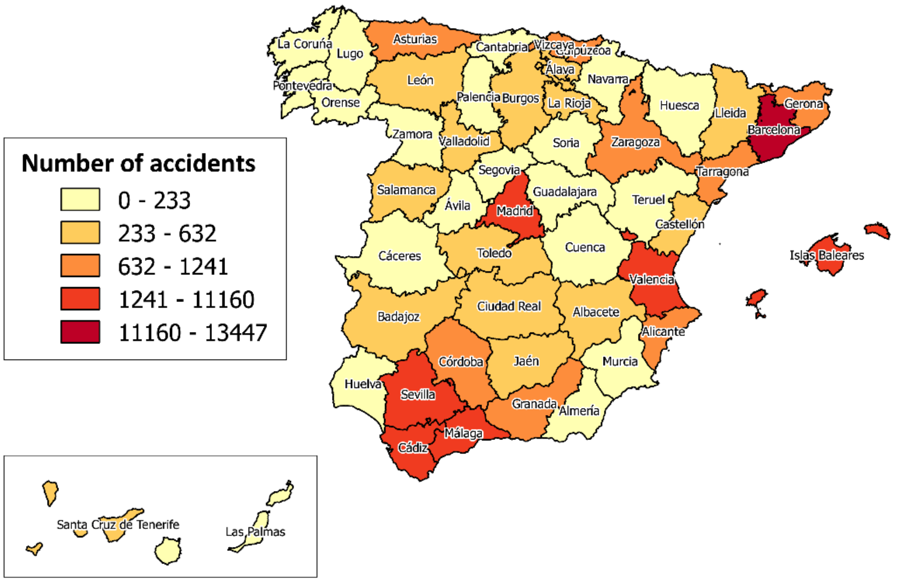
	Endogenous variable: Number of urban traffic accidents			
Independent Variables	**(1) Entire sample with GDP per capita squared as explanatory variable**	**(2) Entire sample without GDP per capita squared as explanatory variable**	**(3) Provincial Capitals >200,000 inhabitants with GDP per capita squared as explanatory variable**	**(4) Provincial Capitals >200,000 inhabitants without GDP per capita squared as explanatory variable**
GDP per capita	-0.018 (0.05)	-0.01 (0.02)	-0.12 (0.06)*	-0.001 (0.02)
GDP per capita^2	0.00016 (0.0009)	-	0.002 (0.001)**	-
Age	-0.007 (0.03)**	-0.07 (0.03)**	-0.16 (0.09)*	-0.15 (0.09)
Longitude	0.005 (0.007)	0.005 (0.006)	0.01 (0.004)***	0.01 (0.003)***
Latitude	0.06 (0.03)*	0.06 (0.03)*	0.12 (0.04)***	0.11 (0.03)***
Population density	0.0013 (0.0004)***	0.001 (0.0004)***	0.001 (0.0004)***	0.001 (0.0004)***
Hospital density	-15107 (12638.63)	-15248 (12605.72)	29066.86 (35490.57)	27829.07 (35362.14)
D$^{Smart\_city}$	0.09 (0.06)	0.09 (0.06)	0.15 (0.09)	0.14 (0.09)
D$^{subway\_rail}$	0.02 (0.01)	0.02 (0.1)	-0.14 (0.13)	-0.13 (0.15)
Importance manufacturing	1.83 (1.10)*	1.80 (1.06)*	3.56 (1.50)***	2.89 (1.33)**
Importance construction	-0.19 (1.54)	-0.20 (1.53)	1.45 (2.74)	1.02 (2.75)
Motorization	0.0003 (0.0009)	0.0003 (0.0009)	0.004 (0.001)***	0.003 (0.001)***
Intercept	-7.07 (1.47)***	-7.11 (1.45)***	-8.06 (3.99)**	-8.34 (3.92)**
Year fixed effects	YES	YES	YES	YES
Wald test (joint sign.)	198.25***	189.73***	-	-
Breusch-Pagan/Cook-Weisberg test for heterogeneity (Ho: Constant variance)	1369.67***	1359.94***	60.69***	66.13***
Wooldridge test – autocorrelation (Ho: No first order autocorrelation)	73.88***	79.43***	41.62***	45.03***
ADF test – nonstationarity (Ho: nonstationarity)	-0.55**	-0.55**	-0.52**	-0.52**
Doornik-Hansen test for multivariate normality	12861.74***	11553.73***	1808.81***	1549.32***
No. Observations	600	600	216	216
No. Provinces	50	50	18	18

Note 1: standard errors in brackets, robust to heteroscedasticity and grouped by province. Regressions specify a within-group AR(1) correlation structure for panels. Population used as exposure variable.

Note 2: Statistical significance at 1% (***), 5% (**), 10% (*), respectively. STATA does not give the Wald test in the regressions for the subsample of most highly populated provincial capitals.

FIGURES

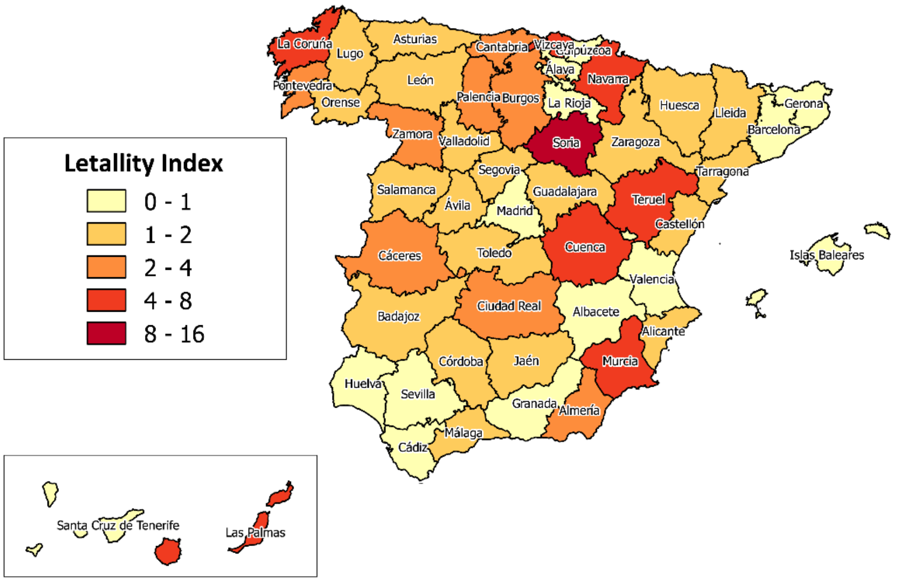
Figure 1. Number of traffic accidents for Spanish provinces



Source: Authors.

Figure 2. Lethality/severity index for Spanish provinces

(no. fatalities/no. accidents)



Source: Authors.