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The influence of economic incentives linked to road safety indicators on accidents: the case of toll concessions in Spain

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ABSTRACT

The goal of this paper is to evaluate whether the incentives incorporated in toll highway concession contracts in order to encourage private operators to adopt measures to reduce accidents are actually effective at improving safety. To this end, we implemented negative binomial regression models using information about highway characteristics and accident data from toll highway concessions in Spain from 2007 to 2009. Our results show that even though road safety is highly influenced by variables that are not managed by the contractor, such as the annual average daily traffic (AADT), the percentage of heavy vehicles on the highway, number of lanes, number of intersections and average speed; the implementation of these incentives has a positive influence on the reduction of accidents and injuries. Consequently, this measure seems to be an effective way of improving safety performance in road networks.

Keywords**:** Interurban toll highway; concession contract, performance-based indicators, incentives; road safety incentives; road accident; negative binomial regression.

Highlights:

> Safety based incentives are becoming popular to reward or penalize highway private operators in toll concession contracts. > Most concession contracts link these incentives (bonuses and penalties) to indicators based on accident, injury and fatality rates. > This paper finds that safety incentives have a statistically significant influence on road safety. > Ceteris paribus, there are more accidents and injuries on highway segments without incentives than on highway segments with incentives.

1. Introduction

In the past few decades road management approaches have substantially evolved all over the world. Traditionally, construction, maintenance and operation of road networks used to be handled by in-house personnel employed by government-owned road agencies. However, in recent years many road authorities have tended to implement models aimed at contracting out the management of the whole, or part, of the road life-cycle activities with private companies. The aim of contracting-out is to take advantage of the greater efficiency that is expected to be provided by the private sector in delivering public services.

One of the most popular ways of contracting-out road management is through toll concession contracts. This type of contract consists of transferring the management of the life-cycle activities of a certain road stretch to a private consortium that will be entrusted with the design, construction, financing, management and operation for a fixed or variable period of time that is contractually agreed in advance. The private concessionaire will obtain the revenues to finance road management expenses mostly from tolls charged to road users. Toll prices and the way to update them over time are usually set in the concession contracts.

Other kinds of sophisticated contracts have also been proposed during this time, such as Public Private Partnerships (PPPs), including the Design Build Operate Finance (DBFO) model implemented in the United Kingdom, have been developed to contract-out road management activities. One of the principles of PPP contracts was to pay the contractor according to the service provided. To that end, a set of performance-based indicators were defined in these contracts in such a way that a better fulfilment of these indicators would entitle the contractor to receive a higher payment. These performance-based indicators intend to reflect the quality of service to the user by measuring lane availability, state of the pavement and signalling, road safety, etc.

These indicators incorporated in PPP contracts have also been introduced in some toll highway concession contracts through economic incentives associated with the fulfilment of performance-based indicators to encourage contractors to reach the highest level of service. The term incentive refers to any kind of economic profit with which the concessionaire will be rewarded according to the contract if its performance is good enough. The main reason behind introducing incentives in toll concession contracts is to encourage the contractors to provide a better service by aligning the social and the private benefits in order to produce a more efficient outcome to society.

Incentives related to performance-based indicators in PPPs are defined in such a way that if the contractor performs below a certain quality threshold, the contractor will be penalized while if the contractor does it above a certain quality threshold, it will be rewarded (Rangel, 2011; Vassallo, 2007). Some of the most common performance-based indicators introduced in toll highway concession have to do with congestion, road accidents, pavement surface conditions, impact on the environment, and availability. Toll concession contracts usually specify the rewards and penalizations clearly in their terms.

In this paper, we will focus on the economic incentives in toll highway concessions linked to explicit road safety indicators. In Spain, some concessionaires are entitled to extend their concession terms if their accident levels are further below the average of highways with similar

characteristics in terms of alignment, AADT, etc.
Spain turns out to be a good example for this research because the country has extensive experience in managing and financing highways through PPPs. Most of the PPPs have been put into effect through concession contracts that have a long tradition in Spanish administrative law. The first highway concessions in Spain were awarded in 1967 (Izquierdo and Vassallo, 2004). From the beginning, highway concessions in Spain were granted to private consortia through competitive bids. Most of the highway concessions awarded in Spain have been toll highways.

The aim of this research is to analyze whether the economic incentives to improve road safety in toll concession contracts implemented in Spain are effective at improving road safety. To this end, we used an econometric model based on negative binomial regressions to analyze the effect of safety incentives on accidents in toll highways. The results indicate that for some of the models tested ceteris paribus there is a statistically significant difference in the number of accidents and injuries on road segments without incentives when compared with other segments with incentives.

This paper is organized as follows: In section 2, we describe the practical experience in the introduction of safety-based incentives in road management contracts in different countries and particularly in toll highway concessions in Spain. In section 3 we provide the literature review of models explaining the variables influencing road safety ratios. In section 4 we explain the variables and the data sources employed for the empirical analysis. In section 5 we develop the methodology and explain the results. In the sixth and last section, we discuss the results and highlight the main conclusions.

2. Safety-based incentives in road management contracts

2.1 Cross-country experience

Europe is the world's region with the longest tradition of incorporating economic incentives linked to safety-based indicators in road management contracts such as PPPs or toll concessions. This happened for instance in Spain, Finland, Hungary, Norway, Portugal and the United Kingdom. Italy introduced price-caps tied to road safety indicators in such a way that the concessionaire is allowed to set higher tolls if safety ratios are better (Vassallo et al., 2009).

Safety-based incentives are characterized by three attributes: first, the indicator used to measure safety performance; second, the thresholds above or below which bonuses and penalties are implemented; and third, the way economic incentives are put into effect.

Safety indicators play a key role in providing information on performance. They are often used to define safety priorities or reach action plans based on benchmarking. The design of the road safety indicators is quite heterogeneous. There are differences both in the variable adopted to measure the outcome and in the final formula employed. Most of the contracts include number of injuries, number of fatalities or a combination of number of light accidents, serious accidents and fatal accidents to build the indicator (Rangel, 2011).

It is a generalized practice to include exposure to risk expressed by traffic (risk expressed by traffic on the road). In fact, only the first British shadow toll road contracts did not introduce traffic, at the time they used absolute number of personal injury accidents as indicator. The rest of the contracts with safety incentives took into account this factor in some way. Very often, the initial accident data is divided by the annual traffic—usually measured in terms of millions or billions of vehicles-kilometres. E18 road (Muurla–Lohja) in Finland, the M6 road in Hungary, several toll highways in Portugal (the IP-4, for instance) and the latest roads awarded in Spain use this methodology. The advantage of introducing the exposure to the risk (traffic) explicitly is that distortions in road safety results are reduced. However, the number of accidents, injuries and fatalities do not necessarily increase linearly with traffic flow, drivers may be more careful in denser traffic. Although the number of vehicles at risk is proportional to traffic flow, the number of accidents, injuries and fatalities should not necessarily be proportional to the traffic volume (Aljanahi et al, 1999).

Regarding the threshold above or below which incentives are to be applied, many contracts include a process for comparing highways with similar characteristics in terms of traffic, number of carriageways, etc. With this approach it is possible to control the global evolution of casualties by many factors, most of them not managed by the road operator. Some road contracts where thresholds are set in this way are the E-18 road (Grimstad – Kristiansand) in Norway, and some roads awarded in the United Kingdom (for example, A1 & M25).

Regarding the way of rewarding the contractor, we have identified two major ways of doing it: extending the term of the contract, as it is usually done in toll highway concession contracts in Spain; or modifying the corresponding toll or fee.

2.2. Toll highway concessions in Spain

Historically Spain experienced several shifts in the way different governments understood road management and financing. As a consequence of that, we now find different types of roads and highways according to the way they are managed and operated. The trunk network is mostly managed in two different ways: free highways, which are built, managed and operated by the central and regional governments (11,000 km); and toll highways (3,016 km), which are managed by private companies through concession contracts (Ministerio de Fomento de España, 2009a). In the last few years some governments in Spain, particularly regional governments, have started to develop PPP contracts based on shadow-toll (Vassallo and Pérez de Villar, 2010; Rangel, 2011) and availability payment approaches (Harding et al., 2010). However, these highways—some of them not yet operational—still represent a small percentage of the trunk network.

Spain has extensive experience in managing and financing highways through concession contracts that have a long tradition in Spanish administrative law. From the beginning, highway concessions in Spain were competitively awarded to private consortia through competitive bids. This is substantially different from the situation in other European countries such as France and Italy, who directly entrusted toll highways to public-private companies which were mostly controlled by the government. The Spanish approach has been successful because of two reasons. First, the strong competition between bidders ensures important efficiency gains. And second, the simplicity of the tender enabled the government to have the toll highway available for the users in a short time (Vassallo and Izquierdo, 2010).

In this paper we will focus our analysis only on toll highway concession for several reasons. First, they have similar management approaches. Second, road alignments and maintenance requirements are fairly similar across toll highway concessions. Third, previous research (Rangel, et al. 2012) has already focused on evaluating the influence of road management (toll vs. free highways) on different safety ratios in Spain. And fourth, in this paper we want to focus on the effect of incentives, which at the time of writing were only implemented in some toll highway concessions.

Toll concession contracts awarded from 2002 onwards were characterized by introducing incentives linked to the management and maintenance of highways. The contractor must meet certain performance indicators such as state of the pavement (roughness and skid resistance), congestion (average travel time), road accidents, queuing in toll plazas, quality perception of users measured through annual surveys conducted by the road authority and vehicle breakdown (services, availability and response time).

For safety performance, the indicators used were the Risk Index (RI), and the Mortality Index (MI). The thresholds and incentives defined in the contracts work in the following way:

- The concessionaire will be entitled to one additional year of the concession contract if, at least, 90% of time during the 35 years of the concession, both RI and MI remain between 90% and 75% of the annual average value of those toll highway concessions with similar Annual Average Daily Traffic (AADT) (+/- 5,000 vehicles/day).

- The concessionaire will be entitled to two additional years of the concession contract if, at least, 90% of time during the 35 years of the concession, both RI and MI remain below 75% of the annual average value of those toll highways with similar Annual Average Daily Traffic (AADT) (+/- 5,000 vehicles/day).

The incentive is expected to materialize in additional profits for the concessionaire since two additional years would entail additional revenue much higher than the additional maintenance expenditure. The bonus, however, is not as big as it appears to be at first sight because, if the bonus was going to be given it would take place at the end of the concession period. In order to rightly quantify for the extra-profit produced by this incentive, we have to calculate its present value by discounting the net revenues of the additional years at the weighted average cost of capital (WACC), which for concessions in Spain is around 7.5%. The calculation, which would vary depending on the traffic levels at the end of the concession period, shows that the incentive would be able to increase the present value of the cash-flow no longer than 2% compared to the scenario where the bonus was not ultimately obtained. This implies that the incentive is not expected to have a great influence on the final value of the concession.

Other European countries that have been introducing safety-based indicators in road management contracts implemented much higher incentives. Vassallo et al. (2009) found that in some management contracts such as the E18 Muurla-Lohja in Finland, incentives were ten times higher than they are in toll highway concessions in Spain.

3. Models to evaluate the influence of certain variables on road safety: a literature review

In this section we conduct a literature review to know the effect of certain variables that influence road safety. In addition, we show the latest trends in road safety modelling.

Although the ordinary least square regression model (OLS) is applied in the road safety literature (Hakim et al., 1991; Zlatopher, 1988), some other authors have questioned its suitability (Jovanis and Chang, 1986; Miaou et al., 1992; Miaou and Lum, 1993). This method assumes that the dependent variable is continuous and normally distributed with a constant variance. This technique lacks the distributional property necessary to describe adequately random, discrete and non-negative events such as traffic accidents. Consequently the statistic results derived from these OLS models are questionable. One concern in using multiple linear regressions is that the number of traffic accidents may not have a normal distribution but instead follow a Poisson distribution.

The relationships using the Poisson distribution have been developed by means of the technique of Generalized Linear Models (GLMs). The Poisson distribution represents a significant advance to describe traffic accident data. However, one of the stated limitations of the Poisson regression model is that it presupposes that the variance of the accident frequency is equal to its mean when in practice the variance of the traffic accident data tends to be larger than the mean. This extra variation is known as overdispersion and, if it is present, the estimated coefficients may be biased and inefficient. Overdispersion does not affect the values of the model parameters, but can affect the Wald statistics or likelihood statistics for testing the hypothesis about the parameters. To overcome this problem the more suitable approach is the negative binomial (NB) regression model.

Zero Inflated models are also an option when there are excessive zeros in the database. These models represent an alternative way to handle data characterized by a significant amount of zeros or more zeros than the one would expect in a traditional Poisson or NB (Carson and Mannering, 2001; Lee and Mannering, 2002; Qin et al., 2005). However, Lord et al. (2005, 2007) have questioned the validity of these models in most safety modelling circumstances.

Bayesian models have also been applied in crash analysis (Huang et al., 2008; Haleem et al., 2010; Haque et al., 2010; Pei et al., 2011). However, some authors seem to suggest that the Poisson regression and the NB models possess most of the desirable statistical properties in describing vehicle accident events. The Poisson and NB regression models have been widely used to analyze count data where the dependent variable is discrete and defined for non-negative integers corresponding to the number of events occurring in a given intervals (Miaou and Lum, 1993; Noland and Oh, 2004; Chang, 2005; Caliendo et al., 2007; Arenas et al., 2009). In light of these findings, negative binomial models were applied in this study.

Accident rates and accident frequency are the most common dependent variable used by predictive models. The relationship between accident rate or accident frequency and traffic flow show a great variation in their results.

Many studies show a statistically significant relationship between accident rate and accident frequency with traffic flow. Results show that accident rate decrease with increasing traffic flow (Martin, 2002; Hauer and Bamfo, 1997); and accident frequency increases with traffic flow (Mohamed et al., 2000; Persaud et al., 2000; Anastasopoulos and Mannering, 2009).

Other studies have been carried out in recent years to establish the relationships between accidents and the effect of different vehicle mix (Tay, 2003; Hiselius, 2004; Wong et al., 2007; Abdel-Aty and Haleem, 2011, Pei et al., 2011), the frequency of intersections (Ivan and

O'Mara, 1997), environmental factors (Chang, 2005; Caliendo et al., 2007; Fridstrøm et al., 1995; Shankar et al., 1995), geometric infrastructure characteristics (Chang, 2005; Hauer et al., 2004), number of lanes (Noland and Oh, 2004; Chang, 2005; Milton and Mannering, 1998), and speed limits (Fridstrøm et al., 1995; Ossiander and Cummings, 2002; Wong et al., 2005).

The next section describes the data set used for modelling.

4. Data selection and description of the variables adopted

The models we calibrated in this paper are based on data from 2007, 2008 and 2009. In 2007, there were 2,972.4 km of toll highways in Spain, in 2008 there were 2,997.1 km of toll highways and in 2009 there were 3,016.3 km of toll highways (Ministerio de Fomento de España, 2007a, 2008a, 2009a).

The data used for our empirical model came from two different sources: police-reported accident data supplied by the Ministry of Internal Affairs, and traffic data supplied by the Ministry of Public Works. On the basis of these databases we built up the database for this research by combining both accident data and traffic data.

The sample for the models was made up of road segments from the interurban toll highway concessions in Spain set up by the road authority, with an average length of road stretch of 9.60 km. The total number of segments and the length by year are presented in Table 1.

Table 1
Road segment data.

Year	Segments		Length (Km)
	Nº	%	
2007	237	34	2,222.62
2008	206	30	1,959.93
2009	253	36	2,494.06
Total	696	100	6,676.61

A total of 696 road segments were extracted out of 836 from the 2007, 2008 and 2009 traffic map, after selection criteria based on complete information for traffic flow and infrastructure variables. We considered stretches with and without accidents to avoid selection bias. The study includes only toll highways. We did not get the whole data from the Spanish toll highway network because not all the information that we needed was available. Therefore, the road segments in our database may or may not coincide over the years.

In order to design the model, we intended to identify a set of exogenous variables that might potentially influence road safety ratios and do not depend on the concessionaire's ability to manage the road through a better design or maintenance. We did not include variables related to the road alignment or signalling for two reasons. The first one is that we decided to incorporate just those endogenous variables that do not depend on the concessionaire's ability to manage the road. Concessionaires in Spain are free to design the alignment and signaling system as they want within a set of minimum standards. They are free for instance to use standards above the minimum requirements if they think this will be better for the operation of the road. The second

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reason is that information about alignment characteristics of the road is not public information in Spain.

The exogenous variables that we used for this model are related to traffic flow such as (1) Average annual daily traffic (AADT), (2) Percentage of heavy goods vehicles (%HGV) and (3) Average speed (SPEED); and certain characteristics of infrastructure such as (4) Length of the road stretch (LENGTH), (5) Number of lanes (LANES) and (6) Number of intersections (INT). Finally, we selected a dummy variable (7) Incentives (INC), which evaluates whether the private contractors have incentives or not to improve safety if the highways are managed by them.

Data for AADT, %HGV, SPEED and length of the stretches was available from the Ministry of Public Works (Ministerio de Fomento de España, 2007b, 2008b, 2009b). Traffic flow is counted as the number of vehicles through a fixed section in both directions. Portable counting instrument and permanent inductive loop were used to count the number of vehicles. %HGV was calculated from HGV and AADT, and LANES was calculated using the number of lanes and the length of each stretch. LANES is the mean weighted by length.

The number of intersections for each stretch (INT) was obtained from the traffic map (Ministerio de Fomento de España, 2007b, 2008b, 2009b) by using Geographic Information System (GIS), the analyses was performed using ArcGis 10.1 The GIS application was used as a tool to integrate the information in two databases. The first database included the alphanumeric information about intersections and the second one included geographical information on a digital map of toll highways in Spain. Each stretch of the sample was analyzed using the GIS application to count the number of intersections.

We analyzed each concession contract in force in 2007, 2008 and 2009 to know which segments had road safety incentives (INC). The first Spanish concession contract awarded with implementation of road safety incentives was in 2002. We analyzed all of the contracts in place from 2002 to 2009. All of the contracts considered in the study have the same kind of incentives (enlargement of the contract duration), and they are measured in the same way as explained in section 2.2. INC is a dummy variable, which indicates the presence or not of incentives to improve safety in each stretch.

Data for accidents was supplied by the Ministry of Internal Affairs (Ministerio del Interior, 2007-2009). For this study, the response variables are the yearly number of accidents, injuries and fatalities. Hence, three different models were analyzed.

The descriptive statistics of endogenous and exogenous variables are provided in Table 2 and Table 3. The first descriptive statistics for the traffic variables AADT and %HGV and length indicated the need to use the logarithm transformation to expand low values and contract high values. The measures of central tendency take similar values through logarithm transformation. The natural logarithms of AADT, %HGV and length were used to minimize heteroskedasticity. After transformation, the range of values (maximum and minimum) of those variables were substantially reduced. The standard deviation is very low compared with the mean; therefore, the distribution was further improved. However, the chi square goodness of fit test rejects the null hypothesis that the variables follow a normal distribution.

Table 2
Descriptive statistics of endogenous variables.

Years	Variables	Mean	S.D	Minimum	Maximum	Sum
2007	Accidents	3.38	4.49	0	29	802
	Injuries	6.39	9.27	0	70	1,515
	Fatalities	0.25	0.61	0	4	60
2008	Accidents	2.07	4.16	0	27	427
	Injuries	3.64	7.51	0	50	24
	Fatalities	0.12	0.52	0	5	708
2009	Accidents	2.80	4.17	0	21	708
	Injuries	4.97	7.75	0	46	1,257
	Fatalities	0.09	0.43	0	5	24

Table 3
Descriptive statistics of exogenous variables.

Years	Variables	Mean	S.D	Minimum	Maximum	Sum
2007	AADT	21,566.27	15,660.01	1,608	71,198	-
	%HGV	12.87	5.97	3.56	34.13	-
	SPEED	122.36	13.83	89.40	174.50	-
	Length	9.38	7.01	0.28	43.26	2,222.62
	LANES	4.09	0.44	4	8	-
	INT	1.23	0.77	0	3	-
	INC	0.18	0.38	0	1	42
2008	AADT	21,868.18	15,110.88	1,732	66,296	-
	%HGV	12.45	5.89	2.99	32.61	-
	SPEED	112.33	7.00	73.00	120.70	-
	Length	9.51	7.17	0.13	42.84	1,959.93
	LANES	4.14	0.54	4	8	-
	INT	1.24	0.75	0	4	-
	INC	0.22	0.41	1	0	45
2009	AADT	22,790.14	16,373.35	1,370	73,175	-
	%HGV	12.37	9.35	2.36	54.23	-
	SPEED	112.77	6.42	73.00	120.70	-
	Length	9.86	6.88	0.13	29.05	2,949.06
	LANES	4.20	0.65	4	8	-
	INT	1.27	0.76	0	3	-
	INC	0.10	0.30	0	1	25

5. Methodology and modelling results

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In this paper we applied NB regression models to know the relationship between safety incentives given to the concessionaires and road safety in toll highways in Spain, controlling by other variables related to traffic flow and characteristic of the road stretches which are not manageable by the concessionaire.
Before modelling the relationship between safety incentives and accidents, injuries and fatalities in toll highways, we tested the hypothesis that toll highway stretches with safety incentives present a lower number of accidents, injuries and fatalities.

5.1 Test of hypotheses

The aim of testing the hypotheses is to compare toll highway stretches with incentives and toll highway stretches without incentives. Since different stretches do not have the same traffic and same length, we used accident, injury and mortality indexes divided by millions of vehicle-kilometres. These indexes were calculated with the purpose of being able to compare toll highway stretches with incentives with toll highway stretches without incentives for each of the three years of the sample: 2007, 2008 and 2009.
The accident index is defined as $AI = \frac{\text{number of accidents} * 10^6}{\text{length} * \text{AADT} * 365}$; the injury index is defined as $\text{II} = \frac{\text{number of injuries} * 10^6}{\text{length} * \text{AADT} * 365}$; and the mortality index is defined as $\text{MI} = \frac{\text{numer of fatalities} * 10^6}{\text{length} * \text{AADT} * 365}$.

The statistical distribution of these three metric measures is highly skewed and leptokurtic. It means that most of the stretches have a low number of accidents, while only a relatively small set of stretches have a high number of accidents. This fact limits the possible statistical tests that we can use to compare toll highway stretches with incentives with toll highway stretches without incentives. In the end, we decided to compare stretches using the Wilcoxon Signed Rank test (Wilcoxon, 1945), which is non-parametric and is not affected by skewness in the distribution. The test compares two samples for each year under the null hypothesis that both samples have the same median value. The alternative hypothesis is that both medians are different.

Table 4 presents the comparison of toll highways with incentives and without incentives using the Wilcoxon Rank Signed test. In this test, the null hypothesis is that there is no difference in the number of accidents, injuries or fatalities. The test tries to falsify this null hypothesis, to find out whether there is a statistical significant different between toll highways with safety incentives and toll roads without safety incentives.

The table shows the p-value of the hypothesis test, considering 95% level of confidence. Thus, if the p-value is greater than 0.05 we cannot reject the null hypothesis so we cannot claim that there is difference between toll highway stretches with incentives and toll highway stretches without incentives. However, if the p-value is equal or lower than 0.05 we reject the null hypothesis, and conclude that the median of accidents is different between toll highway stretches with incentives and toll highway stretches without incentives. For informative purposes, we also show the mean value for toll highways with and without incentives.

Summarizing the results, we found evidence that during 2008, toll highway stretches with safety incentives in Spain had a statistically significant lower number of accidents, injuries and fatalities compared to the toll highway stretches without incentives. Besides, in 2009 the accident and injury indexes were statistically lower in PPP stretches with incentives compared with toll highway stretches without incentives.

In the rest of the cases, we did not find evidence of differences, that is, we could not reject the null hypothesis, probably due to the limited size of the sample corresponding to toll roads with safety incentives. Compared to the overall population of toll road stretches, there are relatively few toll highway stretches with incentives in the Spanish highway network. This asymmetry in the sample is probably the cause of the results of the tests that do not reject the null hypothesis. However, that does not mean that the null hypothesis is true, it only means that test is inconclusive. Indeed, the harmful effects of accepting the null hypothesis in the absence of enough evidence has long been known in transport research (Hauer, 2004).

In any case, the data clearly supports the hypothesis that in 2008 and 2009 toll highways with safety incentives were safer than toll highways without incentives. In 2007, and in the case of fatalities in 2009, our results are not conclusive. Because of that we decided to apply a negative binomial regression which is described in the next subsection.

Table 4
Average values of the indexes AI, II and MI for toll highways with and without safety incentives (p-values in brackets)

	Inc.	No inc.	p-value	Inc.	No inc.	p-value	Inc.	No inc.	p-value
		2007			**2008**			**2009**	
Accidents	10^{-5}	0.061	(0.28)	$3\ 10^{-6}$	0.041	(0.00)	$1.2\ 10^{-5}$	0.041	(0.00)
Injuries	$3\ 10^{-5}$	0.110	(0.28)	$4\ 10^{-6}$	0.069	(0.00)	$2\ 10^{-5}$	0.072	(0.00)
Fatalities	$4\ 10^{-6}$	0.003	(0.28)	0	0.002	(0.04)	$8\ 10^{-7}$	0.001	(0.08)

5.2 Modelling accidents, injuries and fatalities

Negative binomial regression (NB) was applied to determine the relationship between accidents (model 1), injuries (model 2) and fatalities (model 3) and traffic variables, number of lanes and number of intersections for each stretch, average speed and road safety incentives offered to the concessionaire. In this work the response variables are respectively accidents, injuries and fatalities.

Table 5 summarizes the NB results. The significance of coefficients was checked using Wald statistic (in brackets), which rejects the null hypothesis that the coefficient is zero with a level of 95% confidence.

In order to select the best estimation models, Akaike Information Criterion (AIC) (Akaike, 1974) and the Bayesian Information Criterion (BIC) (Schwarz, 1978) were used. AIC and BIC identify the best approximating model among a class of competing models with different numbers of parameters. The smaller the value of AIC and BIC the better the model. Other measures were also evaluated such as deviance, log-likelihood and Pearson chi-square statistics.

To measure the overall goodness-of-fit statistics, the log-likelihood ratio $\rho^2(= 1 - LL(\beta)/LL(0))$ value of the model (analogous to R-square test in linear regression

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models) was used. $LL(\beta)$ is the log-likelihood at converge, and $LL(0)$ is the log-likelihood at zero. It is an indication of the additional variation in accident frequency explained by the model to the constant term alone (Fridstrøm et al., 1995).

Table 3 shows that all the variables have the expected sign according to the literature review. A positive sign indicates an increase in the number of accidents, injuries and fatalities whereas a negative sign indicating a decrease. Besides, all variables were statistically significant at 99.9% and 99% levels in the accident and injury models.

Accidents increase with the increase of AADT. The coefficient sign of AADT is positive, suggesting that greater AADT is associated with higher accidents, injuries and fatalities. A similar conclusion was reached for the length. The longer the length of the road section, the more likely accidents, injuries and fatalities will occur on theses sections. These results confirm the hypothesis proposed by Mohamed et al. (2000), Persaud et al. (2000) and Anastasopoulos and Mannering (2009).

The expected number of accidents and injuries decreases with increasing percentage of trucks. %HGV was found to be statistically significant for the accident and injury models. The coefficient signs are negative for all models. This result is in line with Hiselius (2004). The coefficient of Log(%HGV) in the fatalities model is smaller in magnitude than the same coefficient in accident and injury models. This could be related to the reduction of speed that heavy vehicles impose on light vehicles in the traffic flow. The crashes are much more likely to result in fatal outcomes in the presence of %HGV than if the crashes do not involve a higher %HGV in the traffic stream.

According to the results of the model, accidents in toll highways slightly decrease with the increase of average speed, which is not a common result even though it is in line with some authors such as Navon (2013). A reason to explain this result may be the fact that the standard deviation of the variable SPEED in our database is very low so the range of speeds for the segments is short. The coefficient sign of SPEED is negative for all models, but its value turns out to be very small (-0.011, -0.014 and -0.001) so the effect on accidents, injuries and fatalities seems to be very low. This variable was found to be statistically significant for the accident and injury models, but not for fatalities.

The INC variable showed the expected negative sign in all models, suggesting that establishing incentives in the contracts is associated with lower accidents, injuries and fatalities. This variable was found to be statistically significant for the accident and injury models, but not for fatalities. There are more accidents and injuries on highway segments without incentives than on highway segments with incentives.

The results show that road safety tends to improve over the years. In 2007 there were more accidents, injuries and fatalities than in 2008 and 2009. This has been a general trend in Spain in the last few years because the government has been increasing the measures to reduce accidents through a stricter penalty points system. In general terms, the penalty points system is a system through which road safety authorities deduct points of the driver’s license of the person committing certain traffic violations. The use of this system came into force in July 2006 and was enacted in 2005 as Law 17/2005 of July 2005.

A larger number of LANES is associated with more accidents, injuries and fatalities. The reason for this is that in highways with more lanes there are more interactions between drivers so the probability of crashing increases. This result is in line with the findings by Noland and Oh (2004), Chang (2005) and Milton and Mannering (1998).

The coefficient sign of INT is positive for all models, suggesting that a larger number of intersections are associated with more accidents, injuries and fatalities. This variable was found to be statistically significant for the accident and injury models. These results confirm the hypothesis proposed by Ivan and O'Mara (1997).

Table 5
Negative binomial regression models for accidents, injuries and fatalities.

Independent Variables		Coefficients (Wald statistics)		
		Accidents (model 1)	**Injuries (model 2)**	**Fatalities (model 3)**
Constant		-5.741 [a] (30.307)	-5.357 [a] (30.539)	-12.159 [a] (23.410)
Log(AADT)		0.738 [a] (98.676)	0.780 [a] (128.817)	0.742 [a] (14.699)
Log(%HGV)		-0.837 [a] (44.611)	-0.905 [a] (57.133)	-0.346 (1.662)
SPEED		-0.011 [c] (5.700)	-0.014 [b] (11.031)	-0.001 (0.019)
INC	stretch with incentives	-0.683 [a] (16.086)	-0.757 [a] (23.522)	-0.033 (0.006)
	stretch without incentives	0	0	0
YEAR	2009	-0.690 [a] (27.626)	-0.901 [a] (52.261)	-1.339 [a] (17.839)
	2008	-0.845 [a] (36.828)	-1.090 [a] (68.504)	-0.963 [c] (9.386)
	2007	0	0	0
Log(length)		0.915 [a] (183.579)	0.962 [a] (242.037)	1.229 [a] (44.456)
LANES		0.241 [b] (8.496)	0.316 [a] (15.997)	0.365 [c] (5.230)
INT		0.210 [b] (10.427)	0.229 [a] (14.394)	0.211 (1.899)
AIC		2,683.878	3,305.914	557.309
BIC		2,729.332	3,351.367	602.763
Deviance (D^p)		795.545	1,058.324	300.310
Pearson Chi-Square (X^2)		700.180	921.193	691.236

Log-likelihood at converge	-1,331.939	-1,642.957	-268.655
Log-likelihood at zero	-1,520.676	-1,889.159	-317.204
$\rho^2 = 1 - LL(\beta)/LL(0)$	0.12	0.13	0.15
Overdispersion parameter (k)	1.160	1.543	1.008

[a] p<0.001
[b] p<0.01
[c] p<0.05

Elasticity values computed from the three models are displayed in Table 6. Elasticity shows the change in probability when an explanatory variable changes. As AADT, %HGV and length were estimated as logarithmic models, the elasticities are equivalent to the value of the coefficient estimated. 10% increase in AADT would increase accident frequencies in 7.4%. The results show that length has the greatest effect on the models estimated among all the independent variables.

Table 6
Elasticity estimates for the accident, injury and fatal models.

Variables	Elasticities		
	Accident	Injury	Fatal
AADT	0.74	0.78	0.74
%HGV	-0.84	-0.91	-0.35
Length	0.92	0.96	1.23

6. Discussion and Conclusion

After testing the hypothesis that incentives can be related to an improvement in road safety in toll highways, we found that the hypothesis is true for two of the years we analyzed, 2008 and 2009 (with the exception of fatalities in 2009), but it cannot be shown to be true or false for 2007. The main reason behind this result might be that the sample is not big enough to provide conclusive results. Compared to the overall number of road stretches in 2007, the number of stretches with incentives is still small to reach enough statistical significance.

However, the results from the NB regression models demonstrate that toll highways with safety incentives are safer than toll highways without incentives in 2007, 2008 and 2009. The road safety incentive variable was found to be statistically significant for the accident and injury models, but not for the fatality model. This result proves that indicators related to accidents and injuries reflect better the ability of concessionaires to influence safety ratios than fatality ratios.

Overall, from our research we can conclude that there is enough evidence to claim that safety incentives given to private concessionaires seem to have a positive influence on road safety ratios. The reason why this evidence is not so strong is likely to be the fact that road operators have low incentives for road safety in Spain. As we have already mentioned earlier in the paper, safety incentives in Spain are not a substantial revenue source for the private sector so they are not large enough to encourage concessionaires to adopt strong measures to improve road safety. Consequently concessionaires are not expected to invest a lot in road safety improvements.

A hypothesis derived from the results of this paper is that bonuses and penalties related to road safety should be greater to achieve a more notable reduction of accidents. In this respect, an important direction for future research would be to analyze the optimal size of the economic incentives set up in these types of contracts.

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