The causal effect of road concessions on road safety*

Pedro Jorge Alves† Lucas Emanuel‡ Rafael H. M. Pereira§

Abstract

Reducing road fatalities is a key policy concern in several countries. Nonetheless, there is limited evidence on whether highway concessions and Public Private Partnerships (PPP) can bring road safety benefits, despite the growing number of countries adopting this policy to finance and manage road infrastructure. In this paper, we use a difference-in-differences approach to examine the causal effect of highway concessions on road safety outcomes using daily crash data from Brazilian Federal highways between 2007-2017. We find that concessions significantly improve road safety measures, including fatality rates and the number of people and vehicles involved in crashes. On average, procured roads had 15 fewer deaths then publicly managed highways for every 1000 crashes each year, and avoided 16 thousand deaths between 2007-2017. Moreover, these effects are marginally larger for every additional year of treatment but only become statistically significant a few years after the concession implementation. Finally, our results suggest that including safety-based incentives in concession contracts can substantially improve road safety performance.

JEL Classification: I18, I15, H42, R42.

Keywords: Road crashes; Road Safety; Differences-in-Differences.

Resumo

A redução de fatalidades em rodovias é uma preocupação central em vários países. No entanto, existem poucas evidências sobre se concessões de rodovias e Parcerias Público-Privadas (PPP) podem trazer benefícios à segurança rodoviária, apesar do crescente número de países que adotam essa política para financiar e gerenciar sua infraestrutura. Neste artigo, usamos um modelo de diferença-em-diferenças para estimar o impacto de concessões sobre segurança rodoviária usando dados diários de acidentes em rodovias federais brasileiras entre 2007-2017. Constatamos que as concessões melhoram significativamente várias medidas de segurança no trânsito, reduzindo as taxas de letalidade e o número de pessoas e veículos envolvidos em acidentes. Em média, rodovias concessionadas tiveram 15 mortes a menos que as rodovias administradas publicamente para cada mil acidentes por ano e evitaram 16 mil mortes entre 2007 e 2017. Além disso, encontramos que esses efeitos ficam marginalmente maiores a cada ano adicional de exposição ao tratamento mas que eles se tornam estatisticamente significativos apenas alguns anos após a implementação da concessão. Finalmente, nossos resultados sugerem que a inclusão de incentivos baseados em desempenho de segurança viária nos contratos de concessão melhoraram substancialmente a segurança nas rodovias.

Palavras Chaves: Acidentes de trânsito; Segurança rodoviária; Diferenças-em-Diferenças

Classificação JEL: I18, I15, H42, R42

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†Institute for Applied Economic Research (Ipea), e-mail: pedro.alves@ipea.gov.br.

‡Institute for Applied Economic Research (Ipea), e-mail: lucas.emanuel@ipea.gov.br.

§Institute for Applied Economic Research (Ipea), e-mail: rafael.pereira@ipea.gov.br.

1 Introduction

Road traffic crashes represent the eighth leading cause of death globally, summing 1.35 million deaths and 50 million injured people each year (WHO, 2018). Various studies investigate how road safety is influenced by factors such as weather conditions (Theofilatos and Yannis, 2014; Brijs, Karlis and Wets, 2008), speed limits and road design (De Pauw et al., 2014; Wang, Quddus and Ison, 2013), law enforcement and awareness campaigns (Lewis, Watson and Tay, 2007), as well as individuals attitudes and skills (Shinar, 2017; Anstey et al., 2012). Nonetheless, there is still little understanding about whether the implementation road concessions can help improve road safety performance, particularly in countries in the Global South.

Since the 1990s, it has become increasingly common for governments to use road concessions via Public Private Partnerships (PPP) as an alternative means to finance and manage roads (Bel and Foote, 2009; Galilea and Medda, 2010; Albalate and Bel-Piñana, 2019). Between 1990 and 2015, several countries worldwide have awarded over 950 PPP road projects totalling an investment of 267,039 million dollars (Albalate and Bel-Piñana, 2019). A common motivation behind road procurement is the expectation that private sector operators can more efficiently upgrade and maintain road quality, bringing about both economic as well as road safety outcomes (Grimsey and Lewis, 2007). Nonetheless, private operations can often face potential conflicts of interest due to trade-offs between profits and the quality and safety of services (Hart, 2003), raising questions about whether road concessions could effectively improve road safety.

This paper examines the impact of road concessions on road safety outcomes using detailed daily data on traffic crashes in all of Brazilian federal highways over a 10-year period between 2007-2017. Using a difference-in-differences (diff-in-diff) approach, we test whether the introduction of road concessions significantly reduces the number and severity of road crashes in treated roads after concession. As exogenous variation in the road safety, we exploit the transition from public to private management in some but not all Brazilian states to provide both within- and between-states comparisons over time. The analysis looks at various road safety outcomes such as including number of crashes per kilometer, number of deaths per crashes, number of deaths per people involved in crashes, among others.

The few studies that previously have addressed this question suggest that the road concessions through PPP could reduce the number of traffic crashes (Rangel, Vassallo and Arenas, 2012; Rangel and Vassallo, 2015; Baumgarten and Middelkamp, 2015; Albalate and Bel-Piñana, 2019). Nonetheless, these studies are largely focused on developed countries, even though most global road traffic deaths occur in low- and middle-income countries (Abubakar, Tillmann and Banerjee, 2015). Moreover, the methods previously used in this literature are largely based on negative binomial or panel regression models that do not capture causal effects (see section 2). This paper advances the literature by showing how a quasi-experimental research design can help estimate the causal effects of road concessions on road safety outcomes. The method employed in this study also considers multiple robustness tests and allows one to capture heterogeneous effects with regard to the time when the concession is implemented.

The remainder of this paper is as follows. Section 2 reviews the literature on road safety and road concessions around the world. Data and methods are presented in Section 3 and results presented in Section 4 Finally, Section 5 discusses the main conclusions about the case study of Brazil and some lessons that can be drawn for road safety performance more broadly.

2 Literature review

Every year, traffic crashes cost approximately 130 billion euros to countries in the European Union (equivalent to 2% of Europe's GDP) (European Commission, 2010), and around 1.8 trillion dollars globally (approximately 3% of the world's GDP) (iRAP, 2015). In Brazil, road fatalities is the 10th leading cause of death and the second most common external cause of death, with over 33 thousand deaths a year and more than a million of potential years of life lost by road traffic injuries (Andrade and Mello-Jorge, 2016).

Reducing road fatalities has become a key policy concern in several countries (WHO, 2018). This issue has also received substantial attention from researchers who investigate how different factors affect road safety outcomes. Multiple studies analyze the extent to which the incidence and severity of road crashes are influenced by speed limits and the geometric and traffic characteristics of highways (Milton and Mannering, 1998; Wang, Quddus and Ison, 2013; De Pauw et al., 2014) or weather conditions (Theofilatos and Yannis, 2014; Brijs, Karlis and Wets, 2008). Others have investigated the role played by law enforcement and awareness campaigns (Lewis, Watson and Tay, 2007), as well as individuals attitudes and skills (Shinar, 2017; Anstey et al., 2012).

The work of Hermans et al. (2009), for example, uses a data envelopment analysis (DEA) to compare road safety performance indicators (SPI) 21 European countries. The authors find that some of the key factors shaping road safety include the use of alcohol and drugs by drivers, speeding, vehicle types, infrastructure and trauma management. In a detailed study in Brazil, Lima et al. (2008) investigated the determinants of road crashes on Brazilian highways between 2004 and 2005 based on inspection and field research in sections of highways BR-116 and BR-324. The authors found that poor road signs close to urban areas, inadequate traffic conditions, behavior of pedestrians and drivers and unfavorable weather conditions are the main causes of crashes.

Many of the key factors discussed in the literature - such as road maintenance and signs, speed controls, law enforcement and trauma management teams - are directly affected when governments outsource road management through road concessions. Nonetheless, despite the growing number of countries using road concessions and Public Private Partnerships (PPP) as a policy strategy to finance and manage road infrastructure (Bel and Foote, 2009; Galilea and Medda, 2010; Albalate and Bel-Piñana, 2019), there are still very few studies that investigate whether this type of policy bring any road safety benefits.

In some of the earlier studies on this topic, Rangel and colleagues (Rangel, Vassallo and Arenas, 2012; Rangel, Vassallo and Herraiz, 2013; Rangel and Vassallo, 2015) evaluated whether safety-based incentives incorporated in highway concession contracts in Spain helped reduce road crashes between 2007 and 2009. These economic incentives include for example bonuses and penalties for contractors who do not meet certain certain safety performance indicator. Using a negative binomial regression model, the authors find that the implementation of these incentives positively affect the reduction in 0.252 of the expected number of accidents comparing with public highways, indicating that tolled highways with safety performance incentives are safer than conventionally procured roads. A similar result has been found by Albalate and Bel-Piñana (2019), who studied the effects of PPPs on road safety outcomes between 2008 and 2012 in Spain, using a panel-data fixed-effects method. In this case, using a poisson regression as example, the authors found that roads managed under PPP has, on average, a 0.41 drop in the annual number of accidents with victims compared to regular roads.

Looking at the case of Mexico, Geddes, Li and Rouhani (2015) used fixed-effect multiple regression models to estimate the association between road concessions and the number of crashes and fatal collisions in federal and state highways between 1997 and 2009. After aggregating annual data at the municipality level, the authors found that procured roads had on average reduces in -19.80 all accidents per kilometer in federal roads. However, results were not statistically significant for fatal crashes and no significant effects were found after including fixed effects.

Finally, the paper by Pereira, Pereira and Santos (2017) also aggregates road crash data at the municipal level to investigate the effects of the introduction of tolls on road safety in Portugal's highways between 2008 and 2014. Exploiting the fact that decisions to implement road tolls are taken at national policy level without the direct involvement of the municipalities that are affected, the authors uses a differences-in-differences regression to overcome potential endogeneity problems in the data. The treatment group consisted of 59 municipalities that contained some segment of a tolled highway while the control group consisted of the remaining 219 municipalities in Portugal. The study shows that the introduction of tolls significantly improved road safety in highways, with a reduction between 21.1% and 16.4% in total number of crashes and a between 27.2% and 22.4% in number of victims. The authors warn, though, that these results were also followed by a small increase (4%) in the number of victims with minor injuries in other types of roads. This result is consistent with known traffic diversion effects (Albalate, 2011; Albalate and Bel, 2012), where the implementation of tolls induces some traffic shift to non-tolled adjacent secondary roads. A similar result was found in Germany by Baumgarten and Middelkamp (2015), who found that the introduction of tolls for heavy vehicles on highways between 2000 and 2010 increased the total number of crashes in adjacent roads by by 3.70%.

I summary, the accumulated evidence in the literature suggests significant association between tolled road concessions and better road safety performance. Nonetheless, most of these studies are focused on developed countries and based on statistical analyses that do not capture causal effects, with few exceptions (Baumgarten and Middelkamp, 2015; Pereira, Pereira and Santos, 2017). There is particularly little rigorous evidence on the effectiveness of road safety programs in the Latin American context (Martinez, Sanchez and Yañez-Pagans, 2019). In the next sections we advance this literature by using a quasi-experimental research design to examine the causal effect of toll road concessions on road safety outcomes in Brazil, a middle-income country with one of the largest road networks under private concessions in the world (Brochado and Vassallo, 2014; Neto et al., 2018). Compared to previous studies, we use detailed daily data on traffic crashes aggregated for each month at the road level. Furthermore, the method deployed in this paper uses fixed controls and effects on multiple robustness checks and road safety indicators, what allows us to measure how the effect of road concessions on road safety outcomes change over time.

3 Context of road concessions in Brazil

The Brazilian national government launched first phase of the Federal Highway Concession Program in 1995, in a context of severe fiscal constraint and having recently overcome a period of hyperinflation. The first phase included the procurement of six sections of highways with terms ranging from 20 to 27 years. The second phase started occurred in 2008, the third one in 2013 and the last phased started between 2018 and 2019 1. Up until 2017, approximately 10215.4 km (12.50%) of all federal highways were managed by private contractors concession contracts ANTT (2018).

Table 1: Extension of federal highways Brazil (Km)

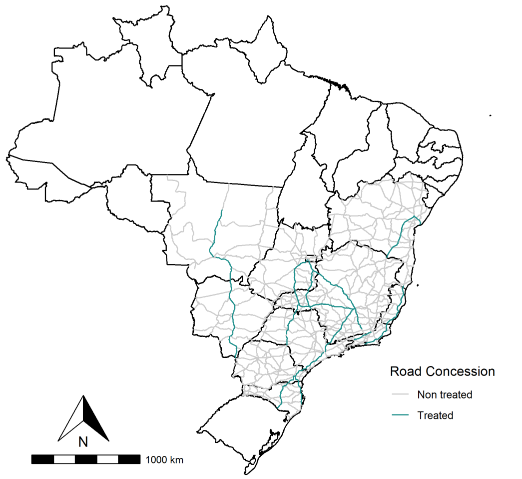
	Extension	Number of Roads
Public Concession		
1º Phase	1,602.9	7
2º Phase	3,755.4	12
3º Phase	4,056.6	13
4º Phase	800.5	5
Public	117,471.9	347
Total	127,687.3	384

Note: National Department of Transport Infrastructure (DNIT) and Brazilian Land Transportation Agency (ANTT).

Companies running road concessions are obliged by contract to perform regular road maintenance and improvements, including the construction of double lanes, walkways, and installation of speed cameras and traffic signs. All concession contracts require companies to provide roads assistance including tow trucks, medical assistance, and traffic inspection and control centers. Since the second phase of road concessions, however, companies were only allowed to start charging tolls after the completion of initial recovery works and services on road segments considered most urgent. Furthermore, for those roads procured in the third phase, the collection of tolls were only approved if companies would meet recovery goals as well as if they managed to improve road safety outcomes compared to other concessions. This difference between concession contracts of phase 2 and 3 contributes is explored in our data analysis.

In this paper we only consider those road concessions from the second and third phases. This is because there is no detailed road crashes data before the year 2000, and because there is not enough information on road safety performance from concessions in the forth phase since its implementation after 2019. We also restrict our baseline comparison group to only include roads in the states where at least one road segment was procured. Figure 1 shows the road segments (treated and non-treated) of the federal highways considered in our analysis.

Figure 1: Federal highways in our sample.



Notes. Note: The figure only shows the highways of states where at least one federal roads has been procured during the second and third phase of brazilian concessions.

4 Methods

4.1 Data

We use data on daily road crashes between 2007 and 2017 from the national information system on Federal highway crashes, organized by the Brazilian Federal Highway Police Department (PRF). This is a public data set that compiles detailed information on all road crashes on federal highways, including the location and characteristics of the crash such as severity, number of deaths, number of people injured, number and types of vehicles involved[1]. Spatial data on the Brazilian national highways come from the National Department of Transport Infrastructure (DNIT).

To allow for a more controlled analysis, we only compare treated highways (manged by private operators under concession) and control group (highways managed by the federal government), within the same state. Therefore, we analyze all the road crashes on federal highways in states that have at least one road segment under concession in a period of eleven years between January 2007 and December 2017, the second and third phases of the Brazilian roads concession program. We aggregate the daily cases by road segment, state and month of the year in our analyses. The final data set contains on average more than 92,000 crashes a year spread over 104 federal road segments in 11 states.

We run the analysis considering multiple road safety performance measures (table 2). For the sake of brevity we only present the full results for two outcome variables on road crash fatality: the number of deaths per total number of crashes in each road segment in a given month, and the number of deaths per total number of people involved in those crashes.The results for all other road safety outcomes are presented in table 6.1 in the Appendix.

[1] The data can be downloaded at dados.gov.br/dataset/acidentes-rodovias-federais

Table 2 presents the descriptive statistics of various road safety measures in 2007 and 2017 for federal highways in our sample. Although the number of crashes per road kilometer has dropped in this period, there was an increase in the number of deaths per crash and per people involved, a worrying results suggesting an increase in the fatality of road crashes in between 2007 and 2017.

Table 2: Descriptive statistics of road safety measures in Brazilian federal highways under concession, 2007 and 2017.

	2007		2017	
Variables	Mean	Std. Dev.	Mean	Std. Dev.
Deaths per crash	0.068	0.137	0.091	0.171
Deaths per people involved	0.030	0.055	0.037	0.060
Crashes per kilometer	0.289	0.432	0.195	0.292
People involved per kilometer	0.618	0.946	0.443	0.678
Death per kilometer	0.012	0.020	0.009	0.014
Injured per kilometer	0.179	0.246	0.185	0.294
Vehicles per kilometer	0.502	0.809	0.321	0.511
Lightly injured per kilometer	0.131	0.188	0.151	0.255
Seriously injured per kilometer	0.048	0.070	0.034	0.052

Note: This table provides summary statistics on all road crashes in federal highways that had at least one road segment procured during the second and third rounds of the Brazilian concession program.

Based on evidence from previous studies, we included some covariates in our estimations. Some authors have shown road crashes are positively related to population size, (Pereira, Pereira and Santos, 2017), unemployment rates (Ruhm, 2015) and intensity of urbanization (Ossenbruggen, Pendharkar and Ivan, 2001; Kmet and Macarthur, 2006). Others studies also suggest that road crashes can be affected by weather conditions (Theofilatos and Yannis, 2014; Brijs, Karlis and Wets, 2008). In this study, we included divide the highway-level control variables in three broad categories. The first group are annually demographic and economic indicators at municipality level from the Brazilian Institute of Geography and Statistics (IBGE): GDP per capita, total number of formal sector workers, population size and a dummy for the month of the year with the largest harvest of any agricultural product as a proxy for heavy duty vehicles traffic. The second group consists of weather variables at municipal level: average precipitation and average temperature by year from Instituto Nacional de Meteorologia (INMET). Finally, the third group consists of geographic variables: distance from the road segment to nearest large city above 750 thousand inhabitants. A list of of variables and data sources used in the analysis is presented in the Appendix (Table 6.4).

Covariates the municipal such as GDP per capita and average precipitation were attributed to road segments when there is and intersection between a road segment and a municipal boundary. In case the same road segment crosses the boundaries of more than one municipality, we considered the average values weighted by proportion of the segment length in each municipality. Finally, to clean up the data, we excluded sections that totaled less than 100 accidents over the whole period of analysis. From the data point of view, the removal of these highways is due to the improbability of having a highway that had less than 100 accidents during 10 years of analysis or that there was no accident in any year of our analysis.

4.2 Empirical Strategy

The aim of the analysis is to evaluate the average impact of the implementation of road concessions on the road safety performance of federal highways in Brazil. The ideal scenario would be to compare the fatality rates observed in each treated segment of highway with its counterfactual had the concession never been implemented. However, since we are unable to observe such counterfactual, we approach this problem by using a quasi-experimental, differences-in-differences strategy.

This empirical strategy estimates the effect of a treatment (in our case, the period of the concession operation) on a response variable (here, the fatality rate) by comparing the average change over time in the outcome variable for the treatment group (procured roads) and the average variation over time in the control group (non-procured roads) (Angrist and Pischke, 2009). Our basic specification is given by the following difference-in-differences (DID) specification:

$$Y_{imt} = \beta PPP_{it} + X'_{imt}\Theta + \omega_m + \lambda_t + \varepsilon_{imt} \tag{1}$$

where Y_{imts} is an outcome observed for road segment i, occurred in month m and year t, and X_{imt} represents the set of municipal controls described in the previous section. The id fixed effect μ_i accounts for unobserved time-invariant determinants of crashes outcomes occurred in the same road segment (such as road geometric characteristics), while the inclusion of month and year fixed effects, ω_m and λ_t, adjusts for shocks that are common to all road segment at a specific moment in time (such as variations in traffic levels over time). The indicator variable PPP equals one for drivers exposed to the concession period and zero for drivers exposed to the concession. The key parameter of interest is then β, which measures whether drivers exposed to the affected roads after the concession period have lower probability to be involved in a fatal road crash. Additionally, we clustered standard errors at the road segment level to make their estimation robust to serial correlation and heteroskedasticity (see Bertrand, Duflo and Mullainathan, 2004). We assume that conditional on time and road segment fixed effects characteristics, the variation in the concession status is exogenous.

We also allow the effect to be heterogeneous with regard to the operation time of the concession in the highway. We estimate therefore:

$$Y_{imt} = \sum_{j=1}^{10} \beta_j PPP_{jit} + X'_{imt}\Theta + \omega_m + \lambda_t + \varepsilon_{imt} \tag{2}$$

where PPP_{jit} are dummies indicating whether the road segment i in the year t and month m has benefited from PPP for j years. In other words, we define our parameters of interest (treatment variables) as dummy variables indicating the number of years the road segment has been covered by the PPP. Hence we are able to analyze how the average effect of road concessions on road safety performance varies over time each since the introduction of road concessions. Afterwards, we test the robustness of our estimates to the existence of dynamic changes that might coincide with the implementation of concessions. For that, we consider first estimating the model with additional dummies indicating years before concession. We check therefore whether causes happen before consequences (Angrist and Pischke, 2009), by allowing the model to have heterogeneous anticipatory effects (leads), in addition to the heterogeneous post-treatment effects (lags) already included in the model. We estimate therefore:

$$y_{it} = \sum_{k=1}^{6} \beta_{-k} PPP_{-kit} \sum_{j=1}^{10} \beta_j PPP_{jit} + X'_{imt}\Theta + \omega_m + \lambda_t + \varepsilon_{imt} \tag{3}$$

We set the coefficient on β_0 equal to zero to use the year immediately prior to the concessions start as a reference. If the model we estimate in equation 2 incorrectly attributes pre-existing trends in fatality rates to our treatment effect, then dummies indicating years before adoption should matter in equation 3 and anticipatory effects captured in β_{-k}, should show up as significant.

The identifying assumption is that the time trend in the probability of road crashes in treated highway segments would have a similar trend as the one observed in similar non-treated highway segments in the absence of the policy intervention. A crucial methodological concern that could impact our causal interpretation of results relates to the endogenous nature of concessions. There is the possibility that the implementation of road concessions in certain highway segments is statistically associated to unobserved roads segment characteristics that also affect traffic crashes, preventing us from obtaining unbiased estimates. If this unobserved component changes between road segments but is fixed across time, the road segment fixed-effect included in the model should be sufficient to allow for a causal interpretation of the estimated effects. If however this endogeneity is based on dynamic shocks to roads crashes, then we might face problems in identifying the pure effect of policy intervention.

We try to address this potential endogeneity problem in different ways. First, we attempt to "clean the path" between the program and fatality by including a substantial set of controls in our specifications. These include annual precipitation, GDP per capita, formal sector workers, population; and distance to nearest large city interacted with linear trends. We also include a dummy variable for indicating the beginning of toll collection period, and a variable of the predominant agricultural harvest month in each road segment to control seasonal fluctuations in number of trucks. We also show how robust are the estimates when road segment with large fatality rates are allowed to converge to the average fatality rate observed in the data. If those segments with large fatality rates are naturally catching up those with average fatality rates, then estimates should converge towards zero when accounting for this behavior. As another test for pre-existing time trends, we run models that include linear and state linear trends. Finally, we test the robustness of our results by using month×year of crash fixed effects to control for time varying characteristics common to all road segments and for the effects of seasonality on road safety outcomes.

Finally, as the concession policy may affect accidents on neighboring highways, we check for spillover effect among neighboring road segments by applying the spatial extension of the difference-in-differences estimator recently proposed by Delgado and Florax (2015). This strategy allows us to explicitly consider the local spatial dependence of the treatment variable, so that the outcome of road segment i depends not only on their own treatment, but also on the treatment status of close neighbors. For that, we use a binary contiguity matrix build based on the inverse distance that is row-normalized to ensure row sums equal to 1, under the criterion that the minimum distance is sufficient to ensure that all highways have at least one neighbor. This spatial model is expressed as follows:

$$Y_{imt} = \beta PPP_{it} + \rho \sum_{j=1}^{N} w_{ij} PPP_{it} + X'_{imt}\Theta + + \sum_{j=1}^{N} w_{ij} X'_{imt}\Phi + \omega_m + \lambda_t + \varepsilon_{imt} \qquad (4)$$

This equation includes a spatial lag of the treatment dummy as well as as spatial lags for explanatory variables. The indirect effect (spillover effect) at this scenario can be interpreted as a substitution effect. In other words, we verify whether the changes in the flow of vehicles from the treatment roads to their neighboring road segments could explain our results.

5 Results

5.1 Basic specification

The Panel A of Table 3 reports regression results of the average effect of concessions over the whole period (2007-2017) for the three main outcomes considered in our analysis: number of crashes per Km, number of deaths per crash and number of injured people per crash. The specification in column (1) consider only fixed effects, without controlling for other variables, while specification in column (2) also control of covariates.

A first look at these results suggests that the implementation of road concessions did not affect the number of crashes, but it did reduce the severity of crashes. Our estimates indicate that, on one hand, the implementation of highway concessions reduced crash fatalities, leading to 15 fewer deaths than publicly managed highways for every one thousand crashes. On the other, procured roads had 45 more injured people per 1000 road crashes then publicly managed highways in the period of analysis. Nonetheless, Panel B of Table 3 show that these effects vary over time and that the road safety benefits of road concessions are not immediate. These results indicate that the reduction in number of crashes only become statistically significant after the 8th year after the implementation of a road concession while the effect on road fatality and injured people only become significant for a few years. Moreover, the magnitude of such effects is marginally larger for every additional year of treatment exposure. In the tenth year after implementation, road concessions save on average 32 lives for every ten thousand crashes and reduce 326 crashes for every one thousand Kilometers of procured highways.

When we look at other road safety outcomes weighted by road length (Appendix, Table 6.1), the effects only become statistically significant 8 years after the concessions are implemented. On the after 10th year after implementation, procured roads led to an average of 702 fewer people and 670 fewer vehicles involved in crashes for every one thousand kilometers of procured roads.

Combined, these findings show that the introduction of highway concessions reduced road fatality rates and improved road safety outcomes, though such improvements only became significant a few years after the concession is implemented. We believe this temporal heterogeneity of the effects arise from a combination of factors. First, it takes a few years for contractor companies to finish more substantial road investments and effectively improve road safety. Second, publicly managed highways are more likely to face poor maintenance and accumulate over time the negative effects of road degradation on road safety. For the remainder of the paper, we consider the full specification with covariates as benchmark.

Table 3: Main results

	Crashes per km		Deaths per road crash		Injured per road crash	
	(1)	(2)	(1)	(2)	(1)	(2)
			Panel A			
Treat	0.007	0.006	-0.012**	-0.015**	0.032	0.045*
	(0.061)	(0.061)	(0.005)	(0.006)	(0.024)	(0.024)
Observations	13,728	13,728	13,378	13,378	13,378	13,378
R-squared	0.854	0.856	0.165	0.166	0.219	0.224
			Panel B			
Treat 1yr	-0.041	-0.044	0.004	0.001	0.037*	0.050**
	(0.047)	(0.046)	(0.013)	(0.014)	(0.022)	(0.021)
Treat 2yr	0.025	0.025	-0.007	-0.011	0.025	0.038
	(0.072)	(0.072)	(0.006)	(0.007)	(0.026)	(0.026)
Treat 3yr	0.019	0.016	-0.006	-0.009	0.056	0.076*
	(0.079)	(0.079)	(0.010)	(0.011)	(0.038)	(0.039)
Treat 4yr	0.012	0.013	-0.014	-0.018	0.028	0.042
	(0.075)	(0.075)	(0.011)	(0.012)	(0.031)	(0.028)
Treat 5yr	0.037	0.039	-0.014*	-0.016*	0.040	0.052
	(0.066)	(0.065)	(0.007)	(0.008)	(0.040)	(0.037)
Treat 6yr	0.067	0.072	-0.014	-0.016	0.010	0.020
	(0.073)	(0.075)	(0.009)	(0.010)	(0.033)	(0.031)
Treat 7yr	-0.098	-0.092	-0.017	-0.019	0.012	0.011
	(0.079)	(0.079)	(0.012)	(0.013)	(0.036)	(0.035)
Treat 8yr	-0.272***	-0.265***	-0.016*	-0.018*	0.066	0.064
	(0.090)	(0.092)	(0.009)	(0.010)	(0.045)	(0.044)
Treat 9yr	-0.387***	-0.369***	-0.014	-0.017	0.086	0.067
	(0.103)	(0.106)	(0.011)	(0.012)	(0.058)	(0.057)
Treat 10yr	-0.389***	-0.366***	-0.029**	-0.032**	-0.004	-0.033
	(0.100)	(0.103)	(0.014)	(0.014)	(0.059)	(0.058)
Observations	13,728	13,728	13,378	13,378	13,378	13,378
ID FE	✓	✓	✓	✓	✓	✓
Control variables		✓		✓		✓
Crash month FE	✓	✓	✓	✓	✓	✓
Crash year FE	✓	✓	✓	✓	✓	✓

Note: This table shows the results of estimating Equation (1) in Panel A and Equation (2) in Panel B. Standard errors clustered at the road-segment level. Column (1) results for fixed effects only, while column (2) results for fixed effects controlling for covariates. Control variables are: GDP per capita, formal sector workers, population, average precipitation, average temperature and distance to nearest large city.
*** p<0.01, ** p<0.05, * p<0.1.

5.2 Heterogeneous Response

We now explore a few other dimensions of potential heterogeneity in order to better understand the possible causal channels between road concessions and road safety. For this purpose, we analyze the road safety benefits of road concessions depending on whether concession contracts had a road safety performance incentive. We also conduct separate analyses to check whether the road safety effects could be particularly concentrated in urban or rural areas or in day/night crashes.

A key source of heterogeneity could be the difference in road safety incentives in concession contracts between the second and third phases of road concessions in Brazil. As previously discussed in section 3, companies in the third phase had stronger incentives to improve road quality because they were only allowed to start charging tolls after they met certain road improvements and safety performance goals. When we look at columns 1-2 of table 4, we verify that concessions with safety performance incentives had marginally larger effects in reducing the number of deaths per crash on average. On the fifth year after the implementation of a road concession, the impact on the reduction of road fatality rates was two times larger in procured roads under contracts with safety-based incentives than for regular contracts without those incentives. The results of table 4 also show that road concessions were particularly effective in reducing fatality rates of crashes that occur in rural areas and at night. This indicates that improvements in road maintenance and highway signage have had only a small, if any, effect in reducing fatalities during the day and in urban contexts.

Table 4: Heterogeneity over day period, land use and phase period of concession

	Death per road crash					
	(1)	(2)	(3)	(4)	(5)	(6)
	Without road safety incentive	With road safety incentive	Urban area	Rural area	Day	Night
	Panel A					
Treat	-0.017**	-0.021**	-0.002	-0.023***	-0.007	-0.023***
	(0.007)	(0.010)	(0.004)	(0.007)	(0.005)	(0.008)
Observations	8,145	8,539	12,137	12,747	13,123	12,896
	Panel B					
Treat 1yr	-0.002	0.003	-0.004	0.006	-0.003	-0.006
	(0.008)	(0.024)	(0.005)	(0.020)	(0.006)	(0.018)
Treat 2yr	-0.003	-0.019*	0.008	-0.017*	-0.007	-0.013
	(0.008)	(0.010)	(0.007)	(0.009)	(0.006)	(0.012)
Treat 3yr	-0.014	-0.008	-0.006	-0.019	-0.013**	-0.008
	(0.008)	(0.015)	(0.006)	(0.012)	(0.005)	(0.018)
Treat 4yr	-0.012	-0.030	-0.005	-0.026*	-0.006	-0.033***
	(0.008)	(0.019)	(0.005)	(0.013)	(0.011)	(0.012)
Treat 5yr	-0.016*	-0.034*	-0.002	-0.023**	-0.004	-0.037***
	(0.008)	(0.019)	(0.007)	(0.010)	(0.007)	(0.012)
Treat 6yr	-0.018*		-0.013	-0.021*	-0.013	-0.022**
	(0.010)		(0.010)	(0.011)	(0.009)	(0.011)
Treat 7yr	-0.027**		-0.005	-0.022	-0.007	-0.037**
	(0.013)		(0.009)	(0.016)	(0.010)	(0.014)
Treat 8yr	-0.018**		-0.002	-0.026**	-0.011	-0.026**
	(0.009)		(0.008)	(0.012)	(0.009)	(0.012)
Treat 9yr	-0.022**		-0.013	-0.020	-0.011	-0.030*
	(0.011)		(0.010)	(0.014)	(0.009)	(0.017)
Treat 10yr	-0.041***		0.003	-0.047***	-0.020*	-0.046**
	(0.013)		(0.012)	(0.017)	(0.011)	(0.018)
Observations	8,145	8,539	12,137	12,747	13,123	12,896
ID FE	✓	✓	✓	✓	✓	✓
Crash month FE	✓	✓	✓	✓	✓	✓
Crash year FE	✓	✓	✓	✓	✓	✓
Control variables	✓	✓	✓	✓	✓	✓

Note: This table shows the results of estimating Equation (1) in Panel A and Equation (2) in Panel B. Standard errors clustered at the road-segment level. Presented results account for fixed effects controlling for covariates. Control variables are: GDP per capita, formal sector workers, population, average precipitation, average temperature and distance to nearest large city.
*** p<0.01, ** p<0.05, * p<0.1.

5.3 Robustness checks

Due to the regional linkage among close highways, it is reasonable to expect that some spatial effects were neglected by the previous results. We account for the possible existence of spatial spillovers in Table 5. Column (1) shows a spatial specification similar to those estimated in our main results but with the geographical interactions between a binary contiguity matrix and our treatment variable, while column (2) show specification that also include the spatial lags of the covariates. As it can be observed, the results indicate that the road safety benefits has a direct impact on lethality rate, with point estimate virtually similar to our benchmark results. Nevertheless, the estimation of the indirect spillover effect is not significant, which suggests no evidence of spillover effect for other road segments.

Table 5: Robustness: Including spatial spillovers, 2007-2017

	Deaths per crash	
	(1)	(2)
	Panel A	
Direct effect	-0.017***	-0.017***
	(0.006)	(0.006)
Indirect effect	0.005	0.005
	(0.006)	(0.006)
Observations	13,378	13,378
ID FE	Yes	Yes
Crash month FE	Yes	Yes
Crash year FE	Yes	Yes
Controls	Yes	Yes
Spatial Controls	No	Yes

This table shows the results of estimating Equation (4). Standard errors clustered at the road-segment level. Control variables are: GDP per capita, formal sector workers, population, average precipitation and average temperature. *** p<0.01, ** p<0.05, * p<0.1.

In order to support a causal interpretation of the results, we perform several robustness exercises. Table 6 reports the following modifications in Equations 1 and 2: In column (1), we substitute the year of crash fixed-effect and month of crash fixed-effect for a month$\times$year of crash fixed-effect to control for time varying characteristics common to all road segments and for the effects of seasonality on fatality outcomes. In column (2), we add linear trend within states, while in columns (3) we substitute the ID fixed effect for ID specific trends, to capture potential diverging trends across different states and road segments, respectively. Next, to control for seasonal fluctuations in the flow of trucks and others vehicles, we add an indicator variable for the predominant agricultural harvest month in each road segment in column (4), a dummy variable indicating the month/year when toll collections started in column (5), and the distance to nearest large city interacted with linear trends, in column (6). Finally, in column (7), we show that our estimates are robust to different definitions of the comparison group, by using all federal road segments in the country.

Table 6: Robustness check - Additional Controls and Fixed Effects

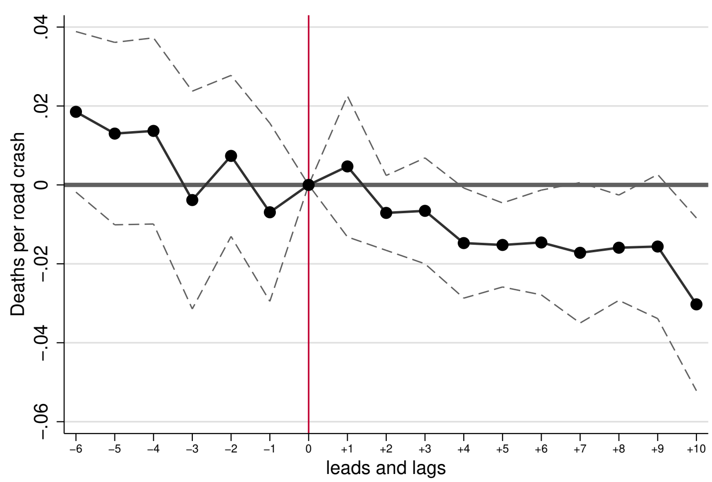
	Deaths per Crash						
	(1)	(2)	(3)	(4)	(5)	(6)	(7)
	Panel A						
Treat	-0.016**	-0.014***	-0.015**	-0.022***	-0.012*	-0.015**	-0.013***
	(0.006)	(0.005)	(0.006)	(0.007)	(0.006)	(0.006)	(0.005)
Observations	13,378	13,378	13,378	13,248	13,378	13,378	24,165
	Panel B						
Treat 1yr	0.001	0.003	0.001	-0.014	0.001	0.002	0.003
	(0.014)	(0.013)	(0.014)	(0.008)	(0.014)	(0.013)	(0.013)
Treat 2yr	-0.011	-0.008	-0.011	-0.016**	-0.011	-0.011	-0.009
	(0.007)	(0.006)	(0.007)	(0.006)	(0.009)	(0.007)	(0.007)
Treat 3yr	-0.009	-0.007	-0.009	-0.017***	-0.010	-0.007	-0.005
	(0.011)	(0.009)	(0.011)	(0.006)	(0.012)	(0.011)	(0.010)
Treat 4yr	-0.018	-0.015	-0.018	-0.023***	-0.018	-0.014	-0.016
	(0.012)	(0.010)	(0.012)	(0.008)	(0.012)	(0.010)	(0.011)
Treat 5yr	-0.016*	-0.018**	-0.016*	-0.020**	-0.016	-0.020**	-0.013**
	(0.008)	(0.009)	(0.008)	(0.009)	(0.010)	(0.009)	(0.006)
Treat 6yr	-0.016	-0.018*	-0.016	-0.022**	-0.016	-0.018*	-0.012
	(0.010)	(0.010)	(0.010)	(0.010)	(0.011)	(0.010)	(0.008)
Treat 7yr	-0.019	-0.022	-0.019	-0.025*	-0.019	-0.020	-0.013
	(0.013)	(0.014)	(0.013)	(0.014)	(0.014)	(0.013)	(0.010)
Treat 8yr	-0.018*	-0.021**	-0.018*	-0.025**	-0.018	-0.019**	-0.016*
	(0.010)	(0.010)	(0.010)	(0.010)	(0.011)	(0.009)	(0.009)
Treat 9yr	-0.018	-0.020*	-0.017	-0.022**	-0.018	-0.022*	-0.017
	(0.012)	(0.012)	(0.012)	(0.010)	(0.013)	(0.011)	(0.011)
Treat 10yr	-0.033**	-0.030**	-0.032**	-0.034**	-0.032**	-0.035***	-0.032***
	(0.014)	(0.013)	(0.014)	(0.014)	(0.015)	(0.013)	(0.011)
Observations	13,378	13,378	13,378	13,248	13,378	13,378	24,165
ID FE	✓	✓		✓	✓	✓	✓
Month*year of Crash FE	✓						
Control variables	✓	✓	✓	✓	✓	✓	✓
Crash month FE		✓	✓	✓	✓	✓	✓
Crash year FE		✓	✓	✓	✓	✓	✓
Distance to nearest large city						✓	
Including a toll start dummy					✓		
Harvest month				✓			
ID specific trend			✓				
State linear trend		✓					
Concerning all states							✓

Note: This table shows the results of estimating Equation (1) in Panel A and Equation (2) in Panel B. Standard errors clustered at the road-segment level. Control variables are: GDP per capita, formal sector workers, population, average precipitation, average temperature and distance to nearest large city.
*** p<0.01, ** p<0.05, * p<0.1.

Even after accounting for multiple robustness checks in Table 6, including divergent trends across road segments and for the potential influence of other variables omitted from the general specification adopted, we find that point estimates are strikingly similar across a number of alternative specifications. This set of estimates support the hypothesis that the estimated safety benefits from road concessions is not a mere statistical coincidence. The road concession program in Brazil was able to shift the trend of fatality rates in federal highways and effectively improve road safety performance.

Finally, we test the validity of the causal effect by estimating the coefficients of pre-treatment and pos-treatment effects, a common test in the differences-in-differences framework (see Autor (2003)). Figure 2 plots all leads and lags coefficients and 95% confidence intervals from the estimation of equation 3 for road fatality outcomes. The test confirms that there was no significant difference in fatality rates between publicly managed and procured roads before the introduction of concessions. This suggests the virtual absence of different pre-trends and yields strong evidence that support the main identifying assumption. After the implementation of concessions, passing on obligations to private companies, we document a significant reduction on the number of deaths per road crash. Additionally, as can be seen, the lags coefficients barely changed, both in magnitude and in dynamic over time, providing stronger support to our main specification.

Figure 2: Event-study results



Note: This figure plots the coefficients of Equation (3). Control variables are: GDP per capita, formal sector workers, population, average precipitation, average temperature and distance to nearest large city. The year immediately prior to the concession is used as the reference period. Dashed lines show 95 percent confidence intervals.

6 Conclusion

In this paper we analyzed the impact of highway concessions on road safety performance using detailed daily data on road crashes on Brazilian federal highways over a 10-year period 2007-2017. Using a difference-in-differences approach, we provide causal evidence that the implementation of highway concessions effectively improved multiple road safety measures, including crash fatality rates, number of people and vehicles involved in crashes.

Our results show that, for every one thousand crashes, procured roads had on average 15 fewer deaths then publicly managed highways each year. Back-of-the-envelop calculations suggest the highway concession program in Brazil avoided 16 thousand deaths between 2007-2017. Considering the average economic and social cost estimated by the National Transport Confederation (CNT, 2017) of 45,419 thousand reais per road fatality, this would translate into an annual gain of approximately 738.8 million reais over the 10-year period we analyzed.

This paper advances previous studies by presenting robust causal evidence that highway concessions can help improve road safety performance. It also shows how concession contracts with safety-based incentives can substantially improve the road safety outcomes. Moreover, the analysis presented in this paper allowed us to determined for the first time the temporal heterogeneity in the road safety benefits of highway concessions. In the case of procured federal highways in Brazil, our findings indicate that such benefits only start to show a few years after concessions are implemented depending on the outcome analyzed, and that these effects become marginally larger for every additional year of treatment exposure.

These results consider fixed-effects controlled for several covariates known in the literature to influence road crashes. The results are also consistent after considering multiple robustness checks and after looking at different heterogeneity effects by period of the day, whether road segments are located in rural or urban areas, and the time of the year when crashes occurred.

A limitation of this study is that it could not analyze road concessions implemented before the year 2000 and after 2019 due to the lack of sufficient data. Moreover, the data currently available does not allow one to control for road speed limits, enforcement of drunk driving, seatbelt, and mobile phone restrictions.

From a policy perspective, a couple lessons can be drawn from this study. First, the findings of this paper could help improve the road concession program in Brazil to calibrate contract parameters used in future bidding processes. Second, these findings provide strong evidence that the social and economic evaluation of road concessions should consider how this type of policy can effectively promote broader road safety benefits but that such benefits are not immediate and increase over time.

Bibliography

Abubakar, II, T Tillmann, and A Banerjee (2015). "Global, regional, and national age-sex specific all-cause and cause-specific mortality for 240 causes of death, 1990-2013: a systematic analysis for the Global Burden of Disease Study 2013," *Lancet*, 385(9963): 117–171.

Albalate, Daniel (2011). "Shifting death to their alternatives the case of toll motorways," *Journal of Transport Economics and Policy (JTEP)*, 45(3): 457–479.

Albalate, Daniel and Germà Bel (2012). "Motorways, tolls and road safety: evidence from Europe," *SERIEs*, 3(4): 457–473.

Albalate, Daniel and Paula Bel-Piñana (2019). "The effects of public private partnerships on road safety outcomes," *Accident Analysis & Prevention*, 128 53–64.

Andrade, Silvânia Suely Caribé de Araújo and Maria Helena Prado de Mello-Jorge (2016). "Mortality and potential years of life lost by road traffic injuries in Brazil, 2013," *Revista de saude publica*, 50 p. 59.

Angrist, Joshua D and Jörn-Steffen Pischke (2009). *Mostly harmless econometrics: An empiricist's companion*, Princeton university press.

Anstey, Kaarin J, Mark S Horswill, Joanne M Wood, and Christopher Hatherly (2012). "The role of cognitive and visual abilities as predictors in the Multifactorial Model of Driving Safety," *Accident Analysis & Prevention*, 45 766–774.

ANTT (2018). "AGÊNCIA NACIONAL DE TRANSPORTES TERRESTRES," *Concessões Rodoviárias*.

Autor, David H (2003). "Outsourcing at will: The contribution of unjust dismissal doctrine to the growth of employment outsourcing," *Journal of Labor Economics*.

Baumgarten, Patrick and Jens Middelkamp (2015). "On interurban road pricing schemes and the impacts of traffic diversion on road safety in Germany: Empirical findings and implications," *European journal of transport and infrastructure research*, 15(2): .

Bel, Germà and John Foote (2009). "Tolls, terms and public interest in road concessions privatization: a comparative analysis of recent transactions in the USA and France," *Transport Reviews*, 29(3): 397–413.

Bertrand, Marianne, Esther Duflo, and Sendhil Mullainathan (2004). "How much should we trust differences-in-differences estimates?" *Quarterly Journal of Economics*, 119(1): 249–275.

Brijs, Tom, Dimitris Karlis, and Geert Wets (2008). "Studying the effect of weather conditions on daily crash counts using a discrete time-series model," *Accident Analysis & Prevention*, 40(3): 1180–1190.

Brochado, Mariana Rodrigues and José Manuel Vassallo (2014). "Federal toll road concession program in Brazil: is it moving in the right direction?" *Journal of Infrastructure Systems*, 20(2): p. 05014001.

CNT, Confederação Nacional do Transporte (2017). "Pesquisa CNT de rodovias 2017," Accessed on 07-15-2020.

De Pauw, Ellen, Stijn Daniels, Melissa Thierie, and Tom Brijs (2014). "Safety effects of reducing the speed limit from 90 km/h to 70 km/h," *Accident Analysis & Prevention*, 62 426–431.

Delgado, Michael S. and Raymond J.G.M. Florax (2015). "Difference-in-differences techniques for spatial data: Local autocorrelation and spatial interaction," *Economics Letters*, 137 123–126.

European Commission (2010). "Functional Foods. Directorate General for Research and Seventh Framework Programme (European Commission)."

Galilea, Patricia and Francesca Medda (2010). "Does the political and economic context influence the success of a transport project? An analysis of transport public-private partnerships," *Research in Transportation Economics*, 30(1): 102–109.

Geddes, R Richard, Xiaodi Li, and Omid M Rouhani (2015). "The Effects of Private Road Management on Traffic Safety: Evidence from Mexico," in *Transportation Research Board 94th Annual Meeting*,(15-3463): .

Grimsey, Darrin and Mervyn Lewis (2007). *Public private partnerships: The worldwide revolution in infrastructure provision and project finance*, Edward Elgar Publishing.

Hart, Oliver (2003). "Incomplete contracts and public ownership: Remarks, and an application to public-private partnerships," *The economic journal*, 113(486): C69–C76.

Hermans, Elke, Tom Brijs, Geert Wets, and Koen Vanhoof (2009). "Benchmarking road safety: Lessons to learn from a data envelopment analysis," *Accident Analysis & Prevention*, 41(1): 174–182.

iRAP (2015). "International Road Assessment Programme."

Kmet, Leanne and Colin Macarthur (2006). "Urban–rural differences in motor vehicle crash fatality and hospitalization rates among children and youth," *Accident Analysis & Prevention*, 38(1): 122–127.

Lewis, Ioni, Barry Watson, and Richard Tay (2007). "Examining the effectiveness of physical threats in road safety advertising: The role of the third-person effect, gender, and age," *Transportation Research Part F: Traffic Psychology and Behaviour*, 10(1): 48–60.

Lima, Ieda Maria de Oliveira, José Carlos Figueiredo, Patrícia Alessandra Morita, and Philip Gold (2008). "Fatores condicionantes da gravidade dos acidentes de trânsito nas rodovias brasileiras,"Technical report, Texto para Discussão.

Martinez, Sebastian, Raul Sanchez, and Patricia Yañez-Pagans (2019). "Road safety: challenges and opportunities in Latin America and the Caribbean," *Latin American Economic Review*, 28(1): p. 17.

Milton, John and Fred Mannering (1998). "The relationship among highway geometrics, traffic-related elements and motor-vehicle accident frequencies," *Transportation*, 25(4): 395–413.

Neto, Campos, Carlos Álvares da Silva, Sérvulo Vicente Moreira, and Lucas Varjão Motta (2018). "Modelos de concessão de rodovias no Brasil, no México, no Chile, na Colômbia e nos Estados Unidos: Evolução histórica e avanços regulatórios,"Technical report, Texto para Discussão 1343 Instituto de Pesquisa Economica Aplicada (Ipea).

Ossenbruggen, Paul J, Jyothi Pendharkar, and John Ivan (2001). "Roadway safety in rural and small urbanized areas," *Accident Analysis & Prevention*, 33(4): 485–498.

Pereira, Alfredo Marvão, Rui Marvão Pereira, and JP Santos (2017). "For whom the bell tolls: road safety effects of tolls on uncongested SCUT highways in Portugal," *GEE Papers*, 74.

Rangel, Thais and José Manuel Vassallo (2015). "Modeling the effect of contractual incentives on road safety performance," *Transport policy*, 40 17–23.

Rangel, Thais, José Manuel Vassallo, and Blanca Arenas (2012). "Effectiveness of safety-based incentives in Public Private Partnerships: Evidence from the case of Spain," *Transportation research part A: policy and practice*, 46(8): 1166–1176.

Rangel, Thais, José Manuel Vassallo, and Israel Herraiz (2013). "The influence of economic incentives linked to road safety indicators on accidents: The case of toll concessions in Spain," *Accident Analysis & Prevention*, 59 529–536.

Ruhm, Christopher J (2015). "Recessions, healthy no more?" *Journal of health economics*, 42 17–28.

Shinar, David (2017). *Traffic safety and human behavior*, Emerald Group Publishing.

Theofilatos, Athanasios and George Yannis (2014). "A review of the effect of traffic and weather characteristics on road safety," *Accident Analysis & Prevention*, 72 244–256.

Wang, Chao, Mohammed A Quddus, and Stephen G Ison (2013). "The effect of traffic and road characteristics on road safety: A review and future research direction," *Safety science*, 57 264–275.

WHO (2018). *Global status report on road safety 2018*, World Health Organization.

Appendix

Table 6.1: Other outcomes - road crash dataset

	People per km	Deaths per km	Vehicles per km	Soft injured per km	Serious injured per km
	(1)	(2)	(3)	(4)	(5)
			Panel A		
Treat	-0.030	-0.000	-0.018	0.031*	0.014
	(0.151)	(0.002)	(0.140)	(0.016)	(0.011)
Observations	13,728	13,728	13,728	13,378	13,378
			Panel B		
Treat 1yr	-0.107	0.001	-0.095	0.026	0.024**
	(0.109)	(0.002)	(0.100)	(0.017)	(0.011)
Treat 2yr	-0.002	0.004	0.004	0.018	0.020
	(0.174)	(0.004)	(0.158)	(0.019)	(0.014)
Treat 3yr	-0.035	0.000	-0.025	0.055*	0.021
	(0.197)	(0.002)	(0.184)	(0.030)	(0.014)
Treat 4yr	-0.013	-0.001	-0.003	0.041**	0.001
	(0.185)	(0.002)	(0.169)	(0.019)	(0.015)
Treat 5yr	0.045	-0.002	0.077	0.030	0.021
	(0.151)	(0.002)	(0.142)	(0.027)	(0.015)
Treat 6yr	0.147	-0.000	0.160	0.009	0.010
	(0.176)	(0.002)	(0.162)	(0.022)	(0.013)
Treat 7yr	-0.157	-0.005*	-0.123	-0.002	0.013
	(0.175)	(0.003)	(0.161)	(0.028)	(0.015)
Treat 8yr	-0.514***	-0.007***	-0.470**	0.045	0.019
	(0.195)	(0.002)	(0.183)	(0.033)	(0.019)
Treat 9yr	-0.732***	-0.009***	-0.675***	0.065	0.002
	(0.223)	(0.003)	(0.210)	(0.045)	(0.020)
Treat 10yr	-0.702***	-0.008***	-0.670***	-0.018	-0.015
	(0.215)	(0.003)	(0.204)	(0.045)	(0.025)
Observations	13,728	13,728	13,728	13,378	13,378
ID FE	✓	✓	✓	✓	✓
Control variables	✓	✓	✓	✓	✓
Crash month FE	✓	✓	✓	✓	✓
Crash year FE	✓	✓	✓	✓	✓

This table shows the results of estimating Equation (1) in Panel A and Equation (2) in Panel B. Standard errors clustered at the road-segment level. Control variables are: GDP per capita, formal sector workers, population, average precipitation, average temperature and distance to nearest large city.
*** p<0.01, ** p<0.05, * p<0.1.