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The effects of public private partnerships on road safety outcomes

Daniel Albalate, Paula Bel-Piñana*

Universitat de Barcelona, Departament d'Econometria Estadística i Economia Aplicada, Av. Diagonal 690, 08034 Barcelona, Spain

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ABSTRACT

Public Private Partnerships (PPP) have become common in providing high-quality infrastructure in many countries worldwide. One of the main reasons for PPP agreements is to improve efficiency and quality in the delivery of public services, as well as to boost investments for expensive projects. Despite PPPs having been particularly widespread in the case of the construction and rehabilitation of high-capacity road infrastructure, their impact in terms of road safety outcomes is still unexplored. This paper studies the effects of PPPs on road safety outcomes by taking advantage of the variety of production models provided in the Spanish highway network. Results based on a panel-data fixed-effects method show that the most relevant aspect influencing road safety outcomes is the quality of design of the road. However, we find evidence suggesting that privately operated highways (PPPs) are positively correlated with better road safety outcomes for roads with similar quality. This finding that should be confirmed by further research raises interest in the mechanisms that could produce this link between management models and road safety.

1. Introduction

Road accidents are among the main causes of death around the world. According to the World Health Organization (2015), more than 1.2 million people die every year on the roads, and for each person that dies there are at least 20 others that sustain nonfatal injuries, as a result of traffic crashes. Apart from the human suffering, the economic costs associated with these tragedies are high in terms of health spending, insurance costs, productivity losses and congestion costs. The last estimates of the European Commission (2010) calculate that 130 billion euros - approximately 2% of the GDP - are economic costs associated with road accidents. More recently, the International Road Assessment Program (2015) has found that the global economic cost of road deaths and serious injuries is about 1.8 trillion dollars per year in the world, an average of 3% of the GDP in each country.

There is a collective public interest in improving global road safety. Nonetheless, road transport remains as one of the most dangerous modes of transport. In 2015, in the European Union alone, the total number of fatalities from road accidents was 26,134, while from railways and airplanes the number of lives lost was just 27 and 150, respectively.[1] Improving road safety is linked to lower social and economic costs and more sustainable development. Therefore, multitudinous initiatives are currently being taken by transport authorities worldwide.

From 1990–2015 governments around the world have awarded more than 950 PPP road projects with a total amount of investment of 267,039 million dollars.[2] In many developed and developing countries, PPPs are an important and attractive alternative for financing and managing road highways (Engel et al., 2003; Bel and Foote, 2009; Albalate, 2014). One of the most common strategies proposed by policy makers to reach better road safety outcomes has been to upgrade the quality of the roads. Nevertheless, public debt burden and fiscal stress have led governments to find ways of achieving better roads without compromising the state's accountability. The provision of better roads through public private partnership (PPP) has become almost normal practice to circumvent budgetary restrictions (Hammami et al., 2006; Albalate et al., 2017). Thus, governments find an ally in the private sector to meet the challenge of providing new and better road infrastructure.

Another important argument for the implementation of PPPs has been to increase economic efficiency (Grimsey and Lewis, 2002; World Bank, 2012). Given that the private sector is profit-making, the lifecycle costs should be optimized. However, within the property rights theory of ownership based on incomplete contracting, it has been argued that although private management may improve productive performance it may harm the quality of services (Hart et al., 1997; Hart, 2003), and

* Corresponding author.
E-mail addresses: albalate@ub.edu (D. Albalate), paulabel@ub.edu (P. Bel-Piñana).

[1] Eurostat database. Data for 28 EU Member States.
[2] The World Bank database.

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indirectly, the safety outcomes of the service delivered. Supporters of private management claim that the private sector can provide public services more efficiently than governments, but critics claim that private companies will prioritize economic revenues over the quality and safety of services. Empirical evidence of the productive performance of road investment, as between PPPs and traditional procurement, is limited and findings show mixed results (Blanc-Brude et al., 2009; Raisbeck et al., 2010; Chasey et al., 2012).

However, other scholars argue that it is precisely the drive to improve the quality of services that brings about PPPs (Harris, 2004; Hodge and Greve, 2007). According to the European Commission (2003), the quality of services achieved under PPPs is better than traditional procurement due to the fact that the private sector introduces innovation in service delivery, promotes better integration of services, improves economies of scale and allows performance-based contracts. Nevertheless, there is a lack of empirical evidence of the relationship between quality and ownership or management models, particularly where road safety is concerned.

Indeed, an improved design and maintenance of roads would reduce accidents and provide users with more efficient mobility, comfort and lower vehicle operating costs (Burningham and Stankevich, 2005). Moreover, some practitioners suggest that there are fewer accidents on private roads than public roads (Samuel and Poole, 2000; Sisiopiku et al., 2006; Block, 2009), advocating for the road safety benefits of PPPs. Contrarily, others advise that private management can be more costly and might lead to problems with safety and quality (Kusnet, 2007). However, the effects of management on quality measured in road safety outcomes have not yet been deeply analyzed.

In this paper we aim to shed light on this gap by analyzing empirically the effects of PPP models (PPPs vs. traditional public procurement and management) on road safety outcomes in Spain, where there is a mix of production models composed of public highways and those privately managed under PPP agreements. We apply different count data models, within the framework of panel-data econometric techniques, in order to evaluate the role of PPPs on the determination of the number of accidents with victims and the number of victims (casualties).

The remainder of the article is organized as follows: Section 2 provides a literature review on PPPs and road safety. Section 3 defines the Spanish mixed model of highway management that allows us to compare both public and PPP models within the same network and countrywide experience. Section 4 provides the data and variables used and the empirical strategy employed. Results are presented in Section 5. In Section 6 we conclude.

2. Literature on public-private partnerships and road safety

2.1. Public-Private partnership: A definition

A public private partnership (PPP) can be broadly defined as a contractual agreement between public administration and at least one private company, in which the private party is engaged to finance, build or rehabilitate and manage a project through a long-term contractual agreement until the contract expires and the asset returns to public ownership (Grimsey and Lewis, 2004).

However, there are several aspects to this concept that include some common features. Firstly, a PPP is a cooperative activity between the public and private sectors (Osborne, 2002; Van Ham and Koppenjan, 2001). Secondly, risks are shared between parties (HM Treasury, 2003; OECD, 2008). Thirdly, various tasks are bundled under the same contract (Grimsey and Lewis, 2004; Hodge et al., 2010). Fourthly, these contracts can take many forms[3] such as; build, operate and transfer (BOT), build, own, operate and transfer (BOOT), design, build, finance and operate (DBOT), and rehabilitate, operate and transfer (ROT) (GAO, 1999; World Bank, 2012). Fifthly, two types of infrastructure investment are available in PPP projects: greenfields and brownfields. Investing in a new infrastructure asset is considered as a greenfield project and investing in an existing asset at the operational phase is a brownfield project. Greenfield assets have high levels of business, construction and demand risks, while brownfield investments are perceived to be the lowest-return and lowest-risk sector of infrastructure investment (Bitsch et al., 2010). Therefore, operational risk on brownfield projects should be smaller than in greenfield investment due to the asset having been working for some time.

2.2. Public-Private Partnerships and road safety outcomes

Although the empirical literature has not explored the direct impact of PPPs on road safety, we can identify two strands of related literature. On the one hand, research on the role of tolls in producing traffic shift onto alternative roads (re-routing effects). On the other hand, research exploring the influence of the introduction of performance-based incentives in road management contracts.

2.2.1. Re-routing effects and road safety

Re-routing literature provides evidence that road accidents are higher on roads that are alternatives to tolled highways, due to the fact that charging for the use of the better road may encourage too many drivers to choose alternative free minor roads, which are generally of poorer quality or not prepared to receive high amounts of traffic. This literature is connected to our work in the sense that PPPs are generally associated with user payments via tolls, even though other PPP models may involve shadow tolls, which are not charged to users but to taxpayers. Publicly operated highways might also charge tolls to users, as is common in the United States and was common in some European countries such as France, Italy and Portugal before the privatization of their networks.

One of the earliest works is Lyles et al. (1990). This study evaluates the crash frequency and crash rate of large trucks in Michigan. The most significant findings were that crash rates were five to seven times higher on lowest class roadways than those on the controlled access system. Similarly, a recent study, also for the US, by Swan and Belzer (2013), estimates the crash cost per vehicle mile traveled for trucks that diverted from the Ohio Turnpike to avoid paying tolls. Results show that crash costs are highest for the roads to which truck traffic was diverted.

In Europe we also find similar studies. Broughton and Gower (1998) analyzed the effects of motorway tolls on the number of accidents in the United Kingdom. Results show that a 10% diversion of motorway traffic from the toll motorways in Kent would increase the number of accidents in the entire county by about 3.5%. In this same line of research, Albalate (2011) tests whether charging for the use of highways might negatively affect road safety outcomes on the adjacent free roads. The author found that road accidents in Spain are higher on routes adjacent to toll motorways than those adjacent to free motorways, controlling for traffic and other potential determinants of road safety. And more recently, Baumgarten and Middelkamp (2015) analyzed the impact of the implementation of the German heavy good vehicle toll and the re-routing effects on road safety outcomes. Results of this study indicate that interurban toll charging causes traffic diversion, producing a negative impact on Germany's road safety outcomes.

Finally, at a national scale, we find the work by Albalate and Bel (2012), which investigates the relationship between different types of road quality and their impact on national safety outcomes in Europe.

[3] Industrial organization requires that to be considered a PPP the bundling of construction and operation must be under the same contract (Martimort and Pouyet, 2008; Bennett and Iossa, 2006).

Their findings suggest that, distinguishing between free and tolled motorways, the former were associated with a statistically significant reduction in traffic fatalities, probably as a consequence of the re-routing effect.

2.2.2. Public-private partnership and safety incentives in contracts

Some theoretical approaches to PPPs hold that the introduction of performance-based incentives in road management contracts may contribute to improving road safety outcomes (Grimsey and Lewis, 2007). However, empirical analyses of these effects are scarce and limited to few works.

This literature is based on the assumption that many aspects of improving road safety, for example pavement maintenance and renewal, safety emergency assistance, safety equipment, etc., can be introduced into the contract through an incentive mechanism.

As far as we know, empirical studies on this incentive scheme in road contracts can only be found for the case of Spain. By using a dataset with public and private highways in a cross-section setting for the year 2006, Rangel et al. (2012) found that there are more fatalities, injuries and accidents on highways without road safety incentives than on highways with incentives. Also, Rangel et al. (2013) evaluated incentive schemes by using data only from private highways between 2007 and 2009, finding that road incentives are significant factors reducing the number of accidents and injuries but not decreasing the number of fatalities. More recently, Rangel and Vassallo (2015) expanded the previous dataset, including all types of highways - not only private but also public - confirming that there are more accidents on highways without incentives than those with incentives.[4]

Some of these papers included a variable controlling for the road management model. However, it was not the main focus of their analyses (see Rangel et al., 2012 and Rangel and Vassallo, 2015). These papers conclude that toll highways (privately managed) are safer than the second generation of public highways. However, in the case of Rangel et al. (2012) results indicated that the first generation of public highways, is safer than the second generation of public highways. This result was considered by the authors as an odd feature of their findings and, subsequently, it was reversed in Rangel and Vassallo (2015).

The contribution of this paper to the literature is twofold. Firstly, it differs from the previous research on re-routing by exploring the direct safety effect on the road managed under PPP schemes, and not on the adjacent alternative roads stressed by the diversion of traffic. Secondly, we provide a panel-data econometric estimation to explore the role of the PPPs on road safety outcomes, distinguishing by the quality of design of roads in a long panel-data fixed-effects model. Therefore, we separate the quality of road design into different tiers, which allows us to make a more robust comparison between the private and public management models, avoiding the bias produced by the different engineering qualities of the infrastructure.

3. The Spanish mixed road network

The highway network in Spain is quite singular compared to most European countries. Spain has a long tradition of building and managing road highways through PPPs. However, since the end of the 80 s different types of management can be found (Bel and Fageda, 2005; Albalate et al., 2009; Albalate, 2014). The first private highways were awarded in Spain at the end of the 60 s. Having overcome the hardest years of the autarky, the Spanish economy was growing fast but transportation infrastructures were insufficient for productive activities. An expanded and modern highway network was required at a time when the public budget was insufficient to afford such investment. The government opted for private funding and by the second half of the 70 s more than 1800 km of private highways were already constructed.

In the early 80 s, the democratic transition and the oil crisis increased the financial expenses and construction costs, bringing the private highway expansion work to a halt. However, a large number of kilometers of the Spanish network was single and dual carriageways and the growth of the highway network was still necessary.[5] The new government that took office in 1982 and remained until 1996 − politically opposed to continued expansion of the highway network with private participation − approved the first program of public highways[6] and started to build the first generation of publicly managed free highways. However, this first generation of free highways was constructed by enlarging and doubling existing carriageways.[7] The three main reasons for doubling were economics (to take advantage of the existing road), traffic flow (private highways had not solved the traffic congestion on the adjacent roads), and safety (highways are safer) (Sánchez et al., 2007). At the end of the 80 s more than 2000 km of first generation free highways were already constructed but the geometric design of the roads (road design) was inferior to that of private highways. This lower quality standards were later recognized by the Spanish government and parliament with the enactment of law 55/1999, which acknowledged “the problem of the inadequacy of the first generation highways to the current and more demanding road safety criteria” (BOE, 312 p. 46097–46098).[8] The privatization of management tasks (operation and maintenance) of these roads did not change significantly these physical limitations.

In 1993 the government terminated the first program of public highways although the expansion of the network continued to develop but without doubling the existing carriageways. In 1996 the government changed and interest in private financing of highways was renewed. From 1996–2006 > 800 km of private highways were already awarded. Nevertheless, the government continued constructing public highways.[9] At the end of 2006 the Spanish highway network totaled around 9700 km. Private operators managed 2700 km and the public sector 7000 km (2000 km of which correspond to first generation public highways, and the remaining 5000 km to the second generation).

The private sector also plays a significant role in the management of free of charge highways under shadow toll financing schemes. At the end of the 1990s, the Spanish government evaluated the state of roads across the country and found a need for improvements in quality, accessibility and safety throughout the public highway network. The so-called first generation highways, mostly constructed during the 1980s by duplicating the existing conventional routes, displayed outdated technical and functional features that were obsolete under the latest construction, conservation and exploitation regulations. They required

[4] This paper dismisses the use of a panel-data specification arguing that spatial and temporal correlation problems were not expected in the sample analyzed.

[5] See MOPU (1984).

[6] Within the Plan General de Carreteras 1984–1991.

[7] The following roads belong to the first generation of highways: A-1 Madrid – Burgos, A-2 Madrid – Zaragoza, A-3 Madrid – Valencia, A-31 Conexion A-3 – Alicante, A-4 Madrid – Sevilla, A-2 Igualada – Martorell, A-5 Madrid – Badajoz, A-6 Adanero – Benavente and A-66 Gijón – Sevilla. The operation and maintenance of the A-2 and A-31 were fully transferred to the private sector in 2007. In addition, 146 km of the A-1, 106.8 km of the A-3 and 170.7 km from the A-4 were also transferred to the private sector in the same year. Also, in 2012, 49 km of the A-66 were transferred.

[8] Law 55/99, of December 29, introduced the form of the *"service contract for the management of highways, […] by which the contractor is awarded the execution of actions to maintain these infrastructures in optimal road conditions for a period of up to twenty years, and [which] may be extended […] to the activities of conservation, adaptation, reform, initial modernization, replacement and major repair of the highway; all with the purpose of solving the problem of the inadequacy of the first generation highways to the current and more demanding road safety criteria*". These management options were further developed by law 13/2003 on public works concessions and law 30/2007 on public contracts.

[9] In 1999 the state modified the technical normative. See Order 2107/1999 of the 27th December (BOE, 27/12/1999).

improvements to layout parameters, surface regularity and other features of the road surface and safety elements, all in order to reduce travel times and accidents. The investment needed to carry out large-scale improvements to homogenize the quality standards of the whole freeway network, including the re-conditioning of first generation highways, would have imposed a massive burden on public expenditure planning. So, the government and congress modified the administrative contracting rules, expanding the range of possible contracts, always with the goal of either deferring and/or limiting the payment from the treasury, or its impact on the budget calculations (Bellod, 2006; Benito and Montesinos, 2003). As indicated by Tello (2008), technical advisor at the Transportation Ministry in Spain, private management of road maintenance allowed for the stipulation of quality standards in the contract terms, which were measurable by means of objective parameters and should result in a better quality of service.

The privatization was not targeted road by road, but was designed as a widespread, general freeway improvement plan, affecting the whole network of old radial highways (2100 km), which, at the time, carried 17% of total road traffic in Spain. No variations were made to take account of differing potential profitability. In fact, most of the contractors needed assistance from the government in 2010 and 2011, a few years after privatization, due to financial distress that coincided with the economic crisis. This prevented completion of the privatization plan, leaving about 1000 km of first generation freeways under public management. All ten contracts auctioned had been awarded to private corporations, so no road had to be run by the public sector due to a lack of interest from private companies.[10]

Nowadays, 24% of the total highway network is managed by private companies and 76% by the public sector. However, the first generation of public highways − 50% managed by private operator and 50% by the public sector − has inferior geometric design than the private motorways and the second generation of public highways as we argued above. Table 1 shows the length of the Spanish highway (RCE) by road operator and quality of the geometric design of roads. Note we do not assign the quality level using different sources or criteria. There is only one criteria that is common for all roads. Low quality roads, privately or publicly managed, are first generation highways developed and financed in the 80′s by the public sector. All high quality highways, whether publicly or privately managed, are greenfield highways (built from scratch) with initial design and standards typical of high capacity roads.

The 82% of Spanish highways have high design and construction quality: 67% managed by the public sector (public_h) and 15% by PPPs under build-operate-and-transfer concessions (ppp_h). Differences between private and public high quality roads are minimal from the physical perspective. Both have separated carriageways for each direction of circulation, similar lane and shoulder widths, and do not cross any other path. The only difference between them is that publicly managed high quality highways offer free access to road users with limited access to neighboring properties, while privately managed highways have no access to neighboring properties and are exclusively for car traffic under user toll schemes.

Furthermore, the regulatory framework on technical requirements is no different between public and private high quality highway projects. Although the first regulation on technical requirements was applied to the private sector projects of the 60′s and 70′s – when only the private sector was building new motorways -, new publicly funded highways – second generation of highways – in the 90′s were subject to that same regulation.[11] A new construction technical requirements framework was approved in 1999 and still eludes any possible differences by management model. [12]

Table 1
Spanish highway composition by road operator and quality of road design.

Operator	Kilometers	% of km
Public High	7566	67%
Public Low	1054	9%
Total Public	8620	**76%**
PPP High	1717	15%
PPP Low	1042	9%
Total Private	2759	**24%**
Total	11379	**100%**

Note: Own elaboration.

Of the 18% of highways that are classified as of low quality of construction, half are publicly managed (public_l) and the other half by private operators (ppp_l) under operation and management contracts. These low-quality highways have the same road design characteristics because both belong to the first generation of public highways which were constructed by doubling existing conventional carriageways. That being said, low-quality PPP highways have undergone some conditional improvements and rehabilitation works since their privatization at the end of 2007.

We choose to analyze the case of Spain because of the particular mixed model that allows for a comparison between PPPs and public models within the same national network. Thus, we are able to compare different forms of delivery with similar road designs. This allows us to better pinpoint the true effects of PPPs on road safety performance.

4. Methods and data

4.1. Methodology

The most common methodology for modeling road accidents is based on count models because the nature of accident occurrence is random, discrete, non-negative and does not follow a normal (Gaussian) distribution.[13] Different approaches have been applied to evaluating road safety determinants. Many different prediction models are available for estimating the number of accidents linked to a set of exogenous variables (see Lord and Mannering, 2010; Mannering and Bhat, 2014). Given the characteristics of the outcome variables described above, count-data regression models based on a Poisson or on a negative binomial distribution are the most commonly used.[14] Nevertheless, a strong restriction of the Poisson model is that the mean and the variance have to be equal. This is the so-called equidispersion assumption. Unfortunately, this assumption is often violated when variance exceeds the mean, which indicates overdispersion in the data. It is when count data display overdispersion that the negative binomial regression model is more appropriate (Miaou and Lum, 1993; Hadi et al., 1995; Abdel-Aty and Radwan, 2000; Lord, 2006). The negative

[10] In September 2012, an additional 49 km of public highways were transferred to private operators. However, in this study, we have not counted these 49 km as privately managed, because the data we analyzed are from 2008 to 2012.

[11] See ORDER of April 21, 1964 that approved the instruction of the general direction of roads 3.1.IC on geometric characteristics and layout and ORDER of March 12, 1976 that approved the document from the Road Instruction: Complementary rules of 3.1.l.C, "Highways Tracing" (In Spanish)

[12] See ORDER of December 27, 1999, which approves the Standard 3.1-IC Layout, of the Instruction of Roads. Also see Order FOM / 273/2016, of February 19. (In Spanish)

[13] Other common models contain crash modification functions that cannot be applied in our setting given that we lack information on highway design changes and infrastructure variables. Obtaining these types of data to conduct further research using these models may certainly give more insights for the interpretation of our results. Indeed, it would provide a better identification of the role of infrastructure and engineering design.

[14] If the distribution of counts contains a much larger than expected number of zeros, Zero Inflate models are more appropriate (Lord et al., 2005b).

binomial distribution allows for a more flexible modeling of the variance than the Poisson model and ensures the avoidance of biased standard errors and inefficient estimated coefficients.

Since the seminal paper of Hausman et al. (1984), panel count models have been applied in road safety analysis in order to correct for unobservable time-invariant heterogeneity. Poisson and negative binomial panel data have been used in both random effects and fixed effects alternatives (Noland, 2003; Chin and Quddus, 2003; Yaacob et al., 2011; Hosseinpour et al., 2014). The random-effects model assumes that the individual effects are uncorrelated with the independent variables. If this is the case, then the random-effects model is unbiased, consistent and more efficient than the fixed-effects model. If the unobserved individual heterogeneity is correlated with the exogenous variables, then the random-effects model will produce inconsistent estimates. In this case the fixed-effects model, which always provides consistent estimates – but is less efficient than the random-effects model - is the most reliable choice.

4.2. Model choice

Our data on road accidents are collected in panel form (846 control stations followed for 5 years, from 2008 to 2012) and a simple pooled Poisson model is first employed as a benchmark model. In the Poisson model, the assumption of independent observations over individual control stations and across time is consistent with the strong assumption that the mean and the variance have to be equal. The Wald test and the Likelihood Ratio tests allows us to reject the null hypothesis of no overdispersion, thus we conduct a pooled negative binomial regression as a preferred model[15] . We assume that individual effects are independent across control stations for a given year but note that individual effects can be correlated over time for a given control station. For this reason, panel-data models should be more appropriate than pooled models. The Likelihood Ratio test is used to check whether the data are better modeled using a panel structure or a pooled estimator with constant overdispersion. Results corroborate the reasoning that a panel structure is more appropriate[16] .

As described above, in order to consider differences across control stations, two approaches can be used: random effects and fixed effects. In this study, both panel random-effects and fixed-effects negative binomial regression models have been applied and compared. Because we have some unobserved time invariant characteristics of the infrastructure variables at control stations such as lane widths, road curvature, and intersections that may violate the strict exogeneity assumption required for random effects, the recommended model used must be fixed effects. Fixed effects are specific to each control station, accounting for the time invariant unobserved heterogeneity from the specific features of their associated road stretches. Notwithstanding the above, we conduct the Hausman test and results allow us to reject the null hypothesis of no systematic differences between the two models. This is the same as confirming the correlation between unobserved heterogeneity and the regressors, which indicates that the conditional fixed-effects negative binomial model is the only one ensuring consistent results.

In spite of the suitability of the fixed-effects negative binomial model there have been two different formulations. Firstly, the conditional estimation of fixed-effects negative binomial model developed by Hausman et al. (1984). Secondly, the unconditional estimation of fixed-effects negative binomial model proposed by Allison and Waterman (2002) and Greene (2007). The main difference is that in the conditional fixed-effects negative binomial model, the fixed effects enter the model through the dispersion parameter rather than the conditional mean function adopted by unconditional estimation. The conditional fixed-effects modeling implies that the time invariant variable can coexist with the effects, therefore time invariant variables are not dropped out from the model. Because the main variable of interest in this study is *PPP*, which is time invariant, the appropriate estimator is the conditional fixed-effects negative binomial model. In addition, using the conditional fixed-effects estimator, the incidental parameters problem (panel level heterogeneity) is avoided because the likelihood function is conditioned for each observed panel outcome by the sum of the counts for that panel. Once we eliminate the panel level heterogeneity, applying usual asymptotic theory with fixed time, and observations tending to infinity, the conditional fixed-effects estimator is consistent.

In order to obtain empirically the effects of PPPs on road safety in the Spanish highway network, the following reduced form equation is estimated, employing the conditional two-way fixed-effects negative binomial model:

$$Y_{it} = \alpha + \beta PPP_i + \delta X_{it} + \mu_i + \gamma_t + \varepsilon_{it}$$

where the dependent variable Y_{it} is a count of accidents (acc_with) or victims (vic) in control station i and year t, α is the constant term in the model. The main variable in the estimation is PPP_i which identifies whether the highway was awarded and managed under a PPP scheme or by the public administration. In a disaggregated model we substitute this variable with four other variables: high-quality public highway (public_h), low-quality public highway (public_l), high-quality private highway (ppp_h) or low-quality private highway (ppp_l). X_{it} is the vector of road safety standard determinants, μ_i is the control station-specific fixed effect from which we obtain the locally specific road safety data and γ_t is the year-specific fixed effect. Finally, ε_{it} is the error term. The subscripts i and t define the cross-section and the time dimension of our data, respectively.

In the equation the number of counts y_{it} is assumed to follow a negative binomial distribution with $E(y_{it}) = \Theta_i\lambda_{it}$ and $\mathrm{var}(y_{it}) = (1 + \Theta_i)\Theta_i\lambda_{it}$ where $\lambda_{it} = exp^{(X_{it}'\beta)}$ and $\Theta_i = \alpha_i/\phi_i$. As previously defined, α_i is the individual specific fixed effects and ϕ_i is the negative binomial overdispersion parameter which can vary across individual effects and can take any value. Nevertheless, to estimate the parameters for the fixed-effects negative binomial model, the overdispersion parameter ϕ_i has been dropped out for conditional maximum likelihood.[17]

Furthermore, we use the exposure variable $vehikm_{it}$ because it is known that traffic flow varies from one control station to another and the total annual vehicles per km traveled could affect the count.[18] This means that the outcome variable needs a rate which is just a count per unit of vehicles/km traveled. The negative binomial manages exposure variables by using natural logarithms to change the outcome variable from a rate into a count. The exposure variable is entered in the log link function as the natural logarithm and it is required to have a fixed coefficient equal to one. The coefficient of one allows turning the count into a rate.

4.3. Data and variables

4.3.1. Data

This study draws on a dataset extracted from the Spanish traffic map database (Mapa de tráfico, 2012) published annually by the Spanish General Traffic Directorate. The database is generated from two

[15] The χ^2statistic of the Wald test rejects the null hypothesis with a p-value = 0.000. The χ^2statistic of the LR test rejects the null hypothesis with a p-value = 0.000.

[16] The χ^2statistic of the LR test rejects the null hypothesis with a p-value = 0.000.

[17] See Cameron and Trivedi (2005).

[18] For example, a count of 15 annual number of accidents with victims out of 50 million of vehicles per km traveled is much smaller than a count of 15 out of 10.

different sources. Traffic data are supplied by the Ministry of Public Works. Road accidents data are provided by the Ministry of Homeland Affairs, responsible for road safety in Spain. Accidents data cover all reported accidents with at least one person injured, recording the number of injuries and number of deaths, at the moment that the accident occurs, in segments belonging to different road categories of the state road network (RCE). The Spanish RCE on traffic map 2012 is segmented in 4788 homogeneous lengths of 5.44 km. In each segment there is a control station that records annual and historical information on accidents, injuries and fatalities, and traffic mix. Since we are merely interested on high capacity roads, we avoid using data related to two undivided dual carriageway and single carriage roads. In order to avoid selection bias we considered interurban and urban segmented road stretches with and without accidents recorded. Therefore, a total of 4234 highway control stations were extracted out of 5528 from the 2008 to 2012 database. Control stations without complete information for safety outcomes and traffic flow were excluded. The traffic map database also includes information on infrastructure characteristics such as number of lanes.

4.3.2. Dependent variables

The count dependent variables considered in this study are the annual number of accidents with victims (acc_with) and the annual number of victims (vic) recorded in each control station. The variable annual number of victims is the sum of the annual number of injuries and the annual number of fatalities. We aggregate injuries and fatalities in one variable because data on injuries and fatalities are recorded at the moment the accident occurs. If a victim does not immediately die, we cannot identify if she finally dies because of the accident. Information on these variables has been obtained from the 2012 traffic map database.[19]

The main variable of interest in this study is management (PPP), however as we are interested in estimating the true effects of management, a quality categorization of the geometric design of roads has been conducted. Of the total highway network 24% is managed by private companies and the remaining 76% by the public sector. However, the geometric design of roads differs. The variable management is introduced in the model as a binary variable that identifies whether the road is a PPP (value 1), or it is publicly managed (value 0). This variable, once it is disaggregated to deal with the different quality of design, is substituted by four binary variables. The high-quality public highway (public_h), low-quality public highway (public_l), high-quality PPP highway (ppp_h) or low-quality PPP highway (ppp_l). All of these are dummy variables. Thus, we need to drop out one of them to avoid perfect collinearity, and coefficients must be interpreted with respect to the variable excluded from the model (public_h). All information on these variables is obtained from the 2012 traffic map database and from the 2012 Spanish toll highways annual report. Also, we take advantage of the research conducted by Sánchez et al. (2007) to identify the low-quality public highways. Table 2 reports the descriptive statistics of the dependent variables by operator and quality of the road design.

4.3.3. Exogenous variables

Our empirical model of road safety determinants must build on the grounds of previous research. It is well known that personal income, traffic conditions, infrastructure features, weather conditions and road users' behavior might affect road accidents.

There has been significant interest on the relation between road accidents and traffic conditions such as traffic flows (Martin, 2002; Lord et al., 2005a; Anastasopoulos and Mannering, 2009), traffic mix (Albalate, 2011; Castillo-Manzano et al., 2016) and speed of driving (Nilsson, 2004; Pei et al., 2012; Quddus, 2013). On the one hand, most studies reveal a positive relationship between accidents and traffic flow and traffic mix (Wang et al., 2013). However, other studies found that heavy vehicles do not seem to be associated with poorer road safety outcomes (Albalate, 2011; Castillo-Manzano et al., 2016). Thus, our model will control the number of vehicles per km (vehi_km) and the percentage of heavy vehicles (heavy_vehi). The variable *vehi_km* is defined as vehi_km = total average annual daily traffic * length of segment * 365. The variable *heavy_vehi* is the percentage of heavy vehicles in the total average annual daily traffic. Both variables are obtained through data compiled in the 2012 traffic map database. Also, we include the average age of the vehicle fleet of the province (age_vehi). The variable *age_vehi* was elaborated from data provided by the Spanish General Traffic Directorate.

On the other hand, the impact of variation in speed on road safety has been widely investigated but results suggest that speed has heterogeneous effects on road safety (Wang et al., 2013; Imprialou et al., 2016) and no conclusive results are derived. Because we could not confirm this as a variable our model does not contribute to the debate on the role of speed.

Road design is another factor that needs to be taken into account when analyzing road safety. Several researchers have focused on analyzing the relationship between accidents and a variety of different features of the infrastructure such as lane widths, number of traffic lanes, median shoulder, pavement, road curvature, intersections and signalization (Abdel-Aty and Radwan, 2000; Noland and Oh, 2004; Meuleners et al., 2008). In general terms, results conclude that the road's characteristics have a statistically significant impact on safety (Albalate et al., 2013; Wang et al., 2013). Thus, improvements in road infrastructure have a positive effect in protecting users (Pérez, 2006; Gomes and Cardoso, 2012). In order to control for infrastructure features we include the number of lanes and the type of road - depending on whether it is an urban road or interurban road. This is introduced by including the variable interurban, which is a dummy variable taking value 1 for control stations placed in interurban sections and 0 otherwise. This is the only physical feature that we can include because information on these aspects is very limited in the traffic map database.

Climate and weather conditions have also been important variables in analyses of road safety investigation. Most studies show that conditions such as rainfall affect accident outcomes (Eisenberg, 2004; Hermans et al., 2006; Caliendo et al., 2007). For this reason we include in our equation of determinants the annual number of rainy days. The variable *rainy* is the annual average number of rainy days by province. Data were provided by the Spanish State Meteorological Agency.

It is widely known that individual driving behavior is a crucial determinant of road accidents. Among others, alcohol consumption, speeding or non-use of seat belt cause more accidents and might increase their seriousness. Many analyses of the effectiveness of enforcement laws such us speed limits, legal limits of blood alcohol content and seat belt laws have been carried out in recent years (Loeb, 2001; Dee et al., 2005; Albalate, 2008). Results suggest that the impact of laws and regulations may depend on the driving population under examination (Albalate et al., 2013). We therefore include variables of demographic characteristics of the population as in the number of young people between 20–29 years old (*pop_20a29*) and the elderly population above 80 years old (*pop_ < 80)*. In addition, we include the number of liters of alcohol consumed per capita at home (*alcohol_pc)* to account for the risk of drunk driving.

We also include the GDP per capita in order to account for the importance of income as a determinant of road accidents.

Data for all of the socio-economic variables are desegregated by province except for the variable *alcohol_pc*, which is only available by

[19] Note that all our dependent variables involve injuries and fatalities, because we want to avoid problems of under-reporting. Although they might still pertain, - which is a limitation that we can hardly solve – most accidents with victims are widely reported. Even in the case of less severe injuries, that could lead to under-reporting, we do not have any reason to believe there are differences in reporting by road management model, such as could bias our results.

Table 2
Descriptive statistics of the dependent variables by operator and quality of road design.

Operator	acc_with					vic				
	Obs	Mean	S.D	Min	Max	Obs	Mean	S.D	Min	Max
Public	3141	22.14	48.97	0	1498	3138	34.97	63.55	0	691
Public_h	2592	19.54	37.05	0	344	2590	31.23	58.24	0	512
Public_l	549	34.47	82.06	0	1498	548	52.62	82.01	0	691
Private	1093	14.54	28.44	0	286	1093	24.5	46.4	0	444
PPP_h	729	7.87	13.04	0	133	729	13.24	21.41	0	175
PPP_l	364	27.91	42.71	0	286	364	47.04	69.25	0	444
Total	4234	20.18	44.22	0	1498	4231	32.26	59.76	0	691

autonomous community. The variable *GDP_pc* and the variables *pop_20a29* and *pop_ < 80* were collected from the Spanish National Statistics Institute database. The variable *alcohol_pc* was obtained from the Spanish Ministry of Industry.[20]

Table 3 provides information for the descriptive statistics of all these control variables.

As a result, our main equation is the following:[21]

$$Y_{it} = \alpha + \beta PPP_i + \delta_1 interurban_{it} + \delta_2 lanes_{it} + \delta_3 heavy\_vehi_{it} + \delta_4 GDP\_pc_{it} + \delta_5 alcohol\_pc_{it} + \delta_6 age\_vehi_{it} + \delta_7 pop\_20a29_{it} + \delta_{832tuuuu} pop < 80_{it} + \delta_9 rainy_{it} + \gamma_{10} year_{it} + \mu_i + \varepsilon_{it}$$

Where,

$interurban_{it}$: is a dummy variable with value one for highways belonging to interurban environment and vale 1 for those placed in urban areas.

$lanes_{it}$: is the number of lanes for each segment.

$heavy\_vehi_{it}$ is the percentage of heavy vehicles from the total AADT by control station.

GDP_pc_{it}: is the annual GDP per capita at current prices by province.

$alcohol\_pc_{it}$: is the annual liters alcohol consumption per capita inside of home by regions.

age_vehi_{it} : is the average vehicle fleet age by provinces.

pop_20a29_{it}: is the total population driving age between 20 and 29 year old by province.

$pop\_ < 80_{it}$: is the total population driving age older than 80 years old by provinces.

$rainy_{it}$: is the annual average number of rainy days by province.

μ_i : is the control station fixed effects and

γ_t: is the year-specific fixed effect

ε_{it} is the error term.

Note that fixed effects models may also account for those unobserved factors that do not change over time. This mitigates the problem of some possible omissions of variables we do not have in our database, such as infrastructure features or average speed, that are hardly likely to change, annually, on the same stretch of road.

5. Results

In this section we present the effects of PPPs on two road safety outcomes: the annual number of accidents with victims (acc_with) and the annual number of victims (vic). We first estimate pooled count data in both Poisson and negative binomial models, after that we conduct panel negative binomial estimations with random effects and conditional fixed effects. Table 4 reports the coefficient estimates for the four models regressed for both dependent variables (acc_with and vic). A positive sign indicates an increase in the annual number of accidents with victims (acc_with) and the annual number of victims (vic), whereas a negative sign indicates a decrease. Recall that our preferred model is the conditional fixed-effects model.

As we can see in Table 4, the expected number of accidents and victims for the variable *PPP*, is statistically significant and negative for all the models regressed. PPPs are associated with a lower number of accidents and victims. However, this result could be biased if PPPs are more present in roads with high-quality design. Therefore, we disaggregate variable into three variables indicating the interaction between the production model and the quality of the road. Results are reported in Table 5 for the four models regressed and for both dependent variables (acc_with and vic). The results associated with the variables related to models and quality must be interpreted with respect to the category excluded, to avoid perfect collinearity. In our case, the benchmark variable excluded is *public_h*.

Results show that the annual number of accidents with victims (acc_with) and the annual number of victims (vic) decrease when the quality of the road design is high. It means that highways with high-quality road design are safer than those with low quality design, as expected. Thus, it is clear that beyond the production model, the quality of design is a major determinant of road safety. As a consequence, any comparison must take into account the homogeneity of quality of design.

Interestingly, the annual number of accidents with victims (acc_with) and the annual number of victims (vic) on highways that have high-quality of design (ppp_h and public_h) is lower under a PPP. This is what the statistically significant and negative coefficient tells us about the comparison between the PPP high-quality road and the public high-quality road. This result is consistent in all models regressed, providing first evidence of the road safety benefits of PPPs. When considering the coefficients associated with the highways of low-quality design (ppp_l and public_l), we observe that the expected number of victims (vic) is larger with respect to the low-quality public road, as expected. However, note that the coefficient of the low-quality PPP road is substantially smaller than the coefficient associated with the low-quality publicly operated road, for the number of victims. Thus, we confirm that given the same quality of design, PPPs have a better safety performance when measured in terms of casualties (injuries and deaths). This result is not sustained when we measure the safety outcomes via the number of accidents with victims, given that the coefficients we obtain with the conditional fixed-effects model are roughly the same for the PPPs and for the public low-quality roads.

Note, however, that one could argue that our results on PPPs might be skewed by the context of a privatization program that took place in 2008, on a set of 1000 km of the first generation of freeways. A potential bias would arise from the infrastructure quality jump that could be pre-supposed with the rehabilitation of these roads. If these roads

[20] All these controls are measured at provincial level due to a lack of information on the specific drivers using the road at each control station. Thus, we control for this factor using the indirect proxy of the values at provincial level.

[21] Note that fixed effects models may also account for those unobserved factors that do not change over time. This mitigates the problem of some possible omissions of variables we do not have in our database, such as infrastructure features or average speed, that are hardly likely to change, annually, on the same stretch of road.

Table 3
Descriptive statistics of control variables.

Variable	Units	Mean	Std. Dev.	Min	Max
interurban	Dummy	0.861994	0.344941	0	1
lanes	Number of lanes by control station	4.304503	0.866894	3	8
heavy_vehi	Percentage of heavy vehicles from the total AADT by control station	14.93672	8.619115	0.934113	61.22128
vehi_km	Total AADT* length of segment * 365 by control station	51800000	51300000	176718.4	3.14e+08
GDP_pc	Annual GDP per capita at current prices by province	21279.37	4257.559	14763	37675
alcohol_pc	Annual litres alcohol consumption per capita inside of home by regions	23.5958	3.577236	15.62	34.91
age_vehi	Total average age vehicle fleets by province	11.52345	1.002196	9.09857	14.23427
pop_20a29	Total population driving age between 20 and 29 year old by province	177262.2	223154.8	10134	934239
pop_ < 80	Total population driving age older than 80 year old by province	64405.79	70338.2	8577	295942
rainy	Annual average number of rainy days by province	94.7201	40.59686	8	203.5

Table 4
Regression models for accidents with victims and victims by road operator.

Independent	Dependent Variable (acc_with)				Dependent Variable (vic)			
Variables	Poisson	NegBin	RENB	FENB	Poisson	NegBin	RENB	FENB
Constant	−11.82***	−10.65***	−14.06***	−17.32***	−11.87***	−10.12***	−12.76***	−14.82***
	(-0.113)	(-0.519)	(-0.654)	(-0.828)	(-0.087)	(-0.572)	(-0.619)	(-0.76)
PPP	−0.410***	−0.221***	−0.438***	−0.710***	−0.342***	−0.143***	−0.437***	−0.607***
	(-0.00988)	(-0.0475)	(-0.0729)	(-0.0977)	(-0.00768)	(-0.0522)	(-0.0679)	(-0.0867)
interurban	−0.0103	−0.225***	0.0387	−0.139	0.0202***	−0.131*	0.125	−0.222*
	(-0.00897)	(-0.0615)	(-0.0957)	(-0.126)	(-0.00726)	(-0.0684)	(-0.0905)	(-0.114)
lanes	0.0615***	0.0497**	0.141***	0.213***	0.0576***	0.0424	0.118***	0.149***
	(-0.00299)	(-0.0242)	(-0.0329)	(-0.0472)	(-0.0024)	(-0.0269)	(-0.0302)	(-0.0403)
heavy_vehi	−0.00506***	0.0037	0.0250***	0.0222***	−0.00425***	0.00325	0.0271***	0.0232***
	(-0.000567)	(-0.00247)	(-0.00266)	(-0.00306)	(-0.000446)	(-0.00272)	(-0.0027)	(-0.00309)
GDP_pc	4.78e-06***	0.00000108	0.0000086	2.36e-05**	3.57e-06***	−0.00000283	−4.64e-07	0.00000697
	(-0.00000153)	(-0.00000667)	(-0.00000904)	(-0.0000115)	(-0.00000118)	(-0.00000737)	(-0.00000838)	(-0.0000103)
alcohol_pc	−0.0465***	−0.0514***	−0.0859***	−0.0697***	−0.0376***	−0.0471***	−0.116***	−0.0948***
	(-0.00,153)	(-0.00693)	(-0.00734)	(-0.00767)	(-0.00,118)	(-0.00767)	(-0.0076)	(-0.00826)
age_vehi	−0.200***	−0.268***	−0.164***	0.0404	−0.170***	−0.271***	−0.228***	−0.0885*
	(-0.00751)	(-0.032)	(-0.0412)	(-0.0536)	(-0.00581)	(-0.035)	(-0.0385)	(-0.048)
pop_20a29	−7.43e-07***	−1.32e-06***	−7.40e-07***	−1.10e-06***	−3.87e-07***	−1.37e-06***	−7.59e-07**	−1.12e-06***
	(-6.73e-08)	(-0.00000045)	(-2.79e-07)	(-0.00000032)	(-5.33e-08)	(-4.97e-07)	(-3.15e-07)	(-3.46e-07)
pop_ < 80	3.79e-06***	5.34e-06***	0.0000013	2.34E-07	2.37e-06***	5.19e-06***	1.74e-06*	0.00000123
	(-1.95e-07)	(-0.00000136)	(-8.24e-07)	(-9.18e-07)	(-1.55e-07)	(-0.0000015)	(-9.09e-07)	(-9.84e-07)
rainy	−0.000253	−0.000842	0.00318***	0.00528***	0.000387***	−0.00115	0.0013	0.00305***
	(-0.000158)	(-0.00,073)	(-0.000872)	(-0.00102)	(-0.000,123)	(-0.000804)	(-0.000857)	(-0.000994)
ln(vehi_km)	1	1	1	1	1	1	1	1
ln_r	–	–	0.262***	–	–	–	0.0736	–
			(-0.0618)				(-0.069)	
ln_s	–	–	1.441***	–	–	–	2.078***	–
			(-0.0907)				(-0.117)	
lnalpha	–	0.210***	–	–	–	0.453***	–	–
		(-0.0267)				(-0.0249)		
Observations	3918	3918	3918	3616	3916	3916	3916	3614
Number of groups	–	–	826	738	–	–	826	738
Log Likelihood	−37221.072	−13769.297	−13430.502	−9027.9368	−55640.509	−15553.963	−15342.747	−10443.27

Note: Time dummies are not reported. Standard errors in parentheses. *** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$.

were performing poorly before privatization and received an investment boost that could significantly change their safety outcomes – statistically linked to PPPs – our results on PPPs could be biased. In order to check whether our results were skewed by this specific privatization and rehabilitation plan we ran our models again without these roads. Interestingly, our results in Table 6 point in the same direction, with or without these roads in the sample. Moreover, we realized that the coefficients for PPPs appear to be larger (in absolute terms) without these privatized roads. This means that without including the privatized roads the safety advantage of PPPs is even higher. If a bias did exist due to the rehabilitation plan, we would find lower coefficients (in absolute terms) without these roads. However, our evidence reveals the opposite. When we split the sample by the different quality and models, the coefficients and their statistical significance are pretty much the same, with or without privatized highways in the sample. Tables 6 and 7 summarize the selected results for this robustness check.[22]

Once we have described the effects of the core variable, we proceed to interpret the coefficients of the rest of the control variables. Relating to infrastructure characteristics, the number of accidents and victims decreases when the road highway is placed on the interurban environment (interurban). However, the more lanes the road highway has (lanes), the more accidents and victims are found. This effect is in line with Abdel-Aty and Radwan (2000) and Noland and Oh (2004). A large percentage of heavy vehicles (heavy_vehi) is related to more accidents

[22] We also computed two sample t-tests of mean differences between groups of publicly managed roads before privatization in order to check whether roads privatized were precisely the ones performing worse before privatization. Our results for the two years before privatization indicate that mean differences in safety outcomes between privatized and never privatized highway was not statistically significant.

Table 5
Regression models for accidents with victims and victims on management by road operator and quality of the road design.

Independent	Dependent Variable (acc_with)				Dependent Variable (vic)			
Variables	Poisson	NegBin	RENB	FENB	Poisson	NegBin	RENB	FENB
Constant	−12.79***	−10.84***	−15.92***	−19.11***	−12.79***	−10.15***	−14.82***	−16.68***
	(-0.115)	(-0.517)	(-0.659)	(-0.825)	(-0.0885)	(-0.568)	(-0.633)	(-0.755)
ppp_h	−0.691***	−0.409***	−0.810***	−1.210***	−0.658***	−0.364***	−0.726***	−0.983***
	(-0.0155)	(-0.0587)	(-0.0895)	(-0.115)	(-0.012)	(-0.064)	(-0.0838)	(-0.104)
ppp_l	0.0695***	0.146**	0.601***	0.860***	0.124***	0.243***	0.601***	0.744***
	(-0.0132)	(-0.071)	(-0.102)	(-0.149)	(-0.0102)	(-0.0788)	(-0.0956)	(-0.117)
public_l	0.354***	0.252***	0.759***	0.837***	0.299***	0.209***	1.119***	1.288***
	(-0.0106)	(-0.0594)	(-0.0779)	(-0.103)	(-0.00839)	(-0.0663)	(-0.0777)	(-0.0984)
interurban	−0.165***	−0.260***	−0.0789	−0.254**	−0.104***	−0.149**	−0.0215	−0.358***
	(-0.0101)	(-0.063)	(-0.0985)	(-0.13)	(-0.0081)	(-0.0703)	(-0.0942)	(-0.117)
lanes	0.0264***	0.0134	0.0696**	0.0868*	0.0185***	0.00401	0.0492	0.0427
	(-0.00316)	(-0.0243)	(-0.0334)	(-0.0474)	(-0.00254)	(-0.0269)	(-0.0315)	(-0.0408)
heavy_vehi	−0.00950***	−0.00243	0.0176***	0.0151***	−0.00914***	−0.00319	0.0157***	0.0116***
	(-0.000579)	(-0.00255)	(-0.00273)	(-0.0031)	(-0.000457)	(-0.00279)	(-0.00284)	(-0.00318)
GDP_pc	1.09e-05***	0.0000108	3.42e-05***	4.98e-05***	1.07e-05***	0.00000677	2.67e-05***	3.58e-05***
	(-1.57e-06)	(-6.67e-06)	(-9.12e-06)	(-0.0000115)	(-1.21e-06)	(-7.32e-06)	(-8.54e-06)	(-0.0000103)
alcohol_pc	−0.0301***	−0.0483***	−0.0728***	−0.0604***	−0.0218***	−0.0449***	−0.0937***	−0.0767***
	(-0.00,158)	(-0.00682)	(-0.00704)	(-0.00733)	(-0.00122)	(-0.00753)	(-0.00744)	(-0.00784)
age_vehi	−0.148***	−0.257***	−0.0573	0.160***	−0.121***	−0.270***	−0.120***	0.0143
	(-0.00751)	(-0.0321)	(-0.0417)	(-0.0539)	(-0.0058)	(-0.0351)	(-0.0391)	(-0.0477)
pop_20a29	−1.14e-06***	−1.61e-06***	−6.66e-07***	−8.50e-07***	−7.76e-07***	−1.65e-06***	−8.94e-07***	−1.09e-06***
	(-6.79e-08)	(-4.51e-07)	(-2.57e-07)	(-2.86e-07)	(-5.38e-08)	(-0.0000005)	(-2.81e-07)	(-3.01e-07)
pop_ < 80	4.58e-06***	5.78e-06***	9.36e-07	9.37e-08	3.17e-06***	5.59e-06***	1.47e-06*	0.00000094
	(-1.98e-07)	(-1.35e-06)	(-7.59e-07)	(-8.19e-07)	(-1.57e-07)	(-0.0000015)	(-8.13e-07)	(-8.58e-07)
rainy	0.000948***	−0.000378	0.00483***	0.00653***	0.00150***	−0.000766	0.00342***	0.00480***
	(-0.000162)	(-0.000721)	(-0.000863)	(-0.000991)	(-0.000126)	(-0.000795)	(-0.000863)	(-0.000964)
ln(vehikm)	1	1	1	1	1	1	1	1
ln_r	–	–	0.273***	–	–	–	0.0476	–
			(-0.0619)				(-0.0654)	
ln_s	–	–	1.418***	–	–	–	1.935***	–
			(-0.0888)				(-0.107)	
lnalpha	–	0.188***	–	–	–	0.436***	–	–
		(-0.0269)				−0.025		
Observations	3918	3918	3918	3616	3916	3916	3916	3614
Number of groups	–	–	826	738	–	–	826	738
Log Likelihood	−35897.563	−13739.078	−13320.552	−8917.891	−53606.947	−15527.577	−15186.797	−10292.309

Note: Time dummies are not reported. Standard errors in parentheses. *** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$.

Table 6
Robustness check. Sample without privatized highways. Selected Results.

Independent	Dependent Variable (acc_with)				Dependent Variable (vic)			
Variables	Poisson	NegBin	RENB	FENB	Poisson	NegBin	RENB	FENB
PPP	−0.766***	−0.440***	−0.931***	−1.401***	−0.707***	−0.388***	−0.855***	−1.201***
	(0.0151)	(0.0604)	(0.0898)	(0.115)	(0.0117)	(0.0657)	(0.0836)	(0.104)
Observations	3592	3592	3592	3313	3590	3590	3590	3311
Number of groups	–	–	753	674	–	–	753	674
Log Likelihood	−33805.079	−12419.596	−12155.178	−8164.3641	−49074.647	−13995.293	−13834.749	−9411.8005

Note: Other Covariates are not reported but were included in the regression models. Only coefficients for production model related variables. Standard errors in parentheses. *** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$.

Table 7
Robustness checks. Sample without privatized highways. Selected Results.

Independent	Dependent Variable (acc_with)				Dependent Variable (vic)			
Variables	Poisson	NegBin	RENB	FENB	Poisson	NegBin	RENB	FENB
ppp_h	−0.660***	−0.401***	−0.769***	−1.197***	−0.626***	−0.358***	−0.677***	−0.943***
	(0.0156)	(0.0610)	(0.0897)	(0.116)	(0.0120)	(0.0663)	(0.0835)	(0.105)
ppp_l	0.334***	0.234***	0.718***	0.814***	0.269***	0.191***	1.046***	1.266***
	(0.0107)	(0.0617)	(0.0774)	(0.104)	(0.00850)	(0.0686)	(0.0775)	(0.0989)
Observations	3592	3592	3592	3313	3590	3590	3590	3311
Number of groups	–	–	753	674	–	–	753	674
Log Likelihood	−33323.613	−12412.224	−12113.788	−8134.2687	−48584.423	−13991.302	−13745.775	−9333.9876

Note: Other covariates are not reported but were included in the regression models. Only coefficients for production model related variables. Standard errors in parentheses. *** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$.

and victims. This result may be explained by the fact that even though the average speed drops with more presence of heavy vehicles, trucks slow down the flow and safe distances are less respected. In the case of sudden braking the collision probability increases and as trucks are heavier than domestic vehicles the probability of victims also increases. This effect is in line with Jovanis and Chang (1986). The coefficient of the variable GDP per capita is positive and statistically significant in almost all the models reported. The number of accidents and victims increases in provinces with more GDP per capita suggesting that people who live in provinces that are richer are more risk prone because greater income is generally associated with more trips and movements. Accidents and victims decrease with the annual liters of alcohol consumption per capita inside the home (alcohol_pc). This result is counterintuitive because it is expected that regions with greater alcohol consumption have more accidents. However, the coefficient of *alcohol_pc* is negative and statistically significant in all models regressed. This result may be related to the fact that the variable of alcohol consumption is specifically in the home. People who drink more inside the home may be more concerned about the dangers of alcohol impaired driving and may not take the same risks of drunk-driving. Unfortunately, we were unable to introduce a variable capturing the alcohol consumption outside the home. The variable *age_vehi* shows an unstable behavior: in some models it is statistically significant and positive, while in other model regressions it is statistically significant and negative. These results make it difficult to obtain clear conclusions, however there is significant evidence that the average age of vehicle fleets has some effect on road safety outcomes.

The demographic variables *pop_20a29* and *pop_* < 80 have been employed as a proxy for people's driving behavior. The number of accidents and victims decreases in provinces with a young driving population but increases with an older cohort of population. The coefficient associated with the variable *rainy* is positive and statistically significant. The number of accidents and victims increases in control stations where more rainy days are registered. This effect is in line with Hermans et al. (2006) and Caliendo et al. (2007).

6. Discussion: on the effects of PPPs on road safety

Given our findings we consider necessary to understand the reasons behind the positive correlation between PPPs and road safety outcomes. Below we dare to elaborate on the mechanics of the safety effects PPPs can achieve. Hereafter, we offer some theoretical channels provided by the economics literature through which PPPs may differ from public models in road safety actions.

The analytical framework of incomplete contracts in the classical works by Hart et al. (1997) and Hart (2003) already established in the economics literature that private production, even if returns depend on demand, creates incentives to reduce costs by means of reducing quality when this is not contractible or easy to measure. The contracting firm may thus sacrifice quality to reduce total costs unless quality is clearly defined and highly specific. In that case, the cost reduction incentives might not offset the quality-enhancing incentives provided by demand risk transfers. The theory, retaken by recent contract theory authors, implies that the greater vertical integration typically associated with PPPs is preferable when quality is contractible and ease to measure (Martimort and Pouyet, 2008; Iossa and Martimort, 2015).[23] Also, PPPs are preferred where quality measures and investments may generate positive externalities. Bennett and Iossa (2006) analyze synergies between different project phases, predicting that construction and operational bundling, typical of PPs, facilitates to internalize the benefits of quality enhancing investment on operational costs.

The case of highways seems to fit very well into this analytical framework to explain the systematic differences we found on safety outcomes. On the one hand, returns of private contractors depend on demand but do not have the cost-reduction incentives indicated above because road quality is contractible and very easy to measure. On the other hand, PPPs that bundle construction and operation may exploit synergies from quality-enhancing investments, what induces more efforts in quality that may attract more users and reduce the likelihood of damages and other maintenance and operational costs.

In the context of this study, technical construction regulations are equal for both PPPs and Public sector managers. However, this is a minimum level of standards that private operators are free to improve. Under this framework we may identify 4 different incentives at work to improve road safety in PPPs.

1) PPPs have more incentives than public operators to increase traffic. All PPPs in Spain are remunerated according to the volume of users. Some under direct user fee schemes (tolls collection), others under shadow toll schemes (budget payments). PPPs are therefore transferring traffic risk to the private operator, whose incentive to provide good quality standards are to attract users. Quality and safety are valued by road users in their route choice. In Spain, all PPP highways have free conventional alternatives. PPPs have, therefore, competition for traffic. On the contrary, the Public Sector does not have incentives to increase traffic. Thus, incentives to increase traffic are not offset by cost-reduction incentives at the expense of quality, given that it is easy to measure and contractible.
2) PPPs and public sector managers are subject to different civil liabilities. Any construction or technical default or failure would imply not only the renewal of the road but also possible economic sanctions and potential civil liabilities. Safety risks produced by any aspect of infrastructure and road operation might be subject to civil liabilities only in the case of PPPs. Therefore, incentives work in the direction to cover the PPP from these risks by extending and providing higher safety standards in all tasks (construction, operation and maintenance), given that in roads there are sound synergies and positive externalities between theses project phases and tasks. Probably this explains our results more favorable to BOT-type PPPs than to O&M PPP contracts.
3) Some PPPs have quality/safety regulated incentives in their contracts. Benefits from road safety efforts may improve returns, for instance obtaining a contract extension (longer duration). Thus, PPP managers will likely take actions to work on that direction. The public sector management units do not get any return from better road safety outcomes.
4) Road privatization is generally associated with strict regulatory frameworks. Recent PPPs must work within a strict regulatory framework that involves quality measurement, for instance, the firm's transparency, implementation of policies to reduce the accident or congestion rates, treatment of winter viability, reduction of queues at tolls and availability of real-time information, among others. It is often remarked that private ownership and regulation are substitutes. The privatization of motorways is usually associated with more and increasingly sophisticated regulations, to keep control of this strategic asset. Conversely, if the owner is the public sector there is less need for regulation given that the state has more leeway for arbitrariness (Albalate et al., 2009). Concession contracts establish a set of indicators of status and quality of service that oblige the concessionaire to guarantee the maintenance of the infrastructure in the most optimal conditions for the user. Also, in the bidding process, an important part of the valuation given to candidates is derived from the technical, functional and static characteristics of roads. Private management of roads allows for the stipulation of quality standards incorporated in the contract terms and measurable by means of objective parameters, resulting in a better quality of service.

[23] See Albalate et al. (2017) for a categorization of vertical integration among different PPP contract types.

In all, the role of risk and incentives is more relevant for PPPs than for the public sector. PPPs are special purpose vehicles created with the only aim to build and operate the highway under a contractual framework. This means that dealing with adverse risks is essential for single-project PPP managers than for public sector managers. The public sector has a large portfolio of projects, can better diversify risks, does not face the prospect of bankruptcy but must deal with competition for the public funds. All this do restrict the incentives of the government to increase the safety and quality.

All these channels may imply that private operators take actions or decisions that favor road safety, which may provide arguments for going private. Nonetheless, public operators might also learn from the better actions and performance of private operators in order to improve their outcomes, without going private. In any case, we defer to further research the better understanding of the safety differences between PPPs and traditional public sector procurement and management.

7. Conclusions

In this paper we provide the first empirical examination of the role of PPPs on road safety outcomes for a national highway network. After confirming that highways with high quality road design are safer than those with low quality road design, disregarding the production model and realizing that a true comparison between models must consider homogeneous design quality, we found heterogeneous effects depending on the production model. Our results show that highways under PPP schemes are positively correlated with better road safety outcomes for the high-quality standard (road design) highways. The annual number of accidents with victims and the annual number of victims on highways is lower under Public-Private Partnerships. Results seem to be also favorable for private models on highways with low quality road design, but only in the case of the number of victims. The differences between PPPs and public models in low-quality roads is not statistically significant for the number of accidents, so we should be cautious about the implications of our results on the superiority of PPPs for this kind of road. To some extent, we find more support to Build-Operate-and-Transfer PPPs than to Rehabilitate, Operate and Maintain PPPs in Spain. This result is, however, explained by the assignment of these kinds of contracts specifically to the first generation of highways.

These findings are important in several ways. Firstly, in order to promote road safety the infrastructure should support high road design characteristics. The design and initial construction are crucial because once the road is built it is very costly and difficult to modify the geometrical design. Thus, our results indicate that beyond the road management model, the most important factor in determining road safety outcomes is the quality standard of the road infrastructure. Secondly, for the same quality standard, we found a positive correlation between PPPs and better road safety outcomes. Note, however, that given the limitations of our analysis that make impossible to fully isolate the effects of private management it is not possible to claim causality without any reasonable doubt, so our findings should be taken cautiously given that confounders and alternative explanations cannot be rejected yet. Being this said, we believe this finding merits further research and analysis with better and more appropriate methodological approaches to disentangle any other confounding factor and to better understand the mechanics through which management models may affect road safety outcomes.

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D. Albalate: Associate Professor of Economics at University of Barcelona (Spain). His main research interests are Privatization and Regulation, Public Policy Formation and Evaluation, Infrastructure and Transportation. Has published research articles in international scientific journals on Concessions, Public-Private Partnerships, infrastructure policy and road safety.

P. Bel-Piñana: Corresponding author. Lecturer at University of Barcelona (Spain). Her main research interests are concessions in infrastructure, PPP in road transport, road safety and transport policy implications.