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On the impact of average speed enforcement systems in reducing highway accidents: Evidence from the Italian Safety Tutor

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ABSTRACT

At the end of 2005, *Autostrade per l'Italia* (*ASPI*) 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. The aim of this study was to empirically test the extent to which Safety Tutor led to a reduction in both total and fatal accidents on Italian highways during the period of 2001–2017. To do so, we carried out a generalized difference-in-differences estimation using a unique panel dataset that exploits the heterogeneous accident data within all tolled motorway sectors in a quasi-experimental setting. To deal with the potential endogeneity of the non-random placement of Safety Tutor sites, we utilized an instrumental variable strategy by using the network of motorway sectors managed by *ASPI* and its controlled concessionaires from 2005 onwards (i.e., when the technology was available) as an instrument to predict Safety Tutor adoption. We found that a 10% increase in Safety Tutor coverage led to an average reduction in total accidents of 3.9%, whereas there is no evidence of a significant causal effect of Safety Tutor in reducing fatal accidents.

1. Introduction

Speeding has been recognized as one of the major causes of road accidents, and the relationship between speed and crash risk has been extensively investigated (Aarts and Van Schagen, 2006; Hauer, 2009; Yannis et al., 2013). 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 systems.

Several studies have confirmed the positive effect of fixed and mobile speed cameras on vehicle accident reduction on both rural roads and highways (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 been demonstrated to increase the risk of an accident because sudden braking may disrupt homogenized traffic flow and reduce headway distances between vehicles (Cirillo, 1968; Lave, 1985). Hence, since there is evidence that many drivers regard speeding as normal and socially acceptable (Fleiter et al., 2010; Veisten et al., 2013; Tscharaktschiew, 2016), 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 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 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, an average speed enforcement system, named Safety Tutor, was developed by the major highway concession company, *Autostrade per l'Italia* (*ASPI*), and the Italian traffic police in 2004 to improve safety on high-speed roads. Starting from 23 December 2005, it was progressively deployed along the Italian tolled motorway network, and by 2017, more than 3100 km (considering both carriageways) were monitored by the system through 333 sites. However, although promoters of Safety Tutor credited it with a sharp decrease in accident and mortality rates, after more than 10 years of operation, relatively little is known about the efficiency of this system. Over this period,

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previous studies have focused on its impact in preventing highway accidents only on specific motorway sectors with unique road and congestion features; furthermore, they have considered only total accidents as the main outcome of interest.

Thus, we seek to fill these gaps by empirically testing in a quasi-experimental setting the extent to which Safety Tutor led to a reduction in both total and fatal accidents on Italian highways during the period of 2001–2017. The novelties of this article lie, first, in its application of a counterfactual analysis using a unique panel dataset that allows us to control for many unobservable confounding factors and to exploit heterogeneous accident data within all tolled motorway sectors[1] through a generalized difference-in-differences estimation; second, in its adoption of an instrumental variable strategy to address potential endogeneity issues.

Indeed, the decisions on where to locate the Safety Tutor sites were likely driven by the outcomes of interest, as they may have been first activated along those motorway sectors characterized by higher accident and mortality rates (Falsi, 2009). To deal with this issue, a recent strand of literature has proposed the use of historical instruments to identify the parameter (Baum-Snow, 2007; Duranton and Turner, 2012; Percoco, 2015). Similarly, by exploiting the fact that Italy adopted a concession model regime[2] to manage its highway network, we utilize as an instrument the network of motorway sectors managed by *ASPI* and its controlled concessionaires (named *ASPI_Group*) that had been established approximately 50 years before the development of this average speed enforcement system. In particular, we use a dummy variable indicating whether a motorway sector has been a member of *ASPI_Group* from 2005 onwards (i.e., when the technology was available) as an instrument to predict Safety Tutor adoption and identify its impact in reducing highway accidents. In Section 3.2, we will discuss extensively the rationale behind the choice of the instrument as well as possible threats to its validity.

Our findings reveal that a 10% increase in Safety Tutor coverage led to an average reduction in total accidents of 3.9%, whereas there is no evidence of a significant causal effect of Safety Tutor in reducing fatal accidents. Possible reasons for this are that a general amelioration of vehicle safety systems and motorway paving, as well as a plausible improvement in the quality of health care, rather than the benefits arising from the adoption of Safety Tutor, had the greatest influence in preventing fatal accidents. Our evidence is corroborated by a set of robustness checks that deviate from baseline models, including an investigation of the timing of the effect and placebo regressions.

Finally, considering that 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*), *ASPI* was forced to turn off all the devices in anticipation of their replacement with a similar technology. Therefore, because accident prevention is a major goal of transport institutions and road agencies (as foreseen by the *"Zero Road Deaths and Serious Injuries"* programme (International Transport Forum, 2016)), our study ultimately seeks to provide further evidence that highway concession companies can use to assess the utility of adopting average speed enforcement systems to improve drivers' safety.

The article is organized as follows. In Section 2, we briefly describe the Safety Tutor technology and we review the literature. In Section 3, we explain our empirical strategies, while in Section 4, we present data and descriptive statistics. In Section 5, we present our results, followed, in Section 6, by our robustness checks. Section 7 discusses our findings, and Section 8 concludes.

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 flashes are mounted on the gantry, one for each lane. Whenever a 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 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[3] (Montella et al., 2012, 2015b).

A few international reviews of all available studies evaluating the effectiveness of average speed enforcement systems elucidate their positive contribution to a variety of road safety and traffic-related outcomes (Soole et al., 2013; International Transport Forum, 2018), such as total accident rates, speeding offence rates, traffic flow, and vehicle emissions (Stefan and Winkelbauer, 2006; Collins and McConnell, 2008; De Pauw et al., 2014a).

In the Italian context, a first naïve analysis was provided by *ASPI* itself, which accredited the system; this analysis found a sharp decrease in both average speed (−15%) and peak speed (−25%), with consequent improvements in the injury rate (−27%) and in the mortality rate (−50%), on Safety Tutor sections after only 1 year of operation (Galata, 2007). However, it should be noted that statistical significance testing and the control of confounding factors were absent from these evaluations.

A more robust analysis was provided by Cascetta and Punzo (2011) that showed that Safety Tutor adoption on the *A56 Tangenziale di Napoli* motorway sector led to an average speed reduction from 80.8 km/h to 71.7 km/h by comparing vehicle data from 1-week prior to 1-week after its activation on February 9, 2009. Furthermore, by observing trends between 8 months pre- and 8 months post-activation, they estimated a total accident reduction of 38.8%. Consistent with the previous study, Montella et al. (2015b) estimated 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 of analysis allowed them to observe a significant increase in non-compliance behaviour towards speed limits over time with respect to the results obtained in the period immediately after the system 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* sites have been estimated by Cascetta et al. (2011) and Montella et al. (2015a), whose results showed a reduction in fuel consumption of 387.9 tonnes per year, an improvement in peak period traffic flow through reduced bottlenecking, and a reduction in the standard deviation of average speed from 16.5 km/h

[1] We refer to those motorway sectors managed by 25 private, public, or mixed capital highway concession companies for a total of 6003 km, which represent nearly the 87% of the national network (AISCAT, 2017). For the remaining 939 km of toll-free motorway sectors managed by ANAS (a government-owned company under the control of the Ministry of Infrastructure and Transport), data are not available.

[2] It is a regime where the public authority ensures specific rights to one or more established companies (concessionaires) to construct, overhaul, maintain and operate an infrastructure that, in most cases, is tolled.

[3] By law, Safety Tutor fines are valid if the presence of the device is indicated through special signs on site. Hence, the Italian traffic police is not tasked with speed control but rather with enforcing general traffic laws, regulating traffic, providing safety escort services, and verbalizing accidents throughout the motorway network (Gazzetta Ufficiale, 2010).

to 12.2 km/h. An additional contribution was provided by Montella et al. (2012) that estimated a total accident reduction of 31.2%, with a decreasing pattern over time, by collecting data in an 80 km Safety Tutor section of the *A1 Milano–Napoli* motorway sector (activated on July 1, 2007) over multiple periods between 2001 and 2009.

However, it should be noted that the above studies are heavily influenced by route-specific characteristics, were conducted over relatively short time spans, and focused mainly on total accident reduction. Bearing in mind the difficulty in discerning the impact of Safety Tutor in preventing highway accidents from many other unobservable confounding factors, the present study seeks to overcome these limitations by exploiting heterogeneous accident data within a sizeable set of different motorway sectors, by taking into consideration a longer time-span of analysis, and by including fatal accidents as an additional outcome of interest.

3. Empirical strategies

3.1. Generalized difference-in-differences

To empirically test the impact of Safety Tutor in reducing total and fatal accidents on Italian highways, we collected data for 50 tolled motorway sectors over the period of 2001–2017. Then, we estimated the following semi-log panel equation:

$$\log\left(Y_{ijt}\right) = \beta_0 + \beta_1 Coverage_{it-1} + \theta_k X'_{it} + \alpha_i + \lambda_j + \delta_t + \varepsilon_{ijt} \tag{1}$$

where $\log\left(Y_{ijt}\right)$ is the log of the total number of either $Total\_Accidents$ [4] or $Fatal\_Accidents$[5] that occurred on a motorway sector *i*, managed by concessionaire *j*, observed in year *t*. Our treatment variable is the continuous variable $Coverage_{it-1}$, which takes values between 0 and 1 and is computed as the ratio between the total km covered by Safety Tutor sites[6] and the total length of a motorway sector *i* in year *t*. Since Safety Tutor installations took place in different periods during the course of each year, we lagged the variable by one period to ensure our dependent variables were regressed with respect to a full annual adoption of the system.

X'_{it} is a vector of control variables that includes, first, the total number (in millions) of vehicles of all types ($Vehicles$) transited along a motorway sector *i* in year *t* to control for traffic-related factors; second, a dummy variable ($Congestion$) that takes the value of 1 whether the total number of vehicles transited is at least three times the number of theoretical vehicles[7] that used a motorway sector *i* in year *t* to control for congestion-related factors; and third, the number of interventions ($Interventions$) performed by the road assistance personnel on a motorway sector *i* in year *t* due to any type of vehicle problem (e.g., engine, fuel, brake or tyre problems), weighted by the total km travelled by vehicles, as a proxy of the modernity of vehicles.

However, a substantial body of research has shown that highway accidents are complex events that involve many other factors (Elvik, 2006), such as complex interactions between vehicles (Van Ommeren et al., 2013; Dadashova et al., 2014; Roesel, 2017), environmental conditions (Amin et al., 2014; Bardal and Jørgensen, 2017), roadway characteristics (Lee and Mannering, 2002; Adler et al., 2013), road management (Albalate, 2011; Percoco, 2016), economic conditions (Kopits and Cropper, 2005), and government regulations (Welki and Zlatoper, 2009; Castillo-Manzano and Castro-Nuño, 2012; De Paola et al., 2013).

Thus, we included motorway sector fixed effects (α_i) to control for time-invariant motorway sector unobserved heterogeneity potentially correlated with highway accidents (Mannering et al., 2016), such as the morphological and atmospheric characteristics of the territory (including the consequent speed limits), the different driving behaviours among areas, the different number of lanes and interconnections among motorway sectors, and the presence of additional speed management programmes (e.g., fixed speed cameras). Furthermore, we included concessionaire fixed effects[8] (λ_j) to capture any time-invariant component of road management factors that might affect highway accidents through differences in motorway paving, roadside features, and maintenance programmes. In addition, we included year dummies (δ_t) to control for time-specific factors that can influence accident rates, such as the global economic crisis (which overlaps with our period of analysis), the technological development of vehicle safety systems, and additional government regulations that have been introduced to improve drivers' safety.[9] Finally, ε_{ijt} represents heteroskedasticity- and autocorrelation-consistent standard errors clustered at the highway level because some motorway sectors belong to the same highway.

3.2. Instrumental variable

As previously introduced, the location of Safety Tutor sites is potentially endogenous with respect to highway accidents, so that our parameter of interest, β_1, might be biased. The reason for this phenomenon is that the system might have been first activated along those motorway sectors characterized by higher accident and mortality rates, so that a positive reverse causality could bias the econometric estimation. Since the practice of lagging the endogenous variable does not solve this identification issue (Reed, 2015), we utilized an instrumental variable (IV) strategy by exploiting the membership of certain motorway sectors in *ASPI_Group* from 2005 onwards (i.e., when the technology was available) as an instrument to predict Safety Tutor adoption.

The rationale for this approach is straightforward: *ASPI*, together with the Italian traffic police, developed the Safety Tutor technology in 2004; therefore, it is likely that the system was first installed on those motorway sectors managed directly by the company itself or by its controlled concessionaires[10].

Importantly, the IV estimation relies on two main conditions: first, a strong first stage relationship among the membership of certain motorway sectors in *ASPI_Group* from 2005 onwards and Safety Tutor

[4] We refer to the total number (plus 1) of vehicle accidents occurring on the motorway property that caused injuries or death to people.

[5] We refer to the total number (plus 1) of vehicle accidents occurring on the motorway property that caused at least one death within 30 days of the vehicle accident.

[6] It should be noted that since data concerning the total km covered by Safety Tutor sites are divided between the two carriageways while data concerning highway accidents are aggregated for the two carriageways, we considered a motorway km to be treated by the system if it was covered in at least one of the two carriageways.

[7] We refer to the number of vehicles theoretically needed to cover the total km travelled on a motorway sector *i* in year *t* by transiting along the entire motorway sector. This value is computed as the ratio between the total km travelled by vehicles and the total motorway sector length.

[8] Notably, most of the motorway sectors were managed by the same concessionaire during the period of analysis; hence, the majority of concessionaire dummies are omitted due to collinearity with motorway sector fixed effects.

[9] We refer to three government regulations: 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; and, third, the introduction in 2010 of the obligation that vehicles travelling on highways be equipped with winter tyres or keep snow chains on board during winter months (Gazzetta Ufficiale, 2010).

[10] *ASPI* controlled the following highway concession companies: *Tangenziale di Napoli* (100%), *Autostrada Torino–Savona* (99.9%), *Società Autostrada Tirrenica* (93.7%), *Strada dei Parchi* (60%), *Autostrade Meridionali* (58.9%), and *Società Italiana per il Traforo del Monte Bianco* (51%), which in turn controlled 58% of *Raccordo Autostradale Valle d'Aosta* (Atlantia, 2006). For the sake of clarity, from 2012 onwards, *Autostrada Torino–Savona* and *Strada dei Parchi* were no longer members of *ASPI_Group* (Atlantia, 2013). However, given that these concessionaires adopted the Safety Tutor technology before that year, we have considered their motorway sectors to remain members of *ASPI_Group* because they were eligible for new Safety Tutor installations.

adoption; second, the acceptance of the identifying restriction that the instrument is as good as randomly assigned and do not affect highway accidents through channels other than Safety Tutor adoption, conditional on the control variables.

With respect to the relevance condition, the map in Fig. 1 highlights the motorway sectors that are managed by *ASPI_Group*, while the map in Fig. 2 highlights the motorway sectors where at least one Safety Tutor site was installed within the period of analysis. It is clear that being managed by this group of concessionaires was a major determinant for Safety Tutor adoption, as reported by our large first stage F-statistic in Section 5. Indeed, in 2017, 91% of Safety Tutor sites (1481.2 out of 1632.9 km) were installed within *ASPI_Group* (see Appendix Table A for further details).

With respect to the exclusion restriction, if unobserved characteristics are correlated with both our instrument and the outcomes of interest, then it could be violated. A possible problem with the proposed instrument is that concessionaires that manage motorway sectors within *ASPI_Group* might affect highway accidents through differences in motorway paving, roadside features, and maintenance programmes. To control for these potential confounding factors, we captured their time-invariant differences with the full set of concessionaire fixed effects (λ_j).

Moreover, as extensively reported in the road safety literature, accidents depend mainly on speed and traffic volume (Aarts and Van Schagen, 2006; Hauer, 2009). Considering that speed limits are exogenously enforced by the traffic police and that variables capturing traffic (*Vehicles* and *Congestion*) are included as controls in our specification, there is little left that concessionaires can do on their own to prevent accidents (Ragazzi, 2006). Therefore, even though the exclusion restriction cannot be tested explicitly, the previous evidence increases its plausibility.

In addition, the decision to assign the management of a motorway sector to a particular concessionaire occurred mainly between the 1960s and 1970s (Maggi, 2009), i.e., approximately 50 years before the idea of developing an average speed enforcement system to improve drivers' safety. During those years, *ASPI* was a subsidiary of the government-owned holding group IRI,[11] so that it was commissioned to rebuild and extend road connections after the Second World War. By the end of the 1970s, 95% of the *ASPI_Group* network was already constructed and the Italian highway network reached 5900 km. Since that date, the network's length has barely increased (Ragazzi and Rothengatter, 2005).

Therefore, by exploiting this quasi-random assignment, we can assume the membership of certain motorway sectors in *ASPI_Group* as independent of the volume of highway accidents occurring during the period of analysis. In other words, the conditional independence assumption seems to be valid: our instrument works like a long lag of our endogenous variable, and as such, it can be considered as exogenous, conditional on the control variables.

Finally, Safety Tutor exposure is not homogeneous across motorway sectors, as the percentage of km covered by the system varies across sectors and years (see Appendix Table B for further details). Thus, to identify the parameter, our instrument must also satisfy the monotonicity assumption (Angrist et al., 1996). That is, if a particular motorway sector becomes a member of *ASPI_Group* and decides to adopt the Safety Tutor technology, then this change must not decrease the *Coverage* of any other motorway sector.

Considering that in our context this assumption is satisfied, our IV estimator measures a weighted local average treatment effect (Imbens and Angrist, 1994) and should be considered as the impact of Safety Tutor in reducing highway accidents within the set of compliers, i.e., the motorway sectors that decided to adopt the Safety Tutor technology because they were already members of *ASPI_Group*. Hence, our instrument is a dummy variable given by the following interaction:

$$Instrument_{it} = ASPI\_Group_i \times Post_t \tag{2}$$

where $ASPI\_Group_i$ is a time-invariant[12] dummy variable that takes the value of 1 for motorway sectors managed by *ASPI* and its controlled concessionaires and 0 for all other motorway sectors, while $Post_t$ is another dummy variable that takes the value of 1 from the year 2005 onwards (i.e., when the technology was available) and 0 for all other periods. In so doing, $Instrument_{it}$ is a time-variant dummy variable that in 2005 switches from a value of 0 to a value of 1 for those motorway sectors managed by *ASPI_Group*. Then, our IV estimation corresponds to the following first and second stages:

$$\begin{aligned} Coverage_{it-1} = \gamma_0 + \gamma_1 Instrument_{it-1} \\ + \psi_k X'_{it} + \zeta_i + \omega_j + \varphi_t + \nu_{ijt} \end{aligned} \tag{3}$$

$$\begin{aligned} \log\left(Y_{ijt}\right) = \beta_0 + \beta_1 \widehat{Coverage}_{it-1} \\ + \theta_k X'_{it} + \alpha_i + \lambda_j + \delta_t + \varepsilon_{ijt} \end{aligned} \tag{4}$$

where $Instrument_{it-1}$ is the lagged value of the dummy variable obtained in Equation (2) used to predict our treatment variable ($\widehat{Coverage}_{it-1}$) in the second stage; X'_{it} is the same vector of control variables described in Equation (1); ζ_i, ω_j, and φ_t are motorway sector, concessionaire, and year fixed effects, respectively; while ν_{ijt} represents clustered standard errors.

4. Data and descriptive statistics

For our analysis, *Coverage* data are based on Appendix Tables B and C, while all other data are taken from AISCAT[13] (*Associazione Italiana Società Concessionarie Autostrade e Trafori*, the concessionaires' association).

To rely on a strongly balanced panel dataset, we excluded from our dataset *A33 Asti–Cuneo*, *A35 Milano–Brescia*, *A58 Tangenziale esterna di Milano*, and *A36 Pedemontana Lombarda* motorway sectors because they started their operations at the end of our period of analysis (i.e., in 2008, 2014, 2015, and 2016, respectively), that is, after the activation of several Safety Tutor sections. Likewise, we also excluded *T1 Traforo del Monte Bianco*, *T2 Traforo del Gran S. Bernardo*, *T4 Traforo del Fréjus* Alpine tunnels and *A8/A26 Diramazione*, *A14 Racc. di Ravenna* motorway branches because their characteristics (e.g., speed limits, traffic, and length) are very different from those of the other motorway sectors.

Table 1 reports certain standard descriptive statistics. The simple averages across all motorway sectors of the log of our dependent variables suggest that one out of three accidents is fatal. The average *Coverage* is relatively small (14.1%), while its standard deviation is quite high, indicating that the average percentage of km covered by Safety Tutor sites is significantly higher for motorway sectors in the treatment group. The descriptive statistics of our control variables underline how heterogeneous the motorway sectors are. Finally, it is notable that 62.0% of the highway network has been managed by *ASPI* and its controlled concessionaires, while the Safety Tutor

11 IRI (*Istituto per la Ricostruzione Industriale*) was an Italian public holding company established in 1933 by the Fascist regime to rescue, restructure and finance banks and private companies that went bankrupt during the Great Depression. After the Second World War, IRI played a pivotal role in the Italian economic miracle of the 1950s and 1960s.

12 It is time-invariant because the motorway sectors managed by *ASPI* and its controlled concessionaires are the same throughout the period of analysis.

13 AISCAT data are taken from http://www.aiscat.it/pubblicazioni.htm?ck=1&nome=pubblicazioni&idl=4.

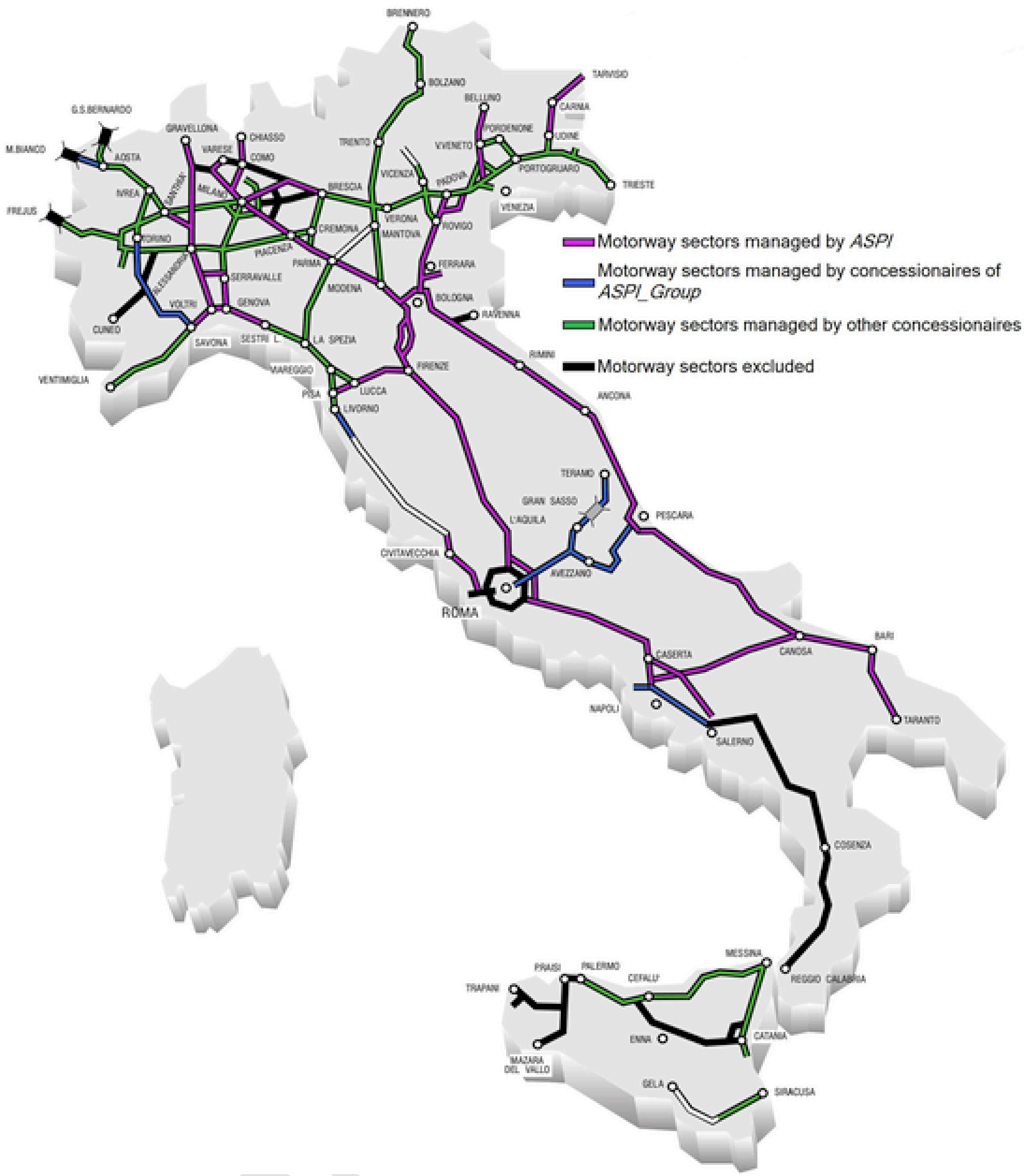

Fig. 1. Map of motorway sectors managed by *ASPI_Group* up to 2017*Source*: Authors' own elaboration based on AISCAT (2017)*Notes*: The excluded motorway sectors are the toll-free sectors managed by ANAS, as explained in Section 1, and the sectors described in Section 4.

technology was available for the last 13 out of 17 years. As a result, the average value of *Instrument* is equal to 0.474.[14]

For the 2001–2017 period, Fig. 3a and 3b plot the evolution of both accident rates (as measured as *Total_Accidents* and *Fatal_Accidents* over *Vehicles*) occurring on Italian highways vs. the expansion of *Coverage*, showing the temporal pattern of the treatment that we exploit. Interestingly, both variables experienced a continuous decrease from 2001 (i.e., well before the Safety Tutor deployment) until 2010, suggesting the importance of disentangling the possible Safety Tutor effect in reducing highway accidents from other confounding factors. Over the following years, which coincide with the maximum length of Safety Tutor sections in operation, the total accident rate has maintained a similar pattern as before, while the fatal accident rate has unexpectedly flattened (see Appendix Table D for the aggregate data by year).

Fig. 3c and 3d plot the evolution of the same accident rates occurring on two different types of motorway sector: the first includes those sectors that installed at least one Safety Tutor site within the period of analysis; the second includes those sectors that have never adopted the Safety Tutor technology. Although both accident rates tend to converge to the same values at the end of the period, it is clear that they are always higher in the treated groups throughout the period of analysis (particularly in Fig. 3c), supporting our endogeneity concerns that the decisions on where to locate the Safety Tutor sites were likely driven by the outcomes of interest. Nevertheless, what matters here is that trends prior to 2005 are basically parallel, which is the key

[14] It is equal to 0.706 (SD = 0.456) for those sectors that installed at least one Safety Tutor site within the period of analysis, while it is equal to 0.223 (SD = 0.417) for those sectors that have never adopted the Safety Tutor technology.

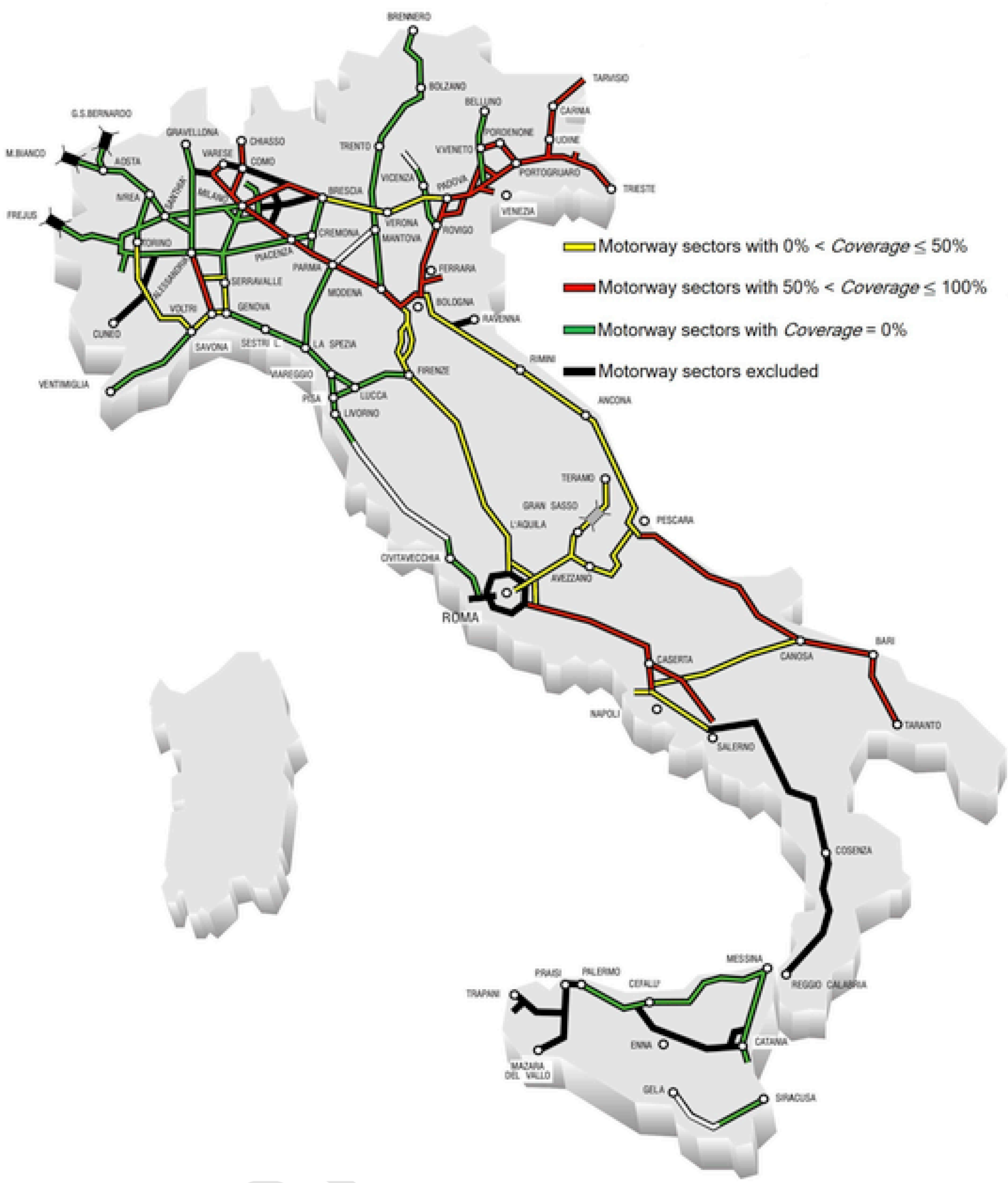

Fig. 2. Map of motorway sectors that adopted the Safety Tutor system up to 2017*Source*: Authors' own elaboration based on AISCAT (2017)*Notes*: The excluded motorway sectors are the toll-free sectors managed by ANAS, as explained in Section 1, and the sectors described in Section 4.

condition for the validity of our generalized difference-in-differences methodology (see Section 6.1 for an additional test).

5. Results

In Table 2, OLS estimates of Equation (1) are reported for both our outcomes of interest. Leaving to one side the naïve pooled estimations in columns 1 and 4, the regression results that include motorway sector and concessionaire fixed effects (columns 2 and 5) suggest that Safety Tutor coverage led to a significant reduction in both total and fatal accidents (−0.684 and −1.065 log points, respectively). However, once we control for time-specific factors (columns 3 and 6) that can influence accident rates (e.g., the global economic crisis and the additional government regulations), the coefficients associated with *Coverage* become substantially lower and less significant (−0.127 and −0.243 log points, respectively). In particular, the previous pattern holds for total accidents, as the estimated coefficient is still negative and significant at the 10% level, while it does not hold for fatal accidents, as year dummies capture the largest part of the variability. Thus, our first interpretation is that time plays a fundamental role in explaining the reduction in fatal accidents, as it captures either some sort of technological development of vehicle safety systems, as well as a general amelioration in motorway paving, which are among prominent factors in reducing the severity of vehicle collisions (see Section 7 for a more detailed discussion). For simplicity, we will further discuss only the estimates in columns 3 and 6 because they were obtained through the most complete specifications in relation to our data, as confirmed by a comparison of R^2 values and standard errors.

As for the relationship between our control variables and the dependent variables, the *Vehicles* and *Congestion* coefficients present the expected sign, given that it is reasonable for an increase in traffic volume to cause an increase in both total and fatal accidents. However, neither coefficients of the latter variable are statistically significant.

Table 1
Descriptive statistics.

	Mean	SD	Minimum	Maximum	Observations
log (*Total_Accidents*) [a]	4.682	1.051	0.000	6.824	850
log (*Fatal_Accidents*) [a]	1.575	0.880	0.000	3.850	850
Coverage [b]	0.141	0.266	0.000	1.000	850
Vehicles [c]	39.976	28.475	1.751	112.724	850
Congestion [d]	0.335	0.472	0.000	1.000	850
Interventions [e]	2.045	0.760	0.150	5.025	850
ASPI_Group [d]	0.620	0.486	0.000	1.000	850
Post [d]	0.765	0.424	0.000	1.000	850
Instrument [d]	0.474	0.500	0.000	1.000	850

Unit of measurement:
[a] Number of units in log.
[b] Proportion of total.
[c] Number of units in millions.
[d] Dummy variable.
[e] Weighted number of units. See Section 3 for the detailed description of each variable.
Source: Authors' own calculations based on AISCAT data

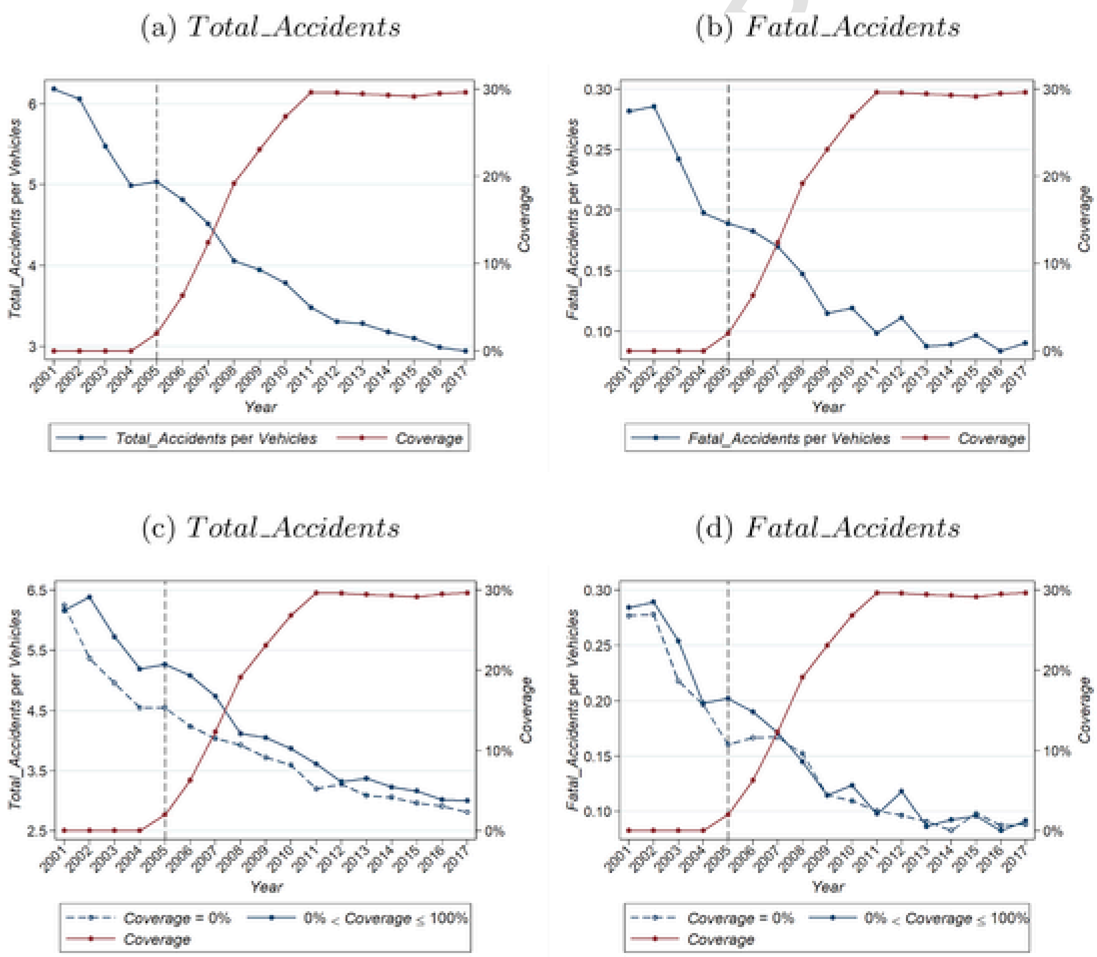

Fig. 3. Descriptive trends, 2001-2017*Notes*: Fig. 3a and 3b plot the evolution of total and fatal accident rates, respectively, vs. the expansion of *Coverage*. Fig. 3c and 3d plot the evolution of the same accident rates divided between treatment and control groups.

The *Interventions* coefficients suggest that an increase in the number of interventions performed by the road assistance personnel reduces fatal accidents (as an efficient assistance to needy drivers reduces the probability of pedestrians on the carriageways), while there is no evidence that it also reduces total accidents.

However, Safety Tutor sites were first activated along those motorway sectors characterized by higher accident and mortality rates, which implies a positive reverse causality (upward) bias of the OLS estimates. Hence, previous results represent an upper boundary, as the true effect should be more negative. To identify our treatment variable, we estimated the system of Equations (3) and (4) by using the

Table 2
Safety Tutor effect in reducing highway accidents (OLS estimates).

	log (*Total_Accidents*)			log (*Fatal_Accidents*)		
	(1)	(2)	(3)	(4)	(5)	(6)
Coverage	−0.276*	−0.684***	−0.127*	−0.238	−1.065***	−0.243
	(0.147)	(0.090)	(0.070)	(0.170)	(0.187)	(0.153)
Vehicles	0.027***	0.015**	0.016**	0.016***	0.007	0.014**
	(0.004)	(0.006)	(0.007)	(0.003)	(0.008)	(0.005)
Congestion	0.232	−0.102	0.029	0.327**	−0.155	0.003
	(0.149)	(0.113)	(0.107)	(0.151)	(0.162)	(0.110)
Interventions	−0.036	0.105**	0.008	0.026	0.094	−0.090*
	(0.119)	(0.0491)	(0.0294)	(0.0724)	(0.0687)	(0.0471)
Constant	3.621***	4.003***	4.382***	0.767***	1.282***	1.794***
	(0.299)	(0.231)	(0.288)	(0.183)	(0.312)	(0.228)
Motorway sector	No	Yes	Yes	No	Yes	Yes
Concessionaire	No	Yes	Yes	No	Yes	Yes
Year	No	No	Yes	No	No	Yes
Observations	800	800	800	800	800	800
R2	0.600	0.259	0.571	0.382	0.158	0.366

Notes: This table reports OLS estimates of Equation (1). Notably, *Coverage* is lagged by one period. Motorway sector, concessionaire, and year fixed effects are included as indicated. Standard errors clustered at the highway level are in parentheses. Significance values: ***p<0.01, **p<0.05, *p<0.10.

network of motorway sectors managed by *ASPI* and its controlled concessionaires from 2005 onwards as an instrument for *Coverage*.

Table 3 reports 2SLS estimates as well as estimates of reduced form equations in which the instrument is used in place of the endogenous variable. *Panel A* reports estimates of first stage regressions, showing that membership in *ASPI_Group* is a strong predictor for Safety Tutor adoption. Indeed, *Instrument* is significant at the 1% level with an F-statistic value well above the rule-of-thumb threshold of 10 suggested by Staiger and Stock (1997), showing that motorway sectors managed by *ASPI* and its controlled concessionaires have, on average, 23.8% of their total length covered by the system. *Panel B* reports estimates of second stage regressions. As expected, the coefficient associated with $\widehat{Coverage}$ in column 3 is consistent in sign with panel data regression, and the absolute value is much higher than the previous OLS estimate, which is in line with our hypothesis that positive reverse causality lead to an underestimated effect.

Thus, according to the semi-log regression interpretation provided by Thornton and Innes (1989), holding constant other variables, a 10% increase in Safety Tutor coverage led to an average reduction in total accidents of 3.9%. Additionally, the coefficient associated with $\widehat{Coverage}$ in column 6 is still negative but not statistically significant. Given that the absence of statistical significance does not allow us to infer that there is no effect, we can conclude that there is a lack of sufficient evidence of a causal effect of Safety Tutor in preventing fatal accidents. The control variables present very similar outcomes to those reported in Table 2, and the same explanations apply. Notably, consistency in sign and significance between OLS and 2SLS estimates corroborates the validity of our findings. Finally, *Panel C*, which reports estimates of reduced form equations, seems to verify our assumption of relevance of the *Instrument* in explaining the pattern of total accidents, while there is no evidence of an *intention-to-treat* effect for fatal accidents.

6. Robustness checks

6.1. Parallel trend assumption and timing of the effect

To provide evidence of the reliability of our previous OLS estimates, we need to check the validity of the specifications. The key assumption is the parallel pre-treatment trend. That is, before treatment, the total highway accidents that occurred on motorway sectors that installed at least one Safety Tutor site should present no significant differences with respect to the total highway accidents that occurred on motorway sectors that have never adopted the Safety Tutor technology. To verify this assumption, and to investigate the timing of the effect, we augmented the specification in Equation (1) with leads and lags before and after treatment, as proposed by Autor (2003). To facilitate visualization, Fig. 4 illustrates the plots of the lead and lag coefficients with 95% confidence interval for our most complete specifications in columns 3 and 6. The coefficients for the three years before the Safety Tutor deployment are not statistically significant for either *Total_Accidents* (Fig. 4a) or *Fatal_Accidents* (Fig. 4b), thereby providing enough evidence for the validity of the parallel pre-treatment trend assumption.

6.2. Placebo regressions

Methodologically, our 2SLS estimates rely on the assumption that, in the absence of Safety Tutor coverage, the differences in highway accidents between treatment and control groups would have remained constant. To assess the validity of this assumption, we performed a confirmation and a falsification test by regressing the log values of two additional dependent variables (*Light_Accidents*[15] and *Heavy_Accidents*[16]) on the treatment variable.

If our baseline estimates in Section 5 correctly reflect the causal effect of Safety Tutor coverage on the reduction of total accidents, we would expect a greater impact of this system in reducing light vehicle accidents only, whereas we would expect no effect in reducing heavy vehicle accidents. Indeed, the Safety Tutor technology was developed to encourage drivers to be compliant with speed limits; however, given that the average speed of trucks is already lower with respect to the Italian highway speed limit of 130 km/h, we would expect that

[15] We refer to the total number (plus 1) of light vehicle accidents (i.e., accidents that involve motorcycles and two-axle vehicles with a height above the ground, at the front axle, lower than 1.30 m) occurring on the motorway property that caused injuries or death to people.

[16] We refer to the total number (plus 1) of heavy vehicle accidents (i.e., accidents that involve two-axle vehicles with a height above the ground, at the front axle, greater than 1.30 m, and vehicles with three or more axles) occurring on the motorway property that caused injuries or death to people.

Table 3
Safety Tutor effect in reducing highway accidents (2SLS estimates; reduced forms).

	log (*Total_Accidents*)			log (*Fatal_Accidents*)		
	(1)	(2)	(3)	(4)	(5)	(6)
	Panel A: First stage (outcome: $\widehat{Coverage}$*)*					
Instrument	0.240***	0.294***	0.238***	0.240***	0.294***	0.238***
	(0.045)	(0.050)	(0.042)	(0.045)	(0.050)	(0.042)
Vehicles	0.002**	−0.004	0.002	0.002**	−0.004	0.002
	(0.001)	(0.006)	(0.006)	(0.001)	(0.006)	(0.006)
Congestion	0.000	0.043	−0.030	0.000	0.043	−0.030
	(0.057)	(0.044)	(0.038)	(0.057)	(0.044)	(0.038)
Interventions	0.002	0.042	0.044	0.002	0.042	0.044
	(0.016)	(0.027)	(0.030)	(0.016)	(0.027)	(0.030)
Constant	−0.062*	0.071	−0.150	−0.062*	0.071	−0.150
	(0.032)	(0.226)	(0.231)	(0.032)	(0.226)	(0.231)
R2	0.289	0.256	0.397	0.289	0.256	0.397
	Panel B: Second stage					
$\widehat{Coverage}$	−1.002**	−1.447***	−0.498**	−1.444***	−1.999***	−0.122
	(0.483)	(0.221)	(0.203)	(0.431)	(0.302)	(0.363)
Vehicles	0.029***	0.018***	0.017***	0.019***	0.010	0.013**
	(0.005)	(0.006)	(0.006)	(0.004)	(0.007)	(0.006)
Congestion	0.218	−0.080	0.007	0.304	−0.128	0.010
	(0.151)	(0.109)	(0.105)	(0.187)	(0.135)	(0.110)
Interventions	−0.020	0.082*	0.023	0.054	0.066	−0.095*
	(0.112)	(0.047)	(0.034)	(0.073)	(0.062)	(0.052)
Constant	3.607***			0.744***		
	(0.296)			(0.199)		
R2	0.570	0.009	0.531	0.263	0.054	0.365
	Panel C: Reduced form					
Instrument	−0.241**	−0.425***	−0.119**	−0.347***	−0.587***	−0.029
	(0.101)	(0.044)	(0.047)	(0.068)	(0.064)	(0.089)
Vehicles	0.027***	0.024***	0.016**	0.017***	0.019*	0.013**
	(0.004)	(0.006)	(0.007)	(0.003)	(0.010)	(0.006)
Congestion	0.218	−0.142	0.021	0.303**	−0.214	0.014
	(0.145)	(0.108)	(0.108)	(0.142)	(0.172)	(0.115)
Interventions	−0.022	0.020	0.001	0.051	−0.018	−0.100*
	(0.114)	(0.048)	(0.028)	(0.070)	(0.068)	(0.051)
Constant	3.669***	3.920***	4.366***	0.834***	1.163***	1.841***
	(0.305)	(0.263)	(0.278)	(0.194)	(0.398)	(0.257)
R2	0.608	0.283	0.573	0.415	0.141	0.361
Motorway sector	No	Yes	Yes	No	Yes	Yes
Concessionaire	No	Yes	Yes	No	Yes	Yes
Year	No	No	Yes	No	No	Yes
Observations	800	800	800	800	800	800
F-statistic	28.79	34.19	32.32	28.79	34.19	32.32

Notes: *Panel A* and *Panel B* report 2SLS estimates of Equations (3) and (4), respectively. In *Panel A*, the outcome is the lagged value of *Coverage*. *Panel C* reports estimates of the reduced form equations. Notably, *Instrument* and $\widehat{Coverage}$ are lagged by one period. Motorway sector, concessionaire, and year fixed effects are included as indicated. In *Panel B*, *Constant* of columns 2,3,5, and 6 is not reported because the 2SLS estimation procedure includes it in the motorway sector fixed effects. Standard errors clustered at the highway level are in parentheses. Significance values: ***p < 0.01, **p < 0.05, *p < 0.10.

the Safety Tutor deployment had no impact in improving heavy vehicle drivers' behaviour.

Table 4 reports 2SLS estimates of the placebo regressions. Again, limiting the discussion to the most complete specifications only, the coefficient associated with $\widehat{Coverage}$ in column 3 is slightly larger than the baseline coefficient (−0.549) and statistically significant, revealing that, holding constant other variables, a 10% increase in Safety Tutor coverage led to an average reduction in light vehicle accidents of 4.2%. In contrast, the same coefficient in column 6 is close to zero (−0.167) and not statistically significant, which verifies our previous hypothesis of no evidence of any effect in reducing heavy vehicle accidents.

7. Discussion

On the clear understanding that the current analysis does not investigate the direct impact of Safety Tutor on either speed reduction or speed compliance, our empirical evidence suggests that the Italian motorway sectors that adopted the average speed enforcement system experienced a significant reduction in total accidents between 2001 and 2017 through one of the aforementioned channels (thereby confirming previous results in the existing literature), while they did not experience the same pattern for fatal accidents. In other words, it seems that Safety Tutor had a greater role in preventing the number of vehicle collisions rather than reducing their severity.

Bearing in mind how time plays a fundamental role in explaining the reduction in highway accidents, we can reasonably conclude that it may have been the technological development of vehicle safety systems, as well as a general amelioration in motorway paving,

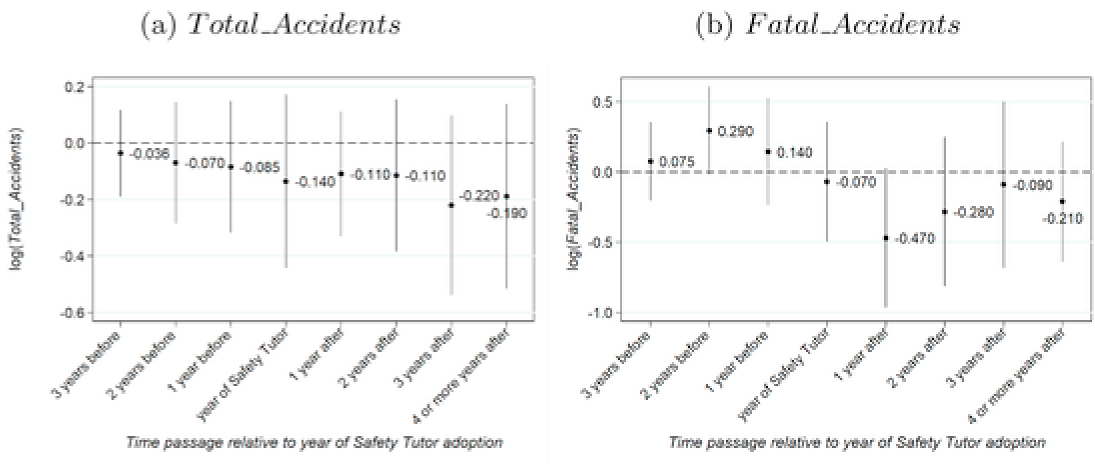

Fig. 4. Timing of Safety Tutor effect in reducing highway accidents*Notes*: Vertical bands represent ± 1.96 times the standard error of each point estimate.

rather than Safety Tutor adoption, that had the greatest influence in reducing fatal accidents.

As studied by Erke (2008) and Sternlund et al. (2017) in other contexts, the introduction of new technologies in modern vehicles, such as the *"electronic stability control"* (ESC) and the *"lane departure warning"* (LDW) systems, may have had a relevant impact in improving driving dynamics. Similarly, the spread of rumble strips and draining asphalt all along the tolled motorway network may have further reduced the probability of serious vehicle collisions (Persaud et al., 2004). Moreover, considering that fatal accidents are counted as those accidents that caused at least one death within 30 days of the vehicle accident, a plausible improvement in the quality of health care may have reduced the total number of fatalities as well (Noland and Quddus, 2004).

Because the analysis of highway accident data has long been used as a basis for directing and implementing regulatory policies and enforcement activities, this study ultimately seeks to provide further evidence that transport institutions and road agencies can use to assess the utility of adopting average speed enforcement systems to improve drivers' safety.

For instance, a simple back-of-the-envelope calculation suggests that the Safety Tutor deployment prevented 12 535 accidents. Considering that the total number of accidents that occurred along the complete tolled motorway network from 2005 onwards was 98 535, the device prevented 1 accident for every 10, roughly. Unfortunately, the lack of data about the average number of injuries and fatalities for each accident, as well as the lack of information about the development, deployment, and maintenance costs of Safety Tutor, do not allow us to carry out a proper cost-benefit assessment. However, we will seek to deeply investigate the social benefits of prevented accidents and the related welfare implications in future research.

8. Conclusions

In Italy, an average speed enforcement system, named Safety Tutor, was developed by *ASPI* and the Italian traffic police in 2004. Then, starting on 23 December 2005, the system was progressively deployed along the Italian tolled motorway network to encourage drivers to comply with speed limits and improve safety.

To date, previous studies have focused on the impact of this system in preventing highway accidents only on specific motorway sectors with unique road and congestion features; furthermore, they have considered only total accidents as the main outcome of interest. Hence, our study has sought to overcome these limitations by empirically testing the extent to which Safety Tutor led to a reduction in both total and fatal accidents on Italian highways during the period of 2001–2017. In so doing, we carried out a generalized difference-in-differences estimation using a unique panel dataset that enabled us to control for many unobservable confounding factors and to exploit heterogeneous accident data within all tolled motorway sectors in a quasi-experimental setting.

To deal with the potential endogeneity of the non-random placement of Safety Tutor sites, we adopted an instrumental variable strategy by using the network of motorway sectors managed by *ASPI* and its controlled concessionaires from 2005 onwards (i.e., when the technology was available) as an instrument to predict Safety Tutor adoption.

Our findings reveal that a 10% increase in Safety Tutor coverage led to an average reduction in total accidents of 3.9%, whereas there is no evidence of a significant causal effect of Safety Tutor in reducing fatal accidents.

Declarations of interest

None.

Acknowledgements

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Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.ecotra.2019.100123.

Appendix.

Table A
Progressive deployment of Safety Tutor sites by concessionaire, 2005–2017
Expand

Table 4
Robustness check – placebo regressions (2SLS estimates; reduced forms).
Expand

	log (*Light_Accidents*)			log (*Heavy_Accidents*)		
	(1)	(2)	(3)	(4)	(5)	(6)
	Panel A: First stage (outcome: Coverage)					
Instrument	0.240***	0.294***	0.238***	0.240***	0.294***	0.238***
	(0.045)	(0.050)	(0.042)	(0.045)	(0.050)	(0.042)
Vehicles	0.002**	−0.004	0.002	0.002**	−0.004	0.002
	(0.001)	(0.006)	(0.006)	(0.001)	(0.006)	(0.006)
Congestion	0.000	0.043	−0.030	0.000	0.043	−0.030
	(0.057)	(0.044)	(0.038)	(0.057)	(0.044)	(0.038)
Interventions	0.002	0.042	0.044	0.002	0.042	0.044
	(0.016)	(0.027)	(0.030)	(0.016)	(0.027)	(0.030)
Constant	−0.062*	0.071	−0.150	−0.062*	0.071	−0.150
	(0.032)	(0.226)	(0.231)	(0.032)	(0.226)	(0.231)
R2	0.289	0.256	0.397	0.289	0.256	0.397
	Panel B: Second stage					
Coverage	−0.934*	−1.492***	−0.549**	−1.070*	−1.316***	−0.167
	(0.494)	(0.232)	(0.215)	(0.551)	(0.270)	(0.474)
Vehicles	0.028***	0.017**	0.018***	0.027***	0.026***	0.019**
	(0.004)	(0.007)	(0.007)	(0.006)	(0.006)	(0.008)
Congestion	0.213	−0.127	−0.046	0.321	0.032	0.153
	(0.147)	(0.116)	(0.111)	(0.253)	(0.116)	(0.118)
Interventions	−0.053	0.058	0.003	0.159	0.170**	0.087*
	(0.109)	(0.050)	(0.039)	(0.135)	(0.067)	(0.049)
Constant	3.475***			1.575***		
	(0.284)			(0.378)		
R2	0.572	−0.023	0.499	0.446	0.048	0.281
	Panel C: Reduced form					
Instrument	−0.224**	−0.438***	−0.131**	−0.257**	−0.387***	−0.040
	(0.105)	(0.041)	(0.049)	(0.122)	(0.073)	(0.116)
Vehicles	0.026***	0.024***	0.017**	0.025***	0.032***	0.019**
	(0.004)	(0.006)	(0.007)	(0.005)	(0.008)	(0.009)
Congestion	0.213	−0.191*	−0.030	0.321	−0.025	0.158
	(0.146)	(0.109)	(0.112)	(0.237)	(0.126)	(0.121)
Interventions	−0.055	−0.005	−0.021	0.157	0.115	0.080
	(0.111)	(0.049)	(0.030)	(0.137)	(0.072)	(0.054)
Constant	3.533***	3.804***	4.197***	1.642***	1.648***	2.293***
	(0.293)	(0.255)	(0.274)	(0.392)	(0.391)	(0.378)
R2	0.603	0.278	0.551	0.497	0.128	0.283
Motorway sector	No	Yes	Yes	No	Yes	Yes
Concessionaire	No	Yes	Yes	No	Yes	Yes
Year	No	No	Yes	No	No	Yes
Observations	800	800	800	800	800	800
F-statistic	28.79	34.19	32.32	28.79	34.19	32.32

Notes: *Panel A* and *Panel B* report placebo 2SLS estimates of Equations (3) and (4), respectively. In *Panel A*, the outcome is the lagged value of *Coverage*. *Panel C* reports placebo estimates of the reduced form equations. Notably, *Instrument* and $\widehat{Coverage}$ are lagged by one period. Motorway sector, concessionaire, and year fixed effects are included as indicated. In *Panel B*, *Constant* of columns 2,3,5, and 6 is not reported because the 2SLS estimation procedure includes it in the motorway sector fixed effects. Standard errors clustered at the highway level are in parentheses. Significance values: ***p < 0.01, **p < 0.05, *p < 0.10.

Concessionaire	Length of Safety Tutor sections by year [km]					
	2005	2006	2007	2008	2009	2010
Autostrade per l'Italia	107.2	339.4	543.1	869.6	1 072.0	1 240.2
Tangenziale di Napoli	0.0	0.0	0.0	0.0	9.4	9.4
Autostrada Torino–Savona [a]	0.0	0.0	0.0	0.0	0.0	29.2
Società Autostrada Tirrenica	0.0	0.0	0.0	0.0	0.0	0.0
Strada dei Parchi	0.0	0.0	121.2	121.2	121.2	121.2
Autostrade Meridionali	0.0	0.0	0.0	0.0	0.0	13.7
Società Italiana per il Traforo del Monte Bianco	0.0	0.0	0.0	0.0	0.0	0.0

Raccordo Autostradale Valle d'Aosta	0.0	0.0	0.0	0.0	0.0	0.0
Total *ASPI_Group* (A)	107.2	339.4	664.3	990.8	1 202.6	1 413.7
Autostrada Brescia–Verona–Vicenza–Padova	0.0	0.0	0.0	37.2	37.2	37.2
Autovie Venete	0.0	0.0	0.0	0.0	0.0	0.0
Total *Other Concessionaires* (B)	0.0	0.0	0.0	37.2	37.2	37.2
Total (A + B)	107.2	339.4	664.3	1 028.0	1 239.8	1 450.9

[a] In 2017, the concessionaire *Autostrada dei Fiori* replaced the concessionaire *Autostrada Torino–Savona* in the management of the *A6 Torino–Savona* motorway sector. However, we have considered this motorway sector to remain a member of *ASPI_Group* because of its eligible for new Safety Tutor installations (as explained in Section 3.2).

[b] Over the next four years (2012–2015), there were no new Safety Tutor installations.

Source: Authors' own calculations.

Table B

Progressive deployment of Safety Tutor sites by motorway sector, 2005–2017

Expand

Motorway sector	Safety Tutor section [a]	Length of Safety Tutor section by year [km			
		2005	2006	2007	2008
T1 Traforo del Monte Bianco	Montebianco Nord (7.7) - Montebianco Sud (10.5)	0.0	0.0	0.0	0.
A1 Milano–Bologna	San Zenone al Lambro (12.1) - Biv.A1/A14 (186.9)	0.0	0.0	0.0	99.
A1 Bologna–Firenze	Firenzuola (27.6) - Badia (18.9)	0.0	0.0	0.0	0.
A1 Firenze–Roma	Orte (489.9) - Roma (534.7)	0.0	0.0	1.7	21.
A1 Coll. Firenze–Roma–Napoli	San Cesareo (3.8) - Monteporzio Catone (11.0)	0.0	0.0	0.0	0.
A1 Roma–Napoli	Roma (534.7) - Caserta Nord (736.7)	0.0	0.0	202.0	202.
A3 Napoli–Salerno	Scafati (25.0) - Angri (29.8)	0.0	0.0	0.0	0.
A3 Napoli–Salerno	Cava Dei Tirreni (42.8) - Salerno (5.7)	0.0	0.0	0.0	0.
A4 Milano–Brescia	Agrate (146.9) - Brescia Ovest (217.0)	70.1	70.1	70.1	70.
A4 Brescia–Padova	Brescia Est (225.9) - Sommacampagna (273.5)	0.0	0.0	0.0	37.
A4 Venezia–Trieste	Venezia Est (20.8) - Biv.A4/A23 (92.0)	0.0	0.0	0.0	0.
A4 Venezia–Trieste	Palmanova (97.8) - Redipuglia (108.7)	0.0	0.0	0.0	0.
A6 Torino–Savona	Carmagnola (14.4) - Marene (33.4)	0.0	0.0	0.0	0.
A6 Torino–Savona	Millesimo (91.1) - Ceva (85.0)	0.0	0.0	0.0	0.
A6 Torino–Savona	Altare (118.5) - Biv.A6/A10 (122.6)	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	12.
A8/A9 Milano–Varese–Chiasso	Origgio Ovest (12.2) - Gallarate (29.0)	0.0	0.0	0.0	0.
A10 Savona–Genova	Celle Ligure (31.6) - Albisola (38.7)	0.0	0.0	0.0	0.
A13 Bologna–Padova	Arcoveggio (1.4) - Padova Zona Ind. (114.2)	7.9	7.9	7.9	94.
A14 Bologna–Ancona	Biv.A14/Casalecchio (9.1) - Rimini Nord (118.4)	29.2	29.6	29.6	95.
A14 Ancona–Pescara	Giulianova (327.0) - Biv.A14/A25 (374.9)	0.0	0.0	0.0	39.
A14 Pescara–Canosa	Biv.A14/A25 (374.9) - Biv.A14/A16 (600.0)	0.0	201.8	201.8	205.
A14 Canosa–Bari–Taranto	Biv.A14/A16 (605.5) - Bari Sud (682.0)	0.0	0.0	0.0	0.
A16 Napoli–Canosa	Baiano Ovest (27.7) - Avellino Ovest (40.0)	0.0	0.0	0.0	0.
A23 Palmanova–Udine	Udine Sud (16.6) - Biv.A23/A4 (3.2)	0.0	0.0	0.0	0.
A23 Udine–Tarvisio	Udine Nord (25.2) - Ugovizza (104.5)	0.0	0.0	0.0	0.
A24 Roma–Torano	Tivoli (14.5) - Carsoli (51.5)	0.0	0.0	37.0	37.
A24 Torano–Teramo	Valle del Salto (74.6) – LAquila Ovest (108.0)	0.0	0.0	33.4	33.
A25 Torano–Pescara	Avezzano (87.1) - Sulmona (137.9)	0.0	0.0	50.8	50.
A26 Voltri–Alessandria	Biv.A26/Predosa-Bettole (44.5) - Biv.A26/A10 (1.7)	0.0	30.0	30.0	30.
A28 Portogruaro–Conegliano	Azzano-Decimo (15.2) - Villotta (6.6)	0.0	0.0	0.0	0.
A30 Caserta–Nola–Salerno	Biv.A30/A1 (1.3) - Castel San Giorgio (42.8)	0.0	0.0	0.0	0.
A56 Tangenziale di Napoli	Astroni (4.3) - Fuorigrotta (9.9)	0.0	0.0	0.0	0.
A56 Tangenziale di Napoli	Vomero (11.4) - Camaldoli (13.2)	0.0	0.0	0.0	0.
A56 Tangenziale di Napoli	Arenella (15.4) - Capodimonte (17.4)	0.0	0.0	0.0	0.

Total	107.2	339.4	664.3	1 028.0

[a] The numbers in parentheses denote the exact entry and exit km of a Safety Tutor section (i.e., where steel gantries with cameras are installed) corresponding to the maximum length between the two carriageways (as explained in Section 3.1) up to 2017.
[b] Over the following four years (2012–2015), there were no new Safety Tutor installations. *Source*: Authors' own calculations.

Table C
Length of motorway sectors, 2001 and 2017
Expand

Motorway sector	Length [km]		Motorway sector	Length [km]	
	2001	2017		2001	2017
T1 Traforo del Monte Bianco	5.8	5.8	*A13 Bologna–Padova*	127.3	127.3
T2 Traforo del Gran S. Bernardo	12.8	12.8	*A14 Bologna–Ancona*	236.0	236.0
T4 Traforo del Fréjus	6.8	6.8	*A14 Racc. di Ravenna*	29.3	29.3
A1 Milano–Bologna	192.1	192.1	*A14 Ancona–Pescara*	133.8	133.8
A1 Bologna–Firenze	91.1	91.1	*A14 Pescara–Canosa*	239.3	239.3
A1 Firenze–Roma	273.0	273.0	*A14 Canosa–Bari–Taranto*	143.0	143.0
A1 Coll. Firenze–Roma–Napoli	45.3	45.3	*A15 Parma–La Spezia*	101.0	101.0
A1 Roma–Napoli	202.0	202.0	*A16 Napoli–Canosa*	172.3	172.3
A3 Napoli–Salerno	51.6	51.6	*A18 Messina–Catania*	76.8	76.8
A4 Ivrea–Santhià	23.6	23.6	*A20 Messina–Palermo*	140.6	181.8
A4 Torino–Milano	127.0	127.0	*A21 Torino–Piacenza*	164.9	164.9
A4 Milano–Brescia	93.5	93.5	*A21 Piacenza–Brescia*	88.6	88.6
A4 Brescia–Padova	146.1	146.1	*A22 Brennero–Verona*	224.0	224.0
A4 Padova–Mestre	23.3	74.1	*A22 Verona–Modena*	90.0	90.0
A4 Venezia–Trieste	180.3	210.2	*A23 Udine–Tarvisio*	101.2	101.2
A5 Torino–Ivrea–Quincetto	51.2	51.2	*A24 Roma–Torano*	79.5	79.5
A5 Quincetto–Aosta	59.5	59.5	*A24 Torano–Teramo*	87.0	87.0
A5 Sarre–Traforo del Monte Bianco	27.0	32.4	*A25 Torano–Pescara*	114.9	114.9
A6 Torino–Savona	130.9	130.9	*A26 Voltri–Alessandria*	83.7	83.7
A7 Genova–Serravalle	50.0	50.0	*A26 Alessandria–Gravellona Toce*	161.2	161.2
A7 Milano–Serravalle	86.3	86.3	*A27 Mestre–Belluno*	82.2	82.2
A8/A9 Milano–Varese–Chiasso	77.7	77.7	*A30 Caserta–Nola–Salerno*	55.3	55.3
A8/A26 Diramazione	24.0	24.0	*A31 Valdastico*	36.4	89.5
A10 Ventimiglia–Savona	113.3	113.3	*A32 Torino–Bardonecchia*	72.4	75.7
A10 Savona–Genova	45.5	45.5	*A33 Asti–Cuneoa*	39.4	55.7
A11 Firenze–Pisa	81.7	81.7	*A35 Milano–Brescia* [a]	62.1	62.1
A11/A12 Sestri–Livorno e Viareggio–Lucca	154.9	154.9	*A36 Pedemontana Lombarda* [a]	30.2	30.2
A12 Genova–Sestri	48.7	48.7	*A56 Tangenziale di Napoli*	20.2	20.2
A12 Livorno–Rosignano	36.6	45.4	*A58 Tangenziale esterna di Milano* [a]	33.0	33.0
A12 Roma–Civitavecchia	65.4	65.4			

[a] *A33 Asti–Cuneo*, *A35 Milano–Brescia*, *A58 Tangenziale esterna di Milano*, and *A36 Pedemontana Lombarda* motorway sectors started their operations in 2008, 2014, 2015, and 2016, respectively. *Source*: Authors' own calculations based on AISCAT data.

Table D
Aggregate data, 2001–2017
Expand

Year	Accidents		Length [km]		*Coverage* [a]
	Total	Fatal	Safety Tutor sections	Motorway sectors	
2001	11 322	513	0.0	5 387.9	0.00%
2002	11 334	533	0.0	5 387.9	0.00%
2003	10 568	470	0.0	5 387.9	0.00%
2004	9 889	391	0.0	5 391.2	0.00%
2005	10 081	378	107.2	5 432.4	1.97%
2006	9 915	375	339.4	5 441.1	6.24%
2007	9 523	357	664.3	5 446.4	12.20%
2008	8 482	307	1 028.0	5 485.9	18.74%
2009	8 234	239	1 239.8	5 485.9	22.60%
2010	7 964	250	1 450.9	5 523.2	26.27%
2011	7 332	208	1 602.0	5 523.4	29.00%
2012	6 450	216	1 602.0	5 548.6	28.87%
2013	6 360	171	1 602.0	5 573.5	28.74%
2014	6 226	176	1 602.0	5 660.2	28.30%
2015	6 344	199	1 602.0	5 725.8	27.98%
2016	6 283	178	1 625.8	5 761.4	28.22%
2017	6 336	192	1 632.9	5 761.4	28.34%

[a] It is computed as the ratio between the total Safety Tutor sections length and the total motorway sectors length.*Source*: Authors' own calculations based on AISCAT data.

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