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Motorways, tolls and road safety: evidence from Europe

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Abstract European governments are increasingly committed to road safety, due to the impact of road accidents in terms of economic loss and as a public health threat. In addition to regulation, providing better road infrastructure is an essential strategy to promote road safety. This paper investigates the relationships between different types of road quality and their impact on national safety outcomes using an international (European) panel data. Since European countries have different motorway network funding strategies—free motorways funded by the budget and tolled motorways funded by users—we pay special attention to the type of funding chosen and consider whether it has any consequences for safety. Our results suggest that extending the motorway network is associated with a reduction in fatality rates, while the rest of road types do not have the same positive effects. However, this virtue is only statistically significant for free motorways; tolled motorways do not provide any significant impact, probably due to socially inefficient pricing and investment policies currently in force.

Keywords Road safety · Tolls · Motorways and transportation

JEL Classification H23 · I18 · R48

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1 Introduction

Road safety is a key concern and policy objective for any public authority in charge of the transportation sector. This is especially true of developed economies, where societies are increasingly more risk-averse. According to World Health Organization rankings, road traffic injuries are among the leading causes of death worldwide. Apart from the public health threat, there are also economic reasons that make road safety an important goal for any economy. Several estimates point out that the economic costs associated with road accidents are as high as 1% of GNP in low-income economies, 1.5% in middle-income economies, and as high as 2% in developed economies (World Health Organization 2004).[1]

Not surprisingly, these concerns have led public policy-makers to seek ways of achieving better safety outcomes. Among the strategies proposed, the provision of better infrastructure, particularly high capacity motorways, is one of the most important. Nonetheless, fiscal constraints and infrastructure requirements make governments more likely to draw on private assistance for the development of motorways, which usually implies the use of tolling for the new or upgraded infrastructures. Given that governments deal with competing expenditures and are limited by budget constraints, tolls are seen as a useful way of financing motorway construction without the need for tax increases or expenditure cuts.

However, not all states have opted for toll motorways. In Europe there are three different pricing methods for funding the motorway network. First, some countries use the public budget and road users are not charged.[2] These are countries with a strong preference for free motorways, such as Germany and the United Kingdom. Second, some countries charge direct tolls to road users by public or private toll concessionaires—for example, France, Italy and Greece. The third option, in place in Spain, is a mixed funding model in which tolled motorways represent a significant share, but most of the network remains free or charge. As a result, approximately a third of the European motorway network is directly charged, and its length has grown dramatically (by almost 50%) in the last ten years.

This study investigates whether pricing motorways has any effect on the expected road safety benefits associated with infrastructure improvements. The rationale behind this concern is the fact that direct tolls cause those not willing to pay for the best roads to divert onto secondary roads, which are usually not prepared to receive high levels of traffic in similar safety standards. In the transportation literature this shift is usually called the re-routing or rat-running effect, and is nonexistent in free motorway networks.

The use of efficient pricing in motorways to internalize road safety externalities could avoid this perverse effect, which produces negative externalities in the untolled

[1] Jacobs et al. (2000) estimated worldwide road accident costs at $518 billion, with the costs in low-income countries exceeding the total annual amount received in development assistance. These costs are derived from vehicle and other damage, health expenditure, and lost production.

[2] We stress that most countries charge fuel taxes to fund free road infrastructure. Therefore, by “free of charge” here we mean “free of toll”. In addition, Germany has recently introduced road charging for heavy goods vehicles following the EU Commission’s proposal of a “Eurovignette”.

alternative through impacts on congestion and safety.[3] Unfortunately, price regulation in the toll motorway industry does not follow any efficient pricing scheme able to control for this social cost. This inefficiency produces prices that distort the allocation of traffic in the road network, with potential impacts on road safety.

Given this distortion, this study takes advantage of the variability inside Europe in order to compare safety outcomes across infrastructure qualities and price regimes. To do so, we use an international panel containing information from 15 countries (EU-15) during the period 1991–2003. The method of estimation is a two-way fixed effects semi-log model, which controls for several covariates and uses the rate of fatalities per million inhabitants as dependent variable. Our objective is to test how infrastructure quality affects aggregate safety outcomes, and how the pricing method for high capacity motorways can affect this result.

Our findings show that motorways are the only type of road expected to have net positive impacts on road fatalities, since their quality and characteristics provide better outcomes. However, this net positive impact is only present when motorways are free of charge; it is lost if motorways are tolled. Since the technical differences between free and toll motorways are irrelevant, this effect must be due to the socially inefficient price system/ that produces re-routing.[4] These results provide a new concern from the public health perspective, but also contribute to the literature on the effects of inefficient pricing methods for network infrastructure.

The present paper is organized as follows. In the next section we discuss the related literature. The third section is devoted to the importance of the re-routing effect on road safety and its consequences for efficient toll regulation. In the fourth section we describe the empirical methodology carried out to test our hypotheses and the data used, and in the fifth we present our main results. Lastly, some concluding remarks can be found in the final section.

2 Related literature on re-routing

Road charging encourages widespread diversion onto minor alternative routes. After the setting of tolls for heavy vehicles in Austria, Rothengatter (2004) reports that truck traffic was diverted onto streets and roads, a clear example of the "rat-running" or "re-routing" effect. According to Verhoef et al. (1996), this shift is positively related to the price elasticity of demand and negatively related to the quality of the adjacent road, producing a shift of certain vehicles onto worse roads. The lower the quality of the adjacent road, the more inelastic the demand for the tolled motorway becomes.

Although some authors have already studied the price elasticity of demand in toll motorways and the importance of alternatives, their estimations are usually based on short sections, tunnels, bridges and entrances to big cities, making the task of

[3] This is only partially true because part of the consequences of a road accident is internalized and only a proportion of the economic costs of road crashes can be considered an externality. In any case, since the pioneering works by Walters (1961) and Vickrey (1969), transport economists have called for the internalization of externalities using road charges in order to seek efficient allocation outcomes.

[4] Statistics from the Spanish Ministry of Transport suggest that toll motorways yield safety outcomes that are similar to, or even better than, those produced by free motorways. In Spain tolled motorways account for 20% of the total motorway network.

comparison more difficult (Oum et al. 1992; Hirschman et al. 1995; Loo 2003, among others). Fortunately, Matas and Raymond (1999) evaluated this elasticity for the Spanish interurban toll motorways, finding a price elasticity of −0.3 in the short run; in the long run, their estimate increases by 50%. These authors also pointed out that charging motorways generates perverse distortions in traffic allocation when taking into account not only the motorway but also the network to which it belongs. Hirschman et al. (1995) and Matas and Raymond (1999) confirm that elasticities are strongly related to the quality of the free alternative.

Road competition also has its importance in the determination of the re-routing effect and, consequently, on price elasticity. In this respect, Engel et al. (2004) find that the number of independently owned roads in a network, even if demand increases at the same rate, prevents high toll settings. The same result is obtained in Braid (1996) with two parallel roads with different capacity constraints.

This perverse effect can probably be solved by the use of efficient pricing considering external costs. Examples of this are the theoretical articles that have evaluated the impact of charges on traffic shift to alternative roads. Nonetheless, congestion is the only externality that these articles consider: all other externalities are disregarded.

Levy-Lambert (1968) and Marchand (1968) were the first to address this issue by considering two parallel roads, one charged and one toll-free. Their results showed that the untolled alternative was being overutilized. Only by reducing the price of the charged road was it possible to alleviate the excessive usage of the free alternative. They defined the second best pricing rule by comparing the gains from reducing congestion in the free road and the costs of inducing more traffic towards the tolled road (i.e., by lowering the price). Verhoef et al. (1996) demonstrated that the optimal toll depends on the relative free-flow travel times and capacities of the two routes, as well as on the price elasticity of demand.

However, they used a single time model, a condition that was relaxed by Braid (1996) and De Palma and Lindsey (2000) who allowed for trip-timing adjustments by considering time-varying tolls in the Vickrey (1969) bottleneck model. Their results showed even higher efficiency gains from second best tolling.

This shift produced by motorway pricing is found to have road safety consequences at the micro level. In this respect, Albalate (*forthcoming*) finds that routes adjacent to toll motorways in Spain suffer more accidents involving victims per km than those adjacent to free motorways, after controlling for traffic density and composition. This impact is attributed to the shift of traffic produced by inefficient toll setting and investment.

This perverse effect was also considered by the DfT Feasibility Study of Road Pricing in the UK, where it is stated 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% 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%.

In this study we use real international data to compare the safety impacts of different types of road infrastructure, but also to estimate whether, given the re-routing effect, there is a difference in the impact of free and tolled motorways on national road safety outcomes. The study contributes to the literature by testing for the first time whether price regimes in motorway networks affect overall road safety outcomes, by damaging the positive safety outcomes expected from high quality roads with low quality alternatives.

3 The economic problem

Let us consider a two link network of parallel roads with the important difference that one road is tolled and one is free. Assuming that optimal pricing is possible, the literature denotes by the term ‘first best pricing’ the scheme that takes into account and internalizes the social costs occurring in a given tolled route through the price, but without considering what happens on the untolled alternative. This means that tolling follows a social marginal cost, which includes producer’s average cost, but also the cost generated by externalities such as congestion, pollution or accidents occurring on the tolled road. Even if this pricing scheme is imposed by a regulator on a private operator, it still ignores external or network effects on the untolled road, which receives the impact of the price set on the tolled motorway. When prices are set on only one road, a share of traffic shifts to the untolled alternative (re-routing): these are journeys whose marginal utility from an additional trip by toll motorway is lower than their marginal cost, which basically comprises the toll fee and the gasoline consumption. If the pricing strategy does not consider the alternative route, then the split of traffic is likely to be inefficient. This means that the alternative route is being overused or underused due to inefficient pricing; in the case of overuse, there is a high risk of congestion and reduced safety.[5]

In order to maximize social welfare, then, planners have to take into account demand and cost interdependencies between the two routes (Verhoef et al. 1996). For this reason optimal pricing should follow what is known as the second best strategy. This strategy involves tolling but considers as a social cost not only externalities occurring on the tolled motorway, but also those experienced in the free alternative. Therefore, when the overall demand is inelastic, the regulator as planner should concentrate on producing the optimal modal split by designing the second best optimal toll. This means that he/she should take into account external costs on both roads when setting the welfare maximizing fee.

Second best pricing takes the whole network into account and for this reason the priced roadway should have a toll that is between zero and the first-best toll. This solution has usually been developed by considering only congestion as an external cost. However, we could also extend this approach to other forms of negative externalities such as pollution or reduced safety. In this regard, we also expect a higher number of accidents on the uncharged alternative because of its inefficient overuse generated by one-route inefficient pricing.[6]

[5] Throughout this discussion we will assume that all drivers value travel time (time costs) in the same way. They have the same preferences regarding travel time.

[6] Although one might also expect the severity of these accidents to be lower due to a slower average speed produced by congestion.

The theory predicts that second best pricing improves overall welfare in comparison with first best pricing, since it accounts for external costs in the whole network and not only on the tolled road. However, in most countries, toll motorways do not have alternatives of similar quality. The capacity and quality asymmetries of the two-link network has important consequences for road safety. Imposing charges on the best high-capacity roads may discourage some drivers from using them and lead them to shift to the low quality alternative. Of course, we expect the share of shifted drivers to be lower if the alternatives are poor quality than in the case of perfect substitutes. As stated above, this re-routing effect will be positively correlated with the quality of the alternatives. As these roads also have lower capacity, this means they will also reach their congestion level faster than in the case of pure substitutes (i.e., free motorways). For this reason the second best price will lie between the second best toll when both routes are pure substitutes and the first best toll. In other words, the need to reduce the price in order to induce the use of the tolled motorway instead of the widely used free alternative is lower when the alternative road is poor quality because drivers are more willing to accept the motorway price for their journey.

Private toll-road operators are typically interested in maximizing profit rather than social surplus, so they cannot be expected to impose first-best pricing. In fact, Verhoef et al. (1996) demonstrate that revenue-maximizing one-route tolling can by definition never be more efficient than optimal one-route tolling. Due to the monopoly power enjoyed by concessionaires, tolls are regulated in most European countries.[7]

Unfortunately, regulated tolls do not follow optimal pricing schemes: neither first best, nor second best. Instead, they are only set to warrant the financial breakeven of the private firms operating the infrastructure, typically by some form of rate or return regulation, and no weight has been put on other social efficiency criteria (Newbery 2000). This policy approach has been triggered by the privatization of toll motorways in Europe (Albalate et al. 2009) and makes it particularly difficult to vary prices according to efficient allocation schemes, as would be required in order to fulfill the function of regulating demand.

According to the theory, optimal one-route tolls designed by a planner should increase with negative externalities occurring on the tolled motorway, and decrease with external costs occurring on the untolled alternative. Setting tolls regardless of what happens in the substitute road produces the re-routing effect and as a result, increases externalities on the untolled route. This leads to inefficiently higher prices—according to a second best strategy—and naturally implies an increase in the traffic volume of lower quality and capacity alternatives. Only the internalization of safety costs produced on the untolled road through the toll setting strategy, or a joint design of infrastructure improvement programs focused on toll motorway alternatives, can solve this inefficiency.

In view of this economic problem, the present paper proposes two main hypotheses to be tested in the empirical part:

H1: The share of motorways in the total network improves road safety because of higher quality standards with respect to other road infrastructures. This is the

[7] The United Kingdom is the only European country without State Toll Regulation. As a result, the sole concessionaire of a tolled motorway in the country decides, freely, the toll charged to road users.

traditional approach to investment policies. High quality roads should promote road safety and acts s a proxy of better road infrastructure in the country.

H2: The safety enhancing impact of motorways as better infrastructure (H1) is offset or is weakened where motorways are tolled and when the pricing does not follow second best efficient criteria. The results derived from this hypothesis represent our main contribution to the literature on infrastructure pricing and road safety policies.

Since this paper confirms both hypotheses, we believe that the inefficiency produced by current tolling strategies and the quality and capacity asymmetries between toll motorways and their alternatives have a negative impact on road safety. First, because tolling does not apply an optimal pricing scheme and considers only financial objectives, ignoring any regulatory function. Second, because external and network effects are not considered by toll operators due to the current regulatory framework. The current toll settings in countries with this price regime are socially inefficient; they increase traffic volumes on lower quality roads and, as a result, increase their safety risk with respect to countries where motorways are free and re-routing does not exist.

4 Empirical strategy

In order to test the impact of different types of road infrastructure and their pricing on national road safety, we use a sample based on 15 European countries (the EU15 prior to enlargement) and 13 years for the total fatality rate per million inhabitants which will serve as the endogenous variables related to overall road safety outcomes (a total of 195 observations). This dependent variable is obtained from the European road accidents database CARE (community database on road accidents in Europe), while data on the rest of variables are collected from other international databases, like Eurostat, World Bank Development indicators, and the World Road Statistics. This exercise should serve to test the impact of different type of roads on road safety outcomes.

In order to test the safety impacts from different price regimes in motorway funding, we take the six European countries whose road networks contain a significant share of toll motorways (Portugal, Spain, France, Italy, Greece and Austria), and replicate the estimation distinguishing between free and toll motorways (78 observations).

Our cross-country approach imposes limitations. The most important one is that we are confined to evaluating a problem that produces micro effects (at route levels) with aggregate data (at national level). Unfortunately, it is impossible to undertake a cross country study assessing this micro effect because few data are available at route level, and in any case it would be impossible to obtain homogeneous data for the countries in our sample. Nonetheless, we believe that our paper makes an important contribution. To date, economic analysis of road externalities has focused mainly on congestion costs, calling for the use of congestion charges as the only first best and second best pricing schemes; our analysis and results highlight new concerns regarding the use of tolls in interurban motorways.[8]

[8] Congestion costs are more likely to appear in urban environments and consequently in access motorways to big cities. Accordingly, interurban tolls are not usually designed to fight congestion but to finance infrastructure projects.

Table 1 Definition of variables and descriptive statistics

Variable	Definition	Mean	Standard deviation
Yi	Road fatality rate per million inhabitants	127.91	3.71
Motorization	Number of passenger cars per 1,000 inhabitants	418.536	93.768
% Unemployment	Unemployment rate (%)	8.748	0.309
Motorways	Proportion in % of motorways (km) over the total road network	1.312	0.935
% Free motorways	Proportion in % of free motorways (km) over the total road network	1.036	0.0712
% Toll motorways	Proportion in % of tolled motorways (km) over the total road network	0.278	0.0324
Primary roads	Proportion in % of primary roads (km) over the total road network	8.942	5.105
Secondary roads	Proportion in % of secondary roads (km) over the total road network	1.83	0.39
Alcohol consumption	Alcohol consumption in litres per capita	11.215	0.173
Education	% Population between 16 and 64 years old with upper secondary education	55.911	18.270
Speed limit	Speed limit in motorways	120.918	0.4977
BAC level	Blood alcohol content level permitted	0.631	0.188
Minimum legal drinking age	Binary variable: 1 where a minimum legal drinking age exists for any purchase of alcohol. 0 Otherwise	0.592	0.491
Rail passenger-km pc	Number of passenger-km per capita in rail modes	0.710	0.273

The model chosen to estimate these panel data models is a common one-way fixed effects semi-log model with time trend that takes the following form:

$$\ln(Y_{it}) = \alpha + \beta X_{it} + s_i + trend_t + \varepsilon_{it} \quad (1)$$

where $\mathbf{Y_{it}}$ is the fatality rate per million inhabitants in the country **i** at year **t**, $\mathbf{X_{it}}$ contains the vector of time-varying control covariates, and $\mathbf{s_i}$ represents the country-specific fixed effects. The rationale behind the use of country fixed effects is that they control for time-invariant country-specific omitted variables, while the introduction of a time trend in the model controls for national time trends. Besides, $\boldsymbol{\varepsilon}_{it}$ is a mean-zero random error. Table 1 shows the dependent variable and the time-varying covariates used and their descriptive statistics. In the appendix we also provide the correlation matrix between variables (Table A1).

The use of a time trend variable is of relevance due to the decreasing trend of road fatalities recorded by EU countries during the period studied.

The used of a fixed effects framework is justified by the obvious unobservable heterogeneity suffered that prevents the use of all relevant variables that can affect road safety. Besides, the Hausman test shows that random effects estimates are not consistent in our framework, by rejecting the null hypothesis of no correlation between regressors and country-specific fixed effects.[9] Nonetheless, we provide results given

[9] The Hausman test measures the correlation between regressors and country specific fixed effects using the lack of correlation as null hypothesis. In our case this is reflected with a $\chi^2 = 305$ and Prob $> \chi^2 = 0.000$, and therefore the model chosen is fixed effects.

by pooled models to check that the use of a fixed effects panel strategy does not have an impact on the main finding of the current paper, which is the difference in the impact of toll and free motorways on road fatalities, but improves the robustness of the results. These results can be consulted in the appendix (Table A2). The estimation method used is the within-group estimator.

The first transportation variable used is Motorization, which denotes the number of passenger cars per 1,000 inhabitants. Although more cars per capita may mean more cars on the road and consequently a higher risk, this variable is usually correlated with transportation development, which at the same time is strongly and negatively related to road fatalities. Better infrastructures, better vehicles and safer transportation systems are usually associated with high motorization in international comparisons. Moreover, highly motorized areas are usually associated with congestion and this is also found negatively related to road fatalities.[10] Moreover, motorization is highly correlated with economic development; we decided not to use any measure of GDP in order to avoid collinearity problems. We also consider the economic cycle (using the unemployment rate), which is expected to affect fatalities.

The core of our analysis is found in the infrastructure variables used. First, we control for the presence of motorways as the road infrastructure providing the highest levels of road safety. The literature on the impact of motorways on road safety outcomes shows mixed results. Although motorways are better quality roads, they may induce more traffic and encourage risky behavior, and so, as a perverse consequence, may favor road crashes. Some micro studies (Milton and Mannering 1998; Martin 2002) provide evidence that infrastructure improvements such as adding lanes may increase accidents, though other researchers such as Flahaut (2004) found significant safety effects associated with infrastructure improvements.

Conventional inter-urban roads include primary and secondary roads. Primary roads are expected to provide better road safety outcomes than (lower quality) secondary roads, but worse than motorways (either tolled or free). Of these three types, secondary roads are expected to provide the worse safety outcomes. All these variables related to road type serve to test our first hypothesis regarding the safety outcomes of road quality.

Besides assessing this effect, we are particularly interested in determining whether the motorway effect (i.e, the effect of the best infrastructure) is the same for different pricing policies. Specifically, we distinguish between km tolled and km free of payment. Our interest lies in the fact that a greater presence of motorways could provide better results for overall road safety outputs (unless they induce risky behavior and more traffic in a way that offsets the safety effect), but that the results may deteriorate when this type of infrastructure is priced. Therefore, this analysis leads us to test our second hypothesis on the offsetting effect of pricing the best quality roads.

A regulatory covariate is also introduced. We include speed limits (on motorways) to account for the fact that higher speed limits are expected to exert a (positive) effect on our fatality rate. It is worth mentioning that here we do not use compulsory seat-belt laws, which are usually included in US studies, since the European Union passed

[10] Although more cars on a road may increase the crash risk, higher levels of traffic slows the average speed, lowering the probability of fatal accidents.

legislation (Directive 91/671/EC on 16 December 1991) on the compulsory use of all seat-belts for all member states in 1991, the first year of our sample. Instead, we include two safety measures, the illegal blood alcohol content limit (BAC) and the minimum legal drinking age (MLDA).

Finally we also control for alcohol consumption, education, and the use of the railway in national mobility. The medical and economics literature show that the first variable has a significant impact on road fatalities, and its discouragement is known to promote road safety. Education is usually considered a good proxy for personal income and for a lifestyle based on more mobility (including going out for dinner, the theater, cinema, tourism, etc.). This variable is not usually used in road safety studies and its impact may provide interesting insights. Finally, the introduction of the main competitor of road transport as another explanatory variable may serve to capture how modal split can affect road safety outcomes. We expect lower fatality rates in countries with more km traveled by rail.

5 Results

5.1 Econometric results

Our results are displayed in Table 2. Specification (1) uses the variable motorways, without distinguishing tolled motorways from free motorways and considering the full sample of 15 EU countries. We start by using the aggregate variable in order to show the expected relationship between the best infrastructure and road fatalities. As can be seen, the coefficient associated to this covariate is large, negative and statistically significant. Therefore, without distinguishing between price regimes, motorways seem to favor road safety, confirming hypothesis 1.

The rest of variables also present the expected signs. The coefficient associated with the unemployment rate is negative and statistically significant, confirming the pro-cyclical path of road fatalities. Alcohol consumption is associated with more road fatalities; motorization shows a negative and statistically significant relationship with the use of rail transport and the time trend variable. As for road quality, we find that a bigger share of secondary roads in the road network produces more fatalities per million inhabitants, but its coefficient is small. Primary roads do not seem statistically significant, probably because they lie between motorways, which promote road safety, and secondary roads, which produce the opposite effect.

The next step involves the results from specifications (2) and (3), where we attempt to assess the importance of motorway pricing regimes for safety outcomes. This is the main part of our empirical contribution. These regressions are applied to the six countries with a significant share of toll motorways inside their motorway network. When we use the aggregate motorway variables—if we replicate specification (1) for this smaller sample—we find consistent results. The coefficient associated with the motorways variable is negative and statistically significant. Nonetheless, there is an important difference: its size is much larger, indicating that motorways are more important for the determination of road safety outcomes in these countries. After confirming the positive effects of better quality roads, we distinguish between free and tolled motorways in specification (3). As we show, the free motorway variable is strongly related

Table 2 Least-squares estimates for semi-log models

Covariates	FE (1)	FE (2)	FE (3)
Motorization	−0.0006*	−0.0008**	−0.0009**
	(0.0003)	(0.0004)	(0.0004)
%Unemployment	−0.0095**	−0.0088	−0.0092*
	(0.0036)	(0.0056)	(0.0054)
Motorways	−0.0439***	−0.2062**	–
	(0.0151)	(0.0829)	
% Free motorways	–	–	−0.3061***
			(0.0852)
% Toll motorways	–	–	−0.0521
			(0.1757)
Primary roads	0.0026	0.0077	−0.0095
	(0.0025)	(0.0182)	(0.0229)
Secondary roads	0.0007*	0.0039***	0.0039***
	(0.0004)	(0.0011)	(0.0010)
Alcohol	0.0219*	0.0374**	0.0655*
	(0.0130)	(0.0157)	(0.0391)
Education	0.0021	−0.0111**	−0.0109*
	(0.0022)	(0.0056)	(0.0055)
Speed limit	0.0015	0.0007	0.0011
	(0.0029)	(0.0029)	(0.0028)
BAC level	0.0119	−0.0574	0.0038
	(0.0646)	(0.0805)	(0.0824)
Minimum legal drinking age	−0.0301	0.0746	0.0428
	(0.0351)	(0.0591)	(0.0677)
Rail passenger- km pc	−0.2766**	−0.4665***	−0.3902**
	(0.1144)	(0.1999)	(0.1937)
Trend	−0.0268***	−0.0209**	−0.0187*
	(0.0048)	(0.0101)	(0.0096)
N	195	78	78
R^2	0.83	0.68	0.71
F (joint significance)	53.52***	41.70***	43.39***

Each model includes a constant term and a trend variable
Standard errors robust to heteroskedasticity are presented in parenthesis
* Statistically significant at the 10% level; ** at the 5% level and *** at the 1% level

to road safety and its coefficient is quite large, larger in fact than the coefficient associated with the motorways' variable when it is introduced alone (Specification 2). In contrast, the toll motorway variable does not seem to play any role in overall road fatalities: its coefficient is not statistically significant, though it presents negative sign. Moreover, its size is much lower than the one associated with free motorways.

This result, in line with hypothesis 2, seems to suggest that only free motorways clearly promote road safety. Since quality standards are similar in both price regimes, as stated in the introduction, if we find more accidents on toll motorways than on free motorways this is not because of safety standards. Thus, there are reasons to believe that the different impacts on road safety associated with different pricing strategies may be due not to the motorway network but to the alternative road network that competes with it.

To check robustness, we decided to run a placebo experiment. We estimated the same regression model with a single change, replacing the dependent variable with the

Table 3 Placebo experiment

Covariates	FE (4)
Motorization	0.0006
	(0.0022)
%Unemployment	0.0362*
	(0.0388)
% Free motorways	0.0875
	(0.2363)
% Toll motorways	0.4260
	(0.4326)
Primary roads	−0.0691
	(0.0603)
Secondary roads	−0.0030
	(0.0036)
Alcohol	0.1230***
	(0.0422)
Education	0.0066
	(0.0191)
Speed limit	−0.0035
	(0.0068)
BAC level	−0.1032
	(0.3248)
Minimum legal drinking age	−0.2416
	(0.1793)
Rail passenger- km pc	−0.2880
	(0.5090)
Trend	−0.0546**
	(0.0251)
R^2	0.53
F test (joint significance)	7.14***

Each model includes a constant term and a trend variable
Standard errors robust to heteroskedasticity are presented in parenthesis
Least-squares estimates for semi-log models ($N = 78$)
* Statistically significant at the 10% level; ** at the 5% level and *** at the 1% level

rate of work-related fatalities per million inhabitants. The objective of this robustness check is to make sure that our results are not led by other elements associated with national characteristics which are captured by infrastructure variables. For instance, one might imagine that countries that invest in free motorways also invest in general personal safety programs, and trends towards safer societies and the increase of safety concerns in the population may confound the statistical impact of pricing roads on road safety. Therefore, this new dependent variable should not be affected by our variables of interest. Results for this test are displayed in Table 3.

After running this regression (Specification 4) we realize that, as expected, the explanatory power of the model estimated falls significantly. More importantly, infrastructure variables do not seem to affect work-related fatalities. In contrast, the unemployment rate, alcohol consumption and the time trend are the only variables showing statistically significant coefficients. Therefore, the placebo experiment is successful.

To sum up, in this section we have found that motorways are the only road type that is positively correlated with road safety improvements. No other roads have a statistically significant positive impact, and secondary roads are even associated with negative effects. Moreover, even using aggregate national data and different estimation models, there are reasons for doubting these positive impacts when motorways are priced (tolls), probably due to the rat-running effect they generate due to inefficient pricing or a lack of investment. Since the presence of motorways is strongly correlated with lower road fatalities we should expect similar coefficients and strong relationships regardless of the pricing regime (i.e., free or tolled). Nonetheless, we find that in our fixed effects estimation only free motorways are associated with statistically significant impacts on overall safety; toll motorways do not play a statistically significant role and their coefficient is significantly lower than that of free motorways.

5.2 Policy implications

Our results may have important public policy implications in the field of transportation and infrastructure management. Extending motorway networks emerges as an important safety enhancing policy. However, our findings suggest that pricing motorways through the mechanisms currently in use may not be able to fully exploit the infrastructure advantages of motorways. On the one side, building motorways is a way of improving safety standards, and no differences would be expected to exist between free and tolled roads. On the other, tolling seems to compensate this positive effect by increasing other crash risks. The reason for this may be the re-routing generated by inefficient tolling, which shifts traffic to low quality alternative roads. If this is the case, more investment in maintenance and quality should accompany toll establishment. In this paper we claim that this investment must be devoted to improving safety in the adjacent alternative routes that receive diverted traffic from the tolled motorway. Nevertheless, this proposal may meet opposition from the toll motorway concessionaire affected by the increased quality of its competing road (Engel et al. 2004). However, this opposition need not be an issue if investment is focused on improving safety at especially dangerous points or stretches of the alternative roads.

Another alternative for regulators and transport managers is the internalization of accident externalities by lowering tolls to one-route second-best levels in order to improve safety outcomes in the whole corridor. This solution derives from the literature on second-best pricing in road networks which we presented above, and which find that first best pricing reduces congestion on the toll road through the fare, but does not take into account external costs in the alternative untolled road which receives the users diverted from the tolled one. Therefore, drivers shifting to congested untolled roads aggravate this congestion. As a result, one-route first-best pricing ignores the spillovers onto the free roads and it is necessary to apply one-route second-best tolling which internalizes congestion across the whole network. This implies a downward adjustment of tolls below first-best levels.

6 Concluding remarks

This paper has shown that motorways are the only type of road associated with reductions in traffic fatality rates. We argue that only free motorways obtain net positive effects at aggregate level (country level), since toll motorways appear to provide mixed impacts. Although toll motorways are better infrastructures, other effects influence their final impact on road safety. This result is especially interesting given the present trend towards increased private participation in infrastructure. Indeed, the use of tolls is becoming widespread all over the world, due to their ability to solve budget constraints and avoid tax increases when governments commit to infrastructure enlargements or quality improvements. For this reason, our study focuses the debate on a new safety concern related to the motorway pricing strategies applied by transportation authorities and policy makers.

Using an international European panel and a fixed effects estimation, we show that road quality plays a role in road safety results, but that price regimes in motorways may also make a difference. We provide econometric evidence of the positive impacts produced by free motorways on road safety outcomes. This evidence is not so significant on tolled roads. On the one hand, motorways provide higher safety standards than conventional roads, but on the other, the existence of the toll encourages drivers to shift to low quality roads. This effect, which is called the re-routing or rat-running effect, is a reasonable interpretation of our results which seems to offset the first positive effect produced by infrastructure quality.

This conclusion also has important public policy implications in the field of transportation and infrastructure management. Policy makers deciding to impose tolls on the best roads must invest more in maintenance and quality in order to improve safety in the adjacent alternative routes which receive diverted traffic from the tolled motorway.

An alternative for regulators and transport managers is the internalization of accident externalities by lowering tolls to improve safety outcomes in the corridor. In our framework, priced-off drivers diverted onto lower quality roads are more prone to suffer accidents; the policy of imposing tolls on the best infrastructures without taking this effect into consideration may increase crashes. Again, a downward adjustment of tolls may be necessary to internalize this perverse spill-over. The potentially damaging effects of this toll regulation on the financial conditions of the toll motorway concessions could be dealt with via budget subsidies.

Future research should aim to overcome some limitations of our analysis, above all the limitation implied by evaluating a problem that produces micro effects at route levels with aggregate data at national level. No doubt, improving the availability of cross country homogeneous micro-data would be an important step forward.

In all, this study provides interesting results for both the road safety and transportation literature. As regards the road safety literature, we shed new light on the role of motorways and the importance of pricing infrastructures, another risk factor which has not been treated in depth before. At the same time, we complement the literature on transport externalities in a framework similar to the one used in theoretical studies based on both financial tolls and congestion charging.

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Appendix

See Tables A1 and A2.

Table A1 Correlation matrix

Covariates	Motorization	Unemployment	Motorways	Free motorways	Toll Motorways	Primary roads	Secondary roads	Alcohol	Education	Speed	BAC level	Mlda	Rail Pass-km pc
Motorization	1												
Unemployment	−0.31	1											
Motorways	0.58	−0.13	1										
Free motorways	0.43	−0.21	0.88	1									
Toll motorways	0.25	0.17	0.12	−0.36	1								
Primary roads	0.39	−0.22	0.41	0.31	0.15	1							
Secondary roads	0.42	−0.37	0.27	0.34	−0.18	0.44	1						
Alcohol	0.34	−0.24	0.37	0.34	0.02	0.24	0.62	1					
Education	0.11	−0.24	0.06	0.35	−0.41	−0.22	−0.11	−0.14	1				
Speed	0.30	0.12	0.23	0.07	0.31	0.21	−0.03	0.20	−0.16	1			
BAC	−0.06	0.23	−0.02	−0.05	0.05	−0.01	0.23	0.41	−0.24	0.30	1		
MLDA	−0.00	0.37	0.18	0.08	0.18	−0.44	−0.40	0.01	−0.24	0.51	0.16	1	
Rail pass-km	−0.26	−0.29	−0.12	−0.17	−0.11	−0.28	−0.09	0.06	0.46	0.06	−0.20	0.26	1

Table A2 Least-squares estimates for semi-log models ($N = 195$)

Covariates	OLS
Motorization	−0.0008***
	(0.0003)
%Unemployment	0.0145***
	(0.0039)
Motorways	−0.0990***
	(0.0206)
Primary roads	0.0068*
	(0.0040)
Secondary roads	−0.0001*
	(0.0000)
Alcohol	0.1537***
	(0.0100)
Education	−0.0106***
	(0.0011)
Speed limit	0.0030**
	(0.0029)
BAC level	−0.7357***
	(.0934)
Minimum legal drinking age	0.1192**
	(0.0541)
Rail passenger- km pc	0.0399
	(0.1043)
N	195
Adj. R^2	0.83

Each model includes a constant term and a trend variable. Standard errors robust to heteroskedasticity are presented in parenthesis
* Statistically significant at the 10% level; ** at the 5% level and *** at the 1% level

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