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The road against fatalities: Infrastructure spending vs. regulation??

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ABSTRACT

The road safety literature is typified by a high degree of compartmentalization between studies that focus on infrastructure and traffic conditions and those devoted to the evaluation of public policies and regulations. As a result, few studies adopt a unified empirical framework in their attempts at evaluating the road safety performance of public interventions, thus limiting our understanding of successful strategies in this regard. This paper considers both types of determinants in an analysis of a European country that has enjoyed considerable success in reducing road fatalities. After constructing a panel data set with road safety outcomes for all Spanish provinces between 1990 and 2009, we evaluate the role of the technical characteristics of infrastructure and recent infrastructure spending together with the main regulatory changes introduced. Our results show the importance of considering both types of determinants in a unified framework. Moreover, we highlight the importance of maintenance spending given its effectiveness in reducing fatalities and casualties in the current economic context of austerity that is having such a marked impact on investment efforts in Spain.

1. Introduction

The need to improve road safety is an increasingly important objective for transport authorities, above all in developed economies. In the European Union (EU), for example, road accidents constitute one of the three leading causes of death and hospital admissions, and are the main cause of death among those under the age of 50 (ETSC, 2003). In addition to the public health costs, estimates indicate that the economic costs of road accidents in the EU total 180 billion euros or 2% of GDP.[1] In Spain, FITSA (2008) estimate the total cost at 16,000 million euros, the value of each life lost being estimated at 858,000 euros. Worldwide, the WHO (2004) estimates road accident costs (including vehicle and other damage, health expenditure and wasted production) at 518 billion dollars.

Public authorities have been active in improving road safety outcomes by (1) providing new or better infrastructure (*infrastructure spending*) and (2) enforcing public measures (*regulation*). The literature examines both approaches to reducing fatalities but few studies focus on both sets of policies at the same time. Exceptions include Noland (2003), who examines their combined impact on the number of crash-related injuries and deaths in the US, and Albalate (2008) and Albalate and Bel (2012), who do the same for Europe, but with a specific focus on general road characteristics (% number of motorways, size of primary network, etc.). Others, including Mitra and Washington (2012), look at the problem of omitted variable bias in previous studies and introduce geometric and traffic information and a range of spatial factors including weather conditions, but they too ignore changes to road regulations.

Our first contribution here, therefore, is to employ a unified econometric model (building on Noland's, 2003, approach) for comparing the relative effectiveness of two groups of policy measures for reducing road casualties in Spain.[2] Investment in infrastructure is considered as government attempts to provide safer roads, while government regulatory programs include both general and specific traffic regulations aimed at improving safety outcomes.

Our second contribution is to compare the performance in terms of safety of spending on infrastructure construction and spending on infrastructure maintenance in Spain, at a time when the motorway network has been expanded and road maintenance investment has been downgraded because of budget constraints.

The rest of this article is organized as follows. Section 2 reviews studies on road safety distinguishing between those that examine the role played by infrastructure and spending and those that evaluate the impact of traffic regulations. Section 3 describes the main

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[1] European Commission. Socio-economic costs and the value of prevention. Available at: http://ec.europa.eu/transport/road_safety/specialist/knowledge/postimpact/the_problem_road_traffic_injury_consequences/socio_economic_costs_and_the_value_of_prevention.htm (Retrieved 01.02.13).

[2] Casualties include both fatal and non-fatal injuries (*Ministerio del Interior, Dirección General de Tráfico*).

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characteristics of road safety in Spain, the country in which we test our hypothesis. The empirical model is explained in Section 4 and we provide our main results in Section 5. Finally, in Section 6 we present our main conclusions.

2. Literature review

The increase in the literature on road safety, in fields as diverse as transportation, economics, public policy and health, is indicative of a growing awareness among academics, practitioners and policy makers of the economic implications of road accidents and the threat they pose to public health.

Two main approaches have been adopted to the study of road safety: First, analyses have been undertaken of the characteristics of the infrastructure (including, investment levels; physical properties such as road curves, width and type of paving; and the number of intersections and junctions) and of traffic conditions (including, congestion levels and vehicle mix). Such studies employ field data for given road sections and count-data regression models to estimate the impact of infrastructure variables on fatality and injury counts. Second, analyses have been undertaken of the impact of the introduction and enforcement of regulatory measures. This line of literature (including analyses of the effectiveness of speed limit modifications, mandatory seat-belt laws, blood alcohol limits, periodic vehicle inspection tests and the use of in-vehicle safety devices) is more closely concerned with behavioral attitudes and exposure to risk. Such studies employ time series and cross-sectional time series analyses with aggregate data and use pooled (OLS) fixed effects estimates or fixed effects negative binomial regression models.

Surprisingly, the two lines of literature have largely ignored each other. Thus, a study adhering to the first line can fail to consider regulatory variables and legislative changes even when employing a cross-sectional time series (i.e., different jurisdictions monitored over a given time period) and another adhering to the second line can overlook the role played by infrastructure in road safety outcomes, thus biasing its estimates.

Given the apparent relevance of both groups of factors, we seek here to build a model that considers both infrastructure/traffic conditions and regulatory interventions as determinants of road safety outcomes. The following literature review serves to emphasize how the two lines have tended to ignore each other and as a result have told only one side of the story.

2.1. Infrastructure characteristics and traffic conditions

Studies of the impact of infrastructure and traffic conditions on safety outcomes are critically dependent on the particular case under study and the specific variables taken into account. So, while findings are mixed, most point to the importance of improved infrastructure. For example, better quality roads, captured by road type, the number of traffic lanes, pavement, and the median shoulder and lane widths (Abdel-Aty and Essam Radwan, 2000; Flahaut, 2004; Noland, 2003; Noland and Oh, 2004; Anastasopoulos et al., 2008; Park et al., 2012) have a beneficial impact. However, other studies (see, for example, Noland, 2003) cite the Peltzman (1975) compensating effect, and show that these factors have just the opposite impact, increasing the risks drivers take. This effect is most apparent when increasing the number of lanes, but it is not so consistently reported when other infrastructure characteristics are enhanced (see, for example, Vitalino and Held, 1991; Milton and Mannering, 1998; Martin, 2002). The number and type of curves, additional turning lanes, the number of intersections and junctions, and better signals are reported to have a significant impact on road safety outcomes (Feber et al., 2003; Meuleners et al., 2008).

Most studies examining traffic flows conclude that traffic conditions and vehicle mix are critical determinants of accidents (Vitalino and Held, 1991; Dickerson et al., 1998; Haynes et al., 2008). Congestion is usually associated with a reduction in road fatalities (Albalate and Fernández-Villadangos, 2010); yet, some studies show that while it might reduce mortalities, the number of non-severe road accidents can be increased (Noland and Quddus, 2005). As for vehicle mix, higher numbers of motorcycles, trucks, sport utility vehicles and vans tend to increase the frequency of fatal crashes, while higher numbers of cars and buses reduce their occurrence (Tay, 2003). In Appendix A we summarize studies (since 2000) in this line of the literature and highlight the specific variables examined.

2.2. Regulations and their enforcement

One of the most influential studies of the impact of regulatory measures and behavioral responses to them is Peltzman's (1975) seminal work which shows how vehicle regulations may have an inverse effect (referred to as 'offsetting behavior' or the Peltzman compensating effect) on final safety outcomes.[3] As such, risky behavior must be at the baseline of any regulatory policy to fight road accidents, since infrastructure improvements or better performance of in-vehicle safety devices are not sufficient to alleviate the problem. The willingness to comply with the law is an essential element for ensuring policy effectiveness (Vereek and Vrolix, 2007).

Many papers evaluating regulatory measures examine policies restricting speed limits and their enforcement. Results are mixed but the consensus appears to be that what is important is not the average speed enforced, but the variation in traffic speed achieved. Speed limits appear to effect both, but the extent of their impact is unclear. See, for example, Lave (1985), Garber and Graham (1990), Lave and Elias (1994), McCarthy (1994, 2005) and Dee and Sela (2003). The effectiveness of mandatory seat belt devices also depends on enforcement. Loeb (1995, 2001) and Cohen and Einav (2003) report significant impacts on road safety, but Derrig et al. (2002), Garbacz (1991), Harvey and Durbin (1986) found little evidence of their effectiveness. Changes to the minimum legal drinking age have been reported as being effective in reducing fatalities among the young. See, for example, Cook and Tauchen (1984), Asch and Levy (1990), Du Mouchel et al. (1987) and Saffer and Grossman (1987). More recently, Carpenter and Stehr (2008) have reiterated the impact of such measures. Dee (2001), Eisenberg (2003), Kaplan and Prato (2007) and Albalate (2008), among others, show that enacting and lowering legal limits of blood alcohol content (BAC) combined with demerit point systems can have an effective impact on road safety outcomes. However, the impact does not seem to be immediate and can vary among different groups of drivers.

Tay (2005) shows the effectiveness of anti drink-driving enforcement and awareness campaigns when activated independently; yet finds their interactive effect to be anti-complementary. Tay (2009, 2010), in line with Harrison and Pronk (1998) and Zaal (1994), also tests anti-speed enforcement and finds a significant impact on safety outcomes. Guria (1999) finds that investment in safety programs (e.g., enforcement and advertising campaigns against drink-driving, speeding or seat belt wearing) produces high incremental returns. Finally, Delaney et al. (2006) find that existing drink-driving enforcement efforts have successfully contributed to reductions in casualty crashes at all severity levels.

Studies of various measures reveal a different impact depending on the driving population under examination. This is the case

[3] See Peterson et al. (1995) for an excellent example of this type of study for air-bag equipped cars, and Sen (2001) for the case of mandatory seat belts.

Table 1
Comparison of fatality rates per million inhabitants across European Countries 1991 and 2010.

Country	Fatality rate 1991	Country	Fatality rate 2010	Country	% Change in fatality rate
Portugal	323	Greece	111	Spain	−76.21
Spain	227	Portugal	79	Portugal	−75.54
Luxembourg	216	Belgium	75	Luxembourg	−70.37
Greece	207	Italy	68	Germany	−68.30
Austria	201	Austria	66	Sweden	−67.81
Belgium	188	Luxembourg	64	Austria	−67.16
France	184	France	62	France	−66.30
Median	153	Median	56	Ireland	−62.69
Italy	143	Spain	54	United Kingdom	−62.65
Germany	142	Finland	51	Netherlands	−62.35
Ireland	126	Ireland	47	Denmark	−61.01
Finland	126	Denmark	46	Belgium	−60.10
Denmark	118	Germany	45	Finland	−59.52
Sweden	87	Netherlands	32	Italy	−52.44
Netherlands	85	United Kingdom	31	Greece	−46.37
United Kingdom	83	Sweden	28		

Source: CARE (Community Road Accident Database). European Commission/Directorate General Energy and Transport (EC/DGET) (2012).

for speed limit regulation (Dee and Sela, 2003), mandatory seat belt laws (Carpenter and Stehr, 2008) and changes to BAC levels (Albalate, 2008).

Recent studies of the impact of driving licenses based on demerit points systems, including Castillo-Manzano et al. (2010) and Castillo-Manzano and Castro-Nuño (2012), report strong initial positive impacts that then quickly fade, thus highlighting the limitations of such strategies.

In Appendix B we summarize studies (since 2000) in this line of the literature and highlight the variables examined.

3. Road safety in Spain

3.1. Spanish road safety outcomes

Table 1 illustrates Spain's success in reducing the number of fatalities on its roads, recording the most marked improvement among its EU counterparts between 1991 and 2010. Fig. 1, however, shows that this improvement has not been linear, with episodes of stagnation and fluctuation in the number of fatalities, and an increase in the number of casualties during the second half of the 90s. Interestingly, the achievement of a lower fatality rate has not been accompanied by a similar fall in the number of accidents and overall casualties.

Table 2 shows significant variation in road safety outcomes at the provincial level. Thus, while some provinces, including Ourense, Álava and Murcia, report reductions of more than 60% in the number of injury crashes between 1996 and 2010, others, such as Cadiz, Cáceres and Girona, present increases of over 40% for the same period. This variation should facilitate our study of the factors that contribute to safety outcomes.

3.2. Infrastructure and investment

While Spain's road network has only grown by 6.15% of road – km in the 20 years between 1990 and 2010 (growing from 156,172 km to 165,787 km), the existing infrastructure has been improved greatly. Successive Spanish governments have increased the proportion of motorways (having almost tripled from 3.8% in 1990 to 9.63% in 2010) and reduced the share of roads under 7 m in width (falling from 77.7% to 61.57% during the same period) in the total road network (see Table 3). By contrast roads with a width greater than 7 m have increased their share in the total network from 18.9% to 38.43% over this twenty year period. If we assume wider roads to be of better quality, then we can expect these improvements to have a significant positive impact on road safety.

The extension of the motorway network and the improvements to the other road types reflect an increase in investment efforts.

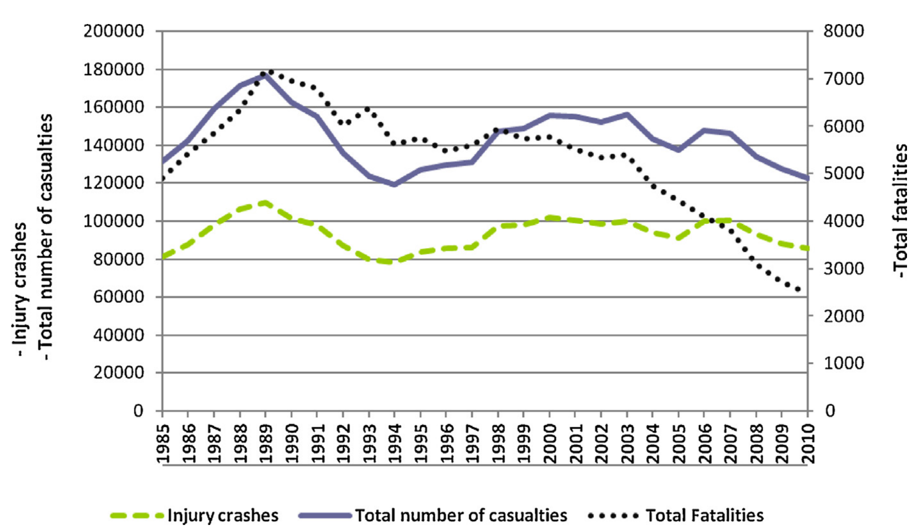

Fig. 1. Trends in road safety outcomes in Spain (1985–2010).

Table 2
Road safety trends in the Spanish Provinces (1996–2010).

Provinces[a]	% Change in injury crashes 1996–2010	% Change in total casualties 1996–2010	Provinces[a]	% Change in injury crashes 1996–2010	% Change in total casualties 1996–2010
Álava	−62	−59	La Rioja	−1	−11
Albacete	−37	−47	Lugo	−58	−62
Alicante	−19	−23	Madrid	39	34
Almería	−10	−9	Málaga	−1	−9
Ávila	34	8	Murcia	−61	−58
Badajoz	7	−6	Navarra	−10	−23
Illes Balears	−23	−26	Ourense	−63	−66
Barcelona	13	16	Asturias	−10	−10
Burgos	−30	−40	Palencia	−29	−31
Cáceres	59	31	Palmas, las	−56	−54
Cádiz	61	71	Pontevedra	−5	−6
Castellón	−30	−39	Salamanca	−3	−9
Ciudad Real	−18	−23	S.C. Tenerife	−7	−15
Córdoba	−29	−29	Cantabria	−20	−20
A Coruña	−46	−51	Segovia	−31	−37
Cuenca	−20	−35	Sevilla	18	12
Girona	42	24	Soria	−12	−14
Granada	−7	−8	Tarragona	25	13
Guadalajara	−10	−25	Teruel	3	1
Guipúzcoa	−1	−11	Toledo	5	−13
Huelva	−13	−17	Valencia	−8	−13
Huesca	−9	−12	Valladolid	−59	−61
Jaén	−14	−23	Vizcaya	27	103
León	−32	−37	Zamora	−53	−58
Lleida	41	19	Zaragoza	0	−7

Source: Based on data provided by the Spanish Traffic General Directorate.
[a] The autonomous cities of Ceuta and Melilla are excluded.

Table 3
Spanish road network and road type shares over total network (1990–2010).

Year	Total network (km)	Motorways[a] (% over total network)	Other roads[b] (% over total network)	Other roads[b] less than 7 m width (% over total network)	Other roads[b] more than 7 m width (% over total network)
1990	156,172	3.28	96.72	77.77	18.95
1991	156,974	3.70	96.30	74.85	21.46
1992	158,324	4.41	95.59	72.18	23.40
1993	159,630	4.64	95.36	70.36	25.01
1994	162,196	4.78	95.22	70.13	25.09
1995	162,617	5.00	95.00	68.43	26.57
1996	162,100	5.24	94.76	67.31	27.44
1997	162,795	5.57	94.43	65.66	28.77
1998	163,273	5.91	94.09	64.93	29.16
1999	163,769	6.29	93.71	63.29	30.42
2000	163,557	6.38	93.62	62.42	31.19
2001	163,799	6.81	93.19	63.02	30.17
2002	164,139	6.95	93.05	62.55	30.50
2003	164,584	7.30	92.70	61.68	31.02
2004	165,152	7.53	92.47	60.50	31.96
2005	165,646	7.94	92.06	59.25	32.81
2006	166,339	8.34	91.66	58.54	33.12
2007	166,011	8.85	91.15	56.97	34.18
2008	165,011	9.16	90.84	64.34	35.66
2009	165,463	9.44	90.56	63.65	36.35
2010	165,787	9.63	90.37	61.57	38.43

Source: Based on data provided by the Spanish Ministry of Transport.
[a] Motorways include tolled motorways, free motorways and dual carriageways.
[b] All other roads excluding motorways and dual carriageways.

Table 4 shows the growth and distribution of investments (both construction and maintenance) made by the public administration and motorway companies for the period 1990–2010. Roughly three-quarters of total public investments have been devoted to network construction (which also includes building better accesses, wider lanes and new connections). Public investment in maintenance has also increased in percentage terms, but these levels are indicative of the greater efforts needed to improve and maintain a mature consolidated network. Motorway company (privately owned in the main) investments have increased markedly between 2000 and 2006 reflecting the new concessions awarded by the Spanish government to build and operate greenfield projects for toll motorways.[4]

[4] A greenfield project is free of any constraints imposed by previous work, so construction can take place without having to remodel or demolish existing structures. Here, this represents a new road or an extension of a currently operating network. A brownfield project, by contrast, involves investment and construction work on existing roads and networks, generally to improve quality.

Table 4
Distribution of investments by type in the Spanish road network (1990–2010).

Year	Total investments[a] (million euro)	Construction[a] (million euro)	Construction[a] (% over total investments)	Maintenance[a] (million euro)	Maintenance[a] (% over total investments)	Motorway company investments (million euro)
1990	3.515	2.847	81	668	19	–
1992	3.935	3.224	82	711	18	–
1994	4.519	3.651	81	868	19	–
1996	3.831	2.954	77	877	23	–
1998	4.734	3.335	70	1.039	30	–
2000	2.278	1.773	78	505	22	262
2002	5.523	4.104	74	1.419	26	1.232
2004	5.649	4.052	72	1.597	28	1.520
2006	3.375	2.528	75	846	25	1.304
2007	7.257	5.096	70	2.160	30	524
2008	7.564	5.020	66	2.544	34	474
2009	7.477	5.089	68	2.388	32	894
2010	6.318	3.873	61	2.446	39	484

Source: Based on data provided by the Spanish Ministry of Transport.
[a] Only investments made by the public administration. Data on the distribution of investments by Motorway companies are not always available.

3.3. Road safety regulations

The fall in road fatalities described above might also be attributed to regulatory interventions. Until 1992, Spanish traffic was regulated by a traffic code drafted and enacted by the Second Spanish Republic in 1934. Yet the growth in traffic volume in the intervening years and its incidence on mortality rates convinced new democratic governments to overhaul the code and to adapt Spanish legislation to modern times. Thus, Law 18/1989 was passed, laying the foundations for Royal Decree 339/1990 on traffic regulation and the eventual traffic rules established by Royal Decree 17/1992.

These regulations remained unchanged for almost 15 years, but a new campaign to promote road safety by increasing driver awareness, targeting above all traffic offenders, led to a major reform of traffic rules in 2005. Law 17/2005 introduced a 'demerit points license', in force now since mid-2006[5] and Law 15/2007 made significant amendments to the penal code to increase sanctions on traffic offenders.

Other specific interventions have been made over the last three decades: compulsory vehicle inspection tests were introduced in 1985 (Royal Decree 2344/1985 specified the type and frequency of inspections) and reformed in 1994 (Royal Decree 2042/1994 brought regulations into line with stricter EU controls); and, a subsidized fleet renewal program (RENOVE) was introduced in 1994 and extended in 1997 to include commercial vehicles and motorcycles (today, the VIVE program, 2008, continues to encourage the withdrawal of old, polluting vehicles from Spain's roads).

Other regulatory measures are designed to impact drivers' behavior. The BAC limit was lowered in 1999 to 0.5 mg/ml from the previous level of 0.8 mg/ml, in line with EU recommendations ("Promotion of Road Safety in the European Union 1997–2001").[6] In 2006, in adherence with the European Road Safety Action Plan 2003–2010, seat-belt use was enforced in rear vehicle seats. And in 2004 the Spanish authorities adhered to European Directive 91/439/EEC, which aimed at promoting mobility in large cities by allowing holders of car driving licenses to ride small motorcycles.[7]

Table 5 summarizes the main policies and programs of intervention promoted by Spanish or European authorities.

4. Methods and data

Here we apply an empirical strategy involving the construction of an econometric model that includes both investment in road infrastructure and new traffic regulations in Spain. To determine the omitted variable bias incurred, we first estimate models without the regulatory measures and, subsequently, full models with all relevant variables.

Based on information from the Spanish Ministry of Transport, we construct a panel data model explaining road safety outcomes across provinces and over time. The panel includes fifty provinces monitored between 1990 and 2010 (1050 observations).[8] The model contains variables that capture specific features of the infrastructure and spending on construction and maintenance, as well as of traffic rules and other controls. To test the importance of these two groups of determinants on road safety we employ the fixed effects negative binomial model (Hausman et al., 1984). This count-data method provides a good fit for the generation of traffic-related fatalities (Karlaftis and Tarko, 1998; Lord and Mannering, 2010), accounting for heterogeneity and allowing for an offset (exposure) variable, in our case the number of vehicles in each province.[9] Our dependent variables are annual death counts (in a 30-day period following the crash) and road accident casualties, which include injuries and fatalities.

We opt for the fixed effects as opposed to the random effects model because the Hausman specification test rejects the null hypothesis of no systematic differences in the coefficients (Chi-square = 60.52; p-value = 0.000). The model takes the following form:

$$Y_{it} = \mu_i + \beta X_{it} + \delta I_{it} + \rho R_{it} + s_i + \varepsilon_{it} \quad (1)$$

where Y_{it} is the number of fatalities or casualties in province i in year t. The two variables provide important dimensions of road safety: *fatalities* captures the severity of accidents by considering

[5] Based on a penalty points system, severe infractions result in a specific number of points being deducted from the offender's license. In Spain, drivers begin with 15 points, unless they are novice drivers, who are awarded just eight. If drivers lose points they can take courses to recover some; however, if they lose them all, they must wait six months to take a training course and a driving test enabling them to recover eight points.

[6] COM(97)131, Commission of the European Communities (1997).

[7] Holders of car driving licenses with more than three years' experience were allowed to ride motorcycles up to 125 cm^3. The measure led to a dramatic rise in the number of registered motorbikes, while the number of accidents also experienced a significant upturn.

[8] The autonomous cities of Ceuta and Melilla on the North Africa coast are excluded.

[9] While it would be better to use distance traveled or average daily traffic data, these variables are not available at the province level and for the whole period. The best proxy available to us is population or vehicles per province.

Table 5
Chronology of regulatory measures introduced in Spain.

Measure	Year	Description
ITV (first enforcement)	1985	First regulation of technical vehicle inspections
Traffic Law/General Traffic Rules	1990/1992	First law regulating traffic and road safety
ITV (second enforcement)	1994	Second regulation of technical vehicle inspections
RENOVE program	1994	Grants promoting fleet renewal
European Program of Road Safety Promotion (1997–2001)	1997	Joint program recommending measures and policies to reduce road fatalities
PREVER program	1997	Grants promoting fleet renewal
BAC (reduction)	1999	Blood alcohol content limit reduced to 0.5 mg/ml
European Road Safety Action Plan 2003–2010	2003	Joint program recommending measures and policies to reduce road fatalities
Motorbike License	2004	Experienced car drivers allowed to drive motorbikes
Seat-Belt	2006	Mandatory seat-belt law in all seats and vehicles
New Traffic Law	2006	Reform of the earlier traffic law (penalty points system)
Penal Sanctions	2007	Penal sanctions for road safety regulation offenders
VIVE program	2008	Grants promoting fleet renewal

the number of deaths; *casualties* treats road safety as a broader, more general concern by including all injuries and fatalities.

As determinants of road safety we consider X_{it}, which contains a vector of time-varying variables, I_{it} is a vector of the infrastructure and investment variables and R_{it} a vector of traffic regulations. The fixed effects property is provided by s_i, which denotes a province-specific fixed effect that controls for time-invariant, province-specific omitted variables. The time trend controls for time patterns affecting safety outcomes, and captures the effect of improved technology and the increasing safety concerns of the public. ε_{it} is the error term. Parameters are estimated by maximum likelihood estimation and the offset term used (number of vehicles per province) accounts for the exposure variable constraining the coefficient of the number of vehicles to 1.[10]

Dependent variables can also be constructed by distinguishing between urban and non-urban areas. As most infrastructure characteristics and investments are associated with non-urban environments (given that most of the spending is the responsibility of supramunicipal governments in charge of interurban roads), here we focus on interurban road safety, although we provide aggregate results for total fatalities.

Data for the regressors are drawn from different sources: infrastructure and spending variables are obtained from the *Spanish Ministry of Transport*. The variables include infrastructure spending (distinguishing between construction and maintenance) made over the last two years per 100,000 inhabitants, the proportion of the province's road network made up of motorways and the percentage share of the rest of roads according to their width. We are aware that using a two-year lag for accumulated investments can be considered arbitrary. However, the results do not change when considering a longer lag and in this way we minimize the loss of observations in the sample. The data for demographic characteristics and motorization are provided by the *Spanish National Institute of Statistics* (INE) and the *General Traffic Directorate* (DGT), respectively.

Finally, traffic-related laws and regulations are considered in the year in which they were enacted. However, given the significant number of measures adopted in Spain (see Table 5), we opt to evaluate those promoted under the European Road Safety Programs (1997–2001, 2003–2010) and the main legislative changes in Spain resulting from the enactment of the General Traffic Rules (1992), the introduction of vehicle renewal and inspection programs (1994, 1997), and the new Traffic and Seat-Belt laws (2006), as single sets of measures instead of introducing dummy variables for each specific regulation. Definitions of our dependent and independent variables are shown in Table 6.

5. Results

Columns (1) and (2) (Table 7) show our results when the dependent variable is the number of fatalities without and with the regulatory variables, respectively. For comparative purposes, column (3) shows the same results without the trend variable. The regressions in (1) and (2) are repeated with non-urban fatalities in columns (4) and (5). Finally, columns (6) and (7) show our results for regressions that consider non-urban casualties (non-fatal and fatal injuries combined) and not only fatalities. In most instances, these results are consistent, with the coefficients being statistically significant in the restricted models for fatalities. Some differences are found in the case of casualties, which is illustrative of the distinct features in their production.

The impact of road maintenance investment on total fatalities is statistically significant, the effect remaining consistent across models. The sign of this coefficient indicates that spending in maintenance is effective in reducing both fatalities and casualties, a result that remains valid with the inclusion of regulatory variables in (2), (5) and (7), although the magnitude of the coefficient falls in (2) and (5). This seems to indicate that the omission of regulatory variables overestimates the impact of maintenance spending. Indeed, the magnitude of the coefficient is more than twice that of the restricted model on fatality counts (0.6038 in (1) vs. 0.2537 in (2) with the inclusion of regulatory regressors). These coefficients are larger for casualties than for fatalities.

By contrast, the impact of road construction spending on road fatalities is only statistically significant when we do not control for the other regulatory variables. The omission of these variables would lead to the erroneous conclusion that both maintenance and construction spending reduce fatalities. While new construction is expected to result in better infrastructure, it also increases road supply and, as a consequence, induces higher demand.[11] Additionally, the Peltzman effect would suggest that better infrastructure leads to higher speeds and greater risk-taking, given the confidence engendered by the quality of the infrastructure. On the basis of our findings, this demand-enhancing policy would appear to have led to greater peril on the roads, thus offsetting the gains of better new infrastructure.

The role of road widths is also taken into account in our models. Disaggregating the results by width of infrastructure, we find

[10] Results without this offset term, but with the number of vehicles included as a regressor in the main equation, do not vary. Indeed, even if we exclude the number of vehicles our main results for infrastructure spending remain statistically significant with the same sign, albeit that the coefficient associated with past spending in maintenance is lower.

[11] Winston and Langer (2006) show that capacity enlargements are not a long-term solution to the congestion problem, since increased capacity results in higher demand.

Table 6
Definition and descriptive statistics of variables employed.

Variables	Definition
Dependent variables	
Fatalities	Number of deaths in road accidents (in a 30-day period following the crash)
Casualties	Number of both fatal and non-fatal injuries in road accidents
Spending variables	
Past inv. construction	Million euro invested per 1000 inhabitants in the construction of new road network during the previous two years
Past inv. maintenance	Million euro invested per 1000 inhabitants in the maintenance of the existing road network during the previous two years
Infrastructure variables	
% Motorways	Percentage of motorways over the total road network in the province
% 5–7 m	Percentage of roads wider than 7 m and narrower than 7 m over the total network in the province
% >7 m	Percentage of roads wider than 7 m over the total network in the province
Regulatory variables	
General Traffic Rules	Binary variable taking value 1 after the enactment of the General Traffic Rules in 1992 and 0 in the years prior to that.
Vehicle Renewal	Categorical variable taking value 1 when grants for fleet renewal are in place for passenger cars (1994), 2 if in addition there exists a program of subsidies promoting commercial and motorcycle vehicle renewal (1997), and 0 otherwise.
European Program 97	Binary variable taking value 1 when the First European Program of Road Safety Promotion (1997) is enacted, and 0 otherwise.
European Program 03	Binary variable taking value 1 when the European Road Safety Action Plan 2003–2010 is in place (2003), 0 for previous years.
New Traffic Law and Seat Belt Law 06	Binary variable taking value 1 when penalty points system and penal sanctions for traffic offenders are enacted (2006) and 0 otherwise.
Other Control variables	
Motorization	Number of vehicles per 1000 inhabitants
Unemployment rate	Share of population unemployed in the province
Elderly	Share of population in the province older than 65 years of age
Doctors	Number of medical doctors per capita in the province

that the impact of there being a greater proportion of narrow single roadway roads (5–7 m) in the total road network is a reduction in the number of fatalities, although this effect disappears without the trend variable. The number of casualties, however, appears consistently unaffected. These narrow roads, in the main urban thoroughfares, are unlikely to carry heavy traffic at high speed and so the risk of accidents and the severity of accidents are low. In non-urban areas, wide two-lane roads tend to be open roads on which traffic speeds are higher as is the risk of crashes involving severe injuries, which may well offset the gains of having wider roads. This would account, therefore, for the non-significant coefficients in all models associated with motorways and roads with a width greater than 7 m. While we expected the widening of roads and the improvement to access roads to improve road safety outcomes, our results fail to confirm these hypotheses. The difference between motorways and conventional roads is greater than that between narrow (5–7 m) and wide (>7 m) roads, which actually may not always be of better quality than the narrow roads. The main difference between them is that 5–7 m roads are always single roadways without separation of carriageways in opposite directions and >7 m might include dual carriageways. In fact, roads less than 7 m wide are also likely to be two-lane roads.

Among the second group of variables (traffic regulations), we find evidence of the influence of the most recent changes in regulations in Spain; but, not all impacts are in the expected direction. First, the New Traffic Law and the new Seat Belt Law, introduced in 2006, present statistically significant negative coefficients for fatalities and casualties, and the European Road Safety Program, 2003–2010, is also statistically effective. These measures significantly reduced the number of fatalities and casualties, demonstrating the importance of such measures as the penalty points system (together with the implementation of penal sanctions for traffic offenders). Surprisingly, the European Program of Road Safety Promotion (1997–2001) gave opposite results. The fact that we used the aggregate program as opposed to individual regulations might mean that they could offset each other. As such, including each variable independently rather than an aggregate dummy variable could drive this result by raising collinearity. This could be interpreted as a limitation to our empirical strategy. However, we evaluated multicollinearity in our models by checking variance inflation factors. They do not indicate significant problems of multicollinearity.[12]

Contrary to expectations, the national programs promoting vehicle renewals are found to be statistically significant and positively correlated with the number of fatalities and casualties. This result, together with that for technical inspections (compulsory since 1994), may well reflect the Peltzman effect, whereby the perception of better safety standards is linked to the taking of greater risks.

Among the control variables, most display significant statistical relationships with the dependent variables and present the expected sign. Only the role of the elderly control variable changes with the introduction of regulatory measures in all models, where the variable actually presents the expected negative sign given that those over 65 years of age tend to be involved in fewer crashes.[13] The risk exposure variable, the degree of motorization, increases the number of fatalities but decreases the number of casualties, whereas the unemployment rate has a marked impact on fatalities and casualties, with those provinces suffering greatest unemployment tending to have lower numbers of both. This result also points to the pro-cyclical nature of road accidents with increased economic activity resulting in a greater exposure to risk due to a higher rate of journeys per person and vehicle. Finally, the number of doctors per capita, which serves as a proxy of the quality of healthcare, presents a negative and significant correlation with

[12] The mean VIF values for the models without regulatory models is 2.48. The introduction of regulatory variables only increases this figure slightly to 3.28. Both values being below 10, which is a standard rule of thumb. No individual VIFs provide values larger than 10.

[13] This flipping sign does not correspond to large pair correlations between elderly and regulatory variables. The largest pair correlation is 0.28. The omission of the elderly variable does not significantly affect the rest of coefficients but is reduces the fit of the model.

Table 7
Negative Binomial estimates for fatality and casualty counts.

Regressors	NB fixed effects fatalities (1)	NB fixed effects fatalities (2)	NB fixed effects fatalities (3)	NB fixed effects non-urban fatalities (4)	NB fixed effects non-urban fatalities (5)	NB fixed effects non-urban casualties (6)	NB fixed effects non-urban casualties (7)
Investment variables							
Past inv. maintenance	−0.6038 (−4.44)***	−0.2537 (−1.96)**	−0.5125 (−3.80)***	−0.7042 (−4.95)***	−0.3284 (−2.42)**	−0.8331 (−6.23)***	−0.6644 (−4.85)***
Past inv. construction	−0.0787 (−2.68)***	−0.0352 (−1.27)	−0.0157 (−0.54)	−0.0719 (−2.37)**	−0.0262 (−0.92)	0.0076 (0.27)	0.0291 (1.03)
Infrastructure variables							
% Motorways	−0.0032 (−0.68)	−0.001065 (−0.26)	−0.0076 (−1.77)*	−0.0013 (−0.27)	0.00103 (0.24)	0.0076 (1.62)	0.00757 (1.63)
% 5–7 m	−0.00145 (−1.71)*	−0.0016 (−2.14)**	−0.00082 (−1.03)	−0.0016 (−1.81)*	−0.0020 (−2.41)**	−0.0003(−0.43)	−0.0005 (−0.75)
% >7 m	−0.0005 (−0.52)	−0.0002 (−0.26)	−0.00003 (−0.04)	−0.00107 (−1.01)			0.00077 (0.86)
Regulation variables							
General Traffic Rules	–	0.00161 (0.03)	−0.0325 (−0.57)	–	0.0355 (0.62)	–	−0.0864 (−1.34)
Inspection and Renewal	–	0.15935 (7.64)***	0.0256 (1.46)	–	0.1664 (7.62)***	–	0.0061(0.26)
European Program-97	–	−0.0360 (−1.79)*	0.0251 (1.24)	–	−0.0414 (−1.97)**	–	0.04829(2.05)**
European Program-03	–	0.0438 (1.73)	−0.0686 (−2.84)***	–	0.05378 (2.03)**	–	0.0237 (0.83)
New Traffic Law and Seat Belt Law-06	–	−0.1822 (−7.46)***	−0.3107 (−13.48)***	–	−0.1968(−7.67)***	–	−0.1086 (−4.30)***
Control variables							
Motorization	0.0008 (4.26)***	0.0009 (4.93)***	−0.00002 (−0.12)	0.00072 (3.30)***	0.0007 (3.81)***	−0.0003 (−1.65)*	−0.0004 (−2.37)**
Unemployment rate	−0.0116 (−8.06)***	−0.01550 (−11.21)***	−0.0161 (−11.16)***	−0.0139 (−9.32)***	−0.01813 (−12.46)***	−0.0179 (−12.54)***	−0.0190 (−12.76)***
Elderly	0.0304 (4.34)***	−0.03094 (−4.08)***	−0.0384 (−4.81)***	0.0284 (3.90)***	−0.0341 (−4.32)***	−0.0065 (−1.08)	−0.0218 (−3.30)***
Doctors	−0.00187 (−5.28)***	−0.00121 (−3.66)***	−0.0017 (−5.07)***	−0.0018 (−4.94)***	−0.00118 (−3.41)***	−0.0012 (−3.91)***	−0.0012 (−3.80)***
Time trend	−0.0454 (−12.42)***	−0.0543 (−10.55)***	No	−0.0433 (−11.26)	−0.0530 (−9.78)***	0.0034 (0.96)	0.0114 (2.10)**
Log Likelihood	−3850	−3743	−3795	−3732	−3621	−6363	−6342

In parenthesis we provide robust to heteroskedasticity Student's-*t* values. Each regression includes province fixed effects.

* Statistically significant at 10%.

** Statistically significant at 5%.

*** Statistically significant at 1%.

road fatalities. These results also suggest different alternatives and policies to improve road safety outcomes, as the better provision or larger supply of health care services in the province.

The coefficient of the time trend, which not only captures technical improvements but also rising public awareness of road safety, indicates that the number of fatalities and casualties have declined over the last two decades.

6. Conclusions

This article has highlighted the importance for road safety studies of the joint consideration of the characteristics of road infrastructure and investment in that infrastructure, on the one hand, and of traffic regulations that impact the behavior of road users and in which aggregate road safety problems are addressed, on the other. While both types of variable are shown to be relevant, we report conflicting evidence in the case of newly introduced safety measures, although well-designed changes in regulations and sanction systems significantly reduce the number of fatalities and casualties. Additionally, we report the overestimation of the impact of maintenance spending when these regulatory measures are not included in the models and the possibility of an erroneous conclusion also being drawn regarding the impact of investment in construction.

Our results do indicate that investing in maintenance produces a safety benefit in terms of a reduction in the fatality rate, a finding that is consistent across models and methods. The social desirability of this result, however, depends on cost-benefit ratios, the calculation of which lies beyond the scope of this study. Yet, the fact that spending on maintenance is much more relevant to road safety than construction spending should encourage governments to implement maintenance programs not only to guarantee efficient connections, but also to enhance safety standards and so reduce the economic and social costs of accidents. Indeed, the Spanish Government recently asked the European Investment Bank to co-finance half of its 1000 million euro road conservation and improvement plan[14] aimed at alleviating the negative impact of cuts in public investment. The importance of such investment is echoed by the Spanish Road Association (AEC), which has warned that the current state of repair of Spain's road network is the worst it has been since 1985 (AEC, 2012).

We show that while investing in new roads is necessary to develop a more efficient transportation network (which in turn can enhance productivity and growth), the resulting increase in mobility (and riskier driving) can have a negative impact on safety outcomes. This result, however, suffers from one of the limitations of this study, namely, the lack of data on the increase in traffic volumes induced by a rise in demand.

Road safety is best modeled, we believe, within a unified framework. Such an approach, moreover, can provide more robust insights as to what each type of variable can contribute to reducing the number of road accidents and casualties. The fact that our results have shown both groups of variables to be relevant means that omitting one or the other will generate biased estimates. Finally, beyond the policy implications of infrastructure spending, our work also highlights the importance of improving health services and considering the role of the economic cycle and demographics on the occurrence of road accidents.

[14] Project promoting Road Safety & Rehabilitation – reported by European Investment Bank on September 17, 2012: http://www.eib.org/projects/pipeline/2012/20120223.htm.

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Appendix A. Selected literature on road infrastructure and traffic conditions published since 2000

Study	Result	Regulatory variables (RV) and Infrastructure variables (IV)
Abdel-Aty and Essam Radwan (2000)	Heavy traffic, speeding, narrow lane width, larger number of lanes, urban roadway sections, narrow shoulder width and reduced median width, all increase the likelihood of accidents.	IV: Section length, horizontal curve, shoulder width, median width, lane width, urban section
Noland (2003)	Results refute claims that infrastructure improvements have been effective at reducing total fatalities and injuries. Number of interstate lanes is positively associated with more deaths and injuries. Seat belt laws were effective.	RV: Seat belt laws IV: Lane miles, number of different road types, number of lanes, lane widths
Flahaut (2004)	Infrastructure plays a substantial role in the co-occurrence of road accidents. All infrastructure variables are found to be statistically significant.	IV: Distance to major junction, proportion of built-up area, type of road, distance to a change in the speed limit, adherence, type of surface, distance to different type of road
Noland and Oh (2004)	An increase in lane numbers and widths is associated with increase in number of accidents, while outside shoulder width is associated with fewer accidents.	IV: Lane miles, mean lanes, lane width, shoulder width, horizontal and vertical curves per mile, mean deflection angle
Noland and Quddus (2004)	Urbanized areas are associated with fewer casualties while areas of higher employment density are associated with more casualties. More deprived areas tend to have higher levels of casualties. The effect of road characteristics is less significant but there is some positive association with the density of A and B types.	IV: Motorway length, different type of road length, number of roundabouts, number of junctions

Study	Result	Regulatory variables (RV) and Infrastructure variables (IV)
Haynes et al. (2008)	Traffic flow is the main determinant. There was no evidence that curves affect number of fatal crashes, but urban roads were significantly and negatively related to two measures of road curvature: ratio of road length to straight distance and the cumulative angle	IV: Junctions per km, road altitude, bend density, detour ratio, cumulative angle, median angle, road length
Anastasopoulos et al. (2008)	Several factors related to pavement condition and quality were found to significantly influence vehicle accident rates including the effects of friction. In terms of geometric factors and their effect on accident rates, median types and width, shoulder widths, number of ramps and bridges and curves were all found to be statistically significant.	IV: Friction indicator, pavement, rutting indicators, width, shoulders width, barriers, ramps, horizontal curves, vertical curves, bridges, rumble strips
Meuleners et al. (2008)	The programs have been effective overall, reducing crash rate by 15%.	IV: Intersection treatments, road section treatment, roundabouts, signals, islands, median, curb extensions (nibs), ban right turns, priority signs
Wanvik (2009)	This study estimates the safety effect of road lighting on accidents at night. The results show that the positive effect of road lighting is greater in relation to fatal accidents than it is on injuries and that the effect of road lighting is significantly smaller during adverse weather and road surface conditions than during fine conditions.	IV: Road lighting, road surface conditions
Albalate and Bel (2012)	Extending the motorway network is associated with a reduction in fatality rates, while all other road types do not have the same positive effects. This result is only statistically significant for free motorways; tolled motorways do not provide any significant impact.	RV: BAC level, Speed limit on motorways IV: Proportion in % of motorways, free and tolled motorways; proportion in % of primary and secondary roads over the total road network
Park et al. (2012)	Wider edge line markings on rural, two-lane highways have positive safety effects on vehicle safety.	IV: Width of edge lines, shoulder width
Gomes and Cardoso (2012)	The application of several low cost engineering measures, aimed at road infrastructure correction and road safety improvement on a multilane road, reduced the annual number of injuries and the annual number of head-on collisions. The annual frequency of accidents with fatalities and serious injuries was also reduced.	IV: The application of corrective measures: curbed median and speed activated traffic signals

Appendix B. Appendix B Selected literature on laws, regulatory and enforcement measures published since 2000.

Study	Result	Regulatory variables (RV) and infrastructure variables (IV)
Loeb (2001)	Seat-belt law was effective but its impact varies depending on the type of injury rates examined.	RV: Seat belt laws
Dee (2001)	BAC laws effective in reducing traffic fatalities, particularly among younger adults	RV: BAC laws, Administrative license revocation, 'dram shop' statute or case law, mandatory jail time for first DUI offense, Zero tolerance law, seat belt laws, Speed limits
Dee and Sela (2003)	Increase in speed limits did not lead to higher fatality rates in overall population, but raised fatality rates of women and elderly	RV: Speed limits, Seat belt laws, Enforcement, License Revocation, BAC level
Cohen and Einav (2003)	Mandatory seat-belt laws unambiguously reduce traffic fatalities	RV: Seat belt laws, speed limits, BAC limits, minimum legal drinking age (MLDA)
Dee et al. (2005)	Graduated driver license (GDL) regulations reduced traffic fatalities among 15–17 year olds by at least 5.6%	RV: GDL laws, Speed limits, seat belt laws, BAC levels, Administrative license revocation, Zero tolerance laws
McCarthy (2005)	Road accidents among elderly drivers is very elastic with miles driven. Administrative license restrictions reduced non-fatal injury crashes but had no impact on driver safety. Speed limit increases led to increase in number of fatal crashes	RV: Alcohol license density, traffic citations, administrative license restriction, BAC laws, Speed limit
Christensen and Elvik (2007)	Inspections were found to reduce the number of technical defects in cars markedly, but had no effects on accident rates.	RV: Inspection system

Study	Result	Regulatory variables (RV) and infrastructure variables (IV)
Kaplan and Prato (2007)	BAC laws are more effective in reducing number of casualties than in cutting number of accidents	RV: BAC laws, Administrative license revocation
Carpenter and Stehr (2008)	Mandatory seat belt laws were highly effective in reducing fatalities and crash-related serious injuries among youths	RV: Seat-belt laws, BAC levels, GDL, zero tolerance laws, speed limits
Albalate (2008)	Lower BAC laws effective for young road users, especially males in urban environments	RV: BAC levels, MLDA, Points license, Random checks IV: % highway miles and % national roads over total road network
Yannis et al. (2008)	Police enforcement of two infringements – speeding and drinking-and-driving – shows significant effect on accidents and fatalities.	RV: Enforcement of infringements: speeding and drinking-and-driving
Vanlaar et al. (2009)	Strong evidence in support of GDL was found. Its positive effects in reducing collisions, fatalities and injuries among novice drivers depend on several components of GDL. This study identifies the most effective components of GDL programs.	RV: Components of GDL program
Castillo-Manzano et al. (2010)	The introduction of a penalty points system in Spain brought about an average reduction of 12.6% in the number of deaths in highway accidents. It would take two years for this effect to disappear. For other safety variables the effect would disappear after one year.	RV: Points license, seat belt laws
Tay (2010)	The number of speed cameras and the number of apprehended drivers have a significant effect in reducing the number of injuries.	RV: Speed cameras and their location, apprehension of offenders
Nikolaev et al. (2010)	After banning hand-held cell phone use while driving the number of fatal automobile accidents decreases.	RV: A ban on hand-held cell phone use while driving
Aparicio Izquierdo et al. (2011)	Penalty points system in Spain reduced the number of fatalities. This change in driver behavior is due to a combination of three factors: penalty points system, stepping up of surveillance measures and sanctions, and the publicity given to road safety issues.	RV: Points license, Reform of the Penal Code (December 2007)
Fell (2011)	The implementation of GDLs can reduce by 8 to 14 percent the number of 16- and 17-year-old drivers involved in fatal crashes (relative to 21–25-year-old drivers), depending on other existing laws.	RV: GDL law
Castillo-Manzano and Castro-Nuño (2012)	Analyses of the effects of implementation of driving licenses based on penalty point systems on road traffic accidents and the duration of these effects suggest that the strong initial positive impact (15–20% reductions in accidents, fatalities and injuries) seems to wear off in under eighteen months due to the absence of complementary enforcement to back up these measures.	RV: Penalty Point System
Tay (2009)	Manned enforcement has a significant impact on both total and serious crashes; automated enforcement only has an effect on total crashes. Manned enforcement provides specific deterrence targeted at high-risk drivers; automated enforcement provides a general deterrence effect on a broad spectrum of the driving population.	RV: Speeding and speed enforcement
Derrig et al. (2002)	The population safety belt usage rate is associated with little or no effect on reducing fatality rates. Higher safety belt usage rates in states with primary enforcement laws points to reductions in fatality rates.	RV: safety belt primary enforcement
Tay (2005)	The anti-drink driving enforcement and publicity campaigns have a significant independent effect in reducing crashes, their interactive effect is anti-complementary. The anti-speeding enforcement and publicity campaigns had no independent effect, their interactive effect is significant.	RV: Random breath tests (RBT), Number of traffic infringement notices issued per month (Speed limits)

Study	Result	Regulatory variables (RV) and infrastructure variables (IV)
Delaney et al. (2006)	Existing drink-driving enforcement efforts have successfully contributed to reducing casualties at all levels of severity. International evidence suggests that random breath test (RBT) programs are cost beneficial. They identify a remaining group of drivers who have not been influenced by current enforcement methods.	RV: Random breath test (RBT)

References

Abdel-Aty, M.A., Essam Radwan, A., 2000. Modeling traffic accident occurrence and involvement. Accident Analysis and Prevention 32, 633–642.

Asociación Española de Carreteras (AEC), 2012. Necesidades de Inversión en Conservación. Asociación Española de Carreteras.

Albalate, D., 2008. Lowering blood alcohol content levels to save lives: the European experience. Journal of Policy Analysis and Management 27 (1), 20–39.

Albalate, D., Bel, G., 2012. Motorways, tolls and road safety: evidence from Europe. Series: Journal of the Spanish Economic Association, 1–17 (Preprints).

Albalate, D., Fernández-Villadangos, L., 2010. Motorcycle injury severity in barcelona: the role of vehicle type and congestion. Traffic Injury Prevention 11 (6), 623–631.

Anastasopoulos, P., Tarko, A., Mannering, F., 2008. Tobit analysis of vehicle accident rates on interstate highways. Accident Analysis and Prevention 40 (2), 768–775.

Aparicio Izquierdo, F., Arenas Ramírez, B., Mira McWilliams, J.M., Páez Ayuso, J., 2011. The endurance of the effects of the penalty point system in Spain three years after. Main influencing factors. Accident Analysis and Prevention 43 (3), 911–922.

Asch, P., Levy, D.T., 1990. Young driver fatalities: the roles of drinking age and drinking experience. Southern Economic Journal 57 (2), 512–520.

Carpenter, C.S., Stehr, M., 2008. The effects of mandatory seatbelt laws on seatbelt use, motor vehicle fatalities, and crash-related injuries among youths. Journal of Health Economics 27 (3), 642–662.

Castillo-Manzano, J.I., Castro-Nuño, M., Pedregal, D.J., 2010. An econometric analysis of the effects of the penalty points system driver's license in Spain. Accident Analysis & Prevention 42, 1310–1319.

Castillo-Manzano, J.I., Castro-Nuño, M., 2012. Driving licenses based on points systems: efficient road safety strategy or latest fashion in global transport policy? A worldwide meta-analysis. Transport Policy 21, 191–201.

Christensen, P., Elvik, R., 2007. Effects on accidents of periodic motor vehicle inspection in Norway. Accident Analysis & Prevention 39 (1), 47–52.

Cohen, A., Einav, L., 2003. The effects of mandatory seat belt laws on driving behavior and traffic fatalities. Review of Economics and Statistics 85 (4), 828–843.

Commission of the European Communities, 1997. COM(97)131: Promoting Road Safety in the EU. The Program for 1997–2001. Communication from the Commission.

Cook, P.J., Tauchen, G., 1984. The effect of minimum drinking age legislation on youthful auto fatalities, 1970–1979. Journal of Legal Studies 13, 169–190.

Dee, T., 2001. Does setting limits save lives? The case of 0.08 BAC laws. Journal of Policy Analysis and Management 20 (1), 111–128.

Dee, T.S., Sela, R.J., 2003. The fatality effects of highway speed limits by gender and age. Economics Letters, 401–408.

Dee, T.S., Grabowski, D.C., Morrisey, M.A., 2005. Graduated driver licensing and teen traffic fatalities. Journal of Health Economics 24 (3), 571–581.

Delaney, A., Diamantopoulou, K., Cameron, M., 2006. Strategic Principles of Drink-Driving Enforcement. Report No. 249, Monash University Accident Research Center, Melbourne.

Derrig, R.A., Segui-Gomes, M., Abtahi, A., Ling-Ling, L., 2002. The effect of population safety belt usage rate on motor vehicle-related fatalities. Accident Analysis and Prevention 34 (2002), 101–110.

Dickerson, A., Peirson, J., Vickerman, R., 1998. Road Accidents and Traffic Flows: An Econometric Investigation, Available from Internet: ftp://ftp.ukc.ac.uk/pub/ejr/RePEc/ukc/ukcedp/9809.pdf

Du Mouchel, W., Williams, A.F., Zador, P., 1987. Raising the alcohol purchase age: Its effects on fatal motor vehicle crashes in twenty-six states. Journal of Legal Studies 26, 249–266.

Eisenberg, D., 2003. Evaluating the effectiveness of policies related to drunk driving. Journal of Policy Analysis and Management 22 (2), 249–274.

European Commission/Directorate General Energy and Transport (EC/DGET), 2012. Road Safety Evolution in EU.

European Transport Safety Council (ETSC), 2003. Transport Safety Performance in the EU. A Statistical Overview.

Feber, D.J., Feldmeier, M.J., Crocker, K.J., 2003. The economic effects of road safety improvements: an insurance claims analysis. Journal of Risk and Insurance, 651–664.

Fell, J.C., 2011. An evaluation of graduated driver licensing effects on fatal crash involvements of young drivers in the United States. Traffic Injury Prevention 12 (5), 423–431.

Fundación Instituto Tecnológico para la Seguridad del Automóvil (FITSA), 2008. El valor de la seguridad vial. Conocer los costes de los accidentes de tráfico para invertir más en su prevención (in Spanish). Report funded by the Spanish General Directorate of Traffic. Universidad Politécnica de Madrid, Madrid.

Flahaut, B., 2004. Impact of infrastructure and local environment on road unsafety. Logistic modeling with spatial autocorrelation. Accident Analysis and Prevention 36, 1055–1066.

Garbacz, C., 1991. Impact of the New Zealand Seat Belt Law. Economic Enquiry 29 (310–316).

Garber, S., Graham, J.D., 1990. The Effects of the new 65 mile-per-hour speed limit on rural highway fatalities: a state-by-state analysis. Accident Analysis and Prevention 22, 137–149.

Gomes, S.V., Cardoso, J.L., 2012. Safety effects of low-cost engineering measures. An observational study in a Portuguese multilane road. Accident Analysis and Prevention 48, 346–352.

Guria, J., 1999. An economic evaluation of incremental resources to road safety programmes in New Zealand. Accidents Analysis and Prevention 31 (1–2), 91–99.

Harrison, W.A., Pronk, N.J., 1998. An Investigation of the Relationship Between Traffic Enforcement and the Perceived Risk of Detection for Driving Offences. Report No. 134, Monash University Accident Research Centre.

Harvey, A.C., Durbin, J., 1986. The effects of seat belt legislation on British road casualties: a case study in structural time series modelling. Journal of the Royal Statistical Society series B 149 (187–227).

Hausman, J., Bronwyn, H.H., Griliches, Z., 1984. Econometric models for count data with an application to the patents-R&D relationship. Econometrica 52, 909–938.

Haynes, R., Lake, I., Kingham, S., Sabel, C., Pearce, J., Barnett, R., 2008. Influence of road curvature on fatal crashes in New Zealand. Accident Analysis and Prevention 40, 843–850.

Kaplan, S., Prato, C.G., 2007. Impact of BAC limit reduction on different population segments: a Poisson fixed effect analysis. Accident Analysis and Prevention 39, 1146–1154.

Karlaftis, M.G., Tarko, A.P., 1998. Heterogeneity considerations in accident modeling. Accident Analysis and Prevention 30, 425–433.

Lave, C., 1985. Speeding, coordination and the 55 MPH limit. American Economic Review 75 (5), 1159–1164.

Lave, C., Elias, P., 1994. Did the 65 mph speed limit save lives? Accident Analysis and Prevention 26 (1), 49–62.

Loeb, P.D., 1995. The effectiveness of seat-belt legislation in reducing injury rates in Texas. American Economic Review 88 (2), 81–84.

Loeb, P.D., 2001. The effectiveness of seat belt legislation in reducing driver-involved injury rates in Maryland. Transportation Research Part E 37 (4), 297–310.

Lord, D., Mannering, F., 2010. The statistical analysis of crash-frequency data: a review and assessment of methodological alternatives. Transportation Research part A 44, 291–305.

McCarthy, P.S., 1994. An empirical analysis of the direct and indirect effects of relaxed interstate speed limits on highway safety. Journal of Urban Economics 36, 353–364.

McCarthy, P.S., 2005. Alcohol, public policy, and highway crashes: a time-series analysis of older-driver safety. Journal of Transport Economics and Policy 39 (1), 109–126.

Martin, J., 2002. Relationship between crash rate and hourly traffic flow on interurban motorways. Accident Analysis and Prevention 34, 619–629.

Meuleners, H.M., Hendrie, D., Lee, A.H., Legge, M.G., 2008. Effectiveness of the Black Spot Programs in Western Australia. Accident Analysis and Prevention 40, 1211–1216.

Milton, J., Mannering, F., 1998. The relationship among highway geometrics, traffic-related elements and motor vehicle accident frequencies. Transportation 25, 395–413.

Mitra, S., Washington, S., 2012. On the significance of omitted variables in intersection crash modeling. Accident Analysis and Prevention 49, 439–448.

Nikolaev, A.G., Robbins, M.J., Jacobson, S.H., 2010. Evaluating the impact of legislation prohibiting hand-held cell phone use while driving. Transportation Research Part A 44, 182–193.

Noland, R.B., 2003. Traffic fatalities and injuries: the effect of changes in infrastructure and other trends. Accident Analysis and Prevention 35, 599–611.

Noland, R.B., Oh, L., 2004. The effect of infrastructure and demographic change on traffic-related fatalities and crashes: a case study of Illinois county-level data. Accident Analysis and Prevention 36, 525–532.

Noland, R.B., Quddus, M.A., 2004. A spatially disaggregate analysis of road casualties in England. Accident Analysis and Prevention 36 (6), 973–984.

Noland, R., Quddus, B.M.A., 2005. Congestion and safety: a spatial analysis of London. Transportation Research Part A 39, 737–754.

Park, E.S., Carlson, P.J., Porter, R.J., Andersen, C.K., 2012. Safety effects of wider edge lines on rural, two-lane highways. Accident Analysis & Prevention 48, 317–325.

Peltzman, S., 1975. The effects of automobile safety regulation. Journal of Political Economy August (4), 677–725.

Peterson, S., Hoffer, G., Millner, E., 1995. Are drivers of air-bag equipped cars more aggressive? A test of the offsetting behavior hypothesis. Journal of Law and Economics 38, 251–264.

Saffer, H., Grossman, M., 1987. Beer taxes, the legal drinking age, and youth motor vehicle fatalities. Journal of Legal Studies 16, 351–374.

Sen, A., 2001. An Empirical Test of the Offset Hypothesis. University of Waterloo, Mimeo.

Tay, R., 2003. Marginal effects of changing the vehicle mix on fatal crashes. Journal of transport economics and policy 37 (3), 439–450.

Tay, R., 2005. The effectiveness of enforcement and publicity campaigns on serious crashes involving young male drivers: are drink driving and speeding similar?? Accident Analysis and Prevention 37 (5), 922–929 (A).

Tay, R., 2009. The effectiveness of automated and manned traffic enforcement. International Journal of Sustainable Transport 3 (3), 178–186 (B).

Tay, R., 2010. Speed cameras: improving safety or raising revenue?? Journal of Transport Economics and Policy (A) 44 (2), 247–257.

Vanlaar, W., Mayhew, D., Marcoux, K., Wets, G., Brijs, T., Shope, J., 2009. An evaluation of graduated driver licensing programs in North America using a meta-analytic approach. Accident Analysis and Prevention 41 (5), 1104–1111.

Vereek, L., Vrolix, K., 2007. The social willingness to comply with the law: the effect of social attitudes on traffic fatalities. International Review of Law and Economics 27, 385–408.

Vitalino, D., Held, J., 1991. Road accident external effects an empirical assessment. Applied Economics 23, 373–378.

Wanvik, P.O., 2009. Effects of road lighting: An analysis based on Dutch accident statistics 1987–2006. Accident Analysis and Prevention 41 (1), 123–128.

Winston, C., Langer, A., 2006. The effect of government highway spending on road users' congestion costs. Journal of Urban Economics 60 (6), 463–483.

World Health Orgnization (WHO), 2004. World Report on Road Traffic Injury Prevention. World Health Organization, Geneva.

Yannis, G., Papadimitriou, E., Antoniou, C., 2008. Impact of enforcement on traffic accidents and fatalities: a multivariate multilevel analysis. Safety Science 46 (5), 738–750.

Zaal, D., 1994. Traffic Law Enforcement: A Review of the Literature. Report No. 53, Monash University, Accident Research Centre, Clayton, Victoria.