

The role of average speed enforcement systems in preventing highway accidents: evidence from Italy

Flavio Bazzana^{a,*}, Mattia Borsati^a, Michele Cascarano^{a,b}

^a *University of Trento, Trento, Italy*

^b *Bank of Italy, Trento, Italy*

Abstract

At the end of 2005, Autostrade per l'Italia and the Italian traffic police progressively deployed along the Italian tolled motorway network an average speed enforcement system, named Safety Tutor, able to determine the average speed of vehicles over a long section to encourage drivers to comply with speed limits and improve safety. Although promoters of Safety Tutor credited it with a sharp decrease in highway accidents all along high-speed roads, previous studies have estimated the impact of this intervention only in specific motorway sectors with unique road and congestion features. The novel contribution of this paper lies in the evaluation of the effectiveness of Safety Tutor in reducing highway accidents at the national level during the period 2001-2015 by using a unique panel dataset that makes it possible to control for many unobserved factors and that exploits the heterogeneity within all motorway sectors. We find that a 10% increase in Safety Tutor coverage is associated with an average reduction in total accidents (-1.3%), injuries (-1.0%), fatalities (-3.6%), and light vehicle accidents (-1.4%). However, to address persistent endogeneity issues in accident analysis contexts, we utilize an instrumental variable (IV) strategy by exploiting the membership of some motorway sectors in the Autostrade per l'Italia group as an instrument for Safety Tutor. The IV estimates reveal no evidence of a significant causal effect of the average speed enforcement system on preventing highway accidents in any of the categories analysed. This study can help highway concessionaires and road agencies in analysing their increasing amount of available data through robust econometric methods to better evaluate accident prevention policies and the relative allocation of resources.

Keywords: Highway safety, Accidents, Average speed enforcement system, Safety Tutor, Policy evaluation

JEL Classification Numbers: D78, L98, R41

*Corresponding author

Email addresses: flavio.bazzana@unitn.it (Flavio Bazzana),
mattia.borsati@unitn.it (Mattia Borsati), m.cascarano@unitn.it (Michele Cascarano)

1. Introduction

Speeding has been recognized as one of the major causes of road accidents (Aarts and Van Schagen, 2006; Hauer, 2009; Montella et al., 2011, 2015b; Yannis et al., 2013), and the relationship between speed and crash risk has been extensively investigated (Neuman, 2003; Montella and Imbriani, 2015). Thus, in an attempt to reduce speeding across road networks, most road agencies have adopted a variety of policies to improve safety such as camera-based speed enforcement approaches.

Several studies have confirmed the positive effect of fixed and mobile speed cameras on vehicle accident reduction on both rural roads and motorways (Goldenbeld and van Schagen, 2005; Jones et al., 2008). However, the cameras' contribution has been shown to be limited to the immediate vicinity of the enforcement activity, achieving speed reduction on only a short section (Champness et al., 2005; De Pauw et al., 2014b). In addition, speed variation between vehicles (due to speed-check cameras) has also been demonstrated to increase the risk of becoming involved in an accident because sudden braking may disrupt homogenized traffic flow and reduce headway distances between vehicles (Cirillo, 1968; Transportation Research Board, 1998). Consequently, since there is evidence that many drivers regard speeding as normal and socially acceptable (Fleiter et al., 2010; Veisten et al., 2013), the need emerged for an innovative speed management system that balances safety with the efficiency of vehicle flows on the road network (Wegman and Goldenbeld, 2006).

This relatively new technology, called an automated average speed enforcement system, is able to determine the average speed of vehicles over a long section by dividing the certified and known distance between two camera sites by the time the vehicle takes to travel between those two sites, thereby encouraging speed compliance over a greater distance (Soole et al., 2012) and eliminating the need for police officers at the scene. Moreover, it provides a nearly perfect probability of catching drivers when speeding (Aarts et al., 2009; Montella et al., 2011). Initially operated in trial form in 1997 in the Netherlands, this system has achieved promising results, resulting in its increased popularity in several highly motorized countries.

In Italy, to improve safety on high-speed roads, a point-to-point (P2P) speed enforcement system, named Safety Tutor, was developed by Autostrade per l'Italia (the major highway concession company) and the Italian traffic police in 2004 and progressively deployed along the Italian tolled motorway network starting on 23 December 2005. By 2018, more than 3 100 km of the highway network (considering both carriageways) were monitored by the system through 333 P2P sites. However, after a 12-year legal process, on 10 April 2018, the Court of Appeals of Rome established that patent rights related to the Safety Tutor technology belonged to another company (Craft S.r.l.), therefore forcing Autostrade per l'Italia to remove the device. In the following months, all Safety Tutor sites were turned off in anticipation of their replacement.

Over time, Autostrade per l'Italia, newspapers, and specialized magazines have underlined how this intervention significantly changed drivers' behaviour

all along high-speed roads, achieving promising results in preventing highway accidents (Falsi, 2009; Autostrade per l'Italia, 2016). However, previous studies have analysed the effect of Safety Tutor only on specific motorway sectors with unique road characteristics and congestion features. Therefore, the aim of this paper is to detect the extent to which Safety Tutor has significantly contributed to improving driver safety at the national level to provide a tool that highway concessionaires and transport policy makers can use to evaluate any benefits associated with average speed enforcement systems, determine the allocation of resources, and assess whether it is worth replacing this device or extending its coverage.

For this purpose, the novelty of the present paper lies in performing the first evaluation of this device on a substantial scale by using a unique 15-year panel dataset to analyse the influence of Safety Tutor on five different types of accident categories in the Italian tolled motorway network during the period 2001-2015: total accidents, injuries, fatalities, light vehicle accidents, and heavy vehicle accidents. The second source of novelty lies in exploiting the heterogeneity within all motorway sectors by including both those that have installed the device and those that have not. In particular, the analysis takes into account those motorway sectors under concession to 24 private, public, or mixed capital companies that represent nearly 85% of the national highway network (the remaining toll-free 15% is managed by ANAS, a government-owned company under the control of the Ministry of Infrastructure and Transport).

By exploiting the longitudinal structure of our dataset, which allows us to control for many unobservable confounding factors, OLS estimates identified a much lower impact of Safety Tutor coverage on reducing highway accidents in comparison to previous studies. In particular, a 10% increase in Safety Tutor coverage is associated with an average reduction in total accidents by nearly 1.3%, injuries by 1.0%, fatalities by 3.6%, and light vehicle accidents by 1.4%. However, after controlling for additional endogeneity issues through an instrumental variable strategy, the results suggest that there is no evidence of a significant causal effect of Safety Tutor on preventing accidents in any of the categories analysed.

The paper is structured as follows: Section 2 briefly describes the Safety Tutor technology and reviews previous studies, Section 3 describes our data collection procedure, Section 4 describes the patterns of Italian highway accidents over time, Section 5 specifies our econometric model, and Sections 6 and 7 provide OLS and 2SLS estimation results. Section 8 provides robustness checks, while Section 9 summarizes the paper's findings and critically analyses some of its drawbacks.

2. The Safety Tutor system and previous evaluations

Safety Tutor, exclusively managed by the national traffic police, is composed of a series of steel gantries installed at multiple locations along a high-speed road section, each one covering from 10 to 15 km. High resolution cameras with infrared flash are mounted on the gantry, one for each lane. Whenever a

90 vehicle crosses over the initial camera site, the lane-related camera records its date and time. Then, these data are processed by an automatic video-based vehicle identification software for vehicle plate recognition that matches vehicle class and registration details. When the same vehicle crosses the exit section, the same operation is performed. As a result, if the calculated average travel
95 speed between the entrance and the exit sections exceeds the speed limit (plus a tolerance equal to a maximum between 5 km/h and 5% of the speed limit), the system automatically follows up with an offence citation to the vehicle owner, ensuring strict and equitable enforcement (Montella et al., 2012, 2015b).

A comprehensive international review of all available studies evaluating the
100 effectiveness of average speed enforcement systems (Soole et al., 2013; International Transport Forum, 2018) elucidates their positive contribution to a variety of road safety and traffic-related outcomes such as accident rates, speeding offence rates, traffic flow, and vehicle emissions (Stefan and Winkelbauer, 2006; Collins and McConnell, 2008; De Pauw et al., 2014a). To date, after more than
105 10 years of operation, previous studies analysing these effects within the Italian context are still limited to specific motorway sectors. A naïve before-after analysis with pre- and post-implementation periods showed significant reduction in both average speeds (-15%) and peak speed (-25%), with consequent improvements in the injury rate (-27%) and in the mortality rate (-50%) on Safety Tutor
110 sections after 12 months of operation (Galata, 2007; Falsi, 2009). More recently, Autostrade per l'Italia underlined a further reduction in the mortality rate by 80% on its network (Autostrade per l'Italia, 2016). However, it is important to note that statistical significance testing and the control of confounding factors were absent from these evaluations.

115 A more reliable evaluation was provided by Cascetta and Punzo (2011) that showed that Safety Tutor installation on A56 Tangenziale di Napoli produced a mean speed reduction from 80.8 km/h to 71.7 km/h by comparing vehicle data from 1-week pre to 1-week post activation on February 9, 2009. Furthermore, comparing total accidents between 8 months pre- and 8 months post-installation
120 demonstrates a significant reduction from 116 to 71 (-38.8%). Consistent with the previous study, Montella et al. (2015b) estimated through an empirical Bayes methodology an average speed reduction for light vehicles from 83.4 km/h to 75.2 km/h within the same A56 Safety Tutor sites by monitoring vehicle speed over four periods between 2009 and 2011. The longer time span under analysis
125 allowed them to observe a significant increase in non-compliance behaviour towards speed limits over time with respect to results obtained in the period immediately after the P2P implementation. The total accident reduction was approximately 32% and, consistent with speed effects, Safety Tutor effectiveness decreased over time. Other ancillary benefits associated with the same A56 devices have been estimated by Cascetta et al. (2010), Cascetta et al. (2011),
130 and Montella et al. (2015a), whose results suggested that they produced significant reduction in fuel consumption of 387.9 tonnes per year, improvements in peak period traffic flow through reduced bottlenecking, and reductions in the standard deviation of average speed from 16.5 km/h to 12.2 km/h (-26%), respectively. An additional contribution was provided by Montella et al. (2012)
135

that estimated a total accident reduction of 31.2%, with a decreasing pattern over time (-39.4% in the first semester versus -18.7% in the fifth) in an 80 km Safety Tutor sector of the A1 Milano-Napoli motorway (activated on July 1, 2007) analysed from 2001 to 2009.

140 Since those studies evaluates the effectiveness of some specific Safety Tutor sites in unique contexts, this paper also aims at checking whether findings at national level are robust with respect to previous evaluations.

3. Data

Bounded by availability of data, we test the effectiveness of Safety Tutor in 145 reducing highway vehicle accidents by estimating an econometric model using a unique 15-year panel dataset (2001-2015) that allows us to observe the trend in accident rates 5 years before the Safety Tutor implementation and 5 years after its temporary maximum coverage, reached in 2011¹.

Hence, for each of the 56 motorway sectors, we collected AISCAT (Associazione Italiana Società Concessionarie Autostrade e Trafori, the concessionaires' 150 association) data on the annual number of total highway vehicle accidents (*ACCIDENTS*), the annual number of injured people (*INJURED*), the annual number of fatalities (*FATALITIES*) caused by vehicle accidents, the annual number of accidents involving only light vehicles (*LIGHT*), and the annual number of 155 accidents involving only heavy vehicles (*HEAVY*), as dependent variables. Moreover, we collected data on the annual average daily number of effective vehicles passing through each motorway sector (*DAILY_TRAFFIC*), classified between light (*DAILY_TRAFFIC_LIGHT*) and heavy (*DAILY_TRAFFIC_HEAVY*) vehicles, and data on the annual mileage extension (in kilometres) of each motor- 160 way sector (*HIGHWAY_LENGTH*).

Then, we collected ASPI (Autostrade per l'Italia) data to compute the related number of kilometres of motorway sectors covered by the Safety Tutor sites as of 31 December each year (*TUTOR_LENGTH*). Our main explanatory variable, *COVERAGE*, is computed as the ratio between the *TUTOR_LENGTH* 165 and *HIGHWAY_LENGTH* variables. Finally, we collected Global Health Observatory data on the annual alcohol consumption per capita (*ALCOHOL_PC*) in litres and ISPRA (Istituto superiore per la protezione e la ricerca ambientale) data on the annual average age of vehicles (*VEHICLES_AGE*) in years as control variables. For the period of analysis, Table 1 shows the main descriptive 170 statistics for the collected data.

It must be noted that since data concerning *TUTOR_LENGTH* are divided between the number of kilometres covered by Safety Tutor in one carriageway from those covered in the other one, while data concerning highway accidents and traffic are aggregated for the two carriageways, we considered a motorway 175 kilometre treated by the device if it was covered in at least one of the two

¹New Safety Tutor sites have been activated in 2016.

Table 1: Descriptive statistics of variables of interest (833 Obs.). See Appendix Table A for detailed variable definitions and sources

Variable	Mean	Std. Dev.	Min	Max
<i>ACCIDENTS</i>	155.972	157.659	0.000	915.000
<i>INJURED</i>	266.299	286.867	0.000	1 734.000
<i>FATALITIES</i>	6.739	8.251	0.000	55.000
<i>LIGHT</i>	125.446	123.807	0.000	751.000
<i>HEAVY</i>	30.527	37.328	0.000	237.000
<i>DAILY_TRAFFIC</i>	99 710.070	78 785.180	0.000	301 600.000
<i>DAILY_TRAFFIC_LIGHT</i>	80 232.050	63 996.830	0.000	254 097.000
<i>DAILY_TRAFFIC_HEAVY</i>	19 478.020	16 734.900	0.000	75 528.000
<i>HIGHWAY_LENGTH</i>	98.732	64.441	5.800	273.000
<i>TUTOR_LENGTH</i>	15.410	40.420	0.000	225.100
<i>COVERAGE</i>	0.114	0.246	0.000	1.000
<i>ALCOHOL_PC</i>	8.013	1.001	6.100	9.690
<i>VEHICLES_AGE</i>	8.617	0.851	7.900	10.760

carriageways (see Appendix Table B for progressive deployment of Safety Tutor sites by year).

Finally, to avoid an overly unbalanced panel dataset, we excluded from our dataset Tangenziale esterna di Milano (TEEM) and Milano-Brescia (Bre.Be.Mi), which are motorway sectors that started their operations in 2014 and 2015, respectively. Table 2 summarizes by year the main aggregate data of the unique panel dataset.

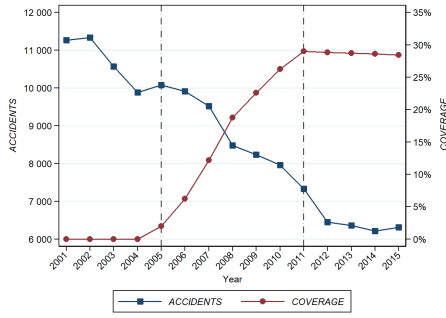
4. Patterns in Italian highway vehicle accidents

For the time period 2001-2015, Figures 1a–1e plot the decreasing trends for all accident categories analysed against *COVERAGE* growth. They show that the number of total accidents, injuries, fatalities, and light and heavy accidents experienced a decreasing trend both before the first Safety Tutor installation in 2005 and after its temporary maximum coverage that was reached in 2011. These phenomena suggest the need to disentangle the Safety Tutor effect from other key factors to explain reductions in accident categories.

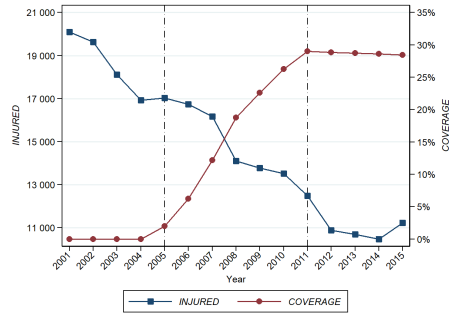
Figures 2a–2e plot annual rates for the five accident categories as measured by their absolute values over the average daily number of effective vehicles, rescaled by 1 000. In each graph, trends are divided between two subsamples: the first includes annual accident rates for those 33 motorway sectors free of any Safety Tutor technology for the overall period of analysis; the second includes annual accident rates for the remaining 23 motorway sectors that installed at least one Safety Tutor site from 2005 onwards (See Appendix Table C for the detailed list of motorway sectors).

A brief analysis reveals the following patterns: rates have fallen over time for all the accident categories under examination; however, they are higher in those motorway sectors that decided to adopt the safety device (with the exception of Figure 2c where *FATALITIES* rates shift between the two subsamples at the

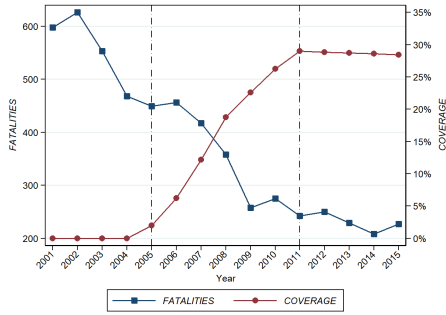
Figure 1: Accident category trends versus *COVERAGE*, 2001-2015



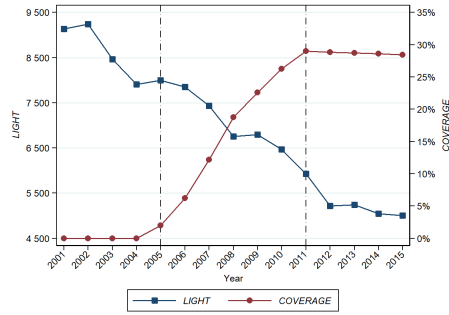
(a) *ACCIDENTS* vs *COVERAGE*



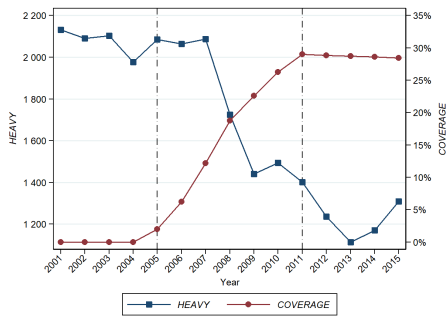
(b) *INJURED* vs *COVERAGE*



(c) *FATALITIES* vs *COVERAGE*



(d) *LIGHT* vs *COVERAGE*



(e) *HEAVY* vs *COVERAGE*

Figure 2: Accident category rates for motorway sectors covered by at least one Safety Tutor site versus accident category rates for motorway sectors not covered by the device, 2001-2015

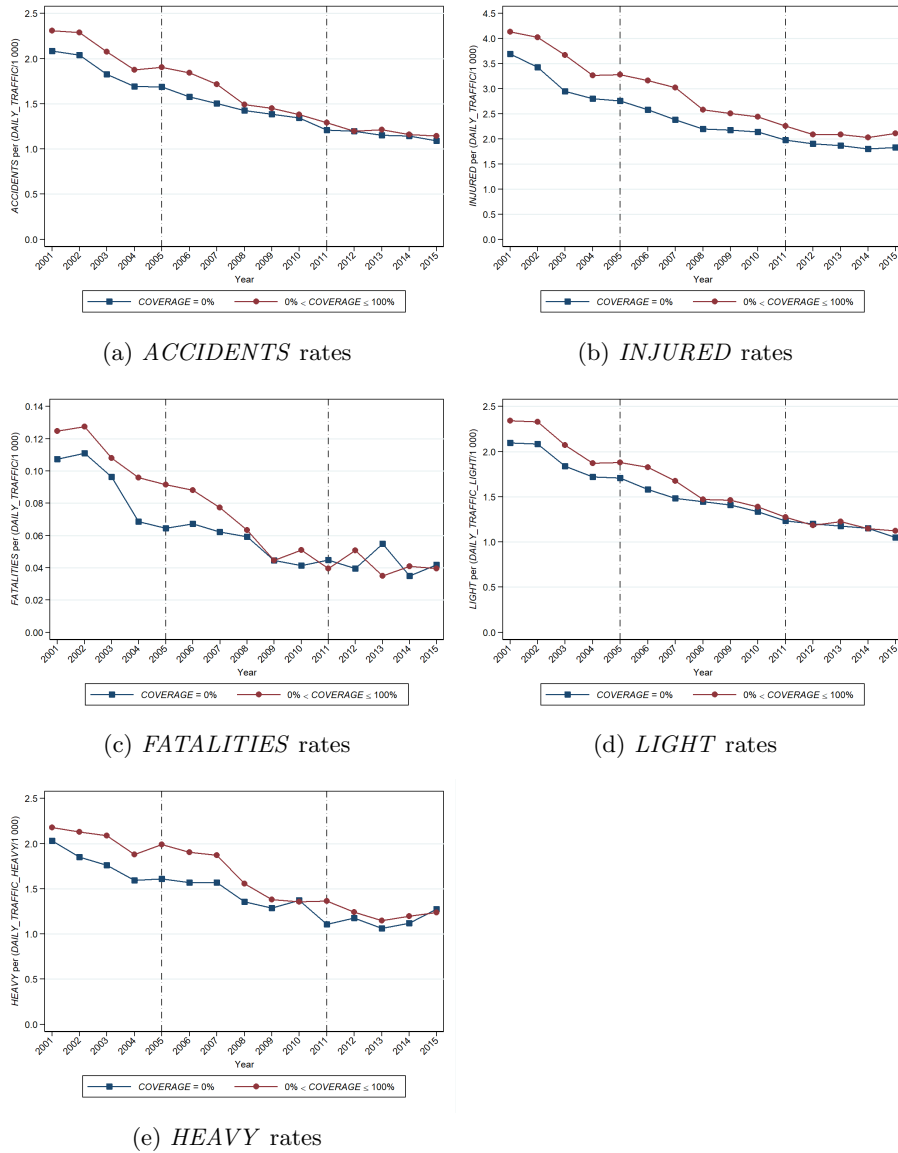


Table 2: Aggregate data for analysis, 2001-2015. *COVERAGE* is given by the ratio between *TUTOR_LENGTH* and *HIGHWAY_LENGTH*

<i>Year</i>	<i>ACCIDENTS</i>	<i>INJURED</i>	<i>FATALITIES</i>	<i>LIGHT</i>	<i>HEAVY</i>	<i>LENGTH</i>		<i>COVERAGE</i>
						<i>HIGHWAY</i>	<i>TUTOR</i>	
2001	11 265	20 087	598	9 134	2 131	5 387.9	0.0	0.0%
2002	11 334	19 624	626	9 243	2 091	5 387.9	0.0	0.0%
2003	10 568	18 117	553	8 465	2 103	5 387.9	0.0	0.0%
2004	9 889	16 919	468	7 912	1 977	5 391.2	0.0	0.0%
2005	10 081	17 038	449	7 996	2 085	5 432.4	107.2	2.0%
2006	9 915	16 735	456	7 851	2 064	5 441.1	339.4	6.2%
2007	9 523	16 172	417	7 435	2 088	5 446.4	664.3	12.2%
2008	8 482	14 100	358	6 757	1 725	5 485.9	1 028.0	18.7%
2009	8 234	13 766	258	6 793	1 441	5 485.9	1 239.8	22.6%
2010	7 964	13 521	275	6 471	1 493	5 523.2	1 450.9	26.3%
2011	7 332	12 480	242	5 931	1 401	5 523.4	1 602.0	29.0%
2012	6 450	10 881	250	5 214	1 236	5 548.6	1 602.0	28.9%
2013	6 360	10 696	229	5 246	1 114	5 573.5	1 602.0	28.7%
2014	6 218	10 472	208	5 047	1 171	5 598.1	1 602.0	28.6%
2015	6 310	11 219	227	5 001	1 309	5 630.7	1 602.0	28.5%

Table 3: Maximums, minimums, and percentage changes by accident category rates. % Δ identifies the percentage change between the 2001 and 2015 rates. Negative numbers indicate downward trends over time. The number in parentheses represents the year of occurrence

Annual rates	<i>COVERAGE</i> = 0%			0% < <i>COVERAGE</i> \leq 100%		
	Max	Min	% Δ	Max	Min	% Δ
<i>ACCIDENTS</i>	2.09 (2001)	1.09 (2015)	-47.6	2.31 (2001)	1.15 (2015)	-50.4
<i>INJURED</i>	3.69 (2001)	1.80 (2014)	-50.4	4.13 (2001)	2.03 (2014)	-48.9
<i>FATALITIES</i>	0.11 (2002)	0.03 (2014)	-60.9	0.13 (2002)	0.04 (2013)	-68.3
<i>LIGHT</i>	2.10 (2001)	1.05 (2015)	-49.9	2.34 (2001)	1.13 (2015)	-51.9
<i>HEAVY</i>	2.03 (2001)	1.06 (2013)	-37.3	2.18 (2001)	1.15 (2013)	-43.2

end of period). This phenomena suggests that Safety Tutor sites have been first
 205 activated along those motorway sectors characterized by higher accident and
 mortality rates, as confirmed by Falsi (2009). Therefore, to estimate the Safety
 Tutor effect, unobserved heterogeneity due to reverse causality is a clear issue.

Descriptive statistics summarizing trends in accident categories rates are
 presented in Table 3. Although all rates tend to converge to the same values
 210 at the end of the period, the difference in the 2001-2015 percentage change
 between the two subgroups for each category is not clear. Motorway sectors
 covered by at least one Safety Tutor site experienced an additional reduction in
FATALITIES rates (-7.4%), *HEAVY* rates (-5.9%), *ACCIDENTS* rates (-2.8%
), and *LIGHT* rates (-2.0%) and an increase in *INJURED* rates (1.5%) with
 215 respect to the percentage changes of the motorway sectors free of the device. At
 first sight, the possible effect of Safety Tutor seems sensibly lower with respect to
 the encouraging results obtained by previous studies summarized in Section 2.
 Thus, confounding factors for explaining highway accident reduction should be
 eliminated to provide a reliable evaluation.

5. Methodology

The aim of this paper is primarily to investigate whether average speed enforcement efforts affect highway safety; therefore, the model presented to explain highway accidents makes such efforts. However, as suggested by Welki and Zlatoper (2007, 2009), the model should contain other determinants that may explain the phenomena to minimize the estimation bias from omitted factors. Highway vehicle accidents depend, among other things, on traffic and congestion, economic conditions, territory and driver characteristics, concessionaires' management, and government regulations. In our model, we decide to limit these factors, as in the following Equation 1:

$$\begin{aligned} \text{Vehicle accidents} = f(\text{enforcement efforts, traffic intensity,} \\ \text{economic conditions, driver characteristics,} \\ \text{road management, other factors}) \quad (1) \end{aligned}$$

220 where *COVERAGE* is our main explanatory variable depicting the enforcement efforts. Considering that exposure to dangerous driving situations increases with the volume of vehicles (Loeb et al., 1994), we control for congestion and traffic intensity using the empirical measure of the average daily number of effective vehicles passing through each motorway sector (*DAILY_TRAFFIC*,
225 *DAILY_TRAFFIC_LIGHT*, and *DAILY_TRAFFIC_HEAVY*). Economic conditions (that are also correlated with the amount of driving activity) are represented by the annual average age of vehicles (*VEHICLES_AGE*) at a national level as a proxy for the technological development of vehicles. Moreover, considering that greater alcohol consumption is assumed to be correlated with the
230 alcohol consumption of drivers (Loeb et al., 1994), we control for that particular driver characteristic through the annual per capita ethanol consumption (in litres) for all beverages (*ALCOHOL_PC*) at a national level as a measure of alcoholic intoxication while driving.

The panel structure of our dataset allows us to control for possibly correlated,
235 time-invariant heterogeneity without observing it. In particular, motorway sector fixed effects capture morphological and atmospheric characteristics of the territory (including the consequent speed limits), the different driving behaviour between areas, and the presence of additional speed management programmes (e.g., fixed speed cameras). Furthermore, as underlined in Section 1, this analysis takes into account the motorway network under concession. As studied by
240 Albalate (2011) and Percoco (2016) in other contexts, different toll fares applied by the 24 licensee companies (and their resulting different economic outcomes) can directly affect the level of road quality and maintenance investments, which in turn can affect accident rates. Considering that for the period of analysis,
245 all motorway sectors were managed by the same companies², the time-invariant

²In 2009 the Società Autostrade di Venezia e Padova S.p.A. was absorbed by Concessioni Autostradali Venete (C.A.V.) S.p.A. concurrent with the opening of the new Passante di Mestre motorway sector.

component of the “road management” effect is captured by motorway dummies as well.

From the time trend perspective, year dummies allow us to capture other confounding factors not explicitly included in the model that contribute to the decreasing trend of accident rates, such as the common improvement of highways (e.g., ameliorated motorway paving) and the technological development of vehicles (e.g., assisted braking and safety systems). Moreover, three government regulations are accounted for through time fixed effects: first, the introduction of a penalty-point system for driving licensees in 2003 (Gazzetta Ufficiale, 2003); second, the introduction of the “Decreto Bianchi” in 2007 (Gazzetta Ufficiale, 2007), which strengthened the penalties for road traffic offences (e.g., excess speed, driving under the influence of alcohol and drugs, driving while using a cell phone) and limited the maximum speed (80 km/h) and maximum specific power of cars (50 kilowatts/ton) for first year drivers; and third, the introduction in 2010 of the obligation that vehicles travelling on highways adopt winter tyres or keep snow chains on board during winter months (Gazzetta Ufficiale, 2010).

Turning to the importance of unit and time fixed effects, Figure 3 shows the heterogeneity across motorway sectors by plotting the average *ACCIDENTS* rates over the average *COVERAGE* for each motorway sector during the period of analysis (where the average sectors treated by Safety Tutor are among those motorways with the highest average accident rates), while Figure 4 shows how time plays a fundamental role in explaining accident reduction by plotting the average *ACCIDENTS* rates for each year (see Appendix Figures A–B for the same graphs related to *INJURED*, *FATALITIES*, *LIGHT*, and *HEAVY* rates).

To empirically test the effectiveness of Safety Tutor in reducing highway vehicle accidents, we used a semi-log model by regressing the following panel equation:

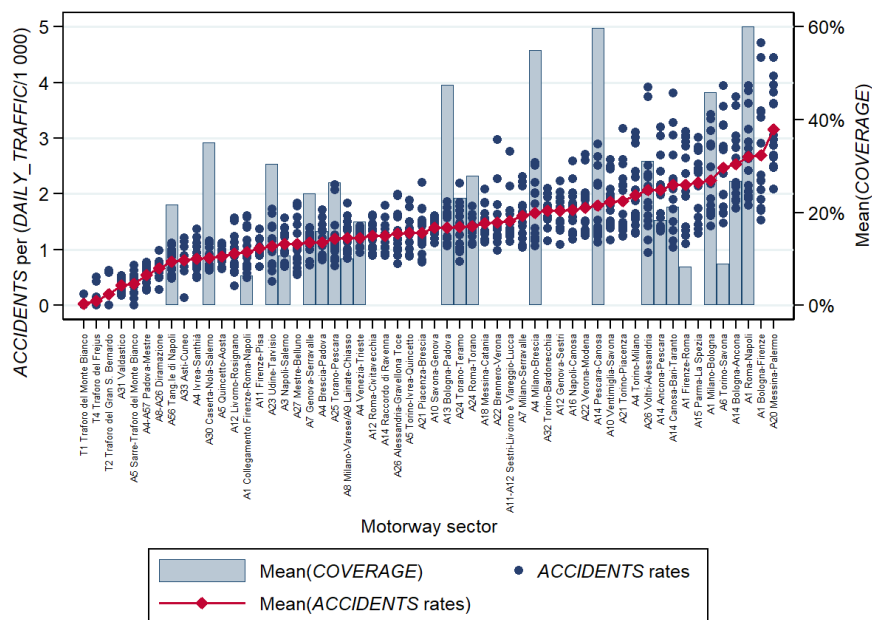
$$\log \left(\frac{Y + 1}{DAILY_TRAFFIC} \times 10000 \right)_{it} = \beta_0 + \beta_1 COVERAGE_{it-1} + b' X_t + \alpha_i + \delta_t + \epsilon_{it} \quad (2)$$

where the dependent variables are given by the logarithm of Y (the set of our variables of interest *ACCIDENTS*, *INJURED*, *FATALITIES*, *LIGHT*, and *HEAVY*) plus 1, weighted by the average daily number of effective vehicles (*DAILY_TRAFFIC*³), and rescaled by 10 000. X_t is a 2-dimensional vector of control variables (*VEHICLES_AGE* and *ALCOHOL_PC*), α_i and δ_t are motorway sector and year fixed effects, respectively, and ϵ_{it} is the error term.

Considering that Safety Tutor installation took place in different periods during the course of each year, we lagged the main explanatory variable by one period to ensure our dependent variables were regressed with respect to

³The *LIGHT* and *HEAVY* variables are coherently weighted by *DAILY_TRAFFIC_LIGHT* and *DAILY_TRAFFIC_HEAVY*, respectively.

Figure 3: Heterogeneity of *ACCIDENTS* rates across motorway sectors



280 full annual *COVERAGE*. Since some motorway sectors belong to the same
 highway, heteroskedasticity- and autocorrelation-consistent standard errors are
 computed by clustering sectors at the highway level. To simplify the notation
 of our dependent variables in the next sections, we will use the following labels:
 285 $\log(ACCIDENTS)$, $\log(INJURED)$, $\log(FATALITIES)$, $\log(LIGHT)$,
 $\log(HEAVY)$. Table 4 shows the main descriptive statistics of our dependent
 variables.

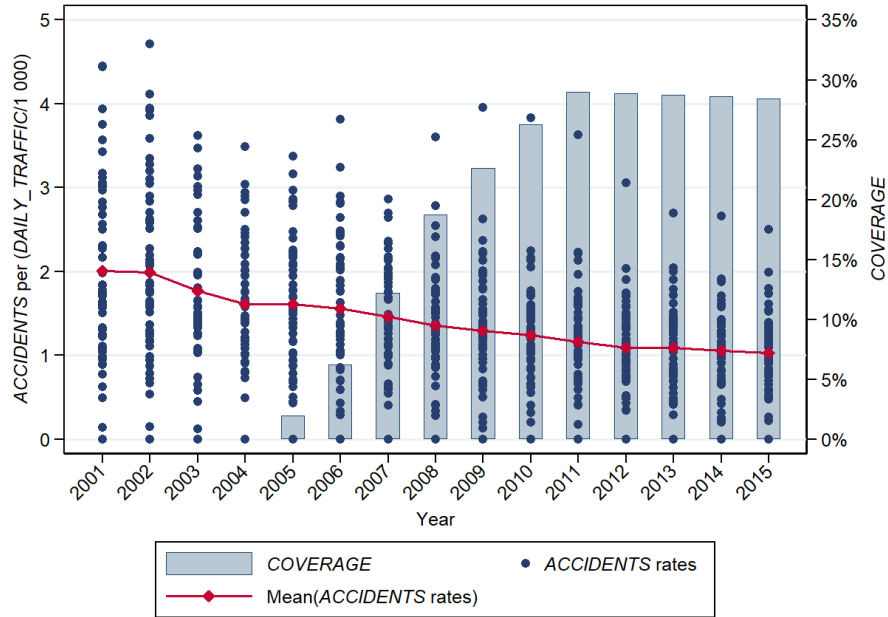
Table 4: Summary statistics of dependent variables (832 Obs.)

Variable	Mean	Std. Dev.	Min	Max
$\log(ACCIDENTS)$	2.522	0.601	0.074	3.855
$\log(INJURED)$	2.976	0.715	0.744	5.118
$\log(FATALITIES)$	-0.301	0.812	-2.717	1.862
$\log(LIGHT)$	2.556	0.571	0.356	3.890
$\log(HEAVY)$	2.522	0.693	-0.676	4.756

6. OLS Estimation Results

For each accident category under analysis, Tables 5–9 report the results from four different semi-log specifications of Equation 2, estimated by OLS

Figure 4: Heterogeneity of *ACCIDENTS* rates across years



290 regressions. Model (1) is a pooled OLS estimation, Model (2) adds motorway
 sector fixed effects, Model (3) includes our set of control variables, and Model
 (4) includes time dummies.

Table 5 reports a possible relationship between Safety Tutor coverage and
 total highway vehicle accident reduction. Model (1), the most parsimonious
 295 specification, shows a small positive (and counterintuitive) correlation between
 the number of accidents and the presence of Safety Tutor sites, but it is not
 significant. Once we control for those different time-invariant factors that can
 directly affect accidents across motorway sectors, Model (2) estimates a negative
 and significant correlation, showing that a 10% increase in Safety Tutor coverage
 300 could on average reduce highway vehicle accidents by 4.6%. The coefficient
 becomes significantly lower (-0.202) once we include in the regression our set
 of controls (Model 3). Consistent with conventional wisdom as well as findings
 reported in previous studies (Loeb et al., 1994), the *ALCOHOL_PC* coefficient
 is positive and significant, as greater alcohol consumption leads to more highway
 305 accidents. As concerns *VEHICLES_AGE*, its estimation is inversely related to
 vehicle accidents, probably because weaker economic circumstances (correlated
 with ageing vehicles) should lead to the diminished use of cars and trucks.
 Moreover, the greater difficulty older motor vehicles have reaching high speeds
 can lead to a reduction in highway accidents.

310 The $COVERAGE_{t-1}$ coefficient becomes lower and less significant when

Table 5: OLS regressions of $\log(ACCIDENTS)$. Clustered standard errors are in parentheses. ***, **, and * denote significance at the 1%, 5%, and 10% levels, respectively. Control for motorway sector and year is as indicated

Dependent variable	$\log(ACCIDENTS)$			
	(1)	(2)	(3)	(4)
$COVERAGE_{t-1}$	0.0511 (0.149)	-0.617*** (0.0652)	-0.202*** (0.0583)	-0.138** (0.0586)
$ALCOHOL_{PC}$			0.125*** (0.0169)	
$VEHICLES_{AGE}$			-0.0535*** (0.0162)	
Motorway sector	No	Yes	Yes	Yes
Year	No	No	No	Yes
Constant	2.493*** (0.0943)	2.564*** (0.00695)	2.000*** (0.240)	2.843*** (0.0318)
Observations	777	777	777	777
R^2	0.000	0.165	0.412	0.463

we add year dummies to the explanatory variables, as can be seen in Model (4). The model shows that a 10% increase in Safety Tutor coverage could on average reduce highway vehicle accidents by 1.3%. This result has a direct interpretation: time plays a fundamental role in explaining the reduction in accidents, as it captures either some sort of technological improvement effect (e.g., technical progress of road surface maintenance and innovation of vehicle safety systems) or a less plausible enhancement of driving behaviour. Hence, year dummies appear as relevant omitted variables because the point estimate decreases without leading the standard error to increase as well. Considering that motorway sector and year fixed effects appear to explain a large part of the variability (as confirmed by an R^2 comparison between specifications), Model (4) is the one that best fits our data.

Table 6 reports a possible relationship between Safety Tutor coverage and the number of people injured by vehicle accidents. Estimations of the four models present a very similar path, as expected. Focusing just on Model (4), the $COVERAGE_{t-1}$ coefficient shows that a 10% increase in Safety Tutor coverage could, on average, reduce injuries by 1.0%.

Table 7 correlates Safety Tutor coverage with the number of fatalities. For all specifications, the estimated coefficients emphasize that this technology has a significant and stronger impact on reducing deaths than on reducing total accidents and injuries. In particular, Model (4) shows that a 10% increase in Safety Tutor coverage could on average reduce fatalities by 3.6%. Our interpretation is straightforward: traffic, congestion, and the dangerousness of some highway sectors (which are among the prominent factors causing vehicle accidents) are not reduced by Safety Tutor technology, but the plausible decrease in the average speed enforced by the point-to-point speed control system (together with the technological improvement of vehicles) could have reduced the severity of

Table 6: OLS regressions of $\log(INJURED)$. Clustered standard errors are in parentheses. ***, **, and * denote significance at the 1%, 5%, and 10% levels, respectively. Control for motorway sector and year is as indicated

Dependent variable	$\log(INJURED)$			
	(1)	(2)	(3)	(4)
$COVERAGE_{t-1}$	0.219 (0.175)	-0.609*** (0.0724)	-0.184*** (0.0630)	-0.108* (0.0597)
$ALCOHOL_PC$			0.125*** (0.0171)	
$VEHICLES_AGE$			-0.0583*** (0.0172)	
Motorway sector	No	Yes	Yes	Yes
Year	No	No	No	Yes
Constant	2.929*** (0.112)	3.017*** (0.00772)	2.491*** (0.254)	3.338*** (0.0400)
Observations	777	777	777	777
R^2	0.006	0.135	0.353	0.421

vehicle accidents. Nevertheless, this model fits the data worse than the previous ones, as the R^2 shows.

Table 7: OLS regressions of $\log(FATALITIES)$. Clustered standard errors are in parentheses. ***, **, and * denote significance at the 1%, 5%, and 10% levels, respectively. Control for motorway sector and year is as indicated

Dependent variable	$\log(FATALITIES)$			
	(1)	(2)	(3)	(4)
$COVERAGE_{t-1}$	-0.534** (0.230)	-1.088*** (0.108)	-0.523*** (0.124)	-0.440*** (0.139)
$ALCOHOL_PC$			0.247*** (0.0341)	
$VEHICLES_AGE$			0.0144 (0.0361)	
Motorway sector	No	Yes	Yes	Yes
Year	No	No	No	Yes
Constant	-0.277*** (0.0940)	-0.218*** (0.0115)	-2.351*** (0.503)	0.238*** (0.0596)
Observations	777	777	777	777
R^2	0.025	0.127	0.254	0.289

340 Tables 8–9 focus on the correlation between Safety Tutor coverage and total
light or heavy vehicle accidents, respectively. While estimated results explaining
light vehicle accident reduction are very similar to those explaining total acci-
dents and injuries, the Model (3) and Model (4) $COVERAGE_{t-1}$ coefficients
explaining heavy vehicle accident reduction are smaller and not significant. Con-
345 sidering that the average speed of trucks is already lower with respect to the
highway speed limit, it is plausible to expect no significant effect of the Safety

Table 8: OLS regressions of $\log(LIGHT)$. Clustered standard errors are in parentheses. ***, **, and * denote significance at the 1%, 5%, and 10% levels, respectively. Control for motorway sector and year is as indicated

Dependent variable	$\log(LIGHT)$			
	(1)	(2)	(3)	(4)
$COVERAGE_{t-1}$	-0.0162 (0.141)	-0.639*** (0.0644)	-0.208*** (0.0593)	-0.151** (0.0589)
$ALCOHOL_PC$			0.125*** (0.0190)	
$VEHICLES_AGE$			-0.0610*** (0.0168)	
Motorway sector	No	Yes	Yes	Yes
Year	No	No	No	Yes
Constant	2.534*** (0.0871)	2.600*** (0.00686)	2.099*** (0.261)	2.878*** (0.0400)
Observations	777	777	777	777
R^2	0.000	0.168	0.422	0.468

Tutor device on improving heavy vehicle drivers' safety. These results coherently support the interpretation previously given to *FATALITIES* estimations.

Table 9: OLS regressions of $\log(HEAVY)$. Clustered standard errors are in parentheses. ***, **, and * denote significance at the 1%, 5%, and 10% levels, respectively. Control for motorway sector and year is as indicated

Dependent variable	$\log(HEAVY)$			
	(1)	(2)	(3)	(4)
$COVERAGE_{t-1}$	0.0278 (0.182)	-0.527*** (0.0966)	-0.127 (0.102)	-0.0367 (0.104)
$ALCOHOL_PC$			0.117*** (0.0282)	
$VEHICLES_AGE$			-0.0551** (0.0213)	
Motorway sector	No	Yes	Yes	Yes
Year	No	No	No	Yes
Constant	2.498*** (0.0948)	2.557*** (0.0103)	2.068*** (0.340)	2.821*** (0.0685)
Observations	777	777	777	777
R^2	0.000	0.052	0.151	0.187

7. IV Estimation Results

350 In the previous section, we identified a positive correlation between Safety Tutor and an average reduction for 4 out of the 5 accident categories analysed. Although the panel structure of our dataset eliminated many unobserved factors, OLS estimates might be still biased because of additional omitted variables and

reverse causality issues. Highway accidents are complex events that involve
355 a variety of human responses to external stimuli (Elvik, 2006; Ayyildiz et al.,
2017), as well as complex interactions between vehicles (Dadashova et al., 2014),
roadway characteristics, traffic-related factors, and environmental conditions
(Amin et al., 2014; Bardal and Jørgensen, 2017).

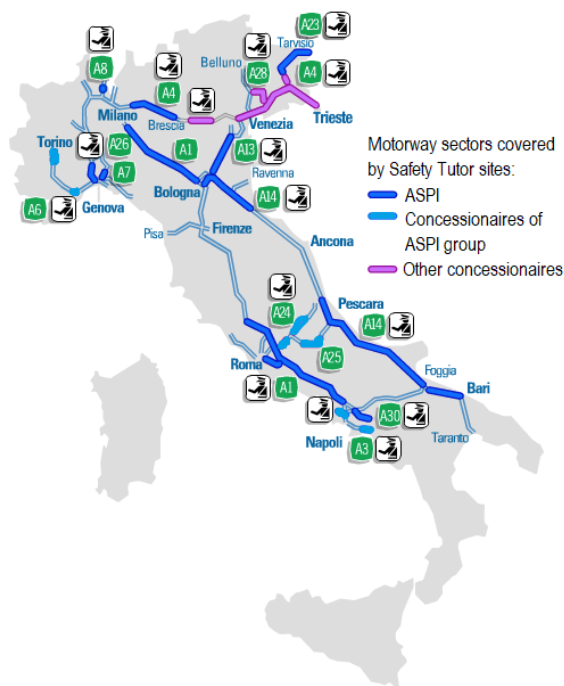
Naturally, it is impossible to control for all possible variables that might be
360 correlated with highway accidents, such as drivers' skills, temporary roadworks,
police enforcement, weather and lighting conditions. For instance, the unob-
served age of drivers and the quality of health care can affect the severity of
injuries and the number of fatalities due to vehicle accidents. Most importantly,
if those unobserved factors are correlated with observed factors, biased param-
365 eters will be estimated, and incorrect inferences could be drawn (Mannering and
Bhat, 2014; Mannering et al., 2016). As concerns reverse causality, Safety Tutor
sites were first activated along those motorway sectors characterized by higher
accident and mortality rates (Falsi, 2009), as confirmed by Figure 2 in Section 3.
For this issue, the practice of lagging the main explanatory variable to control
370 possible simultaneous causation does not solve the problem (Reed, 2015).

To address these identification issues, we utilize an instrumental variable
strategy by exploiting the membership of some motorway sectors in the Au-
tostrade per l'Italia (ASPI) group as an instrument for *COVERAGE*. The mo-
375 tivation is straightforward: ASPI (the major highway concessionaire) and the
Italian traffic police developed the Safety Tutor technology in 2004 (Autostrade
per l'Italia, 2016); therefore, it is more likely that the device was first installed
on those motorway sectors managed by the company itself or by other conces-
sionaires under its control. Between 2005 and 2010 (i.e., the period where the
majority of Safety Tutor installation took place), ASPI controlled Tangenziale
380 di Napoli S.p.A. (100%), Autostrada Torino-Savona S.p.A. (99.9%), Società Au-
tostrada Tirrenica S.p.A. (93.7%), Strada dei Parchi S.p.A. (60.0%), Autostrade
Meridionali S.p.A. (58.9%), and Società Italiana per il Traforo del Monte Bianco
S.p.A. (51.0%), which in turn controlled the 58.0% of Raccordo Autostradale
Valle d'Aosta S.p.A. (Autostrade per l'Italia, 2006, 2011) ⁴.

385 Indeed, if we focus on the geographical exposure of *COVERAGE*, Figure 5
shows the location of Safety Tutor sites in 2015. Hence, it is clear that being
part of ASPI group was a major determinant for the adoption of Safety Tutor, as
it tends to concentrate along those motorway sectors managed by ASPI and its
controlled concessionaires. As Table 10 describes, in 2011 (that is, when Safety
390 Tutor reached its maximum coverage during the period of analysis) 1 450.3 out
of 1 602.0 kilometres of Safety Tutor sites (90.5%) were installed within ASPI
group.

⁴In 2011, Autostrada Torino-Savona S.p.A., Società Autostrada Tirrenica S.p.A., and Strada dei Parchi S.p.A. were no longer members of ASPI group (Autostrade per l'Italia, 2012).

Figure 5: Safety Tutor sites in 2015, formatted by authors



Consequently, our instrument is given by the following equation:

$$INSTRUMENT = TECHNOLOGY \times ASPI_GROUP \quad (3)$$

where *TECHNOLOGY* is a dummy variable equal to 1 (mean = 0.736, standard deviation = 0.441) for those observations from 2005 onwards (i.e., when the Safety Tutor technology was available), and *ASPI_GROUP* is another dummy variable equal to 1 (mean = 0.612, standard deviation = 0.488) for those motorway sectors managed by Autostrade per l'Italia and its controlled concessionaires. Considering that in Equation 2, we regressed the lagged value of the main explanatory variable, our identification strategy is to use the lagged value of this iteration (mean = 0.449, standard deviation = 0.498) as an instrument for $COVERAGE_{t-1}$.

To exploit this variation to estimate causal relationships, our instrument needs to respect three main assumptions (Angrist et al., 1996). First, there might be a correlation between the instrument and the endogenous variable. Since there is a strong relationship between those motorway sectors managed by ASPI group and Safety Tutor adoption (1st Stage F-statistic = 25.06), as discussed above, the *relevance* assumption is satisfied.

Second, the *exclusion* restriction implied by our instrumental variable regression states that, conditional on the controls included in the regression, the

Table 10: Progressive deployment of Safety Tutor sites by concessionaires, 2005-2011

Concessionaires	<i>TUTOR_LENGTH</i>						
	2005	2006	2007	2008	2009	2010	2011
ASPI ¹	107.2	339.4	543.1	869.6	1 072.0	1 240.2	1 276.8
TANG.NAPOLI ²	0.0	0.0	0.0	0.0	9.4	9.4	9.4
TORINO-SAVONA ³	0.0	0.0	0.0	0.0	0.0	29.2	29.2
SAT ⁴	0.0	0.0	0.0	0.0	0.0	0.0	0.0
AUT.PARCHI ⁵	0.0	0.0	121.2	121.2	121.2	121.2	121.2
AUT.MERIDIONALI ⁶	0.0	0.0	0.0	0.0	0.0	13.7	13.7
SITMB ⁷	0.0	0.0	0.0	0.0	0.0	0.0	0.0
RAV ⁸	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Total <i>ASPI_GROUP</i> (A)	107.2	339.4	664.3	990.8	1 202.6	1 413.7	1 450.3
AUTOVIE.VENETE ⁹	0.0	0.0	0.0	0.0	0.0	0.0	104.1
BRESCIA-PADOVA ¹⁰	0.0	0.0	0.0	37.2	37.2	37.2	47.6
Total <i>OTHERS</i> (B)	0.0	0.0	0.0	37.2	37.2	37.2	151.7
Total (A+B)	107.2	339.4	664.3	1 028.0	1 239.8	1 450.9	1 602.0

Notes: [1] Autostrade per l'Italia S.p.A., [2] Tangenziale di Napoli S.p.A., [3] Autostrada Torino-Savona S.p.A., [4] Società Autostrada Tirrenica S.p.A., [5] Strada dei Parchi S.p.A., [6] Autostrade Meridionali S.p.A., [7] Società Italiana per il Traforo del Monte Bianco S.p.A., [8] Raccordo Autostradale Valle d'Aosta S.p.A., [9] Autovie Venete S.p.A., [10] Autostrada Brescia-Verona-Vicenza-Padova S.p.A.

membership in ASPI group has no direct effect on highway accident categories other than its effect through *COVERAGE* (that is, the instrument must not be correlated with any other unobservable determinant of the dependent variable). The major concern here is that concessionaires within ASPI group might affect accident rates through different maintenance programmes or investment policies. However, the motorway sectors' concessionaires do not change over the period of analysis; thus, their time-invariant differences are captured by fixed effects. Moreover, in the road safety literature, accidents always depend mainly on speed and traffic volume (Aarts and Van Schagen, 2006; Hauer, 2009). Considering that speed limits are enforced by the traffic police and that congestion variables are included in our specification, there is little that concessionaires can do on their own to reduce accidents (Ragazzi, 2006). For these reasons, we believe that the *exclusion* restriction is satisfied as well.

Third, the *independence* assumption requires that our instrument is assigned to observations independently of their potential outcomes and treatments; in other words, that ASPI group membership is as good as randomly assigned to motorway sectors. In our application, it is clear that the decision to assign the management of a motorway sector to a particular concessionaire does not appear to be random. However, assignment occurred mainly between the 1960s and 1970s (Bank of Italy, 2015), and hence many decades before the idea of developing an average speed enforcement system to improve drivers' safety. Therefore, we can assume that ASPI group membership is independent of the volume of highway accidents occurring during the period of analysis.

Finally, Safety Tutor exposure is not homogeneous across motorway sectors,
435 as the percentage of kilometres covered by the device varies across sectors and
years (see Appendix Table B for the progressive deployment of Safety Tutor
sites for each motorway sector by year). Thus, to estimate a causal effect of
COVERAGE on reducing highway accidents, our instrumental variable needs
to also satisfy a fourth condition, namely the *monotonicity* assumption (Imbens
440 and Angrist, 1994): if a particular motorway sector becomes a member of ASPI
group and increases its Safety Tutor coverage, then this change must not de-
crease the Safety Tutor coverage of any other motorway sector. In other words,
it means that a certain instrument may induce treatment for some observations
but not for others, but it cannot induce treatment for some and simultaneously
445 induce non-treatment for others.

Considering that the last assumption is also satisfied, our IV estimator is
interpretable as a weighted local average treatment effect; hence, it captures
the causal effect of *COVERAGE* only for those “complier” motorway sectors
that decided to install or to increase Safety Tutor adoption because they are
450 members of ASPI group (i.e., those that respond to the exogenous “shift” in
the endogenous variable induced by the instrument).

Two-stage least squares estimates of Model (4) (which includes both motorway sector and year fixed effects) for all five accident categories of interest are presented in Table 11, where *COVERAGE* is treated as endogenous. If
455 we focus on the *relevance* condition, Panel B displays the strong first-stage relationship between the lagged value of *COVERAGE* and the lagged value of *INSTRUMENT*. It is positive and significant, and it basically predicts the expected value of Safety Tutor exposure based on the instrument. Therefore, the motorway sectors of ASPI group have an average *COVERAGE* of 21.1%. As
460 regards the Panel C results, point estimates of the reduced form regressions of the outcome variables over the instrument are close to zero and not significant for all of our specifications. Thus, there is no evidence of an “intention-to-treat” (ITT) effect (that is, to be a member of ASPI group does not itself affect highway accidents). Reasonably, the corresponding 2SLS results (Panel A) that
465 depict the impact of Safety Tutor are also not significant. With the exception of Column (3), the point estimates are significantly larger than the OLS estimates reported in Panel D. This may be due to attenuation biases induced by measurement error⁵ in the *COVERAGE* variable and to a plausible spillover effect of Safety Tutor sites on other motorway sectors free of the technology. How-
470 ever, standard errors are almost five times larger than OLS as well; therefore, the estimates are barely not significant (p-value of Column (1) = 0.12). The IV results suggest that there is no clear evidence of a significant causal effect of Safety Tutor on preventing highway accidents in any of the categories analysed,

⁵Here, we are referring to “measurement error” broadly construed because we are considering a motorway kilometre treated by Safety Tutor if it is covered by the device in at least one of the two carriageways (as explained in Section 3). In reality, few motorway sectors have a slight different *TUTOR_LENGTH* between the two carriageways.

at least for the subgroup of “complier” motorway sectors.

475 8. Robustness Checks

To ensure that our estimates are not driven by outliers, the following section reports the 2SLS results of Model (4) for all five accident categories of interest using a subsample without peculiar motorway sectors. In particular, we performed the same analysis without considering highway tunnels (T1 Traforo del Monte Bianco, T2 Traforo del Gran S. Bernardo, T4 Traforo del Frejus), the motorway sector with the highest average number of accidents within the period of analysis (A14 Bologna-Ancona), the motorway sector with the highest average Safety Tutor coverage within the period of analysis (A1 Roma-Napoli), and the new motorway sector introduced in 2008 (A33 Asti-Cuneo). Table 12 shows that the 2SLS (Panel A), first stage (Panel B), reduced form (Panel C) and OLS (Panel D) results follow a very similar path; therefore, our previous estimates that include all motorway sectors can be considered consistent.

9. Conclusions

The analysis of highway accident data has long been used as a basis for directing and implementing regulatory policies and enforcement activities designed to improve safety. Therefore, this paper contributes to the vehicle accident analysis literature by accurately testing the effectiveness of Safety Tutor in reducing total accidents, injuries, fatalities, light vehicle accidents, and heavy vehicle accidents on the Italian tolled motorway network during the period 2001-2015.

495 With respect to previous studies that have focused on the impact of specific Safety Tutor sites in unique contexts, the novel contribution of the paper lies, first, in performing a robust evaluation of this device at the national level by using a unique 15-year panel dataset (which makes it possible to observe the trend in accident rates 5 years before the implementation of Safety Tutor and 5 years after its temporary maximum coverage) and, second, in exploiting the heterogeneity within all motorway sectors (including both those that had installed the device and those that had not). By exploiting the longitudinal structure of our dataset, which allowed us to control for many unobserved factors, OLS regressions identified a positive correlation between the device and highway accident reduction. In particular, a 10% increase in Safety Tutor coverage is associated with an average reduction in total accidents of nearly 1.3%, injuries of 1.0%, fatalities of 3.6%, and light vehicle accidents of 1.4%. However, those results appear considerably lower than previous estimates and far from the 80% mortality rate reduction underlined by Autostrade per l’Italia in 2016. Differences between those findings have a direct interpretation: the larger time span taken into account by our empirical analysis highlights how time plays a fundamental role in explaining accident reduction, as it also captures the general improvement of highways (e.g., ameliorated motorway paving), the technological development of vehicles (e.g., assisted braking and safety systems), and the

Table 11: IV regressions of Model (4) for the five accident categories of interest. Panel A reports 2SLS estimates of the coefficient of interest (β_1 of Equation 2), instrumenting for $COVER_{t-1}$ using $INSTRUMENT_{t-1}$. Panel B reports the corresponding first stage. Panel C reports the reduced form of the dependent variables against $INSTRUMENT_{t-1}$. Panel D reports the previous coefficients from the OLS regressions of Tables 5-9. Clustered standard errors are in parentheses. ***, **, and * denote significance at the 1%, 5%, and 10% levels, respectively. Control for motorway sector and year is as indicated

	(1)	(2)	(3)	(4)	(5)
Panel A: 2SLS					
	$\log(ACCIDENTS)$	$\log(INJURED)$	$\log(FATALITIES)$	$\log(LIGHT)$	$\log(HEAVY)$
$COVER_{t-1}$	-0.371 (0.239)	-0.340 (0.237)	-0.130 (0.501)	-0.327 (0.267)	-0.464 (0.515)
R^2	0.446	0.406	0.281	0.459	0.162
Panel B: 1 st Stage					
	$COVER_{t-1}$	$COVER_{t-1}$	$COVER_{t-1}$	$COVER_{t-1}$	$COVER_{t-1}$
$INSTRUMENT_{t-1}$	0.211*** (0.042)	0.211*** (0.042)	0.211*** (0.042)	0.211*** (0.042)	0.211*** (0.042)
R^2	0.342	0.342	0.342	0.342	0.342
Panel C: Reduced Form					
	$\log(ACCIDENTS)$	$\log(INJURED)$	$\log(FATALITIES)$	$\log(LIGHT)$	$\log(HEAVY)$
$INSTRUMENT_{t-1}$	-0.0783 (0.0512)	-0.0718 (0.0498)	-0.0274 (0.109)	-0.0689 (0.0579)	-0.0979 (0.108)
R^2	0.461	0.420	0.274	0.465	0.189
Panel D: OLS					
	$\log(ACCIDENTS)$	$\log(INJURED)$	$\log(FATALITIES)$	$\log(LIGHT)$	$\log(HEAVY)$
$COVER_{t-1}$	-0.138** (0.0586)	-0.108* (0.0597)	-0.440*** (0.139)	-0.151** (0.0589)	-0.0367 (0.104)
R^2	0.463	0.421	0.289	0.468	0.187
1 st Stage F-statistic	25.06	25.06	25.06	25.06	25.06
Motorway sector	Yes	Yes	Yes	Yes	Yes
Year	Yes	Yes	Yes	Yes	Yes
Observations	777	777	777	777	777

Table 12: Robustness checks for IV regressions of Model (4) of the five accident categories of interest. Panel A reports the 2SLS estimates of the coefficient of interest (β_1 of Equation 2), instrumenting for $COVER_{t-1}$ using $INSTRUMENT_{t-1}$. Panel B reports the corresponding first stage. Panel C reports the reduced form of the dependent variables against $INSTRUMENT_{t-1}$. Panel D reports the OLS estimates of the dependent variables against $COVER_{t-1}$. Clustered standard errors are in parentheses. ***, **, and * denote significance at the 1%, 5%, and 10% levels, respectively. Control for motorway sector and year is as indicated

	(1)	(2)	(3)	(4)	(5)
Panel A: 2SLS					
	$\log(ACCIDENTS)$	$\log(INJURED)$	$\log(FATALITIES)$	$\log(LIGHT)$	$\log(HEAVY)$
$COVER_{t-1}$	-0.370 (0.283)	-0.377 (0.283)	0.176 (0.539)	-0.359 (0.321)	-0.205 (0.550)
R^2	0.511	0.440	0.269	0.486	0.205
Panel B: 1 st Stage					
	$COVER_{t-1}$	$COVER_{t-1}$	$COVER_{t-1}$	$COVER_{t-1}$	$COVER_{t-1}$
$INSTRUMENT_{t-1}$	0.194*** 0.0397	0.194*** 0.0397	0.194*** 0.0397	0.194*** 0.0397	0.194*** 0.0397
R^2	0.338	0.338	0.338	0.338	0.338
Panel C: Reduced Form					
	$\log(ACCIDENTS)$	$\log(INJURED)$	$\log(FATALITIES)$	$\log(LIGHT)$	$\log(HEAVY)$
$INSTRUMENT_{t-1}$	-0.0717 (0.0528)	-0.0732 (0.0523)	0.0340 (0.107)	-0.0697 (0.0615)	-0.0398 (0.107)
R^2	0.529	0.459	0.282	0.498	0.211
Panel D: OLS					
	$\log(ACCIDENTS)$	$\log(INJURED)$	$\log(FATALITIES)$	$\log(LIGHT)$	$\log(HEAVY)$
$COVER_{t-1}$	-0.123* (0.0666)	-0.108 (0.0719)	-0.456*** (0.154)	-0.137* (0.0681)	0.00455 (0.120)
R^2	0.530	0.459	0.295	0.500	0.210
1 st Stage F-statistic	23.84	23.84	23.84	23.84	23.84
Motorway sector	Yes	Yes	Yes	Yes	Yes
Year	Yes	Yes	Yes	Yes	Yes
Observations	700	700	700	700	700

515 impact of new government regulations (e.g., the introduction of a penalty-point
system for driving licensees in 2003 and the strengthening of penalties for road
traffic offences in 2007).

Moreover, our estimates might still be biased due to omitted variables and
reverse causality. To address problems stemming from these additional endo-
520 geneity issues, we utilized an instrumental variable strategy by exploiting the
membership of some motorway sectors in the Autostrade per l'Italia group as
an instrument for Safety Tutor. 2SLS results show no evidence of a causal ef-
fect of Safety Tutor on preventing highway accidents in any of the categories
analysed. The key insight is that our IV estimator is informative about the
525 average effect of the subgroup of the “complier” motorway sectors. Moreover,
we are aware that a limitation of our analysis involves the plausible presence of
spillover effects that could attenuate our findings.

There are many possible explanations for this lack of effect: first, Safety
Tutor activation was progressively limited to a few hours per day and alternated
530 between various camera sites installed along the same motorway sector (due to
the large amount of data to be processed); thus, after an initial deterrent effect,
a gradual reduction in drivers' compliance with speed limits might have taken
place a few months following the installation of each camera site, as explained
by Montella et al. (2015b). Second, the 12-year legal process for patent rights
535 might have encouraged the concessionaires to limit investments in new Safety
Tutor installations or to reduce operational activities. Third, the average speed
enforcement has a partial deterrent effect on peak speed, as drivers might speed
in some sectors and then slow down in others, increasing the crash risk. This
explanation can be supported by the absence of significant correlation between
540 Safety Tutor coverage and heavy vehicle accidents even in the OLS estimates,
as trucks are hardly able to exceed highway speed limits. Finally, traffic and
congestion (on which Safety Tutor has no impact) can be a more important
cause of accidents than speed.

As our results show no evidence of a significant causal effect of Safety Tu-
545 tor in preventing highway accidents, we suggest a better implementation of
average speed enforcement systems by increasing both the number of hours of
activation and the utilization of entry and exit camera sites as fixed speed cam-
eras. Moreover, the allocation of resources for accident prevention programmes
on high-speed roads should not focus only on enforcing speed limits, but they
550 might also target improving the paving and increasing the capacity of highly
congested motorway sectors. Since accident prevention is a major goal of trans-
port institutions and road agencies (as foreseen by the “Zero Road Deaths and
Serious Injuries” programme), this paper ultimately seeks to show how the uti-
lization of robust econometric methods (which control for confounding factors
555 and take into account endogeneity issues) can help highway concessionaires in
the analysis of their increasing amount of available data to better evaluate ac-
cident prevention policies.

References

- Aarts, L., van Nes, N., Wegman, F., Van Schagen, I., Louwerse, R., 2009. Safe speeds and credible speed limits (sacredspeer): a new vision for decision making on speed management, in: *Compendium of papers of the 88th TRB Annual Meeting*, pp. 11–15.
- Aarts, L., Van Schagen, I., 2006. Driving speed and the risk of road crashes: A review. *Accident Analysis & Prevention* 38, 215–224.
- Albalade, D., 2011. Shifting death to their alternatives the case of toll motorways. *Journal of Transport Economics and Policy* 45, 457–479.
- Amin, M.S.R., Zareie, A., Amador-Jiménez, L.E., 2014. Climate change modeling and the weather-related road accidents in canada. *Transportation research part D: transport and environment* 32, 171–183.
- Angrist, J.D., Imbens, G.W., Rubin, D.B., 1996. Identification of causal effects using instrumental variables. *Journal of the American statistical Association* 91, 444–455.
- Autostrade per l'Italia, 2006. Balance sheets and financial statements (translated). Retrieved 20 February 2018 from <http://www.atlantia.it/it/pdf/Bilancio2005ITA.pdf>.
- Autostrade per l'Italia, 2011. Balance sheets and financial statements (translated). Retrieved 20 February 2018 from <http://www.atlantia.it/it/pdf/FY2010ITA.pdf>.
- Autostrade per l'Italia, 2012. Balance sheets and financial statements (translated). Retrieved 20 February 2018 from <http://www.atlantia.it/pdf/FY2011ITA-1.pdf>.
- Autostrade per l'Italia, 2016. Section control in italy (translated). Retrieved 22 December 2017 from <http://www.autostrade.it/en/tecnologia-sicurezza/sicurezza/tutor>.
- Ayyildiz, K., Cavallaro, F., Nocera, S., Willenbrock, R., 2017. Reducing fuel consumption and carbon emissions through eco-drive training. *Transportation Research Part F: Traffic Psychology and Behaviour* 46, 96–110.
- Bank of Italy, 2015. Investigation on motorway concessions (translated). Retrieved 12 March 2018 from <https://www.bancaditalia.it/pubblicazioni/interventi-vari/int-var-2015/sestito-audizione-110615.pdf>.
- Bardal, K.G., Jørgensen, F., 2017. Valuing the risk and social costs of road traffic accidents—seasonal variation and the significance of delay costs. *Transport Policy* 57, 10–19.

- Cascetta, E., Punzo, V., 2011. Impact on vehicle speeds and pollutant emissions of an automated section speed enforcement system on the Naples urban motorway, in: *Transportation Research Board 2011 Annual Meeting*, pp. 1–27.
- Cascetta, E., Punzo, V., Montanino, M., 2011. Empirical analysis of effects of automated section speed enforcement system on traffic flow at freeway bottlenecks. *Transportation Research Record: Journal of the Transportation Research Board* , 83–93.
- Cascetta, E., Sorvillo, R., Punzo, V., 2010. Impact on vehicle speeds and pollutant emissions of a fully automated section speed control scheme on the Naples urban motorway, in: *Transportation Research Board 89th Annual Meeting*, pp. 1–18.
- Champness, P.G., Sheehan, M.C., Folkman, L.M., 2005. Time and distance halo effects of an overtly deployed mobile speed camera. Paper presented at the Australasian Road Safety Research, Policing and Education Conference, Wellington, New Zealand.
- Cirillo, J.A., 1968. Interstate system accident research, study II, interim report II. *Public Roads* 35, 71–76.
- Collins, G., McConnell, D., 2008. Speed harmonisation with average speed enforcement. *Traffic Engineering & Control* 49.
- Dadashova, B., Arenas, B.R., Mira, J.M., Aparicio, F.I., 2014. Explanatory and prediction power of two macro models. an application to van-involved accidents in Spain. *Transport Policy* 32, 203–217.
- De Pauw, E., Daniels, S., Brijs, T., Hermans, E., Wets, G., 2014a. Automated section speed control on motorways: An evaluation of the effect on driving speed. *Accident Analysis & Prevention* 73, 313–322.
- De Pauw, E., Daniels, S., Brijs, T., Hermans, E., Wets, G., 2014b. Behavioural effects of fixed speed cameras on motorways: Overall improved speed compliance or kangaroo jumps? *Accident Analysis & Prevention* 73, 132–140.
- Elvik, R., 2006. Laws of accident causation. *Accident Analysis & Prevention* 38, 742–747.
- Falsi, C., 2009. Safety tutor: Nationwide effective speed enforcement infrastructure, in: *16th ITS World Congress and Exhibition on Intelligent Transport Systems and Services*, pp. 1–7.
- Fleiter, J.J., Lennon, A., Watson, B., 2010. How do other people influence your driving speed? exploring the who and the how of social influences on speeding from a qualitative perspective. *Transportation Research Part F: Traffic Psychology and Behaviour* 13, 49–62.

- Galata, A., 2007. Road safety prevention: First 12 months safety tutor results (translated). Retrieved 15 December 2017 from https://dati.asaps.it/notizie/notizie_2007/10_notizie_07/image/tutor_12_mesi.pdf.
- Gazzetta Ufficiale, 2003. Decreto legge 27 giugno 2003, n. 151, coordinato con la legge di conversione 1 agosto 2003, n. 214 , modifiche ed integrazioni al codice della strada. Supplemento ordinario n.133 alla Gazzetta Ufficiale 186.
- Gazzetta Ufficiale, 2007. Decreto legge 3 agosto 2007, n. 117, recante disposizioni urgenti modificative del codice della strada per incrementare i livelli di sicurezza nella circolazione. Gazzetta Ufficiale Serie Generale 195.
- Gazzetta Ufficiale, 2010. Decreto legge 29 luglio 2010, n. 120, disposizioni in materia di sicurezza stradale. Supplemento ordinario n.171 alla Gazzetta Ufficiale 175.
- Goldenbeld, C., van Schagen, I., 2005. The effects of speed enforcement with mobile radar on speed and accidents: An evaluation study on rural roads in the dutch province friesland. *Accident Analysis & Prevention* 37, 1135–1144.
- Hauer, E., 2009. Speed and safety. *Transportation Research Record: Journal of the Transportation Research Board* , 10–17.
- Imbens, G.W., Angrist, J.D., 1994. Identification and estimation of local average treatment effects. *Econometrica* 62, 467–475.
- International Transport Forum, 2018. Speed and crash risk. Retrieved 29 March 2018 from <https://www.itf-oecd.org/sites/default/files/docs/speed-crash-risk.pdf>.
- Jones, A.P., Sauerzapf, V., Haynes, R., 2008. The effects of mobile speed camera introduction on road traffic crashes and casualties in a rural county of england. *Journal of Safety Research* 39, 101–110.
- Loeb, P.D., Talley, W.K., Zlatoper, T.J., 1994. Causes and deterrents of transportation accidents: An analysis by mode. Quorum Books, Westport, CT.
- Mannering, F.L., Bhat, C.R., 2014. Analytic methods in accident research: Methodological frontier and future directions. *Analytic Methods in Accident Research* 1, 1–22.
- Mannering, F.L., Shankar, V., Bhat, C.R., 2016. Unobserved heterogeneity and the statistical analysis of highway accident data. *Analytic Methods in Accident Research* 11, 1–16.
- Montella, A., Imbriani, L.L., 2015. Safety performance functions incorporating design consistency variables. *Accident Analysis & Prevention* 74, 133–144.

- Montella, A., Imbriani, L.L., Marzano, V., Mauriello, F., 2015a. Effects on speed and safety of point-to-point speed enforcement systems: Evaluation on the urban motorway A56 tangenziale di napoli. *Accident Analysis & Prevention* 75, 164–178.
- Montella, A., Persaud, B., D’Apuzzo, M., Imbriani, L., 2012. Safety evaluation of automated section speed enforcement system. *Transportation Research Record: Journal of the Transportation Research Board* , 16–25.
- Montella, A., Punzo, V., Chiaradonna, S., Mauriello, F., Montanino, M., 2015b. Point-to-point speed enforcement systems: Speed limits design criteria and analysis of drivers’ compliance. *Transportation Research Part C: Emerging Technologies* 53, 1–18.
- Montella, A., Punzo, V., Montanino, M., 2011. Design and evaluation of speed limits for an automated section speed control system, in: 90th Annual Meeting of the Transportation Research Board, pp. 1–17.
- Neuman, T.R., 2003. Guidance for implementation of the AASHTO strategic highway safety plan. volume 2. *Transportation Research Board*.
- Percoco, M., 2016. The impact of road pricing on accidents: a note on milan. *Letters in Spatial and Resource Sciences* 9, 343–352.
- Ragazzi, G., 2006. Are highways best run by concessions? The Italian experience. *World Transport Policy & Practice* 12, 22–33.
- Reed, W.R., 2015. On the practice of lagging variables to avoid simultaneity. *Oxford Bulletin of Economics and Statistics* 77, 897–905.
- Soole, D.W., Fleiter, J., Watson, B., 2012. Point-to-point speed enforcement. Technical Report. Austroads Report AP-R415-12, Sydney.
- Soole, D.W., Watson, B.C., Fleiter, J.J., 2013. Effects of average speed enforcement on speed compliance and crashes: A review of the literature. *Accident Analysis & Prevention* 54, 46–56.
- Stefan, C., Winkelbauer, M., 2006. Section control–automatic speed enforcement in the Kaisermühlen tunnel (vienna, a22 motorway). *Kuratorium für Verkehrssicherheit*, Wien .
- Transportation Research Board, 1998. *Managing speed: review of current practice for setting and enforcing speed limits*. National Academy Press, Washington, DC.
- Veisten, K., Stefan, C., Winkelbauer, M., 2013. Standing in cost-benefit analysis of road safety measures: A case of speed enforcement vs. speed change. *Transport policy* 30, 269–274.
- Wegman, F., Goldenbeld, C., 2006. *Speed management: enforcement and new technologies*. Technical Report. Citeseer.

- Welki, A.M., Zlatoper, T.J., 2007. The impact of highway safety regulation enforcement activities on motor vehicle fatalities. *Transportation Research Part E: Logistics and Transportation Review* 43, 208–217.
- Welki, A.M., Zlatoper, T.J., 2009. How highway safety regulations and enforcement activities affect subcategories of motor vehicle fatalities. *Transportation Research Part E: Logistics and Transportation Review* 45, 1030–1038.
- Yannis, G., Louca, G., Vardaki, S., Kanellaidis, G., 2013. Why do drivers exceed speed limits. *European Transport Research Review* 5, 165–177.

Appendix

Table A: Variable definitions and sources

Variable	Variable definition	Source
<i>ACCIDENTS</i>	Annual vehicle accidents occurred within the motorway property that caused injuries or death to people	AISCAT ¹
<i>INJURED</i>	Annual people injured by vehicle accidents	AISCAT ¹
<i>FATALITIES</i>	Annual deaths occurring within 30 days of the vehicle accident	AISCAT ¹
<i>LIGHT</i>	Annual accidents involving only motorcycles and two-axle vehicles with the front axle below 1.30 metres from ground	AISCAT ¹
<i>HEAVY</i>	Annual accidents involving only two-axle vehicles with the front axle above 1.30 metres from ground and vehicles with three or more axles	AISCAT ¹
<i>DAILY_TRAFFIC</i>	Annual average daily number of vehicles of all types transited along a motorway sector, regardless of the kilometres travelled	AISCAT ¹
<i>DAILY_TRAFFIC_LIGHT</i>	Annual average daily number of light vehicles of all types transited along a motorway sector, regardless of the kilometres travelled	AISCAT ¹
<i>DAILY_TRAFFIC_HEAVY</i>	Annual average daily number of heavy vehicles of all types transited along a motorway sector, regardless of the kilometres travelled	AISCAT ¹
<i>HIGHWAY_LENGTH</i>	Annual length (in kilometres) of each motorway sector	AISCAT ¹
<i>TUTOR_LENGTH</i>	Annual length (in kilometres) of each motorway sector covered by Safety Tutor sites	ASPI ²
<i>COVERAGE</i>	Annual ratio between <i>TUTOR_LENGTH</i> and <i>HIGHWAY_LENGTH</i>	Authors' calculation
<i>ALCOHOL_PC</i>	Annual per capita ethanol consumption (in litres) for all beverages	GHO ³
<i>VEHICLES_AGE</i>	Annual average age of circulating vehicle fleet (in years)	ISPR ⁴
<i>TECHNOLOGY</i>	Dummy variable equalling one in 2005-2015	Authors' calculation
<i>ASPLGROUP</i>	Dummy variable equalling one for those motorway sectors managed by Autostrade per l'Italia and its controlled concessionaires	Authors' calculation
<i>INSTRUMENT</i>	Dummy variable equalling the product between <i>TECHNOLOGY</i> and <i>ASPLGROUP</i>	Authors' calculation

Notes: [1] Associazione Italiana Società Concessionarie Autostrade e Trafori, [2] Autostrade per l'Italia, [3] Global Health Observatory, [4] Istituto superiore per la protezione e la ricerca ambientale.

Table B: Progressive deployment of Safety Tutor sites, 2005-2011. For each motorway sector, *Safety Tutor site* shows the exact entry and exit kilometre where cameras are installed, corresponding to the maximum *TUTOR_LENGTH* (between the two carriageways) reached in 2011. *TUTOR_LENGTH* shows the number of kilometres covered by Safety Tutor sites as of 31 December of each year

Motorway sector	Safety Tutor site	<i>TUTOR_LENGTH</i>								
		2005	2006	2007	2008	2009	2010	2011		
A1 Milano-Bologna	San Zenone al Lambro 12.1 - Bivio A1/A14 186.9	0.0	0.0	0.0	99.3	174.8	174.8	174.8	174.8	
A1 Firenze-Roma	Orte 489.9 - Roma 534.7	0.0	0.0	1.7	21.8	44.8	44.8	44.8	44.8	
A1 Roma-Napoli	Roma 534.7 - Caserta Nord 736.7	0.0	0.0	202.0	202.0	202.0	202.0	202.0	202.0	
A1 Collegamento Firenze-Roma-Napoli	San Cesareo 3.8 - Monteporzio Catone 11.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	
A3 Napoli-Salerno	Scafati 25.0 - Angri 29.8	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	
A3 Napoli-Salerno	Cava Dei Tirreni 42.8 - Salerno 51.7	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	
A4 Milano-Brescia	Agrate 146.9 - Brescia Ovest 217.0	70.1	70.1	70.1	70.1	70.1	70.1	70.1	70.1	
A4 Brescia-Padova	Brescia Est 225.9 - Somma Campagna 273.5	0.0	0.0	0.0	37.2	37.2	37.2	37.2	37.2	
A4 Venezia-Trieste	Venezia Est 20.8 - Bivio A4/A23 92.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	
A4 Venezia-Trieste	Palmanova 97.8 - Redipuglia 108.7	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	
A6 Torino-Savona	Carmagnola 14.4 - Marene 33.4	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	
A6 Torino-Savona	Millesimo 91.1 - Ceva 85.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	
A6 Torino-Savona	Altare 118.5 - Bivio A6/A10 122.6	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	
A7 Genova-Serravalle	Isola del Cantone 99.2 - Genova Bolzaneto 125.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	
A8 Milano-Varese/A9 Linate-Chiasso	Origgio Ovest 12.2 - Gallarate 29.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	
A13 Bologna-Padova	Arcoveglio 1.4 - Padova Zona Ind. 114.2	7.9	7.9	7.9	94.2	112.8	112.8	112.8	112.8	
A14 Bologna-Ancona	Biv.A14/Rac. Casalecchio 9.1 - Rimini Nord 118.4	29.2	29.6	29.6	95.1	109.3	109.3	109.3	109.3	
A14 Ancona-Pescara	Giulianova 327.0 - Bivio A14/A25 374.9	0.0	0.0	0.0	39.5	39.5	39.5	39.5	39.5	
A14 Pescara-Canosa	Bivio A14/A25 374.9 - Bivio A14/A16 600.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	
A14 Canosa-Bari-Taranto	Bivio A14/A16 605.5 - Bari Sud 682.0	0.0	201.8	201.8	205.3	205.3	205.3	205.3	205.3	
A23 Palmanova-Udine	Bivio A23/A4 3.2 - Udine Sud 16.6	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	
A23 Udine-Tarvisio	Udine Nord 25.2 - Ugovizza 104.5	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	
A24 Roma-Torano	Tivoli 14.5 - Carsoli 51.5	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	
A24 Torano-Teramo	Valle del Salto 74.6 - L'Aquila Ovest 108.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	
A25 Torano-Pescara	Avezzano 87.1 - Sulmona 137.9	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	
A26 Voltri-Alessandria	Bivio A26/A10 1.7 - Bivio A26/Predosa-Bettole 44.5	0.0	30.0	30.0	30.0	30.0	30.0	30.0	30.0	
A28 Portogruaro-Conegliano	Villotta 6.6 - Azzano-Decimo 15.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	
A30 Caserta-Nola-Salerno	Bivio A30/A1 1.3 - Castel San Giorgio 42.8	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	
A56 Tang.le di Napoli	Astroni 4.3 - Fuorigrotta 9.9	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	
A56 Tang.le di Napoli	Vomero 11.4 - Camaldoli 13.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	
A56 Tang.le di Napoli	Arenella 15.4 - Capodimonte 17.4	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	
Total		107.2	339.4	664.3	1028.0	1239.8	1450.9	1602.0	1602.0	

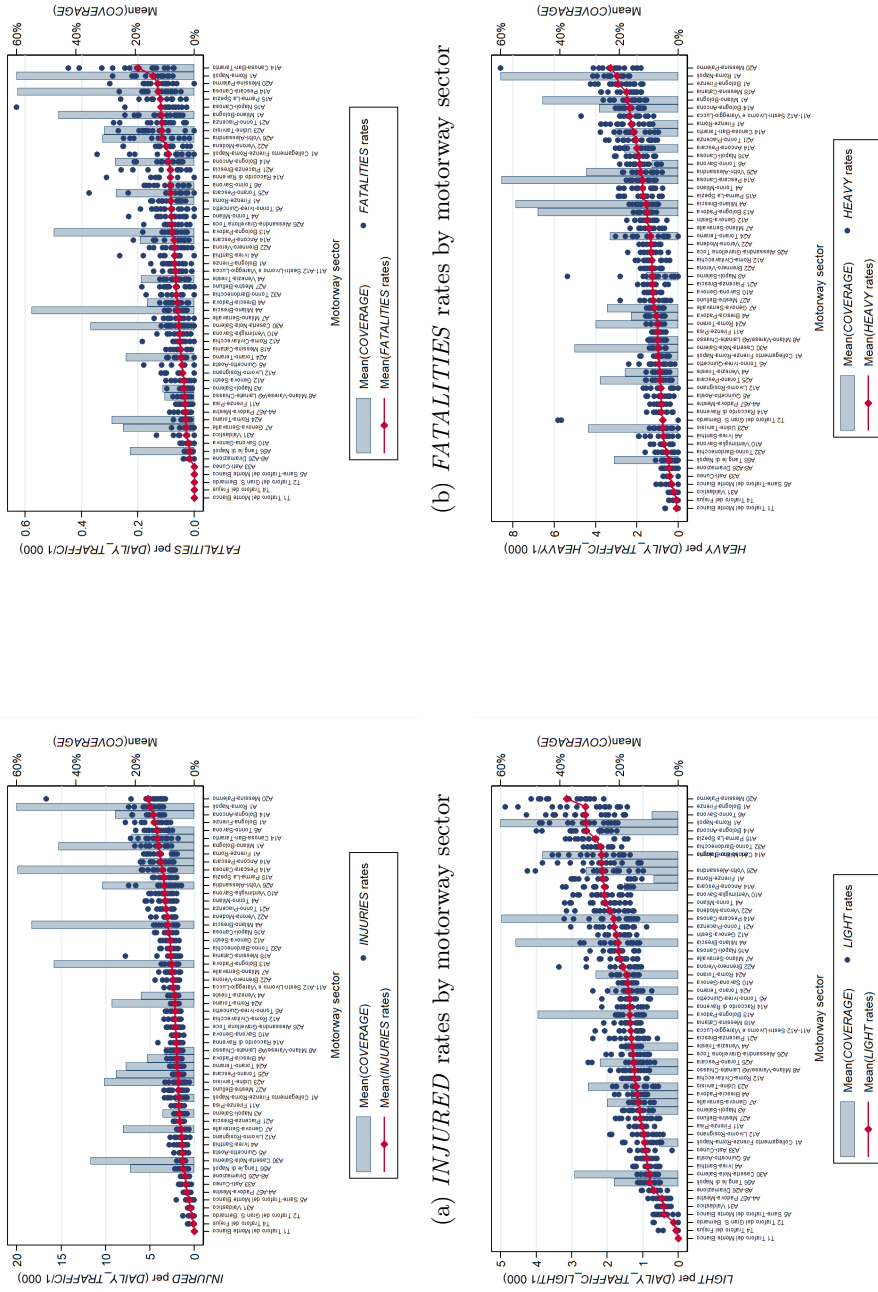
Notes: The other 33 motorway sectors free of Safety Tutor sites are T1 Traforo del Monte Bianco, T2 Traforo del Gran S. Bernardo, T4 Traforo del Frejus, A5 Sarre-Trafo del Monte Bianco, A32 Torino-Bardonecchia, A33 Asti-Cuneo, A5 Quincetto-Aosta, A5 Torino-Ivrea-Quincetto, A4 Ivrea-Santhià, A26 Alessandria-Gravellona Toce, A8-A26 Diramazzone, A7 Milano-Serravalle, A22 Brennero-Verona, A22 Verona-Modena, A31 Valdastico, A15 Parma-La Spezia, A14 Raccordo di Ravenna, A4 Torino-Milano, A4 Padova-Mestre, A27 Mestre-Belluno, A21 Torino-Piacenza, A21 Piacenza-Brescia, A10 Ventimiglia-Savona, A10 Savona-Genova, A12 Genova-Sestri, A12 Livorno-Rosignano, A11-A12 Sestri-Livorno e Viareggio-Lucca, A1 Bologna-Firenze, A11 Firenze-Pisa, A12 Roma-Civitavecchia, A16 Napoli-Canosa, A18 Messina-Catania, A20 Messina-Palermo.

Table C: 2001 and 2015 *HIGHWAY_LENGTH* per motorway sector.

Motorway sector	<i>HIGHWAY_LENGTH</i>		Motorway sector	<i>HIGHWAY_LENGTH</i>	
	2001	2015		2001	2015
T1 Traforo del Monte Bianco ¹	5.8	5.8	A12 Livorno-Rosignano ¹⁷	36.6	40.0
T2 Traforo del Gran S. Bernardo ²	12.8	12.8	A12 Roma-Civitavecchia ⁴	65.4	65.4
T4 Traforo del Frejus ³	6.8	6.8	A13 Bologna-Padova ⁴	127.3	127.3
A1 Milano-Bologna ⁴	192.1	192.1	A14 Bologna-Ancona ⁴	236.0	236.0
A1 Bologna-Firenze ⁴	91.1	91.1	A14 Raccordo di Ravenna ⁴	29.3	29.3
A1 Firenze-Roma ⁴	273.0	273.0	A14 Ancona-Pescara ⁴	133.8	133.8
A1 Roma-Napoli ⁴	202.0	202.0	A14 Pescara-Canosa ⁴	239.3	239.3
A1 Collegamento Firenze-Roma-Napoli ⁴	45.3	45.3	A14 Canosa-Bari-Taranto ⁴	143.0	143.0
A3 Napoli-Salerno ⁵	51.6	51.6	A15 Parma-La Spezia ¹⁸	101.0	101.0
A4 Torino-Milano ⁶	127.0	127.0	A16 Napoli-Canosa ⁴	172.3	172.3
A4 Ivrea-Santhià ⁷	23.6	23.6	A18 Messina-Catania ¹⁹	76.8	76.8
A4 Milano-Brescia ⁴	93.5	93.5	A20 Messina-Palermo ¹⁹	140.6	140.6
A4 Brescia-Padova ⁸	146.1	146.1	A21 Torino-Piacenza ⁶	164.9	164.9
A4-A57 Padova-Mestre ^{9,a}	23.3	74.1	A21 Piacenza-Brescia ²⁰	88.6	88.6
A4 Venezia-Trieste ^{10,b}	180.3	210.2	A22 Brennero-Verona ²¹	224.0	224.0
A5 Torino-Ivrea-Quincetto ⁷	51.2	51.2	A22 Verona-Modena ²¹	90.0	90.0
A5 Quincetto-Aosta ¹¹	59.5	59.5	A23 Udine-Tarvisio ⁴	101.2	101.2
A5 Sarre-Trafofo del Monte Bianco ¹²	27.0	32.4	A24 Roma-Torano ²²	79.5	79.5
A6 Torino-Savona ¹³	130.9	130.9	A24 Torano-Teramo ²²	87.0	87.0
A7 Genova-Serravalle ⁴	50.0	50.0	A25 Torano-Pescara ²²	114.9	114.9
A7 Milano-Serravalle ¹⁴	86.3	86.3	A26 Voltri-Alessandria ⁴	83.7	83.7
A8 Milano-Varese/A9 Lainate-Chiasso ⁴	77.7	77.7	A26 Alessandria-Gravellona Toce ⁴	161.2	161.2
A8-A26 Diramazione ⁴	24.0	24.0	A27 Mestre-Belluno ⁴	82.2	82.2
A10 Ventimiglia-Savona ¹⁵	113.3	113.3	A30 Caserta-Nola-Salerno ⁴	55.3	55.3
A10 Savona-Genova ⁴	45.5	45.5	A31 Valdastico ⁸	36.4	36.4
A11 Firenze-Pisa ⁴	81.7	81.7	A32 Torino-Bardonecchia ³	72.4	75.7
A11-A12 Sestri-Livorno e Viareggio-Lucca ¹⁶	154.9	154.9	A33 Asti-Cuneo ^{23,c}	39.4	55.7
A12 Genova-Sestri ⁴	48.7	48.7	A56 Tang.le di Napoli ²⁴	20.2	20.2

Notes: For each motorway sector, the related highway concession company is [1] Società Italiana per il Traforo del M. Bianco S.p.A., [2] Società Italiana per il Traforo del G.S. Bernardo S.p.A., [3] Società Italiana per il Traforo del Frejus S.p.A., [4] Autostrade per l'Italia S.p.A., [5] Autostrade Meridionali S.p.A., [6] Società Autostrada Torino-Alessandria-Piacenza S.p.A., [7] Autostrada Torino-Ivrea-Valle d'Aosta S.p.A., [8] Autostrada Brescia-Verona-Vicenza-Padova S.p.A., [9] Concessioni Autostradali Venete - C.A.V. S.p.A., [10] Autovie Venete S.p.A., [11] Società Autostrade Valdostane S.p.A., [12] Raccordo Autostradale Valle d'Aosta S.p.A., [13] Autostrada Torino-Savona S.p.A., [14] Milano Serravalle-Milano Tangenziali S.p.A., [15] Autostrada dei Fiori S.p.A., [16] Società Autostrada Ligure Toscana S.p.A., [17] Società Autostrada Tirrenica S.p.A., [18] Autocamionale della Cisa S.p.A., [19] Consorzio per le Autostrade Siciliane, [20] Autostrade Centro Padane S.p.A., [21] Autostrada del Brennero S.p.A., [22] Strada dei Parchi S.p.A., [23] Autostrada Asti-Cuneo S.p.A., [24] Tangenziale di Napoli S.p.A. [a] Until 2009 the Padova-Mestre sector was managed by Società Autostrade di Venezia e Padova S.p.A., [b] It includes also A23 Palmanova-Udine, A28 Portogruaro-Conegliano, A34 Villesse-Gorizia, and a sector of A57 Tangenziale di Mestre, [c] The Asti-Cuneo sector started operations in 2008.

Figure A: Heterogeneity of accident category rates across motorway sectors



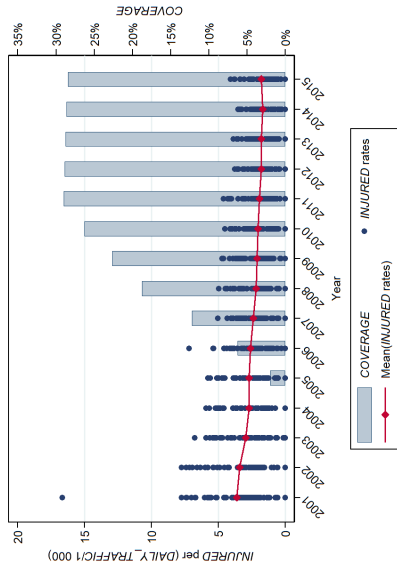
(a) INJURED rates by motorway sector

(b) FATALITIES rates by motorway sector

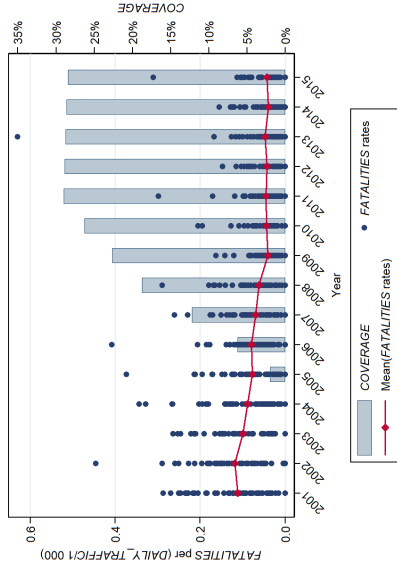
(c) LIGHT rates by motorway sector

(d) HEAVY rates by motorway sector

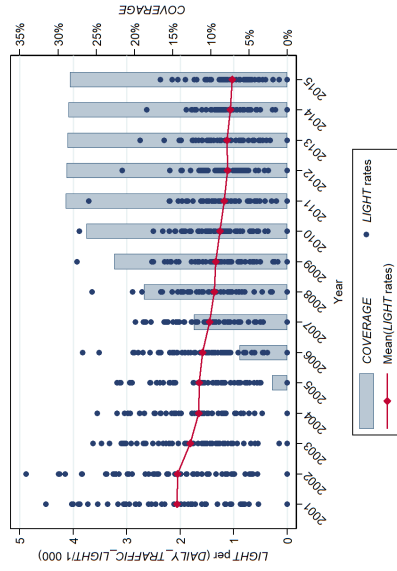
Figure B: Heterogeneity of accident category rates across years, 2001-2015



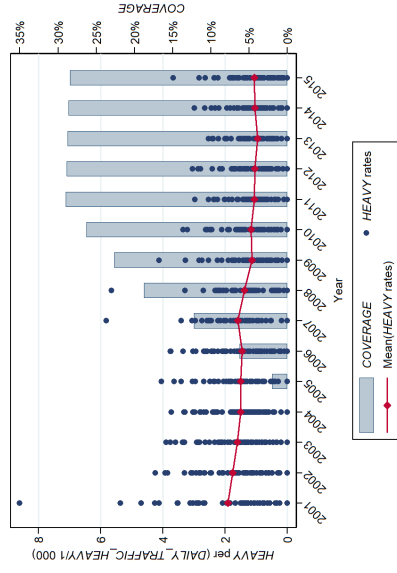
(a) *INJURED* rates by year



(b) *FATALITIES* rates by year



(c) *LIGHT* rates by year



(d) *HEAVY* rates by year