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Shifting Death to Their Alternatives

The Case of Toll Motorways

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Abstract

Interest in the use of tolls to fund and regulate demand on motorways has revived in recent years. However, less attention has been paid to the road safety effects of this policy. Although toll motorway quality is equal to or above that of free motorways, charging users shifts some traffic to low-quality, adjacent alternatives. This study tests whether charging for the use of the better road negatively affects road safety in the worst adjacent road in motorway industries where optimal pricing is not implemented. Results confirm the hypothesis, finding a toll elasticity of accidents involving victims of 0.5.

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1.0 Introduction

Interest in the use of tolls has been renewed over the last decade. In urban environments, tolls are mainly used to fight congestion costs while in inter-urban routes, particularly in the cases of motorways, bridges and tunnels, they play a double role: both funding infrastructure and regulating traffic.

Concerns about congestion, distributional effects and political acceptability are the main aspects to which policy makers attend when they consider whether to use tolls to regulate entrance to big cities or city centres. Indeed, many recent publications reveal the benefits of congestion charges in practice (Santos, 2004; De Palma *et al*., 2005; Leape, 2006; Santos and Gordon, 2006; Hensher and Puckett, 2007), while others examine the public problem of road-pricing acceptance (Brownstone *et al*., 2003; Fujii *et al*., 2004; Raux and Souche, 2004; Jaensirisak *et al*., 2005; Shade and Baum, 2007).

In the case of inter-urban roads, governments usually look to tolls as a solution to budget constraints, especially when investment needs are large. Tolls instituted for these reasons are usually associated with the private sector involvement and the use of standard Build-Operate-and-Transfer franchise contract schemes (Engel *et al*., 2004).

The seminal works of Pigou (1920), Knight (1924), Walters (1961) and Vickrey (1969) established that externalities should be internalised by charging road users in order to obtain allocative efficient outcomes. The concern was mainly to fight congestion costs, and less attention was devoted to externalities that have recently gained increasing attention such as environmental effects, noise and road accidents (Verhoef *et al*., 1995). Indeed, toll setting has usually focused on fighting congestion and funding infrastructure and has ignored road safety outcomes.

In fact, the decision to use tolls has never been challenged on the basis of effects on road safety. Nevertheless, charging tolls on the best roads may shift use by those unwilling to pay for the tolled road (so-called '*rat-running*' drivers) even when its quality is better than that of alternative roads. May and Milne (2000) assert that charges may encourage widespread diversion onto minor routes. This effect, which Verhoef *et al.* (1996) argue may be positively related to the elasticity of demand and negatively related to the quality of the adjacent road, shifts some vehicles to the worst route.[1] Some would use the best road if it was free (or less expensive)

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[1] Among other factors, the first effect is also dependent upon the second. The rationale is that the lower the quality of the adjacent road, the more inelastic is the demand for the tolled motorway owing to the minimisation of the generalised travel costs, which include both time and expected accidents, carried out by the road user.

and consequently, their diversion may produce more accidents and victims. As a result, the schemes used by the toll motorway industry to set prices will be critical on this perverse effect.

As an example of this effect, Rothengatter (2004) claims that after tolls for heavy vehicles were established in Austria, truck traffic was diverted onto streets and roads. Furthermore, the potential negative safety implications of road pricing is recognised in the DfT Feasibility Study of Road Pricing in the UK, which stresses that 'the impact of re-routing, if it were to occur, could in certain places and at certain times result in an increase in accident levels. This is due to the increased number of vehicles using smaller roads, not built for a high level demand, which could lead to higher accident rates' (Department for Transport, 2004, p. 143). Following the same rationale, Broughton and Gower (1998) estimated that a 10 per cent diversion of motorway traffic from the motorways in Kent (UK) would increase the number of injury accidents in the entire county by about 3.5 per cent.[2]

In the present paper, we try to contribute to our understanding of whether to charge users on tolled motorways diminishes road safety in untolled adjacent alternatives. Results do seem to indicate that this negative externality raises serious policy implications. One such consequence is that we need to take into account road safety effects when tolls are created and regulated. In fact, our findings point out that currently tolls are not set in a second-best optimal fashion. Conversely, tolls are established considering only the financial break even of the private company exploiting the road. For this reason there is not enough flexibility in the price setting to address this price inefficiency. Therefore, the present study attempts to contribute to both the road safety and transportation literatures as well as to provide new insights to policy makers.

This study is organised as follows. We briefly introduce the literature that might help us in our attempt to assess the main hypothesis. In the third section, we describe the empirical strategy by defining data, variables and methods. The fourth presents our results from parametric estimation while the fifth discusses some robustness checks. Finally, some concluding remarks are stated in the last section.

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[2] A previous study by Gower *et al*. (1998) suggested that a toll of 2.5p per mile (at 1994 prices) would produce a 10 per cent diversion level. Linked to this, Broughton and Gower (1998) estimated that this increase in the traffic flow would increase the number of injury accidents in the entire county by about 3.5 per cent taking into account traffic flows and alternative road capacities.

2.0 Related Literature

The relationship between tolls and road safety (in adjacent roads) has not been a major topic in the transportation literature. However, studies that have addressed similar concerns regarding road safety have been useful in our attempt to test the main hypothesis. In this section, we briefly refer to those studies more related to our hypothesis.

As a first group of studies, the works by Lave and Elias (1994, 1997), Richter *et al*. (2004) and Friedman *et al*. (2007), who studied the effect of changing speed limits onto road safety levels in adjacent alternatives, tests a somewhat similar hypothesis. Since speed is a key factor in motorway attractiveness against their road alternatives of lower quality, speed limit regulatory changes seem to have an impact on traffic distribution and, as a consequence, on the safety outcomes of the network (Lave and Elias, 1994, 1997). The rationale defended in these articles is that higher speed limits in higher quality motorways promote diversion from slower alternative roads (McCarthy, 2003). On the contrary, other studies show that higher speed limits can produce spillover effects in the whole network (Richter *et al*., 2004; Friedman *et al*., 2007). The so-called 'tainting effect' occurs when changes in speed limits on one set of roads affect not only the average speed of the designated set but also those on surrounding roads, leading to increased safety risk in the whole network. This spillover and network effect is similar to the impact produced by tolls in the adjacent roads.

Two other groups of studies have also examined close issues. The first has focused on which infrastructure characteristics and environmental factors influence road safety outcomes. From this group of studies, we mention Milton and Mannering (1998) and Flahaut (2004). The former isolates the effects of various highway geometries and traffic characteristics. The number of lanes, the road's length, the posted speed, and the share of heavy vehicles are found to be factors influencing crash risk. Flahaut (2004) finds that the two-lane configuration is by far the most frequent type promoting road unsafety. The $2+2$-lane configuration (two in each direction), is associated with safer outcomes. However, Martin (2002) stresses that in light traffic, the number of crashes is higher on three-lane than on two-lane motorways and increases during weekends, which implies that traffic flow and consequently speed, play a more important role than infrastructure quality. In the same direction, Milton and Mannering (1998) and Noland and Oh (2004) find that increases in the number of lanes appear to be associated with increased fatalities and accidents.

The second group of studies has treated the relationship between traffic flows and accidents. Newberry (1988) and Vitalino and Held (1991) find nearly proportional patterns, while Shefer and Rietveld (1997) and Martin (2002) show parabolic functional relationships. Dickerson *et al*. (2000) also confirmed a non-linear pattern, revealing that this nearly-proportional relationship may fail because rates are an aggregation of heterogeneous accident–flow relationships which do not exhibit this proportionality. In particular, the magnitude of accident externality varies between road classifications and geographical areas. For the latter, Noland and Quddus (2005) assert that, while the positive effect of congestion on safety outcomes may not be found in urban zones, it may still be present on motorways and high-speed roads. Furthermore, Shefer and Rietveld (1997) stress that traffic composition plays a role too. An increase in heavy vehicles in traffic adversely affects road safety when combined with speed factors (average and variance).[3]

The present study builds on these results and tries to advance further by clarifying the relationship between setting tolls — where these tolls are not set on an optimal pricing basis — in the best-quality roads (toll motorways) and any accident externalities suffered in the worst quality adjacent roads.

3.0 Empirical Strategy: Data and Methods

To test our main hypothesis, we take advantage of the particular and exceptional situation in Spain, which has both tolled and untolled routes in its motorway network.[4] This mixed and rare model allows us to compare the adjacent, conventional freeways, which exhibit lower quality and are quite homogeneous across the country. These roads are called ‘National Roads’ and belong to the primary network of the state (high-speed conventional roads). For these reasons, comparing those national roads that compete with adjacent tolled motorways gives us the opportunity to test whether their safety outcomes are affected by the regime established in the high-capacity infrastructure.

3.1 Data and variables

Data on accidents is collected from the ‘Traffic Map 2006’ of the Spanish General Traffic Directorate, which is database containing information on accidents involving victims per kilometre of road, registered average

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[3] Rienstra and Rietveld (1996) find that speed variation is higher in motorways and roads with higher speed limits.

[4] See Bel and Fageda (2005) to find the origin of this exception in the European context.

speed and speed variance, the percentage of vehicles driving at speeds above legal limit, and traffic composition from national roads and free motorways. The database does not offer information on toll motorways, since in Spain such infrastructure is franchised to the private sector. Although we have data on accidents in free motorways by section, it is not possible to obtain the same data for toll motorways (privately operated). At the very best, we only have information at a concession level, but even in this case the information is not available for all concessions. Therefore, it is not possible to execute an analysis considering the entire corridor (national road plus private motorway), which limits the scope of this research. Furthermore, the database does not contain data on the provinces that belong to the regions of the Basque country, Canary Islands, and Navarra. Since we are only interested in sections that compete with motorways (tolled and untolled), we use only data collected by the 154 control stations in such areas, avoiding the use of data related to other non-adjacent sections. Table 1 displays the variables used in the next sections, their definition and finally, their descriptive statistics. Also, in the Appendix (Table A1), we report their correlations.

The variable used to identify road safety outcomes is the number of accidents involving victims per kilometre of road that is the variable reported by the 'Traffic Map 2006' database.[5] Fortunately, road characteristics are quite homogeneous across national roads, but we control for infrastructure characteristics where quality differences are large by distinguishing between conventional roads and free motorways (or dual carriageways), both competing with another tolled or untolled motorway.[6] This binary variable receives value 1 when the control station is placed in a motorway (or dual carriageway) and 0 when it is placed in a conventional road. In both cases, however, they are alternatives to a tolled or untolled motorway.

To capture the impact of different toll levels on road safety, we use a continuous variable denoted by 'PRICE' which takes the value 0 when there is no tolled motorway competing with the secondary road, and a positive value when it is adjacent to a tolled motorway. In the latter case we use the average price per kilometre of the tolled motorway.

Table 2 shows some descriptive statistics related to the 154 control stations chosen, first for the total sample and, secondly, by type of

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[5] Control stations collect data on sections of different lengths. This is the reason why the variable reflects the number of accidents involving victims (fatalities and injuries) per kilometre of highway and not the absolute number. Since we have data on the length of the stretches, we will be able to compute the absolute number as well.

[6] Information on specific features of the road section as bendiness or hilliness is not available in the database and would require observational research.

Table 1
Definitions of Variables and Descriptive Statistics

Variables	*Definition*	*Obs.*	*Mean*	*SD*
Acc/km	Number of accidents involving victims/km. on national road (victims include fatalities and injuries)	153	1.12	1.31
nacv	Number of accidents involving victims on national road (victims include fatalities and injuries)	153	15.85	18.68
PRICE	Price-km in the competing toll motorway (euro)	153	0.059	0.0452
ADT	Average daily traffic on national road	153	19,192	21,152
SHARE	Share of corridor's ADT (motorway plus adjacent road ADT) attracted by the conventional road where the control station is placed	153	39.25	20.07
% moto	Share of motorbikes on total national road ADT	153	1.19	0.0258
% heavy	Share of heavy vehicles on total national road ADT	153	17.82	13.20
% foreigners	Share of foreigners on total national road ADT	153	3.17	0.0732
Av. speed	Average speed collected in control stations (km/h)	153	83.42	15.97
Speed variance	Speed variance	146	33.88	25.05
% excess of speed	Share of vehicles at national road violating the speed limit	153	49.56	19.03
Motorway	Free motorway competing against a tolled or untolled motorway (binary variable)	153	0.1818	0.3869
Population in province	Number of citizens living in the province	153	1,461,322	725,245
Border	Control station placed close to international border (binary variable)	153	0.0389	0.1941
Distance	Distance (km) to the nearest big city having more than 200,000 inhabitants	153	86.77	59.61
N intersections	Number of intersections in the stretch	153	8.33	2.688
Rain	Number of annual rainy days	153	75.34	32.49
Snow	Number of annual snowing days	153	2.43	4.50

Note: The total number of control stations of interest is 153. However, some of them do not provide information on average speeds. This is the reason for not having 153 observations in that case.

Table 2
Comparing Types of Alternative

Stations	*ADT*	*SHARE*	*Acc/km*	*% Heavy vehicles*	*% Foreigners*	*Average speed*	*Population*
Sample average	19,192	39.25	1.12	17.8	3.17	83.4	1,461,322
Alternatives to toll	23,867	45.77	1.44	19.9	3.96	82.4	1,847,086
Alternatives to free	10,020	26.46	0.50	13.5	1.60	85.5	704,630

Table 3

Average Daily Traffic and Composition for some Spanish Corridors (2000)

Route	*Type of motorway*	*ADT in motorway*	*% Heavy vehicles in motorway*	*ADT in alternative*	*% Heavy in alternative*	*% Corridor ADT in motorway*	*% Corridor heavy in motorway*
Madrid–Ciudad Real	Free	21,454	25	7,329	16	74	82
Tarragona–Castelló	Tolled	15,996	23	12,853	33	55	46
València–Alacant	Tolled	18,226	10	12,731	13	59	52
Zaragoza–Logroño	Tolled	8,690	11	10,932	47	44	16
Sevilla–Cadiz	Tolled	13,412	7	14,591	10	48	39

Source: Adapted from Bel (2002).

alternative (alternative to a tolled motorway or alternative to a free motorway). Table 3 also displays descriptive data at corridor level.

As is shown in Table 2, those national roads competing with a tolled motorway present higher average daily traffic (ADT) — double for light vehicles and more than three times for heavy vehicles. More importantly, they present higher shares of the corridor's ADT than conventional roads competing with free motorways. Regarding road safety, roads adjacent to tolled motorways suffer more accidents involving victims per kilometre of road than those that compete with untolled motorways. Again, their traffic composition also shows bigger percentages of heavy vehicles and foreigners, while we confirmed that these roads are usually placed in provinces with higher population. Table 3 shows different traffic distributions, especially of heavy vehicles, according to the price regime established in the motorway. This information seems to indicate that something different is happening in routes that are adjacent to tolled motorways.

3.2 Methods

In order to test our main hypothesis we use a three-stage strategy. We argue that having tolls in motorways results in some drivers leaving the best infrastructure and consequently diverts them onto minor low-quality roads. In fact this is reinforced by the work by Matas and Raymond (1999), which finds significant price elasticities in the toll motorway industry in Spain. This increase in traffic pushed by the toll implies safety consequences, since more vehicles are driving on the road of the corridor least prepared to hold high levels of traffic safely. In order to measure the impact of tolls on road safety, we use a three-stage strategy:

Stage 1

First, we provide a demand function explaining absolute ADT and the share of corridor's ADT attracted by the alternative road. Models 1 and

2 try to fulfil this function by including several variables that can affect road traffic over alternatives routes. The key variable is the price charged to the adjacent tolled motorway users. The remaining factors shaping traffic demand are the population living in the province, the quality of the road, distinguishing whether it is a dual carriageway, a motorway or a conventional single carriageway road, the distance to a big city, the proximity to an international border and the average speed in the conventional road.[7] Finally, ε_i is the common random error term $\varepsilon_i \sim \text{iid}\, N(0, \sigma^2)$. The only difference between Model 1 and Model 2 is the dependent variable explained. The estimation method chosen is the use of a robust to heteroskedasticity ordinary least squares (OLS) estimate for a cross-section of 154 control stations placed in conventional roads adjacent to motorways (free and tolled):[8] Q1

$$\begin{aligned}\log ADTi = {} & \alpha + \beta_1 \log(\text{population}_i) + \beta_2\, \text{motorway}_i + \beta_3 \log(\text{price}_i) \\ & + \beta_4 \log(\text{average speed}_i) + \beta_5(\text{distance to big city}_i) \\ & + \beta_6\, \text{border}_i + \varepsilon_i, \qquad (1)\end{aligned}$$

$$\begin{aligned}\log \text{SHARE}_i = {} & \alpha + \beta_1 \log(\text{population}_i) + \beta_2\, \text{motorway}_i + \beta_3 \log(\text{price}_i) \\ & + \beta_4 \log(\text{average speed}_i) + \beta_5(\text{distance to big city}_i) \\ & + \beta_6\, \text{border}_i + \varepsilon_i. \qquad (2)\end{aligned}$$

Stage 2

After the identification of those factors affecting traffic demand, paying special attention to the toll as an enhancing factor (β_3), we can move on and provide an estimation of accidents involving victims per kilometre of road in conventional roads adjacent to motorways, where we expect to find a strong relationship between such fatality rates and ADT (or SHARE). We use the same sample but lose some observations due to the lack of speed variance information.[9] Models 3 and 4 are tested using

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[7] Interurban motorways are not regularly congested in Spain. For this reason, motorway users can drive as fast as the legal speed limit. Then, the average speed in the adjacent free alternative captures how attractive it is to use the slowest option to avoid the charge. Therefore, it can be understood as a proxy of time differences.

[8] The Breusch Pagan/Cook–Weisberg test confirms the need for correcting by heteroskedasticity in the three stages.

[9] Note that, following Shefer and Rietveld (1997) that argue that safety concern must be focused on variance (speed differences) rather than averages, we use here speed variance instead of average speed in the determination of road accidents. Moreover, we added a new variable identifying the percentage of drivers violating speed limits.

both OLS and negative binomial (count data) estimates:

$$\begin{aligned}\log \mathrm{ACVKM})_i = \mu &+ \lambda_1 \log(\mathrm{ADT}_i) + \lambda_2 \log(\mathrm{population}_i)\\ &+ \lambda_3 \log(\mathrm{population}_i^2) + \lambda_4\, \mathrm{motorway}_i + \lambda_5\, \mathrm{heavy}_i\\ &+ \lambda_6\, \mathrm{motorbikes}_i + \lambda_7\, \mathrm{foreigners}_i + \lambda_8 N\, \mathrm{intersections}_i\\ &+ \lambda_9 \log(\mathrm{speed\ variance}_i) + \lambda_{10}\, \mathrm{excess\ speed}_i\\ &+ \lambda_{11}\, \mathrm{rain}_i + \lambda_{12}\, \mathrm{snow}_i + e_i, \qquad (3)\end{aligned}$$

$$\begin{aligned}\log \mathrm{ACVKM}_i = \mu &+ \lambda_1 \log(\mathrm{SHARE}_i) + \lambda_2 \log(\mathrm{population}_i)\\ &+ \lambda_3 \log(\mathrm{population}_i^2) + \lambda_4\, \mathrm{motorway}_i + \lambda_5\, \mathrm{heavy}_i\\ &+ \lambda_6\, \mathrm{motorbikes}_i + \lambda_7\, \mathrm{foreigners}_i + \lambda_8 N\, \mathrm{intersections}_i\\ &+ \lambda_9 \log(\mathrm{speed\ variance}_i) + \lambda_{10}\, \mathrm{excess\ speed}_i\\ &+ \lambda_{11}\, \mathrm{rain}_i + \lambda_{12}\, \mathrm{snow}_i + e_i. \qquad (4)\end{aligned}$$

Count data models appear to be a relevant choice in our framework since data seems to be skewed to the left. These models are necessary to avoid and solve problems in using OLS estimates that are derived from a normality assumption violation. Since we do not suffer from over-dispersion, there are no important differences between Poisson regression and negative binomial models.[10] However, since we note some presence of heterogeneity, we have preferred the use of negative binomial models. Such models simply reduce to a Poisson regression model with $\mathrm{Var}(Y_i \mid X_i) = E(Y_i \mid X_i)$.[11]

Stage 3

Our interest in measuring the impact of tolls on road safety outcomes justifies a third stage. By substituting ADT and SHARE with its explanatory variables, we are able to identify this impact that, given the double log specification, can be interpreted as the toll elasticity of the number of accidents with victims (δ_2). With this purpose, we introduce all statistically significant variables explaining ADT (model 5), and then we add the

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[10] Indeed, we do not find relevant differences when we test a Poisson model instead of the chosen negative binomial model. The negative binomial distribution can be thought of as a Poisson distribution with unobserved heterogeneity.

[11] See Greene (1997). Each Y_i is a random variable and the probability distribution with λi parameter (related to regressors x_i) of the negative binomial model is: $Pr(Y = y_i \mid u) = \exp(-\lambda_i \exp(u_i))\lambda_i y_i / y_i!$ where $\exp(u)$ has a gamma distribution with mean 1 and variance α. Q5

statistically significant coefficients in SHARE determination (model 6). Again, we use OLS and negative binomial:

$$\begin{aligned}\log \mathrm{ACVKM}_i = \mu + [&\delta_1 \log(\text{population}_i) + \delta_2 \log(\mathrm{PRICE}_i)\\ &+ \delta_3 \,\text{motorway}_i + \delta_4 \log(\text{average speed})_i\\ &+ \delta_5 \log(\text{distance to big city}_i) + \delta_6(\text{border})_i]\\ &+ \delta_7 \log(\text{population}_i^2) + \delta_8 \,\text{heavy}_i + \delta_9 \,\text{motorbikes}_i\\ &+ \delta_{10} \,\text{foreigners}_i + \delta_{11} \log(\text{speed variance}_i)\\ &+ \delta_{12} \,\text{excess speed}_i + \delta_{13} N \,\text{intersections}_i + \delta_{14} \,\text{rain}_i\\ &+ \delta_{15} \,\text{snow}_i + e_i. \end{aligned} \tag{5}$$

4.0 Results

Results on these three stages are provided in Table 4. As is clear, the coefficient associated with the variable PRICE appears statistically significant and shows a positive sign in the production of ADT, as well as affecting positively to the Share of corridor's traffic attracted by the free road adjacent to the motorway (Specifications 1 and 2). This first stage was designed to show that having tolls in adjacent motorways enhanced demand for the worst road. The second stage is concerned with the consequence of more vehicles in the road in terms of road safety. Specifications 3 and 4 are used to estimate models 3 and 4, which relate traffic and the share of corridor's ADT attracted to accident outcomes. Q2

As expected, ADT and SHARE appear to be the largest factors affecting road safety. Specifications 5, 6, and 7 provide our main results, in which we replace ADT with its explanatory variables in Specification 5, and we replace the share of the corridor's traffic in Specification 6. In these replacements we include the variable PRICE, which seems to be a determinant of both variables in previous estimations. In all cases we find positive and statistically significant impacts from its associated coefficient, implying that tolls seem partly responsible, through increasing ADT and by raising the share of the corridor's ADT, for the higher number of accidents involving victims reported in national roads. In fact, the higher the price, the more accidents per kilometre of road should be expected in the national road adjacent to a tolled motorway. Also, the negative binomial regression does not change the impact of this variable.

In addition, the double log specification allows us to interpret the coefficients as elasticities. As a consequence, by identifying the toll elasticity

Table 4

Parametric Estimation Results. Least-Squares and Negative Binomial Linear Regression Models of Accidents involving Victims per Kilometre

Independent variables	*OLS log ADT (1)*	*OLS log SHARE (2)*	*OLS log ACVKM (3)*	*OLS log ACVKM (4)*	*OLS log ACVKM (5)*	*OLS log ACVKM (6)*	*Negative binomial ACV (7)*
ADT	–	–	0.3336**	–	–	–	–
			(2.05)				
Share	–	–	–	0.7001***	–	–	–
				(3.47)			
Population	0.3774***	−0.0549	2.031**	1.943**	1.254*	1.021	6.920***
	(5.70)	(0.17)	(1.99)	(2.30)	(1.73)	(−1.34)	(4.34)
Population[a]	–	–	−0.0844**	−0.0844***	−0.0568**	−0.0484*	−0.3817***
			(−2.11)	(−2.65)	(2.01)	(1.66)	(4.02)
Motorway (two carriageways)	0.8893***	0.5210***	0.5339	0.3748	0.4949*	03629	0.6413**
	(4.65)	(5.36)	(1.25)	(0.93)	(1.69)	(1.12)	(2.10)
ADT determinants							
Average speed	−0.1667	0.2725*	–	–	–	0.9434	0.3898
	(−0.45)	(1.74)				(1.17)	(0.64)
Price (toll)	0.4222***	0.2791***	–	–	0.4924***	0.5326***	0.2863***
	(5.73)	(6.05)			(3.34)	(3.34)	(2.74)
Distance to big city	−0.0906*	0.0682**	–	–	0.0406	0.0303	−0.1757*
	(−1.73)	(2.27)			(0.27)	(0.21)	(−1.85)
Border proximity	−0.3800	−0.4449	–	–	–	–	–
	(−0.45)	(−1.19)					
ACV determinants							
Number of intersections	–	–	0.0573	0.0657	0.1309*	0.1169*	0.0113
			(0.38)	(0.43)	(1.74)	(1.65)	(0.50)
Share heavy vehicles	–	–	1.6208*	1.0787	−0.1695	−0.6818	−0.6828
			(1,69)	(1.25)	(−0.18)	(−0.66)	(−0.99)

Share of motorbikes	–	–	−0.3118	−2.626	−3.794	−3.883	−3.035**
			(−0.74)	(−0.72)	(−1.06)	(−1.13)	(−2.07)
Share of foreigners	–	–	2.290***	2.6353***	1.854**	2.403***	1.049*
			(3.99)	(4.23)	(2.30)	(2.92)	(1.95)
Speed variance	–	–	−0.0065	−0.0035	−0.0471	−0.1028	−0.0050
			(−0.83)	(−0.45)	(−0.12)	(−0.27)	(−0.81)
% excess speed	–	–	−0.0080	−0.0098	−0.1395	−0.1634	−0.0069
			(−1.04)	(−1.41)	(−1.43)	(−1.61)	(−1.52)
Rain	–	–	0.0037	0.0023	0.0021	0.0022	0.0040*
			(0.90)	(0.60)	(0.47)	(0.49)	(1.73)
Snow	–	–	−0.01245	−00131	−0.0079	−0.0157	−0.0319
			(−0.61)	(−0.76)	(−0.26)	(−0.51)	(−1.42)
N observations	154	154	146	146	146	146	146
R^2	0.59	0.40	0.50	0.53	0.44	0.35	–
Test *F*	34.93***	19.72***	6.74***	6.98***	6.64***	6.46***	–
Log pseudolikelihood	–	–	–	–	–	–	−509.61
χ^2	–	–	–	–	–	–	150.01***
VIF test (mean)	1.24	1.24	1.61	1.63	1.65	1.72	–

Note: Robust to heteroskedasticity *t* and *z* statistics are reported in parenthesis. Each model contains a constant term. *Statistically significant at 10% level; **5% level and ***1% level.

[a] The number of observation dropped from 153 to 146 due to the lack of information for at least one of the variables used in the specification.

of the number of accidents involving victims, which is around 0.5 according to Specifications 5 and 6, we can obtain a magnitude of the rat-running effect on road safety. This means that a 1 per cent increase in the toll level produces a 0.5 per cent increase in the number of accidents involving victims per kilometre on adjacent roads.

Regarding the remaining variables, traffic composition shows interesting results. A larger share of foreigners is associated with worse safety outcomes, while the share of heavy vehicles and motorbikes do not seem to produce consistent effects across specifications. In fact, past research already found mixed results on the role played by heavy vehicles. Milton and Mannering (1998), for instance, found negative relationships between trucks and crashes but linked this result to the low ADT enjoyed by those routes where trucks make up a high share of traffic. They explain that, 'where ADT is low, truck percentages rapidly increase with only a few additional trucks. Hence, where ADT is low, accident frequencies may decrease because of a lack of conflicts, not because of increased truck traffic'.

Similar discussion may apply in the case of speed-related variables. We have shown that average speed seems to increase the SHARE of ADT attracted by the national road adjacent to the motorway. Higher speeds make this alternative a more attractive route, especially if there is a toll to avoid. Regarding safety outcomes, we do not find statistical significance for speed variance and for the share of drivers violating speed limits. As is shown in previous sections, where ADT levels are low and therefore fewer accidents happen, drivers usually drive fast and this can compensate the Q3
risk effects of excess speed. Lower density results in fewer conflicts on the road, which may limit the effect of speed on the rate of accidents involving victims. Moreover, we find low variability in speed variance across roads. Q4

Similarly, status as a motorway (or a dual carriageway) is associated with more accidents involving victims per kilometre. given the high ADT on these roads. The quality of the road in terms of number of lanes, two carriageways and better pavement, could justify an expectation of the opposite effect, but our results are consistent with those demonstrated by Milton and Mannering (1998), Martin (2002), Flahaut (2004) and Noland and Oh (2004).

Regarding the distance to a big city and the weather variables, we only find statistical significance in the negative binomial regression. For instance, we find that the higher the distance to a big city, the lower the road risk, probably owing to the mobility patterns of rural zones and low ADT. Also interesting is the effect of rain on the determination of accidents. We find a negative effect on road safety, while snow does not provide the same result. The contrary happens in the case of the number of intersections, which seem statistically significant in all specifications where we used OLS estimates (5 and 6) and no statistical significance is found in the case of negative binomial regression.

Variance inflation factors (VIFs) are also tested in order to check possible multi-collinearity problems. As is shown, regressors show very low VIF values (VIF mean < 2), far from the common threshold of 10, which is the rule of thumb associated with potential collinearity. This test is more powerful than correlation analysis, since it captures associations between more than two independent variables.[12]

To summarise, setting tolls in motorways seems to affect road safety in the adjacent roads by shifting traffic, even when we control by several factors that may play a role in the production of road accidents involving victims. The use of tolls is an important factor explaining ADT levels on alternative routes (stage 1), and this traffic increase is also responsible for a higher number of accidents involving victims (stage 2). This effect is consistent across specifications and across estimation strategies. Its magnitude is measured as a toll elasticity of accidents involving victims of 0.5 (stage 3).

5.0 Robustness Checks

Once the main results of our empirical analysis are presented, we provide here some robustness checks to avoid possible technical concerns that can reasonably emerge with the empirical strategy followed.

5.1 Omitted variable bias

Given the many factors affecting road safety and the difficulty to obtain data on them in order to model a full production function of accidents, we need to make sure that we do not have an important problem of omitted variable bias. To check this concern, we undertook a Ramsey RESET test of specification error on the model on accident determinants. The null hypothesis of this test is that there are no omitted variables in the regression model used. The result suggests that we cannot statistically reject this hypothesis (Prob $> F = 0.1848$) and consequently, there is no problem of

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[12] VIF values are given by $(1 - R_i^2)^{-1}$, where R_i^2 is the R^2 from regressing the ith independent variable on all the other independent variables. 'It is a measure of the amount by which the variance of the ith coefficient estimate is increased (relative to no collinearity) due to its linear association with the other explanatory variables' (Kennedy, 2003, p. 213).

omitted variable bias. The estimation procedure also considers and corrects for heterogeneity.

Additionally, the statistical significance of the price variable could mask a higher risk related to conventional roads closed to tolled motorways, given different infrastructure or quality characteristics not considered in our specifications. For this reason, we transform the dependent variable by dividing it by ADT in order to estimate risk levels and reproduce the same estimation strategy. This test provides evidence that conventional roads adjacent to toll motorways are not more dangerous than conventional roads adjacent to free motorways showing that our estimates of the impact of tolls do not suffer from this omitted variable bias problem. Results can be checked in the Appendix (Table A2).

5.2 Endogeneity concerns

Our results raise another reasonable concern, which is the possible existence of inverse causality problems in our estimation strategy. On one hand, one could have in mind a toll company accommodating prices according to road safety outcomes and quality of the alternative roads. However, this is not possible, since in Spain — as in all European experiences with the exception of United Kingdom — toll companies do not set prices; they are regulated and fixed by government without considering what happens in the alternatives.[13] Therefore, toll companies have no ability to change prices and thus can be treated as exogenous.

Another endogeneity concern comes from the fact that, since private franchisers operate these roads, they require enough traffic to recoup their investment and achieve a significant financial benefit. Therefore, it is not unlikely to expect that the construction of a toll road is more attractive and likely when there is a relatively high demand at the corridor level (and therefore a high ADT) if this depends on private initiative.

For this reason, it is important to argue that reverse causality can be excluded from our framework. There are two exercises to be carried out. First, we provide a brief historical description on how governments designed the Spanish motorway network. Second, we perform new econometric estimations with more homogeneous samples on ADT in order to show that our main finding remains unchanged even using corridors of similar ADT:

1. Spanish governments never used free and tolled motorways simultaneously in their design of the motorway network. Instead, each

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[13] See Albalate *et al.* (2009) for an in-depth review on the regulatory practices in the European toll motorway industry.

government had their own preferred funding model. For this reason they did not decide to use tolls in high ADT corridors and free motorways in low ADT corridors. Conversely, they defended one of these two funding strategies and created their part of the network according to their preferred model. In fact, there is academic consensus on this issue as can be consulted in the works by Germà Bel and Xavier Fageda (Bel, 1999; Bel and Fageda, 2005). As a consequence, Spain

Table 5

Parametric Estimation Results. Least-squares and Negative Binomial Linear Regression Models of Accidents Involving Victims

	Low ADT corridors		*High ADT corridor*	
Independent variables	*OLS log ACVKM (8)*	*NB ACV (9)*	*OLS log ACVKM (10)*	*NB ACV (11)*
Population	−2.267**	2.4170*	13.444***	13.898***
	(−2.24)	(−1.91)	(3.13)	(4.13)
Population[a]	0.0991**	−0.1122**	−0.4389***	−0.4655***
	(2.26)	(2.08)	(−2.97)	(−4.03)
Motorway (two carriageways)	−0.0964	0.1660	0.6469**	0.4336**
	(−0.14)	(0.25)	(2.04)	(1.97)
ADT determinants				
Price (toll)	0.4178***	0.2805***	0.9300**	0.3822**
	(3.05)	(2.61)	(2.65)	(2.14)
Distance to big city	0.0398	−0.0158	0.2251	0.0284
	(0.38)	(−0.22)	(0.63)	(0.11)
ACV determinants				
Number of intersections	0.3517*	0.1738	0.5911*	0.3317**
	(1.78)	(1.17)	(1.84)	(2.07)
Share heavy vehicles	−0.7423	−0.4293	2.7721	0.1018
	(−0.77)	(−0.50)	(1.18)	(0.06)
Share of motorbikes	3.656	−1.806	2.654	−3.5658*
	(0.72)	(−0.58)	(−0.45)	(−1.90)
Share of foreigners	1.328*	0.2709	1.741**	1.040*
	(1.71)	(0.48)	(1.98)	(1.68)
Rain	−0.0017	−0.0043	0.0130*	0.0020
	(−0.31)	(−1.22)	(1.69)	(0.39)
N observations	96	96	58	58
R^2	0.34	–	0.47	–
Test *F*	7.68***	–	6.36***	–
Log pseudolikelihood	–	−301.65	–	−232.20
χ^2	–	76.91***	–	54.80***

Note: Robust to heteroskedasticity *t* and *z* statistics are reported in parenthesis. Each model contains a constant term. *Statistically significant at 10% level; **5% level and ***1% level.

[a] The number of observation dropped from 153 to 146 due to the lack of information for at least one of the variables used in the specification.

enjoys a mixed funding model of motorways (more than 20 per cent of kilometres are tolled), and we cannot affirm that toll motorways were built in the most profitable corridors and free motorways on low ADT routes. There was not a determined policy based on ADT, but two models that have been mixed in the territory covering different levels of ADT. Our sample reflects this mixed model where ADT did not influence the settlement of tolls.

2. Table 5 displays the results obtained after sorting the sample by different intervals of ADT. In order to preserve degrees of freedom, we made two samples with observations above- and below-average ADT. Therefore, we run our regressions on a sample with low ADT roads, as well as on high ADT roads, keeping them apart from the rest of observations. As can be checked, the coefficient associated with the variable PRICE is still statistically significant in accident determination even when we use more homogeneous samples of ADT, although its impact is higher for the high ADT sample.

6.0 Concluding Remarks

The use of tolls is becoming widespread around the world because of their ability to regulate traffic demand and fund infrastructure projects. Researchers and practitioners put their efforts into developing the double function of tolls, applying optimal pricing schemes to fight congestion, particularly in urban and metropolitan areas, and solving budget constraints in inter-urban routes. However, the road safety effects are not usually evaluated and, as has been shown in the present study, may be substantial.

Indeed, tolls on the best roads seem to prevent their use by an important share of road users, shifting traffic and road hazard to adjacent and lower quality. After controlling for several factors, we find that those roads competing with tolled motorways experienced more accidents involving victims than roads competing against untolled motorways, and this is so, due to the additional pressure of traffic imposed by toll charges on the adjacent motorways. In fact, we find that the toll elasticity of the number of accidents with victims per kilometre is 0.5.

Further research is needed to understand the reasons behind this effect. For instance, more information on infrastructure characteristics, investments in construction and maintenance, behavioural attitudes and environmental factors should be introduced in the analysis to test the robustness of this relationship. Moreover, case studies and spatial autocorrelation estimation models may also improve estimation strategies in this area. Additionally, improvements in the limited data available should also be sought. Another limitation of the current research is the lack of information regarding private toll motorways per section, which does not allow to replicate the analysis comparing data at corridor level instead of comparing national roads. Therefore, the reader must not understand these results as confirming that tolls do increase road unsafety at corridor level.

In spite of these limitations, our results raise interesting public policy implications. As a direct suggestion, public authorities must address this unexpected consequence of toll charges by designing a selective investment programme focused on solving black points and dangerous stretches of roads close to toll motorways. A share of collected revenues could be used for this purpose.[14]

More importantly, we should also determine whether optimal pricing schemes — probably second best pricing — should take into account and introduce the hazard externality imposed on the alternative roads. In this direction, if high tolls produce more 'rat-running' and shift risk to the untolled alternative, we may have reasons to reduce tolls in order to internalise that externality and minimise road hazard.[15] Perhaps, congestion should not be the sole factor captured by first best pricing. Instead, accident externalities should be included and, furthermore, not only in the same road (second best pricing). If not, governments could consider delivering subsidies on toll payments to certain risk groups.

In practice, interurban tolls are not usually used to fight congestion and therefore, there is no allocative efficiency goals pursued. Instead, tolls are only used to fund the infrastructure and to accomplish this target they are set and regulated only considering the financial breakeven of the private operator. Unfortunately, this does not give enough flexibility to account for the externality produced onto the adjacent free alternative. As a consequence, our results suggest that this policy promotes price-setting inefficiencies from the social perspective by damaging road safety outcomes. Overcoming this pitfall would help in the achievement of the expected welfare gains from toll motorways.

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[14] A black point is a stretch in which a huge number of road accidents are concentrated.

[15] Subsidies would be necessary in return if there is a private concessionaire in charge of toll motorway operation.

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Appendix

Table A1

Correlations between Variables Employed in the Analysis

	Acc/km	*Price*	*SHARE*	*ADT*	*% Motorbikes*	*% Heavy*	*% Foreigners*	*Av. speed*	*Speed variance*	*% Excess speed*	*Motorway*	*Population*	*Border*	*Distance*	*N intersections*	*Rain*	*Snow*
Acc/km	–																
Price	0.26	–															
SHARE	0.51	0.43	–														
ADT	0.60	0.25	0.63	–													
% motorbikes	0.03	0.01	0.03	0.10	–												
% heavy	0.17	0.27	0.10	−0.20	−0.06	–											
% foreigners	0.02	0.10	−0.07	−0.04	0.00	0.06	–										
Average speed	0.05	−0.12	0.27	0.19	0.07	0.32	−0.19	–									
Speed variance	0.08	−0.04	0.12	0.20	0.14	0.22	0.03	0.44	–								
% excess of speed	−0.16	−0.04	0.09	−0.03	0.01	0.35	−0.04	0.51	0.59	–							
Motorway	0.38	0.17	0.53	0.63	0.15	−0.15	−0.07	0.28	0.44	0.19	–						
Population	0.41	0.21	0.31	0.59	0.35	−0.22	−0.07	0.08	0.24	−0.08	0.36	–					
Border	−0.04	−0.06	−0.06	−0.05	0.11	0.00	0.50	−0.08	0.10	−0.01	−0.00	0.10	–				
Distance	−0.35	−0.28	−0.21	−0.45	−0.18	0.22	0.14	0.17	0.08	0.23	−0.29	−0.46	0.21	–			
N intersections	0.24	0.23	0.28	0.42	0.19	−0.27	−0.03	−0.14	−0.14	−0.26	0.21	0.41	0.00	−0.43	–		
Rain	−0.10	−0.07	−0.07	−0.16	−0.14	−0.28	−0.12	−0.22	−0.26	−0.25	−0.16	−0.18	−0.00	−0.19	0.09	–	
Snow	−0.17	−0.11	0.00	−0.15	−0.04	0.19	−0.08	0.35	0.13	0.32	−0.11	−0.12	0.03	0.28	−0.28	−0.05	–

Table A2

Robustness Check. Least Squares and Negative Binomial Estimates. Accidents involving Victims per Kilometre/ADT

Independent variables	*OLS* *log ACVKM/ADT* *(10)*	*NB* *ACV/ADT* *(11)*
Population	−0.2715	0.9670*
	(−0.37)	(−1.75)
Population[a]	−3.147*	−12.083***
	(1.87)	(3.89)
Motorway (two carriageways)	−0.3148**	−0.4136*
	(2.12)	(−1.84)
ADT determinants		
Average speed	0.4527	−0.1882
	(0.67)	(−0.15)
Price (toll)	−0.0473	−0.1419
	(−0.41)	(−1.25)
Distance to big city	0.0942	−0.0624
	(0.59)	(−0.38)
Border proximity	0.6524	0.6130
	(1.43)	(1.34)
ACV determinants		
Number of intersections	−0.1168*	−0.2697*
	(1.78)	(−1.74)
Share heavy vehicles	−0.3315	−0.4326
	(−0.39)	(−0.65)
Share of motorbikes	−2.013	−3.699*
	(0.64)	(−1.68)
Share of foreigners	1.008**	−0.9042*
	(2.02)	(−1.90)
Rain	0.0032	0.0026
	(1.00)	(0.70)
N observations	154	154
R^2	0.23	–
Test *F*	4.17**	–
Log pseudolikelihood	–	−1.314
χ^2	–	32.51***

Note: Robust to heteroskedasticity *t* and *z* statistics are reported in parenthesis. Each model contains a constant term. *Statistically significant at 10% level; **5% level and ***1% level.
[a]The number of observation dropped from 153 to 146 due to the lack of information for at least one of the variables used in the specification.

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March/April 2011

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1 ‘robust to heteroskedasticity’/ please check for syntax
2 ‘as well as affecting positively to’/ please check for sense
3 Compensate for? Or compound?
4 ‘variability in speed variance across roads’/ OK for sense?
5 Are we missing the variance here?
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