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Abstract

The following doctoral thesis, sponsored by *Autostrada del Brennero S.p.A.* (an Italian highway concession company in charge of managing toll roads) consists on empirical essays at the crossroad between transport and regional economics. They focus on different aspects that directly involve motorways (i.e, safety, intermodality, and commuting dynamics) and they are aimed at providing further evidences that transport institutions and policy makers could take into account throughout their decision-making processes.

The first chapter presents a research article recently published[1] (co–authored with my Ph.D. colleague, Michele Cascarano, and my supervisor, Prof. Flavio Bazzana) that seeks to determine the impact of an average speed enforcement system in reducing highway accidents. Indeed, 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. 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, 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.

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[1] Mattia Borsati, Michele Cascarano, Flavio Bazzana. On the impact of average speed enforcement systems in reducing highway accidents: evidence from the Italian Safety Tutor. In *Economics of Transportation*, 2019, 20, 100123. DOI: `https://doi.org/10.1016/j.ecotra.2019.100123`.

The second chapter presents a research article recently published[2] (co–authored with my visiting supervisor, Prof. Daniel Albalate) that seeks to investigate the inter-modal competition between motorway and high-speed rail (HSR) services, as the extent to which HSR demand could be the result of a modal shift from motorways is a relevant issue in any cost-benefit analysis of HSR investments. Indeed, the development of HSR has had a notable impact on modal market shares on the routes on which its services have been implemented. To analyse whether the HSR expansion in Italy has led to a modal shift from motorway to HSR, we empirically test i) whether HSR openings adjacent to motorway sectors have reduced the total km travelled by light vehicles on these sectors during the period 2001-2017; and ii) whether this reduction has been persistent or even more evident after the opening of on-track competition between two HSR operators. To do so, we carried out a generalized difference-in-differences estimation, using a unique panel dataset that exploits the heterogeneous traffic data within all tolled motorway sectors in a quasi-experimental setting. Our findings reveal that neither HSR openings nor the opening of on-track competition led to a modal shift from motorway to HSR services, as the two transport modes are non-competing. Conversely, HSR expansion had a slightly positive impact on motorway traffic.

The third chapter presents a data article (co–authored with my co–supervisor, Dr. Antonio Accetturo) in a "data in brief" format that describes a dataset on municipality-to-municipality commuting patterns in Italy over the 1991, 2001, and 2011 censuses aimed at investigating the role of transport infrastructures and the structural transformation of the economy on worker mobility. At this purpose, a core origin-destination dataset on the number of workers moving between municipalities, or within the same municipality, has been linked with further municipality covariates on jobs location, population, and the distances in meters and journey times in minutes between all municipalities. Even though these data are freely available online, they require some tedious work to organize. Therefore, this data article brings the necessary information together and makes the dataset available on request. The dataset offers applied researchers an alternative source of information to shed new lights on the changing shape of urban systems by analysing i) the impact of infrastructural endowment in providing better job accessibility, or ii) the connection between increasing commuting patterns and the structural transformation of the economy due to the tertiarization process from 1991 to 2011.

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[2] Mattia Borsati and Daniel Albalate. On the modal shift from motorway to high-speed rail: evidence from Italy. In *Transportation Research Part A: Policy and Practice*, 2020, 137, 145-164. DOI: `https://doi.org/10.1016/j.tra.2020.04.006`.

Contents

1

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

Keywords

Highways, Accidents, Average speed enforcement system, Safety Tutor

JEL Classification Numbers

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Co–authors

This research article (Borsati et al., 2019) was co–authored with my Ph.D. colleague, Michele Cascarano, who contributed in designing the empirical strategies, and my supervisor, Prof. Flavio Bazzana, who contributed in collecting the data and interpreting the results.

1.1 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 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, such as UK (Lahrmann et al., 2016) and South Korea (Shim et al., 2020).

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 3 100 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, 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 in-

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[1] We refer to those motorway sectors managed by 25 private, public, or mixed capital highway concession companies for a total of 6 003 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.

strument 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 1.3.2, 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 1.2, we briefly describe the Safety Tutor technology and we review the literature. In Section 1.3, we explain our empirical strategies, while in Section 1.4, we present data and descriptive statistics. In Section 1.5, we present our results, followed, in Section 1.6, by our robustness checks. Section 1.7 discusses our findings, and Section 1.8 concludes.

1.2 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; Montella et al., 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; Lahrmann et al., 2016).

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 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 adopts a counterfactual

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[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).

approach that 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.

1.3 Empirical strategies

1.3.1 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 (that is, both before and after the Safety Tutor deployment), where the treated are those sectors that installed at least one Safety Tutor site within the period of analysis, while the non-treated are those sectors that have never adopted the Safety Tutor technology (see Figure 1.2 for a map of the treatment and control groups). Then, we carried out a generalized difference-in-differences estimation (namely, a "two-way fixed effects" model) by comparing the pre- and post-Safety Tutor differences in total and fatal accidents of the treated and non-treated motorway sectors through the following semi-log[4] panel equation:

$$\log(Y_{ijt}) = \beta_0 + \beta_1 Coverage_{it-1} + \theta_k X'_{it} + \alpha_i + \lambda_j + \delta_t + \epsilon_{ijt} \tag{1.1}$$

where $\log(Y_{ijt})$ is the log of the total number of either $Total\_Accidents$[5] or $Fatal\_Accidents$[6] 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[7] 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 ($Congestion$)

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[4] We adopt a semi-log specification first, because the log transformation of our dependent variable allows to obtain more symmetrically distributed residuals; and second, because it allows to provide clearer economic insights by interpreting how changes in our covariates affect the percentage change in our dependent variable.

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

[6] 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.

[7] 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.

that takes the value of 1 whether the total number of vehicles transited is at least three times the number of theoretical vehicles[8] 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[9] (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[10]. Finally, ϵ_{ijt} represents heteroskedasticity- and autocorrelation-consistent standard errors clustered at the highway level because some motorway sectors belong to the same highway.

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[8] 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.

[9] 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.

[10] 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)

1.3.2 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 (see Appendix Section 1.9 for the theoretical framework).

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[11].

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 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 Figure 1.1 highlights the motorway sectors that are managed by *ASPI_Group*, while the map in Figure 1.2 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 1.5. Indeed, in 2017, 91% of Safety Tutor sites (1 481.2 out of 1 632.9 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).

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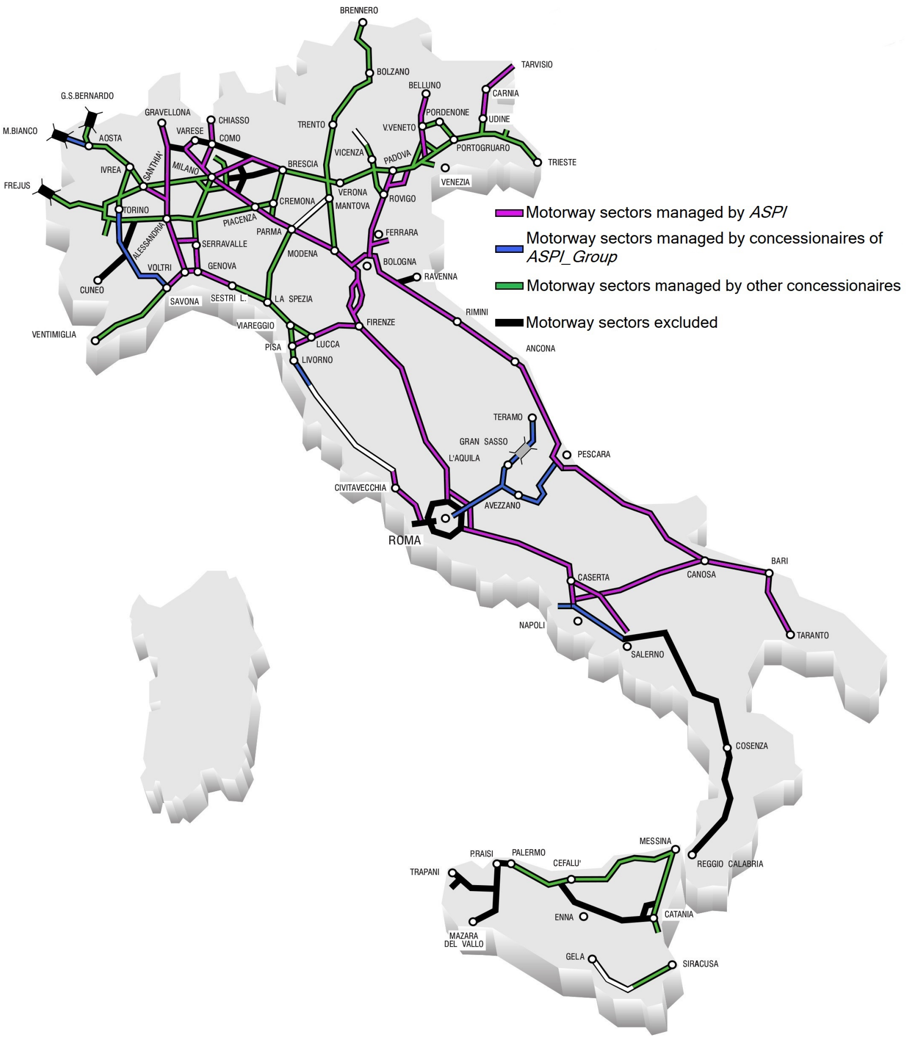
[11] *ASPI* controlled the following highway concession companies: *Tangenziale di Napoli* (100%), *Autostrada Torino–Savona* (99.9%), *Società Autostrada Tirrenica* (93.7%), *Strada dei Parchi* (60%), *Autostrade Meridionali* (58.9%), and *Società Italiana per il Traforo del Monte Bianco* (51%), which 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.

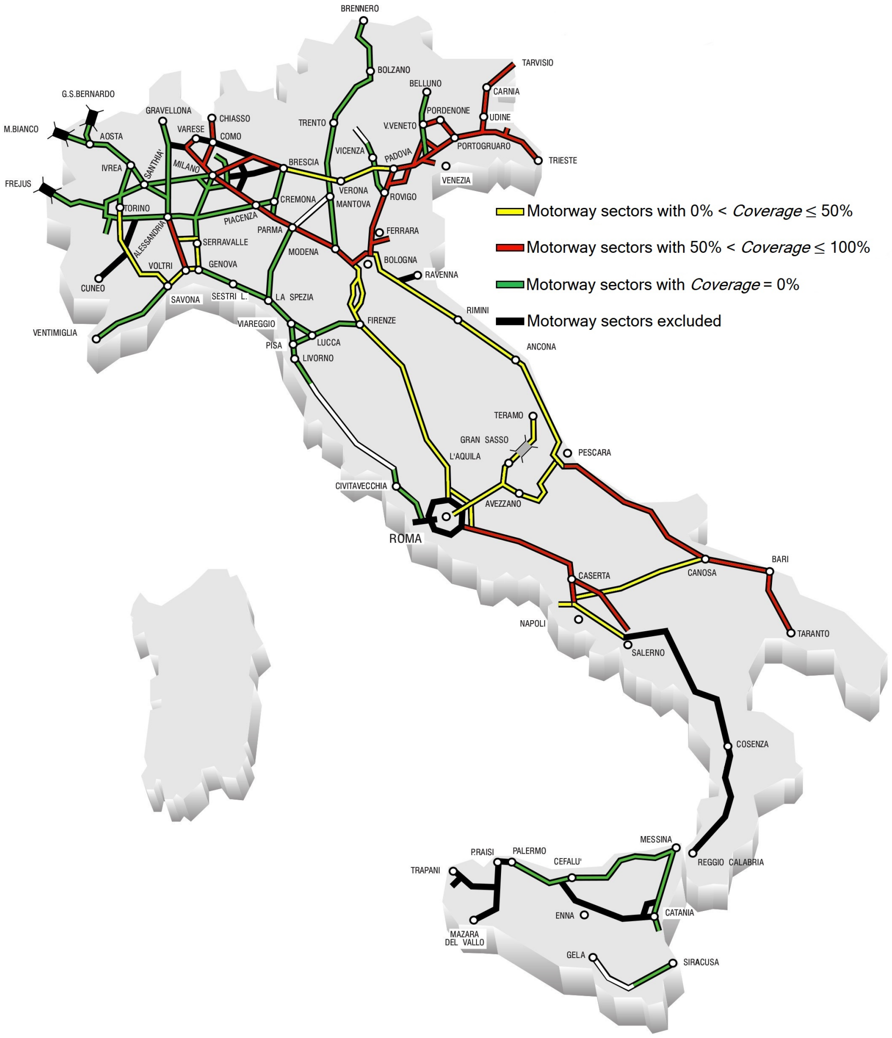
Fig. 1.1: Map of motorway sectors managed by *ASPI_Group* up to 2017



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 1.1, and the sectors described in Section 1.4.

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 ex-

Fig. 1.2: 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 1.1, and the sectors described in Section 1.4.

clusion 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[12], 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 5 900 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:

$$Instrument_{it} = ASPI\_Group_i \times Post_t \tag{1.2}$$

where $ASPI\_Group_i$ is a time-invariant[13] 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:

$$Coverage_{it-1} = \gamma_0 + \gamma_1 Instrument_{it-1} + \psi_k X'_{it} + \zeta_i + \omega_j + \phi_t + \nu_{ijt} \tag{1.3}$$

$$\log(Y_{ijt}) = \beta_0 + \beta_1 \widehat{Coverage}_{it-1} + \theta_k X'_{it} + \alpha_i + \lambda_j + \delta_t + \epsilon_{ijt} \tag{1.4}$$

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[12] 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.

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

where $Instrument_{it-1}$ is the lagged value of the dummy variable obtained in Equation 1.2 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 1.1; ζ_i, ω_j, and ϕ_t are motorway sector, concessionaire, and year fixed effects, respectively; while ν_{ijt} represents clustered standard errors.

1.4 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[14] (*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 1.1 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

Table 1.1: 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 1.3 for the detailed description of each variable.
Source: Authors' own calculations based on AISCAT data

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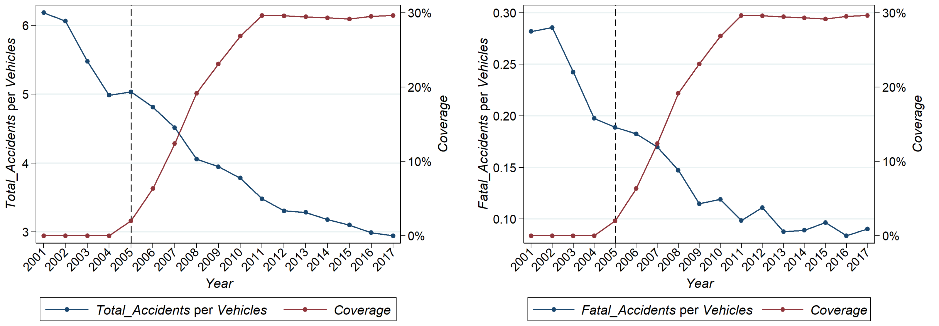
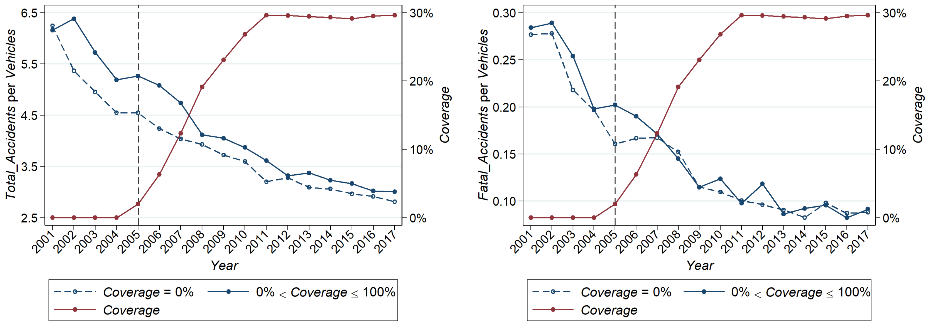
[14] AISCAT data are taken from `http://www.aiscat.it/pubblicazioni.htm?ck=1&nome=pubblicazioni&idl=4`.

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 technology was available for the last 13 out of 17 years. As a result, the average value of $Instrument$ is equal to 0.474[15].

For the 2001-2017 period, Figures 1.3a and 1.3b 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

Fig. 1.3: Descriptive trends, 2001-2017


(a) $Total\_Accidents$ (b) $Fatal\_Accidents$


(c) $Total\_Accidents$ (d) $Fatal\_Accidents$

Notes: Figures 1.3a and 1.3b plot the evolution of total and fatal accident rates, respectively, vs. the expansion of $Coverage$. Figures 1.3c and 1.3d plot the evolution of the same accident rates divided between treatment and control groups.

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[15] 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.

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).

Figures 1.3c and 1.3d 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 Figure 1.3c), 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 condition for the validity of our generalized difference-in-differences methodology (see Section 1.6.1 for an additional test).

1.5 Results

In Table 1.2, OLS estimates of Equation 1.1 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 1.7 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. 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

Table 1.2: 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
R^2	0.600	0.259	0.571	0.382	0.158	0.366

Notes: This table reports OLS estimates of Equation 1.1. 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.

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 1.3 and 1.4 by using the network of motorway sectors managed by *ASPI* and its controlled concessionaires from 2005 onwards as an instrument for *Coverage*.

Table 1.3 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.

Table 1.3: 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: 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)
R^2	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)		
R^2	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)
R^2	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 1.3 and 1.4, 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.

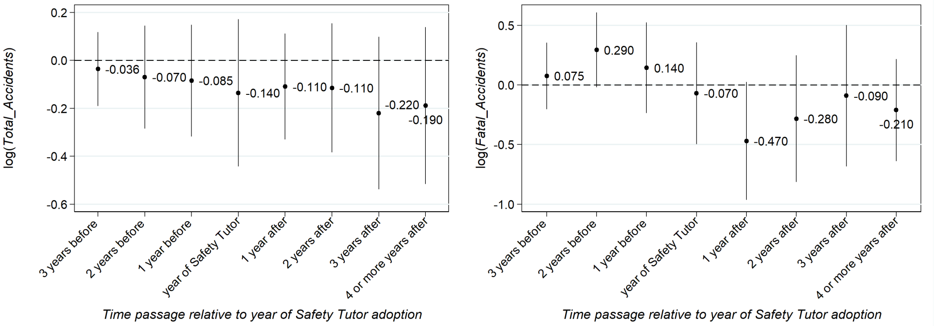
Thus, according to the semi-log regression interpretation provided by Thornton and Innes (1989), holding constant other variables, a 10% increase in Safety Tutor coverage led to an average reduction in total accidents of 3.9%. Additionally, the coefficient associated with $\widehat{Coverage}$ in column 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 1.2, 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.

1.6 Robustness Checks

1.6.1 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 pretreatment 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 1.1 with leads and lags before and after treatment, as proposed by Autor (2003). To facilitate visualization, Figure 1.4 illustrates the plots of the lead and lag coefficients with 95% confidence interval

Fig. 1.4: Timing of Safety Tutor effect in reducing highway accidents



(a) $Total\_Accidents$ (b) $Fatal\_Accidents$

Notes: Vertical bands represent ± 1.96 times the standard error of each point estimate.

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 $Total\_Accidents$ (Figure 1.4a) or $Fatal\_Accidents$ (Figure 1.4b), thereby providing enough evidence for the validity of the parallel pre-treatment trend assumption.

1.6.2 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 ($Light\_Accidents$[16] and $Heavy\_Accidents$[17]) on the treatment variable.

If our baseline estimates in Section 1.5 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 the Safety Tutor deployment had no impact in improving heavy vehicle drivers' behaviour.

Table 1.4 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.

1.7 Discussion

Even tough the current analysis does not investigate the direct impact of Safety Tutor on either speed reduction or speed compliance, it seeks to shed some new lights on the efficiency of this innovative speed management system in improving safety through some robust estimations. Indeed, this is the first article on this

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[16] 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 metres) occurring on the motorway property that caused injuries or death to people.

[17] 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 metres, and vehicles with three or more axles) occurring on the motorway property that caused injuries or death to people.

Table 1.4: Robustness check – placebo regressions (2SLS estimates; reduced forms)

	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)
R^2	0.289	0.256	0.397	0.289	0.256	0.397
	Panel B: Second stage					
$\widehat{Coverage}$	-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)		
R^2	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)
R^2	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 1.3 and 1.4, 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.

topic adopting a counterfactual approach by taking into account the highway accidents occurred along all the Italian tolled motorways for such a long time-span of analysis.

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 (thereby providing some new evidence in the field by downsizing the thesis that this device would drastically reduce road fatalities as well). 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, 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, robust econometric methods should be employed to tackle confounding factors and endogeneity issues in order to provide reliable evaluations on the efficiency of those policies. Since 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, our policy advise is to invest not only in speed enforcement systems, but also in vehicle technologies and road maintenance, which are among other prominent factors in reducing the severity of vehicle collisions.

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.

1.8 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.

1.9 Appendix

Instrumental Variable

The inconsistency of OLS estimations occur when both the exposure to a particular treatment x and the outcome of interest y share common causes u, which represents unmeasured factors that bias the impact of x on y.

If this situation occurs, what is needed is a method to generate only exogenous variation in x. To this end, an instrument z is defined as a variable that predicts the exposure to the treatment x, but conditional on exposure shows no independent association with the outcome y. In other words, the instrument affects the outcome solely through the effect on exposure. This leads to the following path diagram:

$$\begin{tikzcd}
z \arrow[r] & x \arrow[r] & y \\
 & u \arrow[u] \arrow[ur] &
\end{tikzcd}$$

which introduces a variable z that is associated with x but not u. It is still the case that z and y will be correlated, but the only source of such correlation is the indirect path of z being correlated with x which in turn determines y. The more direct path of z being a regressor in the model for y is ruled out. More formally, the variable z is an instrument because it meets the following three assumptions:

- The *relevance condition*: z has a causal effect on x.
- The *exclusion restriction*: z affects y only through x.
- The *independence assumption*: z does not share common causes with y.

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

Concessionaire	Length of Safety Tutor sections by year [km]								
	2005	2006	2007	2008	2009	2010	2011[b]	2016	2017
Autostrade per l'Italia	107.2	339.4	543.1	869.6	1 072.0	1 240.2	1 276.8	1 297.8	1 304.9
Tangenziale di Napoli	0.0	0.0	0.0	0.0	9.4	9.4	9.4	9.4	9.4
Autostrada Torino–Savona[a]	0.0	0.0	0.0	0.0	0.0	29.2	29.2	29.2	29.2
Società Autostrada Tirrenica	0.0	0.0	0.0	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	121.2	121.2	121.2
Autostrade Meridionali	0.0	0.0	0.0	0.0	0.0	13.7	13.7	13.7	13.7
Società Italiana per il Traforo del Monte Bianco	0.0	0.0	0.0	0.0	0.0	0.0	0.0	2.8	2.8
Raccordo Autostradale Valle d'Aosta	0.0	0.0	0.0	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	1 450.3	1 474.1	1 481.2
Autostrada Brescia–Verona–Vicenza–Padova	0.0	0.0	0.0	37.2	37.2	37.2	47.6	47.6	47.6
Autovie Venete	0.0	0.0	0.0	0.0	0.0	0.0	104.1	104.1	104.1
Total *Other Concessionaires* (B)	0.0	0.0	0.0	37.2	37.2	37.2	151.7	151.7	151.7
Total (A+B)	107.2	339.4	664.3	1 028.0	1 239.8	1 450.9	1 602.0	1 625.8	1 632.9

[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 1.3.2).

[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

Motorway sector	Safety Tutor section[a]	Length of Safety Tutor section by year [km]								
		2005	2006	2007	2008	2009	2010	2011[b]	2016	2017
T1 Traf. Monte Bianco	Montebianco Nord (7.7) - Montebianco Sud (10.5)	0.0	0.0	0.0	0.0	0.0	0.0	0.0	2.8	2.8
A1 Milano–Bologna	San Zenone al Lambro (12.1) - Biv.A1/A14 (186.9)	0.0	0.0	0.0	99.3	174.8	174.8	174.8	174.8	174.8
A1 Bologna–Firenze	Firenzuola (27.6) - Badia (18.9)	0.0	0.0	0.0	0.0	0.0	0.0	0.0	8.7	8.7
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	44.8
A1 Coll. Firenze–Napoli	San Cesareo (3.8) - Monteporzio Catone (11.0)	0.0	0.0	0.0	0.0	0.0	7.2	7.2	7.2	7.2
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	202.0
A3 Napoli–Salerno	Scafati (25.0) - Angri (29.8)	0.0	0.0	0.0	0.0	0.0	4.8	4.8	4.8	4.8
A3 Napoli–Salerno	Cava Dei Tirreni (42.8) - Salerno (5.7)	0.0	0.0	0.0	0.0	0.0	8.9	8.9	8.9	8.9
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	70.1
A4 Brescia–Padova	Brescia Est (225.9) - Sommacampagna (273.5)	0.0	0.0	0.0	37.2	37.2	37.2	47.6	47.6	47.6
A4 Venezia–Trieste	Venezia Est (20.8) - Biv.A4/A23 (92.0)	0.0	0.0	0.0	0.0	0.0	0.0	71.2	71.2	71.2
A4 Venezia–Trieste	Palmanova (97.8) - Redipuglia (108.7)	0.0	0.0	0.0	0.0	0.0	0.0	10.9	10.9	10.9
A6 Torino–Savona	Carmagnola (14.4) - Marene (33.4)	0.0	0.0	0.0	0.0	0.0	19.0	19.0	19.0	19.0
A6 Torino–Savona	Millesimo (91.1) - Ceva (85.0)	0.0	0.0	0.0	0.0	0.0	6.1	6.1	6.1	6.1
A6 Torino–Savona	Altare (118.5) - Biv.A6/A10 (122.6)	0.0	0.0	0.0	0.0	0.0	4.1	4.1	4.1	4.1
A7 Genova–Serravalle	Isola del Cantone (99.2) - Genova Bolzaneto (125.1)	0.0	0.0	0.0	12.3	12.3	25.9	25.9	25.9	25.9
A8/A9 Milano–Chiasso	Origgio Ovest (12.2) - Gallarate (29.0)	0.0	0.0	0.0	0.0	16.8	16.8	16.8	16.8	16.8
A10 Savona–Genova	Celle Ligure (31.6) - Albisola (38.7)	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	7.1
A13 Bologna–Padova	Arcoveggio (1.4) - Padova Zona Ind. (114.2)	7.9	7.9	7.9	94.2	112.8	112.8	112.8	112.8	112.8
A14 Bologna–Ancona	Biv.A14/Casalecchio (9.1) - Rimini Nord (118.4)	29.2	29.6	29.6	95.1	109.3	109.3	109.3	109.3	109.3
A14 Ancona–Pescara	Giulianova (327.0) - Biv.A14/A25 (374.9)	0.0	0.0	0.0	39.5	39.5	47.9	47.9	47.9	47.9
A14 Pescara–Canosa	Biv.A14/A25 (374.9) - Biv.A14/A16 (600.0)	0.0	201.8	201.8	205.3	205.3	205.3	225.1	225.1	225.1
A14 Canosa–Taranto	Biv.A14/A16 (605.5) - Bari Sud (682.0)	0.0	0.0	0.0	0.0	0.0	73.0	76.5	76.5	76.5
A16 Napoli–Canosa	Baiano Ovest (27.7) - Avellino Ovest (40.0)	0.0	0.0	0.0	0.0	0.0	0.0	0.0	12.3	12.3
A23 Palmanova–Udine	Udine Sud (16.6) - Biv.A23/A4 (3.2)	0.0	0.0	0.0	0.0	0.0	0.0	13.4	13.4	13.4
A23 Udine–Tarvisio	Udine Nord (25.2) - Ugovizza (104.5)	0.0	0.0	0.0	0.0	0.0	66.0	79.3	79.3	79.3
A24 Roma–Torano	Tivoli (14.5) - Carsoli (51.5)	0.0	0.0	37.0	37.0	37.0	37.0	37.0	37.0	37.0
A24 Torano–Teramo	Valle del Salto (74.6) - L'Aquila Ovest (108.0)	0.0	0.0	33.4	33.4	33.4	33.4	33.4	33.4	33.4
A25 Torano–Pescara	Avezzano (87.1) - Sulmona (137.9)	0.0	0.0	50.8	50.8	50.8	50.8	50.8	50.8	50.8
A26 Voltri–Alessandria	Biv.A26/Predosa-Bettole (44.5) - Biv.A26/A10 (1.7)	0.0	30.0	30.0	30.0	42.8	42.8	42.8	42.8	42.8
A28 Portog.–Conegliano	Azzano-Decimo (15.2) - Villotta (6.6)	0.0	0.0	0.0	0.0	0.0	0.0	8.6	8.6	8.6
A30 Caserta–Salerno	Biv.A30/A1 (1.3) - Castel San Giorgio (42.8)	0.0	0.0	0.0	0.0	41.5	41.5	41.5	41.5	41.5
A56 Tang. di Napoli	Astroni (4.3) - Fuorigrotta (9.9)	0.0	0.0	0.0	0.0	5.6	5.6	5.6	5.6	5.6
A56 Tang. di Napoli	Vomero (11.4) - Camaldoli (13.2)	0.0	0.0	0.0	0.0	1.8	1.8	1.8	1.8	1.8
A56 Tang. di Napoli	Arenella (15.4) - Capodimonte (17.4)	0.0	0.0	0.0	0.0	2.0	2.0	2.0	2.0	2.0
Total		107.2	339.4	664.3	1 028.0	1 239.8	1 450.9	1 602.0	1 625.8	1 632.9

[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 1.3.1) 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

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–Cuneo*[a]	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

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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2

On the modal shift from motorway to high-speed rail: evidence from Italy

Keywords

High-speed rail, Motorways, Inter-modal competition

JEL Classification Numbers

D78, L92, R41, R58

Co–authors

This research article (Borsati and Albalate, 2020) was co–authored with my visiting supervisor, Prof. Daniel Albalate, who contributed in designing the empirical strategy and interpreting the results.

2.1 Introduction

The spread of the railroads has, historically, been one of the main determinants of the urbanization and economic growth of many countries, including the United States (Donaldson and Hornbeck, 2016), India (Donaldson, 2018), Sweden (Berger and Enflo, 2017), Switzerland (Büchel and Kyburz, 2018), and, more recently, China (Diao, 2018; Yu et al., 2018; Huang et al., 2019). In its efforts to achieve better social inclusion, cohesion and accessibility, the development of high-speed rail (HSR) has been one of the central features of the European Union's recent transport infrastructure policy (Vickerman, 1997). Indeed, since the end of the twentieth century, many European countries have implemented huge HSR programmes. Following the opening of the pioneering TGV Paris–Lyon line in France, other mature high-speed (HS) services have been constructed in Spain (AVE), Germany (ICE), and Italy (TAV)[1], each country adopting its own specific model in terms of speed, network integration, type of services and regulatory characteristics (Campos and De Rus, 2009; Perl and Goetz, 2015).

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[1] At the end of 2017, in the European Union, there were 9 067 km of HS lines and 1 671 km under construction.

The rationale underpinning the introduction of HSR has also differed across countries. In some cases, the objective was simply to reduce the travel time between city-pairs (Catalani, 2006), in others it was presented as a "green" solution aimed at limiting the negative environmental impact of air and road transport (Givoni et al., 2009), while in others it was means to address problems of capacity restriction along certain corridors and to facilitate freight transportation (Albalate and Bel, 2012). Each of these objectives has received the support of the European Commission, which in 2011 set specific targets for the development of the HS network, including the tripling of its length by 2030 so as to achieve a 50% shift in medium-distance intercity passenger and freight journeys from road to rail by 2050 (European Commission, 2011). This last objective has special relevance in Italy given the country's extremely low share of rail traffic: in 2007 rail journeys accounted for just 5% of all passenger transit, while trains carried just 12% of the nation's freight (RFI, 2007). Hence, under the Trans-European Networks for Transport (TEN-T) programme, between 2000 and 2017, the European Union provided 23.7 billion euros in grants to co-finance HSR infrastructure investments across the Member States (European Court of Auditors, 2018).

Today, HSR services have transformed modal market shares on the routes on which they have been implemented both by generating new demand and by replacing the demand for other modes of transport (Álvarez-SanJaime et al., 2015). Yet, after more than 50 years of experience of operating HSR around the world, relatively little is known about the nature of its demand (Givoni and Dobruszkes, 2013). Over this period, a substantial body of research has been published on different aspects of HSR, but the majority of it has focused on inter-modal competition between HSR and air services, especially on long point-to-point links, such as the Paris–Lyon (Bonnafous, 1987), Madrid–Barcelona (Román et al., 2007), Madrid–Seville (Jiménez and Betancor, 2012), and London–Paris (Behrens and Pels, 2012) city-pairs. Indeed, studies examining the impact of HSR links on shorter routes, where the car is the competitive means of transport, are, to the authors' knowledge, relatively scarce. Yet, because road traffic reduction is one of the key drivers offsetting HSR investments, we seek to fill this gap by analysing whether the HSR expansion in Italy has led to a modal shift from its motorways to HSR services in a quasi-experimental setting. To do so, we empirically test, first, whether HSR openings adjacent to motorway sectors have reduced the total km travelled by light vehicles on these sectors during the period 2001-2017; and, second, whether this reduction has been persistent or even more evident after the opening of on-track competition on some adjacent HS and conventional lines between the incumbent *Trenitalia* and the new operator *Nuovo Trasporto Viaggiatori (NTV)*, which entered the HS passenger market in 2012.

This second question is an additional issue of interest in analysing the Italian scenario because it represents the first instance of competition between nonsubsidized HSR operators using the same infrastructure and the same market[2]. Compe-

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[2] On 1 June 2000, the two main divisions of the Italian railway company, infrastructure and services, were separated. Infrastructure management was assigned to *Rete Ferroviaria Italiana* (RFI), while passenger services were assigned to *Trenitalia*. Both are subsidiaries of *Ferrovie dello Stato Italiane* (FSI) and entirely publicly owned. The liberalisation process started in 2003, when the Italian Government implemented the

tition provided more HS capacity and forced *Trenitalia* to reduce its average fares (Bergantino, 2015). Moreover, bearing in mind that HSR has reduced the daily commuting travel time in medium and large metropolitan areas by 20-40%, the Italian HSR competes not only with air transport, but also with the car (Cascetta et al., 2011).

We should stress that we exclude the total km travelled by heavy vehicles from our analysis because, although the Italian HSR network was ultimately conceived as a mixed high-speed model equipped with numerous interconnections and line characteristics that would theoretically allow its use by dedicated HS freight trains, to date, not a single freight train has used the new lines (Beria and Grimaldi, 2017).

The novelty of this paper lies in the fact that we carry out a counterfactual analysis using a unique 17-year panel dataset. This allows us to control for many unobservable confounding factors and to exploit the heterogeneous traffic data within all tolled motorway sectors[3] through a generalized difference-in-differences estimation. Considering the difficulties in forecasting rail project demand (Flyvbjerg et al., 2005; Flyvbjerg, 2007; Börjesson, 2014), our contribution seeks to understand the extent to which HSR demand could result from a modal shift from motorways in order to provide additional evidence for estimating the environmental impact of introducing HSR services (De Rus and Nombela, 2007; De Rus, 2011), which is clearly a relevant issue in any cost-benefit analysis of HSR investments.

Our findings reveal that neither HSR openings nor the opening of on-track competition led to a modal shift from motorway to HSR services, as the two transport modes are non-competing. Conversely, HSR expansion had a slightly positive impact on motorway traffic.

The rest of this article is organized as follows. In Section 2.2, we present a brief history of the motorway and HSR networks in Italy and we review the literature. In Section 2.3, we describe our methodological approach and data. In Section 2.4, we present our results, followed, in Section 2.5, by our robustness checks. Section 2.6 critically discusses our findings and Section 2.7 concludes.

2.2 HSR and motorway networks in Italy

2.2.1 History of the projects

Italy's first HS service was launched in 1992 between Florence and Rome, with the so-called *Direttissima*, which allowed the 254 km between the two cities to be covered in about two hours. The development of a high-speed/high-capacity network (in Italian, *alta velocità/alta capacità* or AV/AC) was first conceived during the early '90s as an independent system from the rest of the existing network and accessible to light HS rolling stock only (Albalate and Bel, 2012). In 1996, however, the nature of the project changed and it became a mixed high-speed and freight

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European Directives on rail competition (2001/12/CE, 2001/13/CE, and 2001/14/CE) into the *Decreto Legislativo* n.188 of 8 July 2003.

[3] We refer to those motorway sectors managed by highway concession companies, which represent almost 87% of the national network. Traffic data for the remaining toll-free motorway sectors are not available. See Section 2.2.1 for further details.

line, including many interconnections with existing conventional lines and capable of hosting freight trains (RFI, 2007).

The Turin–Salerno axis, which took a decade to construct (completed in 2009) and which allowed trains to travel at speeds of 250-300 km/h, provided faster connections between the cities making up what can be considered Italy's *"backbone"* (i.e., Turin, Milan, Bologna, Florence, Rome, Naples and Salerno). The sections at either end of the Milan–Venice axis (i.e., Milan–Brescia and Padua–Venice) were completed in 2016 and operated services at speeds of 200-300 km/h, while the upgrading of the Verona–Bologna line was inaugurated in 2009, raising its speed to 200 km/h.

To date, the national network comprises more than 1 000 km of HS lines[4] (see Appendix Tables A and B for the timeline of opening dates, and see Appendix Figure A for a map of the HSR expansion adjacent to motorway sectors), while the supply model adopted by its two operators is a mixed high-speed model (schematised in Figure 2.1), in which *Frecciarossa* and *Italo* trains generally operate only on dedicated tracks that can reach speeds of 300 km/h (fully high-speed services), *Frecciargento* (and also *Italo*) trains operate at a maximum of 250 km/h on HS lines where connections with the conventional infrastructure are available (mixed high-speed and conventional services), while *Frecciabianca* trains operate on conventional lines only (fully conventional services)[5].

Italian motorways, instead, underwent a massive expansion in the 1960s and '70s, coinciding with a period of sustained growth and the mass diffusion of cars. At the end of 1974, the Italian network was more than twice the size of that of France and three times that of the UK, and by 1980 it had reached 5 900 km (Ragazzi, 2006). Since that date, the network's length has barely increased: in 2017 the total length constituted 6 003 km of tolled motorway sectors under concession to 25 private, public, or mixed capital companies, while 939 km of toll-free motorway sectors were managed by ANAS, a government-owned company under the control of the Ministry of Infrastructure and Transport (AISCAT, 2017).

2.2.2 Previous evaluations

Leaving to one side the large number of cost-benefit analyses made of HSR, the introduction of HSR services has primarily encouraged studies of the inter-modal competition between air and rail, stimulated by such questions as airport congestion (Fageda and Flores-Fillol, 2016), the negative environmental impact of air transport (Givoni, 2007), and airlines' service quality (Zhang et al., 2019). Likewise, the liberalisation of the rail market has resulted in several studies that focus on the intra-modal competition between rail operators, particularly in the Italian

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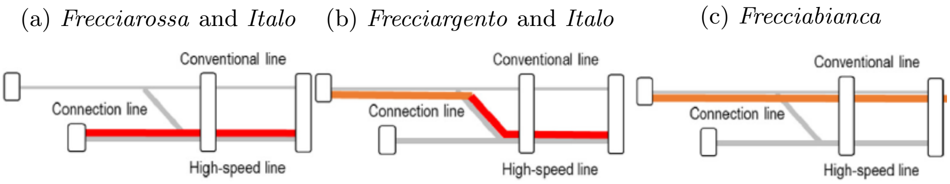
[4] Other HSR projects, such as the central section of the Milan–Venice axis, the Genoa–Milan link, the Naples–Bari link, the Palermo–Messina–Catania link, and three important Alpine lines are under construction or under discussion as regards their redefinition (MEF, 2016; MEF, 2017).

[5] *Frecciarossa*, *Frecciargento*, and *Frecciabianca* are the commercial names of *Trenitalia*'s long-distance market services (*"le Frecce"*), while *Italo* is the commercial name adopted by *NTV* trains.

Fig. 2.1: Schematisation of the mixed high-speed model used in Italy


(a) *Frecciarossa* and *Italo* (b) *Frecciargento* and *Italo* (c) *Frecciabianca*

Source: Beria et al. (2018)

context. The literature examining the competition between car and rail, on the other hand, is very scant.

Limiting our discussion on air-rail competition to a selection of the most relevant studies (many more exist), Bergantino and Capozza (2015) and Martín and Nombela (2007) found that investment in rail infrastructure induces downward pressure on competing airline fares and leads to a significant modal shift towards HSR services. Other studies have explored the reaction of airline fares to rail travel time and airport accessibility both theoretically (Yang and Zhang, 2012) and empirically (Capozza, 2016), finding that airlines tend to set lower fares as rail speed increases. Further, by focusing on the evolution of supply rather than demand, Dobruszkes (2011) and Jiménez and Betancor (2012) provided additional evidence that new HSR connections have reduced the number of air transport operations. In contrast with these studies, Givoni and Banister (2006) and Albalate et al. (2015) considered the potential for cooperation rather than competition between the two transportation modes. They found that, when economically convenient, airlines use HSR links as additional spokes in their network of services from a hub airport to complement and substitute existing aircraft services.

Following the appearance of intra-modal competition in the HSR sector, Bergantino et al. (2015) analysed how the entry of *NTV* has fostered competition not only with the airlines but also with the former incumbent *Trenitalia*. By collecting actual fare data on three HS service routes (Rome to Milan, Turin and Venice) plus two air routes between Milan and Rome, the authors found, first, that on the Rome–Milan link the rail market share increased from 36% in 2008 to 68% in 2012 (while the airline market share fell from 51 to 26% in the same period); and, second, that *Trenitalia*'s fares were 29-34% higher than those of its competitor.

Among the few studies that have examined the effect of HSR expansion on car-rail mode substitution, González-Savignat (2004) designed a discrete choice model to evaluate, ex-ante, the impact of the future HSR on current road users in the Madrid–Barcelona corridor. She identified that HSR would become a more competitive alternative for business car travellers, as a 10% increase in rail travel time would lead to a 9.2% reduction in their probability of choosing HSR. In the case of ex-post evaluations, Givoni and Dobruszkes (2013) provided a comprehensive international review by collecting results from studies analysing different markets. They conclude that the reduction in the number of car passengers (due to the introduction of HSR) on the routes examined is in the order of 10-20%.

However, their evidences are mixed because in the Madrid–Seville link car passengers increased by 23% after HSR services begun (European Commission, 1998). Likewise, on Korean and Taiwanese routes, road transport retained high utilization rate after the introduction of HSR services (Cho and Chung, 2008; Cheng, 2010).

In the case of Italy, Cascetta et al. (2011) explored user behaviour on the multimodal Rome–Naples link of 205 km by using a revealed preference survey carried out in March 2008. They found that the percentages of HSR users that actually used the motorway before the HSR was inaugurated were just 7.8% on weekdays, 12.4% on Saturdays, and 14.4% on Sundays. Indeed, the highest percentage of HSR users were already train users. In a study of the whole area influenced by HS lines, Cascetta and Coppola (2015) analysed data gathered by means of on-board counts on HS trains, highways and domestic flights, between 2009 and 2013. The authors concluded that HSR had a direct impact on the modal split of long distance travel demand and showed that total HSR demand increased by 81% during the period of study, while the variation in domestic travel demand by air and highway were substantially different if observed within the HSR catchment area (-29 and -19%, respectively) with respect to their national trends (-7 and -10%, respectively). Moreover, they estimated a broader effect in terms of modal share in the core area: from 25 to 44% for HS services at the expense of airlines (from 10 to 7%) and highways (from 57 to 45%).

However, it should be noted that the above studies are heavily influenced by route-specific characteristics and are conducted over relatively short time spans; therefore, additional research should be carried out in order to provide consistency of previous findings. Bearing in mind the difficulty in discerning the impact of HSR expansion on car-rail mode substitution from the general trend increase in demand for car travel (Goodwin and Van Dender, 2013), the study we report here seeks to overcome these limitations in the existing literature by taking into consideration a longer time-span of analysis and by exploiting heterogeneous traffic data within a sizeable set of different motorway sectors.

2.3 Empirical analysis

2.3.1 Methodology and data

The objective of this study is to empirically test the impact of i) HSR openings and ii) the opening of on-track competition on the total km travelled by light vehicles on adjacent motorway sectors[6]. For this purpose, we collected data for 52 tolled motorway sectors over the period 2001-2017 (that is, both before and after the HSR expansion), where the treated are those sectors that experienced either an HSR opening on the same route, or the opening of on-track competition on the adjacent HS or conventional line, while the non-treated are those sectors

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[6] We define a motorway sector as "adjacent" to an HSR service when both transport modes connect the same city-pairs through largely parallel routes. Indeed, a large part of the HSR network was built next to highways so as to prevent further land consumption (Beria et al., 2018).

that experienced neither of the two phenomena (see Appendix Figures A and B for a map of our treatment and control groups). Accordingly with the generalized difference-in-differences approach (namely, a "two-way fixed effects" model), each counterfactual is defined by the period before the treatment and by the motorway sectors not affected by the treatment. Then, we estimated the pre- and post-HSR expansion differences in traffic of the treated and non-treated motorway sectors through the following semi-log[7] panel equations:

$$\begin{aligned}\log(Vehicles - Km_{it}) = {} & \beta_0 + \beta_1 HSR_{it}^{Opening} + \beta_2 Vehicles_{it} \\ & + \beta_3 GDP_{it} + \beta_4 \mathit{Airport\ size}_{it} + \beta_5 \mathit{Sector\ length}_{it} \\ & + \beta_6 Toll_{it} + \beta_7 Fuel_t + \alpha_i + \delta_t + \theta_{it} + \epsilon_{it}\end{aligned} \tag{2.1}$$

$$\begin{aligned}\log(Vehicles - Km_{it}) = {} & \beta_0 + \beta_1 HSR_{it}^{Competition} + \beta_2 Vehicles_{it} \\ & + \beta_3 GDP_{it} + \beta_4 \mathit{Airport\ size}_{it} + \beta_5 \mathit{Sector\ length}_{it} \\ & + \beta_6 Toll_{it} + \beta_7 Fuel_t + \alpha_i + \delta_t + \theta_{it} + \epsilon_{it}\end{aligned} \tag{2.2}$$

where the dependent variable in both equations is the logarithm of the total km travelled by light vehicles[8] ($Vehicles - Km_{it}$) on motorway sector i in year t. The main explanatory variables are:

- $HSR_{it}^{Opening}$ (Equation 2.1): continuous variable that takes values between 0 and 1 depending on whether a full or partial HS line was opened adjacent to a motorway sector i in year t. It is calculated as the ratio between the km of HSR in operation and the total HSR length, once completed (see Appendix Table A for further details).
- $HSR_{it}^{Competition}$ (Equation 2.2): continuous variable that takes values between 0 and 1 depending on whether on-track competition between the incumbent and the new operator started on a full or partial HS or conventional line adjacent to a motorway sector i in year t. It is calculated as the ratio between the km of line under competition and its total length (see Appendix Table B for further details).

In both equations, the control variables are:

- $Vehicles_{it}$: light vehicles per capita calculated as the ratio between the number of light vehicles and population of municipalities located within a highway catchment area, i.e., within a 15-km arc distance from exits of a motorway sector i in year t (CERTeT-Bocconi, 2006; Percoco, 2015). Since we cannot observe solely the percentage of km travelled by light vehicles that covered the whole route (i.e., those km travelled by long-distance passengers who are more willing to evaluate HS trains as an alternative mode of transport), this variable aims

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[7] We adopt a semi-log specification first, because the log transformation of our dependent variable allows to obtain more symmetrically distributed residuals; and second, because it allows to provide clearer economic insights by interpreting how changes in our covariates affect the percentage change in our dependent variable.

[8] Technically, light vehicles are motorcycles and two-axle vehicles with a height above the ground, at the front axle, lower than 1.30 meters.

at capturing an approximation of the impact of commuters living in areas with high highway accessibility on the total km travelled. Similarly, it aims at capturing possible increases in trasport demand potentially due to increases in local populations.

- GDP_{it}: weighted average of gross domestic product per capita (in thousands of euros) in the regions of transit for a motorway sector i in year t (weights are based on the percentage of km of motorway sector located in each region). This variable is a proxy of the economic activity surrounding the highway area.
- $Airport\ size_{it}$: passengers (in millions) carried by domestic flights departing from airports located within a 50-km arc distance from exits of a motorway sector i in year t, which is a standard size of an airport's catchment area (Lieshout, 2012; Suau-Sanchez et al., 2014). This variable is a proxy of the competitive transport sector surrounding the highway area.
- $Sector\ length_{it}$: length (in km) of a motorway sector i in year t (see Appendix Table C for details about the length of motorway sectors).
- $Toll_{it}$: revenues per km travelled (in euro cents) as earned by the highway concession company of a motorway sector i in year t calculated as the ratio between total revenues and total km travelled by vehicles on that sector. Note that motorway sectors managed by the same concessionaire have the same $Toll$ value. This variable is a proxy of toll fare.
- $Fuel_t$: weighted average cost of fuel (in euro cents) in year t calculated as the average national cost of gasoline, diesel, and LPG weighted by the percentage of national light vehicles powered by the three different fuel types.
- α_i, δ_t, θ_{it}: motorway sector, year, and GDP-by-year fixed effects.

Heteroskedasticity – and autocorrelation – consistent standard errors ϵ_{it} are clustered at the highway level, because some motorway sectors belong to the same highway. Data of our dependent variable ($Vehicles{-}Km$), as well as $Sector\ length$, and $Toll$ data were obtained from AISCAT (*Associazione Italiana Società Concessionarie Autostrade e Trafori*, the concessionaires' association). $HSR^{Opening}$ and $HSR^{Competition}$ data are based on Bergantino et al. (2015), Beria et al. (2018), and taken from RFI and NTV websites, and the operators' financial statements. Data for $Vehicles$, i.e., the number of light vehicles and population at municipality level, were obtained from ACI (*Automobile Club d'Italia*) and ISTAT (*Istituto Nazionale di Statistica*), respectively, while municipalities located within a 15-km arc distance from motorway exits were identified from the *Automap* website. GDP data were also obtained from ISTAT, while $Airport\ size$ data were provided by Eurostat. Finally, data for $Fuel$, i.e., the average cost of gasoline, diesel, LPG, and the relative number of light vehicles at national level, were obtained from MiSE (*Ministero dello sviluppo economico*) and ACI[9].

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[9] AISCAT data were retrieved from `http://www.aiscat.it/english/pubblicazioni.htm?ck=1&nome=pubblicazioni&idl=4`. ACI data were retrieved from `http://www.aci.it/laci/studi-e-ricerche/dati-e-statistiche/autoritratto.html` and their light vehicle data, at both municipality and national levels, are missing for the year 2001; therefore, they have been considered the same as those for 2002. ISTAT data were retrieved from `http://dati.istat.it/`. Eurostat data were retrieved from `https://ec.europa.eu/eurostat/web/transport/data/database`. MiSE data were

It should be noted that to avoid an overly unbalanced panel dataset, we excluded from our dataset *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 (in 2014, 2015, and 2016, respectively); that is, after the opening of several HSR sections. Likewise we also excluded *T1 Traforo del Monte Bianco*, *T2 Traforo del Gran S. Bernardo*, and *T4 Traforo del Fréjus* Alpine tunnels because their characteristics (e.g., traffic, length, and toll fare) are very different from those of the other motorway sectors, and as such, they are not suitable to be in the control group. Finally, we excluded the *A1 Firenze–Roma* motorway sector because the competitive HS line connecting the two cities had been in operation before 1992.

The rationale for using $HSR^{Opening}$ as our treatment variable is the fact that it can capture any degree of local competition between motorway and HSR because both transport modes connect the same city-pairs located at relatively short distances from each other. The only exception is the Verona–Bologna link where the motorway sector connects the two cities passing through Modena.

It is worth noting that unlike previous studies that opted to measure the effect of intra-modal competition in terms of market shares, our $HSR^{Competition}$ treatment variable considers the competition between HSR operators as a measure of augmented supply at lower fares. Indeed, although *NTV*'s market penetration has been especially rapid[10], *Trenitalia* also reacted by increasing both its capacity and demand[11]. The literature attributes this marked increase in passenger numbers to the maturity of the HSR network as well as to the competition effects (Cascetta and Coppola, 2015). Following the entry of the new operator, travellers enjoyed not only an average reduction in HS fares (as discussed in Section 2.2.2) but also a differentiation of tariffs (e.g., from simple 1st and 2nd classes to the Executive, Business, Premium, and Standard classes), a differentiation of prices (e.g., Base, Economy, and Super-Economy prices), new stations of origin and destination (e.g., Rome Tiburtina and Milan Porta Garibaldi secondary stations), and a better quality of ancillary services (e.g., Wi-Fi and agreements with local tourist attractions). Since we can reasonably expect that all these changes favoured travellers with a low willingness to pay[12], the coefficient associated with $HSR^{Competition}$ seeks to

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retrieved from `https://dgsaie.mise.gov.it/prezzi_carburanti_annuali.php`. Finally, RFI website is `http://www.rfi.it/rfi/LINEE-STAZIONI-TERRITORIO`, *NTV* website is `https://italospa.italotreno.it/societa/la-storia/cinque-anni-di-italo.html`, while *Automap* website is `https://www.automap.it/`.

[10] *NTV* passengers rose from 2 million in 2012 to 12.8 million in 2017. In 2013, *NTV* held the 25% of the HS market share (Bergantino et al., 2015; Nuovo Trasporto Viaggiatori, 2017).

[11] For instance, on the Milan–Rome–Naples line, the supply of HS *Trenitalia* services rose from 71 daily departures in 2009 to 89 in 2012 (Cascetta and Coppola, 2014). On its commercial long-distance services, *Trenitalia* passengers rose from 18.7 million in 2010 to 45 million in 2014 (Beria and Grimaldi, 2011; Dell'Alba and Velardi, 2015).

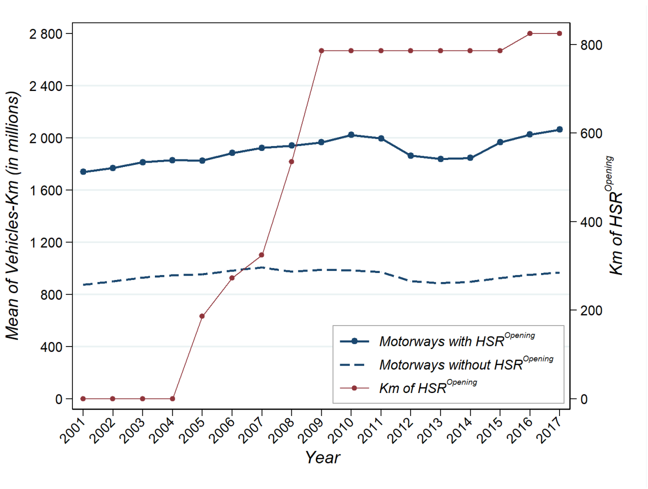
[12] Even though there is evidence of the existence of price leadership in a competitive transport market (Bergantino et al., 2018), previous studies found that direct competition between the two HSR operators led to an average fare reduction of 31% in one year and 34% over two years (Cascetta and Coppola, 2014; Cascetta and Coppola, 2015). Consistent with this, Beria et al., 2016 showed that between September 2013

capture whether on-track competition led to a stronger modal shift from motorway to HSR services.

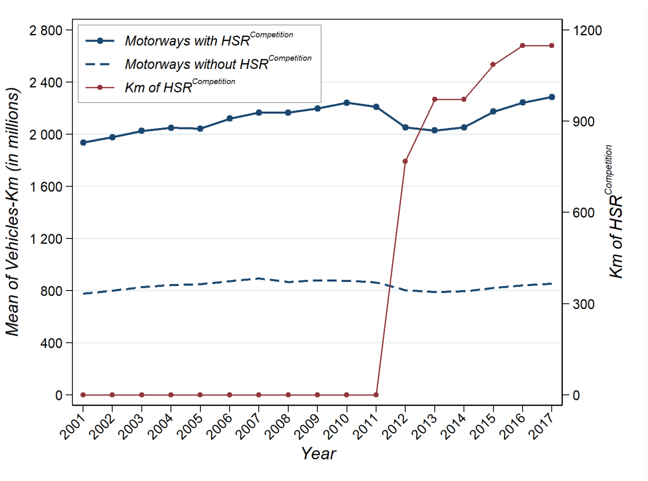
To reinforce the argument for the use of the difference-in-differences methodology, a graphical representation of the common trend assumption is needed. To

Fig. 2.2: Evolution of the average number of km travelled by light vehicles on motorway sectors with and without either $HSR^{Opening}$ or $HSR^{Competition}$, 2001-2017

(a) $HSR^{Opening}$



(b) $HSR^{Competition}$



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and December 2014 the incumbent reduced its economy class prices by about 15% on the Milan–Ancona route.

this end, Figure 2.2 plots the temporal pattern of the treatments that we exploit, together with the evolution of the average number of km travelled by light vehicles on two different types of motorway sector: the first (solid line) includes the treated sectors that experienced either an HSR opening on the same route (Figure 2.2a), or the opening of on-track competition on the adjacent HS or conventional line (Figure 2.2b); the second (dashed line) includes the non-treated sectors that experienced neither of the two phenomena. Even though motorway traffic is, on average, significantly higher in the treated groups, it is clear how the two trends in both scenarios follow a very similar path not only before treatment, but throughout all the period of analysis. Graphically, there is no clear evidence of the possible impact of $HSR^{Opening}$ or $HSR^{Competition}$ in reducing motorway traffic. Note that the 2013 fall in motorway traffic and the subsequent recovery seem more pronounced in the treated groups.

Finally, it could be argued that the non-random route placement of HSR might bias our estimates. In relation to this issue, we can plausibly assume that, conditional on the controls and fixed effects in our quasi-experimental setting, $HSR^{Opening}$ and $HSR^{Competition}$ are exogenous with respect to the total km travelled by light vehicles on the adjacent motorway sectors.

One reason for this is that the decision was taken to build a large part of the HSR network next to highways so as to prevent further land consumption (Beria et al., 2018). Thus, when the route plan is based primarily on geographical factors (e.g., topography and geomorphology) so as to minimize construction costs, the possible endogeneity caused by the non-random location is significantly reduced (Faber, 2014; Yu et al., 2018).

Moreover, the decision on where to locate HSR was also driven by the need to complete the TEN-T corridors, coordinated and co-financed by the European Union (European Court of Auditors, 2018). Designed initially in the ‘90s (Vickerman et al., 1999), they consist of nine core corridors of road, rail, airport, and port infrastructure aimed at promoting long-distance and high-speed intermodal routes across Europe by 2030. All of the Italian HSR network is built along four of these corridors, which cross the country from north to south and from west to east: the Scandinavian–Mediterranean corridor, the Mediterranean corridor, the Rhine–Alpine corridor, and the Baltic–Adriatic corridor (European Parliament and Council, 2013). Since TEN-T investments are focused essentially on achieving faster, more efficient freight transportation, the HSR location can reasonably be assumed to be exogenous with respect to the total km travelled by light vehicles on the adjacent motorway sectors because our analysis excludes heavy vehicles.

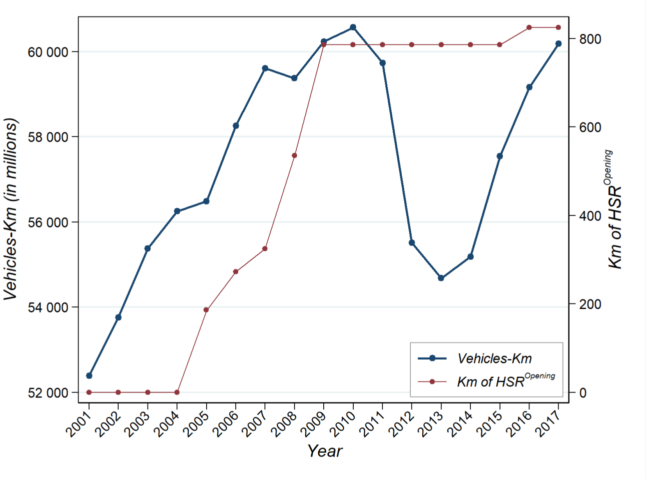
2.3.2 Trends and descriptive statistics

For the period 2001-2017, Figure 2.3 plots the evolution of the total km travelled by light vehicles on the national tolled motorway network vs. the expansion of $HSR^{Opening}$ (Figure 2.3a) and $HSR^{Competition}$ (Figure 2.3b), showing the temporal pattern of the treatments that we exploit. After peaking in 2010, motorway traffic experienced a slump until 2013, coinciding with the maximum number of km of HS lines in operation. However, over the next 4 years the traffic volume recovered its previous level. This pattern suggests the importance of disentangling the possible impact of HSR expansion in reducing motorway traffic from other confounding factors, such as the global economic crisis. The same explanation applies to Figure 2.3b, where both the expansion of on-track competition (started in 2012), and the total km travelled by light vehicles show a parallel increasing trend from 2013 onwards.

Table 2.1 reports the descriptive statistics for the variables in Equation 2.1 (Panel A) and Equation 2.2 (Panel B), differentiated for the treatment and control

Fig. 2.3: Evolution of the total km travelled by light vehicles on motorway sectors vs. the expansion of $HSR^{Opening}$ and $HSR^{Competition}$, 2001-2017

(a) $HSR^{Opening}$



(b) $HSR^{Competition}$

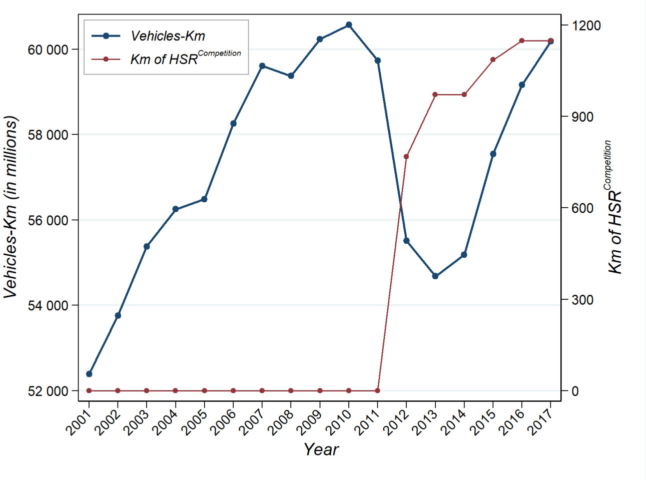


Table 2.1: Descriptive statistic

Panel A	Mean and Standard deviation With $HSR^{Opening}$	 W/out $HSR^{Opening}$	Test of significance of difference
$\log(Vehicles-Km)$	7.300 (0.740)	6.504 (0.890)	***
$HSR^{Opening}$	0.554 (0.470)	0 (0.000)	***
$Vehicles$	0.604 (0.052)	0.656 (0.227)	**
GDP	30.219 (5.121)	28.361 (5.413)	***
Airport size	7.810 (5.178)	2.324 (3.151)	***
Sector length	103.82 (56.81)	100.22 (58.60)	
$Toll$	6.979 (1.599)	8.061 (3.312)	***
$Fuel$	128.65 (21.75)	128.84 (21.69)	

Panel B	Mean and Standard deviation With $HSR^{Competition}$	 W/out $HSR^{Competition}$	Test of significance of difference
$\log(Vehicles-Km)$	7.409 (0.747)	6.436 (0.845)	***
$HSR^{Competition}$	0.262 (0.422)	0 (0.000)	***
$Vehicles$	0.606 (0.046)	0.658 (0.232)	**
GDP	30.007 (4.427)	28.327 (5.592)	***
Airport size	5.977 (5.161)	2.550 (3.486)	***
Sector length	122.75 (63.86)	94.91 (55.24)	***
$Toll$	6.904 (1.539)	8.135 (3.366)	***
$Fuel$	128.65 (21.74)	128.85 (21.69)	

Notes: Significance values: ***$p<0.001$, **$p<0.01$, *$p<0.05$.

groups previously described. On average, the logarithm of the total km travelled by light vehicles is found to be larger on motorway sectors that experienced either an HSR opening on the same route, or the opening of on-track competition on the adjacent HS or conventional line. As expected, the average GDP per capita and the number of passengers carried by domestic flights are higher in the area surrounding these sectors. In contrast, the average number of light vehicles per capita is lower for municipalities located within the highway catchment area of treated sectors, as is the average revenue per km travelled. Finally, the average sector length is almost the same for the two groups in Panel A (but it differs in Panel B), while the average cost of fuel is the same given that it is calculated at the national level. The table also reports the significance of the test of difference in mean.

2.4 Results

Tables 2.2 and 2.3 report the baseline regression results for Equations 2.1 and 2.2, respectively. Models (1) and (2) are pooled OLS estimations. Models (3) and (4) add fixed effects to control for all the different time-invariant factors that may directly affect traffic volumes across motorway sectors. Models (5) and (6) include year dummies to control for the common time trend, such as the impact of the global economic crisis on motorway traffic. Models (7) and (8) also add GDP-by-year fixed effects to capture any regional shocks that might influence the economic activity surrounding the highway area. $Toll$ and $Fuel$ variables could be relevant in explaining car travel demand, however, it might be argued that they may be endogenous with respect to the total km travelled by light vehicles. Therefore, Models (1), (3), (5) and (7) seek to show that these two variables do not affect our results. Indeed, when excluded, the estimated coefficients are not significantly different to the values obtained when they are included. For simplicity, in this section we only discuss the estimates obtained using Model (8) because it is the most complete and extended specification in relation to our data, as confirmed by a comparison of R^2 values and standard errors[13].

Table 2.2: Effect of $HSR^{Opening}$ on the total km travelled by light vehicles on motorway sectors (baseline estimates)

	log($Vehicles-Km$)							
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
$HSR^{Opening}$	0.275	0.297	0.084***	0.082***	0.050**	0.050**	0.041**	0.040*
	(0.190)	(0.194)	(0.020)	(0.020)	(0.020)	(0.020)	(0.019)	(0.020)
$Vehicles$	-1.204***	-0.907***	0.211**	0.157	0.147*	0.162	0.113	0.162
	(0.223)	(0.269)	(0.095)	(0.137)	(0.082)	(0.133)	(0.077)	(0.140)
GDP	0.015	0.017	0.012***	0.015***	0.013*	0.012	0.010*	0.006
	(0.017)	(0.017)	(0.004)	(0.005)	(0.007)	(0.008)	(0.006)	(0.009)
$Airport\ size$	0.058***	0.053***	0.014	0.014	-0.018**	-0.018**	-0.010	-0.010
	(0.016)	(0.016)	(0.010)	(0.010)	(0.008)	(0.008)	(0.008)	(0.008)
$Sector\ length$	0.010***	0.010***	0.011***	0.011***	0.011***	0.011***	0.011***	0.011***
	(0.001)	(0.001)	(0.003)	(0.003)	(0.003)	(0.003)	(0.003)	(0.003)
$Toll$		-0.044		0.007		-0.002		-0.007
		(0.031)		(0.008)		(0.007)		(0.007)
$Fuel$		0.002		-0.000				
		(0.002)		(0.000)				
$Constant$	5.798***	5.702***	5.042***	4.958***	5.063***	5.096***	5.150***	5.270***
	(0.545)	(0.648)	(0.292)	(0.271)	(0.353)	(0.371)	(0.311)	(0.368)
Motorway	No	No	Yes	Yes	Yes	Yes	Yes	Yes
Year	No	No	No	No	Yes	Yes	Yes	Yes
GDP x Year	No	No	No	No	No	No	Yes	Yes
Observations	877	877	877	877	877	877	877	877
R^2	0.653	0.666	0.386	0.390	0.554	0.555	0.580	0.583

Notes: All specifications present OLS estimates and include motorway sector, year, and GDP-by-year fixed effects as indicated. Standard errors clustered at the highway level are in parentheses. Significance values: ***p<0.01, **p<0.05, *p<0.10.

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[13] Note that moving from the most conservative Model (1) to the most extended Model (8), the magnitude of the coefficients associated with $HSR^{Opening}$ decreases without leading to an increase in the standard error. Most importantly, the coefficients remain positive and statistically significant.

In Table 2.2, the coefficient associated with $HSR^{Opening}$ shows that HSR expansion did not lead to a modal shift from motorway to HSR services, since it is positive and statistically significant at the 10% level. Based on the semi-log regression interpretation provided by Thornton and Innes (1989), this coefficient indicates that, holding constant the other variables, a 10 percentage points increase in HSR length leads, on average, to a 0.41% increase in the total km travelled by light vehicles on the adjacent motorway sectors. Thus, our first interpretation is that the two transport modes are non-competing. As for the relationship between our control variables and the dependent variable, the $Vehicles$, GDP, and $Airport\ size$ coefficients present the expected sign. Indeed, it is reasonable for an increase in both the number of light vehicles per capita and the average GDP per capita in the surrounding area of motorway sectors to produce an increase in traffic volumes. On the other hand, it is reasonable for an increase in the number of passengers carried by domestic flights to induce a fall in the total km travelled by light vehicles, meaning that an improvement in the capacity of the airline sector may have a positive impact on traffic reduction. However, neither value is statistically significant. The $Sector\ length$ variable shows that an additional km of motorway is associated with an average 1.11% increase in the total km travelled by light vehicles. Finally, the $Toll$ variable is not significant, although its coefficient also presents the expected sign[14].

In Table 2.3, the coefficient associated with $HSR^{Competition}$ shows that the opening of on-track competition between the incumbent *Trenitalia* and the new operator NTV did not lead to a modal shift from motorway to HSR services either. Indeed, the coefficient is still positive and statistically significant at the 10% level. In this case, the coefficient indicates that a 10 percentage points increase in the length of HS or conventional lines subject to intra-modal competition leads, on average, to a 0.59% increase in the total km travelled by light vehicles on the adjacent motorway sectors. Coherent with our previous interpretation, if the two transport modes are non-competing, it is reasonable to expect the $HSR^{Competition}$ coefficient to be larger than the $HSR^{Opening}$ coefficient because the former captures a delayed effect of the earlier treatment. The control variables present very similar outcomes to those reported above and the same explanations apply.

Thus, the empirical evidence provided by our results, so far, suggests that the increasing demand for HSR services is not the result of a modal shift from motorways. In all likelihood, it is the result of induced demand (i.e., the amount of new demand originating from travellers that did not travel at all before the introduction of HSR or who have increased the frequency of their trips thanks to HSR) and mode substitution from other modes of transport. Yet, the slightly positive impact of HSR expansion on motorway traffic may have been due, first, to a positive impact of HSR on surrounding economic activities, which could have led to an increase in the total number of car journeys along those routes; and, second, to a negative impact of HSR on conventional rail services, which could have led to an unintended increase in car dependency (see Section 2.6 for a more detailed discussion).

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[14] Note that the loss of statistical significance of the control variables is due to the saturation of the models through the inclusion of the full sets of motorway sector, year, and GDP-by-year fixed effects, as they capture most of the variability.

Table 2.3: Effect of $HSR^{Competition}$ on the total km travelled by light vehicles on motorway sectors (baseline estimates)

	$\log(Vehicles - Km)$							
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
$HSR^{Competition}$	0.305*	0.348*	0.064**	0.060**	0.062*	0.062*	0.059*	0.057*
	(0.173)	(0.176)	(0.026)	(0.027)	(0.032)	(0.032)	(0.032)	(0.033)
$Vehicles$	-1.203***	-0.899***	0.201*	0.147	0.153*	0.165	0.123	0.169
	(0.221)	(0.268)	(0.100)	(0.145)	(0.082)	(0.130)	(0.075)	(0.134)
GDP	0.015	0.017	0.011***	0.015***	0.014*	0.013	0.011*	0.007
	(0.017)	(0.017)	(0.004)	(0.005)	(0.007)	(0.009)	(0.006)	(0.009)
$Airport\ size$	0.063***	0.058***	0.021*	0.021*	-0.014*	-0.014	-0.006	-0.005
	(0.015)	(0.016)	(0.011)	(0.011)	(0.008)	(0.008)	(0.007)	(0.007)
$Sector\ length$	0.010***	0.009***	0.011***	0.011***	0.011***	0.011***	0.011***	0.011***
	(0.001)	(0.001)	(0.003)	(0.003)	(0.003)	(0.003)	(0.002)	(0.003)
$Toll$		-0.045		0.006		-0.002		-0.006
		(0.031)		(0.008)		(0.007)		(0.007)
$Fuel$		0.002		-0.000				
		(0.002)		(0.000)				
$Constant$	5.801***	5.698***	5.055***	4.954***	5.028***	5.053***	5.112***	5.225***
	(0.549)	(0.646)	(0.308)	(0.279)	(0.353)	(0.372)	(0.312)	(0.370)
Motorway	No	No	Yes	Yes	Yes	Yes	Yes	Yes
Year	No	No	No	No	Yes	Yes	Yes	Yes
GDP x Year	No	No	No	No	No	No	Yes	Yes
Observations	877	877	877	877	877	877	877	877
R^2	0.652	0.665	0.375	0.379	0.558	0.558	0.585	0.588

Notes: All specifications present OLS estimates and include motorway sector, year, and GDP-by-year fixed effects as indicated. Standard errors clustered at the highway level are in parentheses. Significance values: ***p<0.01, **p<0.05, *p<0.10.

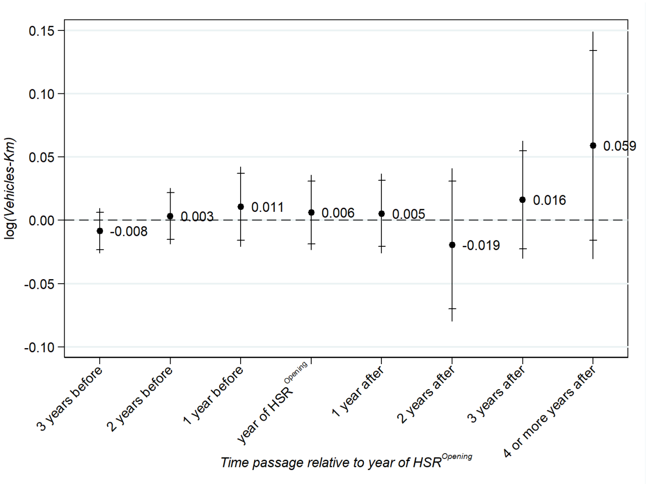
2.5 Robustness Checks

2.5.1 Parallel trend assumption and timing of the effects

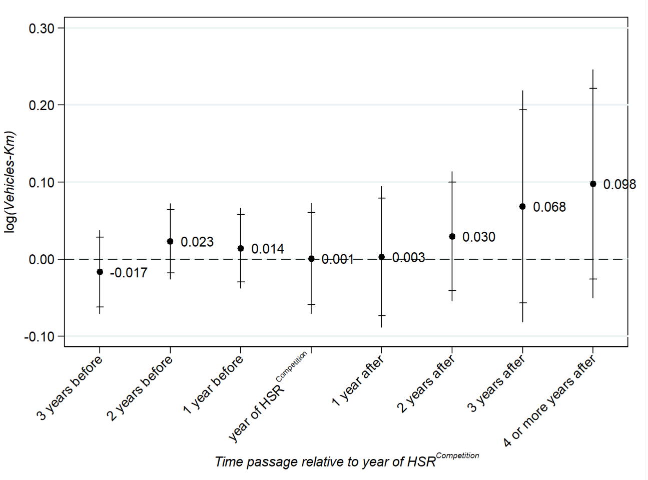
To provide evidence of the reliability of our previous estimates, we need to check the validity of the specifications. The key assumption is the parallel pre-treatment trend. That is, before treatment, the total km travelled by light vehicles on motorway sectors that experienced either an HSR opening on the same route, or the opening of on-track competition on the adjacent HS or conventional line, should present no significant differences with respect to the total km travelled on motorway sectors that experienced neither of these two events. To verify this assumption, and to investigate the timing of the effects, we augmented the difference-in-differences regressions with leads and lags before and after both treatments, as proposed by Autor (2003). To facilitate visualization, Figure 2.4 shows the plots of the lead and lag coefficients with 90% and 95% confidence intervals for our preferred Model (8) of both Appendix Tables D and E.

Fig. 2.4: Timing of $HSR^{Opening}$ and $HSR^{Competition}$ effects on the total km travelled by light vehicles on motorway sectors

(a) $HSR^{Opening}$



(b) $HSR^{Competition}$



Notes: Vertical bands represent ± 1.645 and ± 1.96 times the standard error of each point estimate.

The coefficients for the three years before the introduction of both treatments are close to zero and not statistically significant, which verifies the parallel pre-treatment trend assumption. Between the year of $HSR^{Opening}$ and $HSR^{Competition}$ and all the subsequent years, the coefficients fluctuate with an increasing trend between 0.006-0.059 and 0.001-0.098 log points, respectively, indicating that the HSR expansion took some time to be sufficiently mature to induce an unintended growth of traffic volume; however, they are still not statistically significant. Incidentally, what matters here is that we can exclude any reverse causality issue, as the two patterns provide robust evidence that it is the HSR expansion that led to an increase in motorway traffic rather than the other way round.

2.5.2 Placebo test

Methodologically, our difference-in-differences estimates rely on the assumption that, in the absence of both $HSR^{Opening}$ and $HSR^{Competition}$, the differences in the total km travelled by light vehicles on motorway sectors between treatment and control groups would have remained constant. To assess the validity of this assumption, we perform a falsification test by randomly assigning our treatments to motorway sectors that, in reality, experienced neither of the two events. In so doing, the true treated motorway sectors fall within the control group. If our baseline estimates in Section 2.4 are correctly reflecting the causal effect of HSR expansion

Table 2.4: Effect of $HSR^{Opening}$ on the total km travelled by light vehicles on motorway sectors (placebo estimates)

	$\log(Vehicles - Km)$							
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
$HSR^{Opening}$	-0.483***	-0.482***	0.012	0.011	-0.010	-0.011	-0.004	-0.006
	(0.156)	(0.164)	(0.042)	(0.043)	(0.044)	(0.043)	(0.041)	(0.039)
$Vehicles$	-1.110***	-0.853***	0.162*	0.099	0.122	0.138	0.089	0.141
	(0.254)	(0.299)	(0.089)	(0.131)	(0.073)	(0.124)	(0.068)	(0.130)
GDP	0.010	0.013	0.009*	0.014***	0.012	0.011	0.009	0.005
	(0.016)	(0.016)	(0.004)	(0.004)	(0.007)	(0.008)	(0.006)	(0.008)
$Airport\ size$	0.067***	0.062***	0.016	0.016	-0.018**	-0.018**	-0.009	-0.009
	(0.014)	(0.014)	(0.010)	(0.010)	(0.009)	(0.009)	(0.008)	(0.008)
$Sector\ length$	0.009***	0.009***	0.011***	0.011***	0.011***	0.011***	0.011***	0.011***
	(0.001)	(0.001)	(0.003)	(0.003)	(0.003)	(0.002)	(0.003)	(0.003)
$Toll$		-0.040		0.007		-0.002		-0.007
		(0.032)		(0.008)		(0.007)		(0.007)
$Fuel$		0.004**		0.000				
		(0.002)		(0.000)				
$Constant$	5.945***	5.588***	5.143***	4.996***	5.091***	5.124***	5.176***	5.299***
	(0.519)	(0.595)	(0.326)	(0.295)	(0.369)	(0.384)	(0.318)	(0.371)
Motorway	No	No	Yes	Yes	Yes	Yes	Yes	Yes
Year	No	No	No	No	Yes	Yes	Yes	Yes
GDP x Year	No	No	No	No	No	No	Yes	Yes
Observations	877	877	877	877	877	877	877	877
R^2	0.668	0.680	0.362	0.368	0.546	0.547	0.575	0.578

Notes: All specifications present OLS estimates and include motorway sector, year, and GDP-by-year fixed effects as indicated. Standard errors clustered at the highway level are in parentheses. Significance values: ***p<0.01, **p<0.05, *p<0.10.

Table 2.5: Effect of $HSR^{Competition}$ on the total km travelled by light vehicles on motorway sectors (placebo estimates)

	$\log(Vehicles - Km)$							
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
$HSR^{Competition}$	-0.380**	-0.337*	-0.035	-0.039	-0.013	-0.014	-0.003	-0.003
	(0.160)	(0.168)	(0.037)	(0.039)	(0.042)	(0.042)	(0.038)	(0.039)
$Vehicles$	-1.157***	-0.911***	0.185*	0.118	0.123	0.138	0.088	0.139
	(0.243)	(0.281)	(0.099)	(0.142)	(0.080)	(0.132)	(0.072)	(0.136)
GDP	0.012	0.015	0.006	0.012***	0.012	0.011	0.009	0.005
	(0.017)	(0.017)	(0.004)	(0.004)	(0.007)	(0.008)	(0.006)	(0.009)
$Airport\ size$	0.066***	0.062***	0.018*	0.018*	-0.017**	-0.017*	-0.009	-0.009
	(0.015)	(0.015)	(0.009)	(0.010)	(0.008)	(0.009)	(0.009)	(0.008)
$Sector\ length$	0.010***	0.009***	0.011***	0.011***	0.011***	0.011***	0.011***	0.011***
	(0.001)	(0.001)	(0.003)	(0.003)	(0.003)	(0.003)	(0.003)	(0.003)
$Toll$		-0.039		0.008		-0.002		-0.007
		(0.032)		(0.009)		(0.007)		(0.007)
$Fuel$		0.003*		-0.000				
		(0.002)		(0.000)				
$Constant$	5.903***	5.613***	5.182***	5.022***	5.097***	5.129***	5.177***	5.298***
	(0.551)	(0.628)	(0.323)	(0.293)	(0.374)	(0.386)	(0.322)	(0.373)
Motorway	No	No	Yes	Yes	Yes	Yes	Yes	Yes
Year	No	No	No	No	Yes	Yes	Yes	Yes
GDP x Year	No	No	No	No	No	No	Yes	Yes
Observations	877	877	877	877	877	877	877	877
R^2	0.654	0.665	0.366	0.373	0.547	0.547	0.575	0.578

Notes: All specifications present OLS estimates and include motorway sector, year, and GDP-by-year fixed effects as indicated. Standard errors clustered at the highway level are in parentheses. Significance values: ***p<0.01, **p<0.05, *p<0.10.

on motorway traffic, we would expect the placebo estimates to be close to zero. Tables 2.4 and 2.5 report the placebo regressions. Again, limiting the discussion to Model (8) only, the coefficients associated with $HSR^{Opening}$ and $HSR^{Competition}$ are close to zero (-0.006 and -0.003, respectively) and not statistically significant, which verifies the validity of our identification strategy.

2.5.3 Stable unit treatment value assumption

To provide evidence that a possible violation of the *stable unit treatment value assumption* (SUTVA) is not affecting our estimates, we need to perform an additional robustness check. This assumption states that the potential outcome of one unit should be unaffected by the assignment of the treatment to the other units. In our quasi-experimental setting, this means that the total km travelled by light vehicles on each motorway sector should not be influenced by $HSR^{Opening}$ and $HSR^{Competition}$ on other motorway sectors. This “no interference” condition is

Table 2.6: Effect of $HSR^{Opening}$ on the total km travelled by light vehicles on motorway sectors (sub-sample estimates)

	$\log(Vehicles - Km)$							
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
$HSR^{Opening}$	0.453**	0.499**	0.088***	0.088***	0.055**	0.055**	0.043**	0.043**
	(0.177)	(0.194)	(0.020)	(0.021)	(0.021)	(0.020)	(0.019)	(0.020)
$Vehicles$	-1.124***	-1.041***	0.302***	0.211	0.209**	0.199	0.192***	0.268
	(0.237)	(0.326)	(0.066)	(0.183)	(0.082)	(0.210)	(0.060)	(0.183)
GDP	0.0123	0.012	0.014***	0.016**	0.015	0.015	0.015**	0.014*
	(0.020)	(0.021)	(0.004)	(0.006)	(0.010)	(0.010)	(0.007)	(0.008)
$Airport\ size$	0.048**	0.046**	0.011	0.016	-0.014	-0.014	-0.007	-0.008
	(0.020)	(0.020)	(0.011)	(0.010)	(0.009)	(0.010)	(0.009)	(0.010)
$Sector\ length$	0.009***	0.009***	0.012***	0.012***	0.012***	0.012***	0.012***	0.012***
	(0.002)	(0.002)	(0.003)	(0.003)	(0.003)	(0.003)	(0.003)	(0.003)
$Toll$		-0.010		0.008		0.001		-0.007
		(0.038)		(0.011)		(0.012)		(0.011)
$Fuel$		-0.002		-0.001				
		(0.002)		(0.000)				
$Constant$	5.758***	6.002***	4.730***	4.750***	4.762***	4.756***	4.742***	4.766***
	(0.621)	(0.795)	(0.277)	(0.245)	(0.427)	(0.405)	(0.330)	(0.332)
Motorway	No	No	Yes	Yes	Yes	Yes	Yes	Yes
Year	No	No	No	No	Yes	Yes	Yes	Yes
GDP x Year	No	No	No	No	No	No	Yes	Yes
Observations	605	605	605	605	605	605	605	605
R^2	0.674	0.676	0.464	0.472	0.579	0.579	0.600	0.603

Notes: All specifications present OLS estimates and include motorway sector, year, and GDP-by-year fixed effects as indicated. Standard errors clustered at the highway level are in parentheses. Significance values: ***p<0.01, **p<0.05, *p<0.10.

rarely verified in transport analyses because all routes within an highway network are connected to each other.

For instance, if we imagine the HSR network as a *hub-and-spoke* system, surrounding conventional rails (*spokes*) might act as feeders by linking to the nodes of the HSR routes (*hubs*) passengers who need to be connected with long-haul and faster trains. If this is the case, motorway sectors adjacent to those conventional rails might experience a reduction in the total km travelled.

To check that this possible phenomenon is not affecting our results, we perform the same analysis as in Section 2.4 but drop from the dataset all the non-treated motorway sectors directly connected to the nodes of the HSR routes. By so doing, we are able to compare the total km travelled by light vehicles on the treated motorway sectors with respect to those travelled on a sub-sample of control motorway sectors that are distant from the treated, for which the *hub-and-spoke* dynamic is less plausible. Tables 2.6 and 2.7 report the sub-sample regressions. Again, limiting the discussion to Model (8), the coefficients associated with $HSR^{Opening}$ and $HSR^{Competition}$ are very close to those of the baseline (0.043 and 0.058, respec-

Table 2.7: Effect of $HSR^{Competition}$ on the total km travelled by light vehicles on motorway sectors (sub-sample estimates)

	log($Vehicles - Km$)							
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
$HSR^{Competition}$	0.414**	0.429**	0.068***	0.064**	0.067**	0.067**	0.059**	0.058**
	(0.153)	(0.171)	(0.021)	(0.023)	(0.026)	(0.026)	(0.026)	(0.027)
$Vehicles$	-1.193***	-1.168***	0.292***	0.212	0.220***	0.216	0.204***	0.292*
	(0.191)	(0.261)	(0.070)	(0.194)	(0.076)	(0.199)	(0.052)	(0.160)
GDP	0.020	0.020	0.014***	0.016***	0.016	0.016	0.015**	0.014*
	(0.021)	(0.022)	(0.004)	(0.005)	(0.010)	(0.010)	(0.008)	(0.008)
$Airport\ size$	0.035**	0.035**	0.024**	0.027***	-0.008	-0.008	-0.001	-0.003
	(0.014)	(0.014)	(0.009)	(0.008)	(0.007)	(0.009)	(0.009)	(0.010)
$Sector\ length$	0.010***	0.010***	0.013***	0.012***	0.012***	0.012***	0.013***	0.013***
	(0.002)	(0.002)	(0.004)	(0.004)	(0.004)	(0.004)	(0.003)	(0.004)
$Toll$		-0.003		0.007		0.000		-0.008
		(0.032)		(0.011)		(0.012)		(0.010)
$Fuel$		-0.000		-0.000				
		(0.002)		(0.000)				
$Constant$	5.662***	5.720***	4.689***	4.676***	4.720***	4.718***	4.680***	4.698***
	(0.648)	(0.827)	(0.415)	(0.365)	(0.546)	(0.519)	(0.417)	(0.422)
Motorway	No	No	Yes	Yes	Yes	Yes	Yes	Yes
Year	No	No	No	No	Yes	Yes	Yes	Yes
GDP x Year	No	No	No	No	No	No	Yes	Yes
Observations	612	612	612	612	612	612	612	612
R^2	0.701	0.702	0.451	0.457	0.635	0.635	0.667	0.671

Notes: All specifications present OLS estimates and include motorway sector, year, and GDP-by-year fixed effects as indicated. Standard errors clustered at the highway level are in parentheses. Significance values: ***p<0.01, **p<0.05, *p<0.10.

tively) and still positive and statistically significant. These results lend additional reliability to our previous findings.

2.5.4 Alternative specifications

Table 2.8 reports regression results of the most extended specification (i.e., the one that includes the full sets of motorway sector, year, and GDP-by-year fixed effects) with a different composition of the sample and alternative treatment variables. In particular, Models (1) and (2) perform the same baseline analyses but includes in the dataset also the motorway sectors previously excluded, as they seek to show that the sample restriction described in Section 2.3.1 is not driving our estimates. Indeed, the coefficients associated with $HSR^{Opening}$ and $HSR^{Competition}$ reveal no evidence of a modal shift because they are still positive, although only the former is statistically significant at the 10% level.

Subsequently, Model (3) explores an alternative measure of HSR expansion by using a dummy explanatory variable (rather than a continuous variable) that

Table 2.8: Effect of HSR expansion and HSR competition on the total km travelled by light vehicles on motorway sectors (estimates of alternative specifications)

	log(Vehicle-Km)			
	(1)	(2)	(3)	(4)
$HSR^{Opening}$	0.035*			
	(0.019)			
$HSR^{Competition}$		0.041		
		(0.032)		
$Dummy\_HSR^{Opening}$			0.033*	
			(0.018)	
$HSR^{Opening}$ x $HSR^{Competition}$				0.058
				(0.039)
$Vehicles$	0.077	0.077	0.156	0.167
	(0.105)	(0.103)	(0.141)	(0.137)
GDP	0.004	0.005	0.006	0.007
	(0.010)	(0.011)	(0.009)	(0.009)
$Airport\ size$	-0.003	0.000	-0.010	-0.004
	(0.009)	(0.008)	(0.007)	(0.007)
$Sector\ length$	0.010***	0.010***	0.011***	0.011***
	(0.003)	(0.003)	(0.003)	(0.003)
$Toll$	0.002	0.002	-0.007	-0.007
	(0.008)	(0.008)	(0.007)	(0.007)
$Constant$	5.144***	5.099***	5.272***	5.213***
	(0.401)	(0.406)	(0.370)	(0.375)
Motorway	Yes	Yes	Yes	Yes
Year	Yes	Yes	Yes	Yes
GDP x Year	Yes	Yes	Yes	Yes
Observations	953	953	877	877
R^2	0.447	0.448	0.582	0.587

Notes: All specifications present OLS estimates and include motorway sector, year, and GDP-by-year fixed effects as indicated. Standard errors clustered at the highway level are in parentheses. Significance values: ***p<0.01, **p<0.05, *p<0.10.

takes the value of 1 whether at least half of the HS line was opened adjacent to a motorway sector i in year t, and 0 otherwise. Also in this case, the coefficient associated with $Dummy\_HSR^{Opening}$ is consistent with the baseline provided by Table 2.2 and the same explanation applies.

Finally, an additional issue of interest is to empirically test whether the opening of on-track competition exclusively on HS lines had an impact in reducing motorway traffic. To do so, Model (4) estimates this effect by interacting the main explanatory variables of both Equations 2.1 and 2.2. The positive coefficient associated with $HSR^{Opening}$ x $HSR^{Competition}$ shows that competition between the incumbent *Trenitalia* and the new operator *NTV* on HS lines only did not lead to a modal shift from motorway to HSR services. However, its lack of statistical significance suggests that competition on the HSR network only did not lead to an increase in motorway traffic either. Thus, our first interpretation is that the complementary dynamics between the two transport modes are induced by the HSR expansion rather than competition on HS services (see Section 2.6 for a more detailed discussion).

2.6 Discussion

On the clear understanding that it lies beyond the scope of the current article to draw any general conclusions about HSR programmes, we nevertheless believe that our empirical analysis can provide a number of insights that are, moreover, in line with the findings of studies conducted elsewhere.

Since we have found no evidence of a modal shift from motorway to HSR services, the first insight to be gained is that in terms of modal substitution, modes of transport other than the motorway sector are contributing to the excellent demand performance of the Italian HSR network, as documented by Beria et al. (2018). Indeed, the set of studies reviewed by Givoni and Dobruszkes (2013) show that, in most cases, conventional rail is the main mode of origin for HSR passengers, with air transport in second position. Support for these findings in the Italian scenario is provided by Cascetta et al. (2011), who report that the majority of HS users on the Rome–Naples link were already train users, while the percentages of passengers who used the motorway before the HSR opening were just 7.8% on weekdays, 12.4% on Saturdays, and 14.4% on Sundays. Similarly, Bergantino et al. (2015) and Capozza (2016) shed light on the competitive pressure induced by HSR on airline companies operating on Italy's national routes. Moreover, induced demand could represent a third source of HSR passengers. As Cascetta and Coppola (2014) and Cascetta and Coppola (2015) stress, the contribution of induced demand to total HSR demand is initially low, but tends to rise gradually following the inauguration of the service.

Closely related to this point, the second insight suggests that HSR might have difficulties in attracting car passengers. Here, if we consider travel time as the main factor explaining the level of modal shift from motorway to HSR services, ultimately it is the door-to-door travel time, as opposed to the station-to-station travel time, that matters for the mode choice decision. In other words, access and egress times to/from HSR stations are other determining factors in the overall journey time (Moyano et al., 2018). It is for this reason that HSR investments need to be accompanied by improvements in both the spread of HSR stations and in their accessibility. Furthermore, Givoni and Dobruszkes (2013) remarked how travel time might not be the key parameter for road users, as travelling by car and coach always present advantages and more flexibility in terms of schedule (Bilotkach et al., 2010), route choice, cost (as group size increases), and luggage.

Then, with the premise that the slightly positive impact of HSR expansion on motorway traffic reported here should be interpreted with caution (as the coefficients of interest are barely significant), the third insight is that HSR may have had a positive effect on the economic activities of the surrounding area, which could have led to an increase in the total number of car journeys on these routes. Indeed, although both transport modes connect the same city-pairs, HSR is concerned more with attracting the *"primary"* traffic between a route's nodes (i.e., the largest cities), while motorways connect the *"secondary"* traffic between all the exits along a route, as the average distance travelled by car is significantly less than the average HSR section length. As such, given those differences in the demand characteristics, the two transport modes may interact in a complementary rather than competitive dynamic.

Finally, the last insight to be gained is that HSR development could lead to an unintended increase in car dependency, because while HSR expansion might attract car passengers, it may, at the same time, undermine conventional rail services. In other words, the reduction in demand for conventional rail services (due to the modal shift toward HSR services) may induce rail operators to cut investments in the conventional network. In turn, this deterioration in conventional rail services, combined with a reduction in their frequency of service, may induce passengers to opt for different modes of transport. For instance, the maturation of the HSR network and the entry of *NTV* increased the supply of fully high-speed services aimed at reducing travel time between city-pairs. These long-distance services, operated by *Frecciarossa* and *Italo* trains on dedicated tracks only, may have reduced commuting opportunities between intermediate stops, since the accessibility (and cost) of fully high-speed services cannot match that of mixed high-speed or conventional services. As a result, HSR expansion may lead to a reduction in rail connectivity for people living along the routes on which HSR has been implemented, and to an unintended increase in car dependency. This view is also supported by Sánchez-Mateos and Givoni (2012).

As highlighted by De Rus and Nombela (2007) and Beria and Grimaldi (2011), this opens up the debate as to whether the mobility needs of broad metropolitan areas (such as those found in Italy, where medium-sized towns are located at relatively short distances from each other), should rely more on a fully mixed high-speed model that allows interconnections with existing conventional lines rather than on a model that satisfies the "need for speed" of long-haul routes by exploiting dedicated tracks only. It should be borne in mind that a policy that promotes rail use at the expense of the car should carefully analyse the impact of HS on conventional rail services. Hence, improvements also in the conventional infrastructure and in the related services might induce to a real reduction in motorway traffic. These are relationships that shall we seek to understand in future research. Moreover, once freight trains start using the new HS lines, we shall test whether the HSR expansion leads to a modal shift of freight from motorways to HSR services.

2.7 Conclusions

The development of HSR has transformed modal market shares on the routes on which it has been implemented both by generating new demand and by replacing the demand for other modes of transport.

To date, most previous studies have focused on the inter-modal competition between air and rail and on the intra-modal competition between rail operators, while the literature examining competition between car and rail is scant. However, because the reduction in road traffic (and its negative environmental impact) is one of the key drivers offsetting HSR investments, our study has sought to analyse whether the HSR expansion in Italy has led to a modal shift from its motorways to HSR services.

We have empirically tested, first, whether HSR openings adjacent to some motorway sectors have reduced the total km travelled by light vehicles on these sectors during the period 2001-2017; and, second, whether this reduction has been persistent or even more evident after the opening of on-track competition on some adjacent HS and conventional lines between the incumbent *Trenitalia* and the new operator *NTV*, which entered the HS passenger market in 2012.

In so doing, we carried out a generalized difference-in-differences estimation using a unique 17-year panel dataset. This has enabled us to control for many unobservable confounding factors and to exploit the heterogeneous traffic data within all tolled motorway sectors in a quasi-experimental setting.

Our findings reveal that neither HSR openings nor the opening of on-track competition led to a modal shift from motorway to HSR services, as the two transport modes are non-competing. Conversely, HSR expansion had a slightly positive impact on motorway traffic. Indeed, a 10 percentage points increase in the HSR length leads, on average, to a 0.41% increase in the total km travelled by light vehicles on the adjacent motorway sectors.

2.8 Appendix

Table A: Opening dates of $HSR^{Opening}$ up to 2017

Section	Opening year(s)	Line length (km)	Maximum speed (km/h)	Treated motorway sector
Turin–Salerno axis		**873.5**		
Turin–Novara	February 2006	86.4	300	*A4 Torino–Milano*
Novara–Milan	December 2009	38.6	300	*A4 Torino–Milano*
Milan–Bologna	December 2008	182.0	300	*A1 Milano–Bologna*
Bologna–Florence	December 2009	78.5	300	*A1 Bologna–Firenze*
Florence–Rome	1977-1992	254.0	250	*A1 Firenze–Roma*[a]
Rome–Gricignano	December 2005	186.0	300	*A1 Roma–Napoli* and *A1 Coll. Firenze–Roma–Napoli*
Gricignano–Naples	December 2009	19.0	300	*A1 Roma–Napoli*
Naples–Salerno	June 2008	29.0	250	*A3 Napoli–Salerno*
Milan–Venice axis		**91.6**		
Milan–Treviglio	June 2007	27.0	200	*A4 Milano–Brescia*
Treviglio–Brescia	December 2016	39.6	300	*A4 Milano–Brescia*
Padua–Venice	March 2007	25.0	220	*A4-A57 Padova–Mestre*
Other lines[b]		**114.0**		
Verona–Bologna	July 2009	114.0	200	*A22 Verona–Modena*

[a] We exclude the *A1 Firenze–Roma* motorway sector from the analysis because the competitive HS section was already in operation since 1992.

[b] Short sectors of the Naples–Bari and Palermo–Messina–Catania lines were upgraded during the second half of 2017; however, precise data are not available.

Sources: Authors' own calculations based on Beria et al. (2018), RFI website, and *Trenitalia*'s financial statements.

Notes: Motorway sectors in the control group are *A4-A5 Ivrea–Santhià, A4 Brescia–Padova, A4-A23-A28-A34-A57 Venezia–Trieste, A5 Torino–Ivrea–Quincetto, A5 Quincetto–Aosta, A5 Sarre–Traforo del Monte Bianco, A6 Torino–Savona, A7 Genova–Serravalle, A7 Milano–Serravalle, A8-A9 Milano–Varese e Lainate–Como–Chiasso, A8-A26 Diramazione A8/A26, A10 Ventimiglia–Savona, A10 Savona–Genova, A11 Firenze–Pisa, A11-A12 Sestri–Livorno e Viareggio–Lucca, A12 Genova–Sestri, A12 Livorno–Rosignano, A12 Roma–Civitavecchia, A13 Bologna–Padova, A14 Bologna–Ancona, A14 Raccordo di Ravenna, A14 Ancona–Pescara, A14 Pescara–Canosa, A14 Canosa–Bari–Taranto, A15 Parma–La Spezia, A16 Napoli–Canosa, A18 Messina–Catania, A20 Messina–Palermo, A21 Torino–Piacenza, A21 Piacenza–Brescia, A22 Brennero–Verona, A23 Udine–Tarvisio, A24 Roma–Torano, A24 Torano–Teramo, A25 Torano–Pescara, A26 Voltri–Alessandria, A26 Alessandria–Gravellona Toce, A27 Mestre–Belluno, A30 Caserta–Nola-Salerno, A31 Valdastico, A32 Torino–Bardonecchia, A56 Tang.le di Napoli.*

Table B: Opening dates of $HSR^{Competition}$ up to 2017

Section	Opening year(s)	Line length (km)	Maximum speed (km/h)	Treated motorway sector
Turin–Salerno axis		**873.5**		
Turin–Milan	December 2012	125.0	300	*A4 Torino–Milano*
Milan–Bologna	April 2012	182.0	300	*A1 Milano–Bologna*
Bologna–Florence	April 2012	78.5	300	*A1 Bologna–Firenze*
Florence–Rome	April 2012	254.0	250	*A1 Firenze–Roma*[a]
Rome–Naples	April 2012	205.0	300	*A1 Roma–Napoli* and *A1 Collegamento Firenze–Roma–Napoli*
Naples–Salerno	August 2012	29.0	250	*A3 Napoli–Salerno*
Milan-Venice axis		**88.0**		
Brescia–Verona	March 2016	63.0	Conventional line	*A4 Brescia–Padova*
Padua–Venice	October 2012	25.0	220	*A4-A57 Padova–Mestre*
Other lines		**441.0**		
Verona–Bologna	December 2015	114.0	200	*A22 Verona–Modena*
Bologna–Padua	October 2012	123.0	Conventional line	*A13 Bologna–Padova*
Bologna–Ancona[b]	December 2013	204.0	Conventional line	*A14 Bologna–Ancona*

[a] We exclude the *A1 Firenze–Roma* motorway sector from the analysis to make Equation 2.1 and Equation 2.2 fully comparable.

[b] On-track competition lasted until December 2014, then *NTV* decided to keep only some seasonal services during summer to serve the holiday destinations (Beria et al., 2016).

Sources: Authors' own calculations based on Bergantino et al. (2015), *NTV* website, and *NTV*'s financial statements.

Notes: Motorway sectors in the control group are *A4-A5 Ivrea–Santhià, A4-A23-A28-A34-A57 Venezia–Trieste, A5 Torino–Ivrea–Quincetto, A5 Quincetto–Aosta, A5 Sarre–Traforo del Monte Bianco, A6 Torino–Savona, A7 Genova–Serravalle, A7 Milano–Serravalle, A8-A9 Milano–Varese e Lainate–Como–Chiasso, A8-A26 Diramazione A8/A26, A10 Ventimiglia–Savona, A10 Savona–Genova, A11 Firenze–Pisa, A11-A12 Sestri–Livorno e Viareggio–Lucca, A12 Genova–Sestri, A12 Livorno–Rosignano, A12 Roma–Civitavecchia, A14 Raccordo di Ravenna, A14 Ancona–Pescara, A14 Pescara–Canosa, A14 Canosa–Bari–Taranto, A15 Parma–La Spezia, A16 Napoli–Canosa, A18 Messina–Catania, A20 Messina–Palermo, A21 Torino–Piacenza, A21 Piacenza–Brescia, A22 Brennero–Verona, A23 Udine–Tarvisio, A24 Roma–Torano, A24 Torano–Teramo, A25 Torano–Pescara, A26 Voltri–Alessandria, A26 Alessandria–Gravellona Toce, A27 Mestre–Belluno, A30 Caserta–Nola-Salerno, A31 Valdastico, A32 Torino–Bardonecchia, A56 Tang.le di Napoli.*

Table C: Length of the Italian tolled motorway sectors, 2001 and 2017

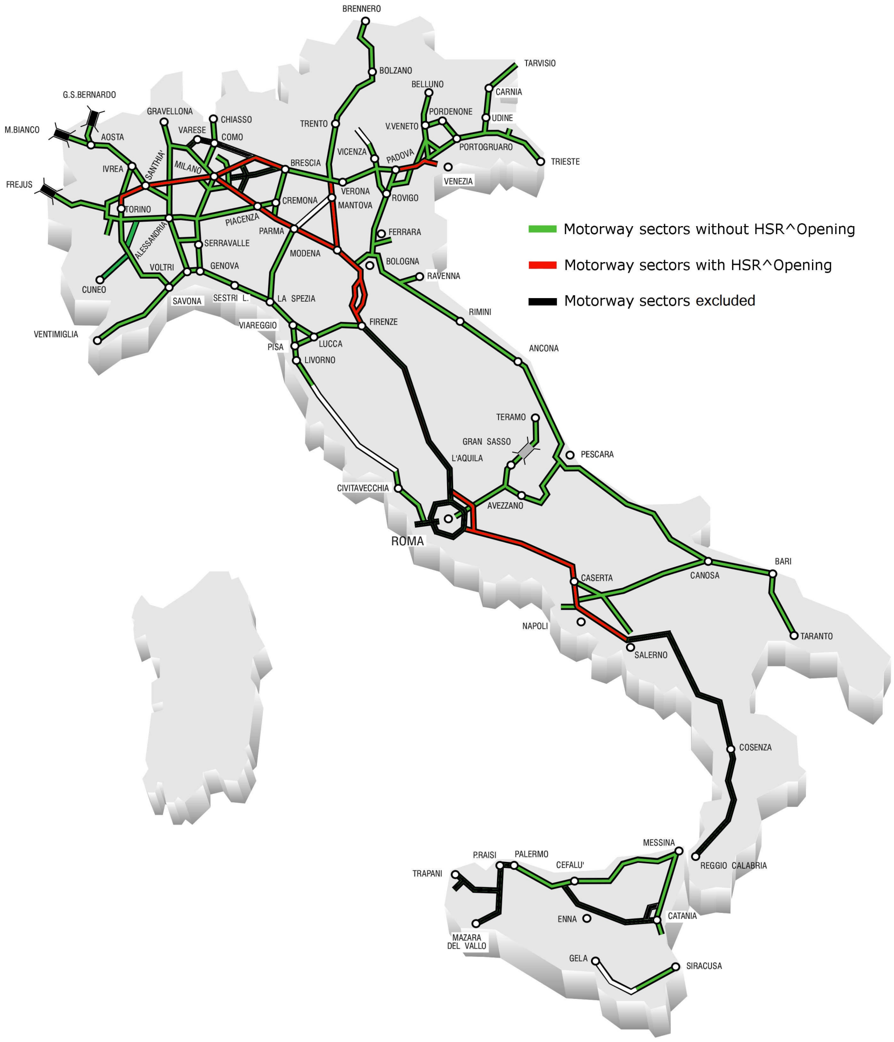
Motorway sector	Length		Motorway sector	Length	
	2001	2017		2001	2017
A1 Milano–Bologna	192.1	192.1	*A13 Bologna–Padova*	127.3	127.3
A1 Bologna–Firenze	91.1	91.1	*A14 Bologna–Ancona*	236.0	236.0
A1 Coll. Firenze–Roma–Napoli	45.3	45.3	*A14 Raccordo di Ravenna*	29.3	29.3
A1 Roma–Napoli	202.0	202.0	*A14 Ancona–Pescara*	133.8	133.8
A3 Napoli–Salerno	51.6	51.6	*A14 Pescara–Canosa*	239.3	239.3
A4 Ivrea–Santhià	23.6	23.6	*A14 Canosa–Bari–Taranto*	143.0	143.0
A4 Torino–Milano	127.0	127.0	*A15 Parma–La Spezia*	101.0	101.0
A4 Milano–Brescia	93.5	93.5	*A16 Napoli–Canosa*	172.3	172.3
A4 Brescia–Padova	146.1	146.1	*A18 Messina–Catania*	76.8	76.8
A4-A57 Padova–Mestre	23.3	74.1	*A20 Messina–Palermo*	140.6	181.8
A4 Venezia–Trieste	180.3	210.2	*A21 Torino–Piacenza*	164.9	164.9
A5 Torino–Ivrea–Quincinetto	51.2	51.2	*A21 Piacenza–Brescia*	88.6	88.6
A5 Quincinetto–Aosta	59.5	59.5	*A22 Brennero–Verona*	224.0	224.0
A5 Sarre–Traforo del Monte Bianco	27.0	32.4	*A22 Verona–Modena*	90.0	90.0
A6 Torino–Savona	130.9	130.9	*A23 Udine–Tarvisio*	101.2	101.2
A7 Genova–Serravalle	50.0	50.0	*A24 Roma–Torano*	79.5	79.5
A7 Milano–Serravalle	86.3	86.3	*A24 Torano–Teramo*	87.0	87.0
A8 Milano–Varese/A9 Lainate–Chiasso	77.7	77.7	*A25 Torano–Pescara*	114.9	114.9
A8-A26 Diramazione	24.0	24.0	*A26 Voltri–Alessandria*	83.7	83.7
A10 Ventimiglia–Savona	113.3	113.3	*A26 Alessandria–Gravellona Toce*	161.2	161.2
A10 Savona–Genova	45.5	45.5	*A27 Mestre–Belluno*	82.2	82.2
A11 Firenze–Pisa	81.7	81.7	*A30 Caserta–Nola–Salerno*	55.3	55.3
A11-A12 Sestri–Livorno/Viareggio–Lucca	154.9	154.9	*A31 Valdastico*	36.4	89.5
A12 Genova–Sestri	48.7	48.7	*A32 Torino–Bardonecchia*	72.4	75.7
A12 Livorno–Rosignano	36.6	45.4	*A33 Asti–Cuneo*[a]	39.4	55.7
A12 Roma–Civitavecchia	65.4	65.4	*A56 Tangenziale di Napoli*	20.2	20.2

[a] *A33 Asti–Cuneo* motorway sector started its operations in 2008.

Source: Authors' own elaboration based on AISCAT, 2017.

Notes: We excluded the motorway sectors described in Section 2.3.1.

Fig. A: $HSR^{Opening}$ expansion in Italy 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 2.2.1, and the sectors described in Section 2.3.1. The white motorway sectors are planned or under construction.

Fig. B: $HSR^{Competition}$ expansion in Italy 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 2.2.1, and the sectors described in Section 2.3.1. The white motorway sectors are planned or under construction.

Table D: Effect of $HSR^{Opening}$ on the total km travelled by light vehicles on motorway sectors (lead and lag estimates)

	$\log(Vehicles - Km)$							
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
3 years before	0.229	0.194	0.047***	0.045***	0.000	0.001	-0.008	-0.008
	(0.246)	(0.232)	(0.011)	(0.012)	(0.009)	(0.009)	(0.009)	(0.009)
2 years before	0.214	0.176	0.068***	0.064***	0.011	0.011	0.002	0.003
	(0.258)	(0.248)	(0.012)	(0.014)	(0.013)	(0.013)	(0.011)	(0.011)
1 year before	0.255	0.213	0.090***	0.088***	0.020	0.020	0.010	0.011
	(0.259)	(0.256)	(0.013)	(0.015)	(0.018)	(0.017)	(0.016)	(0.016)
year of $HSR^{Opening}$	0.275	0.241	0.111***	0.110***	0.020	0.020	0.006	0.006
	(0.260)	(0.259)	(0.014)	(0.016)	(0.016)	(0.016)	(0.015)	(0.015)
1 year after	0.240	0.204	0.104***	0.101***	0.024	0.024	0.006	0.005
	(0.270)	(0.273)	(0.018)	(0.020)	(0.020)	(0.020)	(0.016)	(0.016)
2 years after	0.205	0.159	0.065***	0.068***	0.003	0.003	-0.018	-0.019
	(0.249)	(0.261)	(0.021)	(0.021)	(0.032)	(0.032)	(0.030)	(0.030)
3 years after	0.252	0.236	0.110**	0.111**	0.037	0.038	0.015	0.016
	(0.237)	(0.243)	(0.044)	(0.042)	(0.025)	(0.025)	(0.022)	(0.023)
4 or more years after	0.177	0.214	0.140***	0.137***	0.079*	0.079*	0.061	0.059
	(0.279)	(0.294)	(0.045)	(0.046)	(0.043)	(0.044)	(0.043)	(0.044)
$Vehicles$	-1.211***	-0.925***	0.219**	0.168	0.154*	0.168	0.118	0.166
	(0.229)	(0.274)	(0.092)	(0.135)	(0.081)	(0.130)	(0.076)	(0.137)
GDP	0.014	0.017	0.012***	0.015***	0.015**	0.014	0.011*	0.007
	(0.017)	(0.018)	(0.004)	(0.005)	(0.007)	(0.009)	(0.006)	(0.009)
Airport size	0.060***	0.055***	0.014	0.015	-0.015*	-0.016*	-0.007	-0.007
	(0.017)	(0.017)	(0.011)	(0.011)	(0.008)	(0.008)	(0.008)	(0.008)
Sector length	0.010***	0.010***	0.011***	0.011***	0.011***	0.011***	0.011***	0.011***
	(0.001)	(0.001)	(0.003)	(0.003)	(0.003)	(0.003)	(0.003)	(0.003)
$Toll$		-0.043		0.006		-0.002		-0.007
		(0.031)		(0.008)		(0.007)		(0.007)
$Fuel$		0.002		-0.000				
		(0.002)		(0.000)				
$Constant$	5.831***	5.668***	5.040***	4.972***	5.015***	5.045***	5.101***	5.219***
	(0.562)	(0.659)	(0.295)	(0.263)	(0.354)	(0.374)	(0.313)	(0.372)
Motorway	No	No	Yes	Yes	Yes	Yes	Yes	Yes
Year	No	No	No	No	Yes	Yes	Yes	Yes
GDP x Year	No	No	No	No	No	No	Yes	Yes
Observations	877	877	877	877	877	877	877	877
R^2	0.649	0.662	0.388	0.392	0.556	0.556	0.583	0.585

Notes: All specifications present OLS estimates and include motorway sector, year, and GDP-by-year fixed effects as indicated. Standard errors clustered at the highway level are in parentheses. Significance values: ***p<0.01, **p<0.05, *p<0.10.

Table E: Effect of $HSR^{Competition}$ on the total km travelled by light vehicles on motorway sectors (lead and lag estimates)

	$\log(Vehicles - Km)$							
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
3 years before	0.581	0.563*	0.111***	0.123***	-0.003	-0.003	-0.017	-0.017
	(0.345)	(0.332)	(0.027)	(0.025)	(0.026)	(0.026)	(0.027)	(0.027)
2 years before	0.587	0.571	0.136***	0.141***	0.037	0.037	0.025	0.023
	(0.352)	(0.354)	(0.029)	(0.029)	(0.026)	(0.026)	(0.024)	(0.024)
1 year before	0.528	0.491	0.096***	0.093***	0.036	0.036	0.018	0.014
	(0.353)	(0.369)	(0.032)	(0.032)	(0.028)	(0.029)	(0.025)	(0.026)
year of $HSR^{Competition}$	0.462	0.376	0.004	0.008	0.021	0.020	0.006	0.001
	(0.353)	(0.379)	(0.034)	(0.037)	(0.034)	(0.035)	(0.035)	(0.035)
1 year after	0.493	0.442	0.014	0.018	0.019	0.018	0.011	0.003
	(0.360)	(0.382)	(0.036)	(0.037)	(0.039)	(0.041)	(0.043)	(0.045)
2 years after	0.280	0.281	0.028	0.029	0.047	0.046	0.039	0.030
	(0.375)	(0.397)	(0.033)	(0.033)	(0.036)	(0.036)	(0.044)	(0.042)
3 years after	0.364	0.440	0.123*	0.123*	0.085	0.084	0.078	0.068
	(0.396)	(0.408)	(0.065)	(0.065)	(0.066)	(0.069)	(0.073)	(0.074)
4 or more years after	0.451	0.551	0.203***	0.195***	0.112*	0.111	0.105	0.098
	(0.391)	(0.401)	(0.066)	(0.067)	(0.067)	(0.068)	(0.072)	(0.073)
$Vehicles$	-1.214***	-0.924***	0.197*	0.142	0.141	0.149	0.110	0.152
	(0.226)	(0.272)	(0.103)	(0.147)	(0.089)	(0.138)	(0.082)	(0.142)
GDP	0.015	0.017	0.011**	0.017***	0.014**	0.014	0.011*	0.007
	(0.017)	(0.017)	(0.004)	(0.005)	(0.007)	(0.009)	(0.006)	(0.009)
Airport size	0.061***	0.056***	0.017	0.015	-0.016**	-0.016*	-0.008	-0.008
	(0.016)	(0.016)	(0.010)	(0.010)	(0.008)	(0.008)	(0.008)	(0.008)
Sector length	0.010***	0.009***	0.011***	0.011***	0.011***	0.011***	0.011***	0.011***
	(0.001)	(0.001)	(0.003)	(0.003)	(0.003)	(0.003)	(0.003)	(0.003)
$Toll$		-0.043		0.006		-0.001		-0.006
		(0.031)		(0.008)		(0.008)		(0.007)
$Fuel$		0.002		0.000				
		(0.002)		(0.000)				
$Constant$	5.813***	5.679***	5.063***	4.897***	5.010***	5.029***	5.096***	5.213***
	(0.553)	(0.652)	(0.315)	(0.292)	(0.367)	(0.392)	(0.325)	(0.389)
Motorway	No	No	Yes	Yes	Yes	Yes	Yes	Yes
Year	No	No	No	No	Yes	Yes	Yes	Yes
GDP x Year	No	No	No	No	No	No	Yes	Yes
Observations	877	877	877	877	877	877	877	877
R^2	0.651	0.664	0.384	0.389	0.552	0.552	0.580	0.582

Notes: All specifications present OLS estimates and include motorway sector, year, and GDP-by-year fixed effects as indicated. Standard errors clustered at the highway level are in parentheses. Significance values: ***p<0.01, **p<0.05, *p<0.10.

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3

Panel data on municipality-to-municipality commuting patterns in Italy over the 1991, 2001, and 2011 censuses

Keywords

Commuting, Structural change, Urban and Regional economics

JEL Classification Numbers

R10, R12, R23, R40

Co–authors

This data article was co–authored with my co–supervisor, Dr. Antonio Accetturo, who contributed in identifying the data sources and designing the dataset structure.

Specifications Table

Subject	Economics
Specific subject area	Urban, Regional, Transport Economics
Type of data	Table, .dta file
How data were acquired	From various databases provided by *Istat*, the Italian national institute of statistics
Data format	Cleaned and labeled raw data
Parameters for data collection	Panel data of 2 210 148 observations on 736 716 municipality-to-municipality commuting patterns in Italy over the 1991, 2001, and 2011 censuses; combined with further municipality covariates on jobs location, population, and the distances in meters and journey times in minutes between all municipalities.
Description of data collection	Downloaded from various databases available at `https://www.istat.it/it/`
Data source location	Institution: *Istat*
Data accessibility	Available on request

3.1 Introduction

Structural transformation is defined as the shift of labour and other production factors from low-productivity to high-productivity economic activities. During the last decades, the different economic success of different industries shaped the performance of labor markets across locations. High tech sectors have increased much their productivity, while simple and routine type of occupations have experienced stagnant wages and employment, leading to a job “polarization” towards high skilled and low skilled occupations at the expense of middle skilled occupations (Acemoglu and Autor, 2011; David et al., 2013).

Similarly, in the past thirty years Italy has experienced a substantial deindustrialization in connection with a shift of economic activity to service industries, with neat effects on population dynamics (Accetturo et al., 2019). Moreover, the geography of local labour markets experienced a substantial change, as they decreased from 784 in 1991 to 686 in 2001, up to 611 in 2011. As a result, both time spent and distance travelled by agents commuting to and from work has considerably grown.

While this phenomenon has primarily encouraged studies to investigate the impact of transport infrastructure improvements on worker mobility (e.g., Baum-Snow, 2010; Heuermann and Schmieder, 2018) and urban dynamics (e.g., Duranton and Turner, 2012; Garcia-López et al., 2015; Ahlfeldt and Feddersen, 2017; Baum-Snow et al., 2017), the literature examining the impact of the structural transformation of the economy on commuting flows, on the other hand, is relatively scant (Monte et al., 2018; Brülhart et al., 2019).

3.2 Data

The dataset presented in this data article describes municipality-to-municipality commuting patterns in Italy over three consecutive censuses elaborated by *Istat* (*Istituto Nazionale di Statistica*) in the 1991, 2001, and 2011 years. The data stresses the spatial dimension of commuting flows by reporting the number of workers moving between municipalities, or within the same municipality.

In order to enrich analysis opportunities aimed at answering to different research questions, the core origin-destination dataset has been linked with further municipality covariates over the same time period, such as i) the exact information of the location of jobs across Italian municipalities, ii) the population and the local labour market of belonging of each municipality, and iii) the distances in meters and journey times in minutes between all municipalities, as well as a set of municipality characteristics.

This allows applied researchers to shed new lights on the changing shape of urban systems by analysing the relationship between increasing commuting patterns in Italy and the structural transformation of the economy due to the tertiarization process from 1991 to 2011. Furthermore, the possibility to extend this dataset with additional data sources on the infrastructural endowment may foster research in assessing the role of transportation in providing better job accessibility (Redding and Turner, 2015), affecting housing prices (Levkovich et al., 2016), and reducing wage differentials (Bergantino and Madio, 2019).

The dataset represents a table in “dta”. Variables are in columns, variables names are in the first row. Rows correspond to different observation units, that is, the number of workers commuting between municipalities, or within the same municipality. Since every municipality-to-municipality commuting pattern is observed in the 1991, 2001, and 2011 years, the first column reports the year of observation while the second column reports the unique identification number assigned to every origin-destination pair. Table 1 describes the details of all the remaining variables. They are split in four panels to underline the different data sources. Note that suffix i denotes “origin”, while suffix j denotes “destination”.

Table 3.1: Variable description

Variable	Description
Panel A	
year	Year of data collection
id	Unique identification number for every origin-destination pair
code_regio_i	2 digits code of the region of origin
name_regio_i	Name of the region of origin
code_prov_i	3 digits code of the province of origin
name_prov_i	Name of the province of origin
code_muni_i	3 digits code of the municipality of origin
name_muni_i	Name of the municipality of origin
idcode_i	6 digits *Istat* code of origin (*code_prov_i* + *code_muni_i*)
code_regio_j	2 digits code of the region of destination
name_regio_j	Name of the region of destination
code_prov_j	3 digits code of the province of destination
name_prov_j	Name of the province of destination
code_muni_j	3 digits code of the municipality of destination
name_muni_j	Name of the municipality of destination
idcode_j	6 digits *Istat* code of destination (*code_prov_j* + *code_muni_j*)
idcode_ij	12 digits code of the origin-destination pair (*idcode_i* + *idcode_j*)
name_ij	Name of the origin-destination pair
individuals_ij	Number of workers commuting between the origin-destination pair
chief_town	1=chief town municipality, 0=non-chief town municipality
elevation	1=inner mountain, 2=coastal mountain, 3=inner hill, 4=coastal hill, 5=lowland
altitudine	Height above sea level
coastal	1=coastal municipality, 0 non-coastal municipality
mountain	NM=non-mountain municipality, T=total-mountain municipality, P=partial-mountain municipality
surface	Territorial surface (km^2)
Panel B	

Continued on next page

Table 3.1 – continued from previous page

Variable	Description
ateco_01_02	Number of workers in crop and animal production, hunting and related service activities; forestry and logging
ateco_03	Number of workers in fishing and aquaculture
ateco_05	Number of workers in mining of coal and lignite
ateco_06	Number of workers in the extraction of crude petroleum and natural gas
ateco_07	Number of workers in mining of metal ores
ateco_08	Number of workers in other mining and quarrying
ateco_09	Number of workers in mining support service activities
ateco_10	Number of workers in manufacture of food products
ateco_11	Number of workers in manufacture of beverages
ateco_12	Number of workers in manufacture of tobacco products
ateco_13	Number of workers in manufacture of textiles
ateco_14	Number of workers in manufacture of wearing apparel
ateco_15	Number of workers in manufacture of leather and related products
ateco_16	Number of workers in manufacture of wood and cork (except furniture), manufacture of articles of straw and plaiting materials
ateco_17	Number of workers in manufacture of paper and paper products
ateco_18	Number of workers in printing and reproduction of recorded media
ateco_19	Number of workers in manufacture of coke and refined petroleum products
ateco_20	Number of workers in manufacture of chemicals and chemical products
ateco_21	Number of workers in manufacture of basic pharmaceutical products and pharmaceutical preparations
ateco_22	Number of workers in manufacture of rubber and plastic products
ateco_23	Number of workers in manufacture of other non-metallic mineral products
ateco_24	Number of workers in manufacture of basic metals
ateco_25	Number of workers in manufacture of fabricated metal products (except machinery and equipment)
ateco_26	Number of workers in manufacture of computer, electronic and optical products
ateco_27	Number of workers in manufacture of electrical equipment
ateco_28	Number of workers in manufacture of machineryand equipment n.e.c.
ateco_29	Number of workers in manufacture of motor vehicles, trailers and semi-trailers
ateco_30	Number of workers in manufacture of other transport equipment
ateco_31	Number of workers in manufacture of furniture
ateco_32	Number of workers in other manufacturing

Continued on next page

Table 3.1 – continued from previous page

Variable	Description
ateco_33	Number of workers in repair and installation of machinery and equipment
ateco_35	Number of workers in electricity, gas, steam and air conditioning supply
ateco_36_37_38_39	Number of workers in water collection, treatment and supply; sewerage; waste collection, treatment and disposal activities, materials recovery; remediation activities and other waste management services.
ateco_41_42_43	Number of workers in construction of buildings; civil engineering; specialised construction activities
ateco_45	Number of workers in wholesale and retail trade and repair of motor vehicles and motorcycles
ateco_46	Number of workers in wholesale trade (except of motor vehicles and motorcycles)
ateco_47	Number of workers in retail trade (except of motor vehicles and motorcycles)
ateco_49	Number of workers in land transport and transport via pipelines
ateco_50	Number of workers in water transport
ateco_51	Number of workers in air transport
ateco_52	Number of workers in warehousing and support activities for transportation
ateco_53	Number of workers in postal and courier activities
ateco_55	Number of workers in accommodation
ateco_56	Number of workers in food and beverage service activities
ateco_58	Number of workers in publishing activities
ateco_59_60	Number of workers in motion picture, video and television programme production, sound recording and music publishing activities; programming and broadcasting activities
ateco_61	Number of workers in telecommunications
ateco_62	Number of workers in computer programming, consultancy and related activities
ateco_63	Number of workers in information service activities
ateco_64	Number of workers in financial service activities (except insurance and pension funding)
ateco_65	Number of workers in insurance, reinsurance and pension funding (except compulsory social security)
ateco_66	Number of workers in activities auxiliary to financial services and insurance activities
ateco_68	Number of workers in real estate activities
ateco_69_70_71_73_74	Number of workers in legal and accounting activities; activities of head offices, management consultancy activities; architectural and engineering activities, technical testing and analysis; advertising and market research; other professional, scientific and technical activities
ateco_72	Number of workers in scientific research and development
ateco_75	Number of workers in veterinary activities

Continued on next page

Table 3.1 – continued from previous page

Variable	Description
ateco_77	Number of workers in rental and leasing activities
ateco_78	Number of workers in employment activities
ateco_79	Number of workers in travel agency, tour operator reservation service and related activities
ateco_80	Number of workers in security and investigation activities
ateco_81	Number of workers in services to buildings and landscape activities
ateco_82	Number of workers in office administrative, office support and other business support activities
ateco_84	Number of workers in public administration and defence, compulsory social security
ateco_85	Number of workers in education
ateco_86_87_88	Number of workers in human health activities; residential care activities; social work activities without accommodation
ateco_90_92_93	Number of workers in creative, arts and entertainment activities; gambling and betting activities; sports activities and amusement and recreation activities
ateco_91	Number of workers in libraries, archives, museums and other cultural activities
ateco_94	Number of workers in activities of membership organisations
ateco_95	Number of workers in repair of computers and personal and household goods
ateco_96	Number of workers in other personal service activities
Panel C	
pop	Resident population of the municipality on the census date
name_llm	Name of the local labour market of belonging of the municipality
Panel D	
dist_meters_ij	Distance between the origin-destination pair (meters)
dist_minutes_ij	Journey time between the origin-destination pair (minutes)

Notes: *Panel A* variables (except *chief_town*, *elevation*, *altitudine*, *coastal*, *mountain*, and *surface*) and *Panel D* variables are at the municipality-to-municipality level. *Panel B* variables, *Panel C* variables, and *chief_town*, *elevation*, *altitudine*, *coastal*, *mountain*, and *surface* variables are at the municipality level; therefore, they have been merged twice (i.e., with both the municipality of origin i and the municipality of destination j).

3.3 Experimental Design, Materials, and Methods

The dataset includes 2 210 148 observations and 177 variables. The variables list emerged gradually as we worked with our sources. The dataset construction involves several steps. To smooth the explanation, we split the following section into five parts in order to describe all steps separately. We will refer to:

- *Dataset_A* as 1991, 2001, 2011 data on the number of workers commuting between municipalities, or within the same municipality. The sources are the three origin-destination commuting matrices (*matrici di pendolarismo*) elaborated by *Istat* (Istat, 2019c).
- *Dataset_B* as 1991, 2001, 2011 data on the number of people employed in every *Ateco*[1] economic activity at the municipality level. The sources are the three general industry and services censuses (*censimento generale dell'industria e dei servizi*) provided by *Istat* (Istat, 2014; Istat, 2019b).
- *Dataset_C* as 1991, 2001, 2011 data on the population and the local labour market of belonging of each municipality. The sources are the three general population and housing censuses (*censimento generale della popolazione e delle abitazioni*) provided by *Istat* (Istat, 2014; Istat, 2019a).
- *Dataset_D* as data on distances in meters and journey times in minutes between all Italian municipalities. The sources are the origin-destination distance matrices (*matrici delle distanze*) released by *Istat* (Istat, 2019c).

The following subsections describe how we built the longitudinal dataset combining all the four previous data sources. In particular, it seeks to provide useful information in two different directions: first, on how coherently appending the 1991, 2001, and 2011 data within each data source in order to obtain a balanced panel (see Sections 3.3.1, 3.3.2, 3.3.3, 3.3.4); and second, on how merging data between different data sources (see Section 3.3.5). The procedure is schematized in Figure 3.1.

3.3.1 Dataset_A

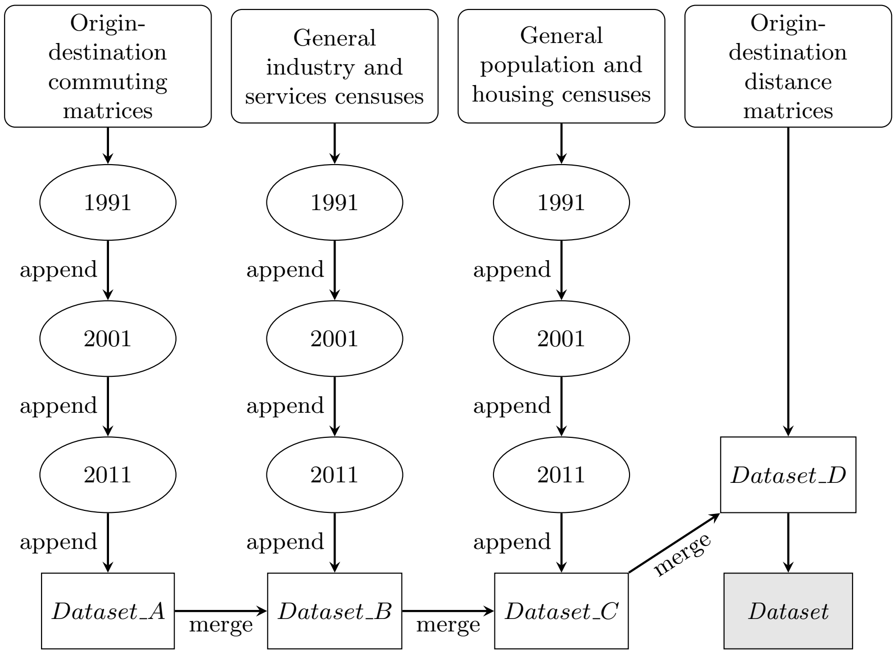
Each origin-destination commuting matrix is provided as a zipped file by (Istat, 2019c). After downloading all three of them, we extracted from each unzipped folder the following "txt" files containing information on travel habits and destinations of the resident population who declared to go to the usual place of study or work every day starting from their municipality and to return daily to the same.

- *Pen_91It.txt*: data file of 3 123 280 records containing 10 variables grouped into a single string. It describes the various commuting characteristics of the 27 540 213 individuals surveyed on the occasion of the 1991 census.
- *matrix_pendo2001.txt*: data file of 3 870 728 records containing 13 variables grouped into a single string. It describes the various commuting characteristics of the 26 764 361 individuals surveyed on the occasion of the 2001 census.
- *matrix_pendo2011.txt*: data file of 4 876 242 records containing 15 variables grouped into a single string. It describes the various commuting characteristics of the 28 871 447 individuals surveyed on the occasion of the 2011 census.

---

[1] The *Ateco* (*Attività Economiche*) classification is the national version of the *Nace* (*Nomenclature Statistique des Activités Économiques dans la Communauté Européenne*) classification, that is, the industry standard classification system used in the European Union.

Fig. 3.1: Dataset construction process



After having separated all variables into different columns, we kept those that were reported in all the three sample years; namely, *Istat* codes[2] of provinces and municipalities of both origin and destination, and the number of people moving between municipalities or within the same municipality. These variables are coherently clustered by a set of individual characteristics such as gender, status (worker or student), means of transport (e.g., on foot, bike, train, tram, subway, bus, car, motorcycle), departure time (before 7:15 A.M., between 7:15 A.M. and 8:14 A.M., between 8:15 A.M. and 9:14 A.M., after 9:15 A.M.), and travel time (between 0 and 15 minutes, between 16 and 30 minutes, between 31 and 60 minutes, more than 60 minutes).

Given our interest in focusing exclusively on the total number of workers moving from municipality i to municipality j within the national borders, we dropped from each sample year those observations related to individuals commuting abroad or for study reasons. Then, we collapsed all observations by the municipality-to-municipality unique code (created by concatenating the origin and destination *Istat* codes) regardless of the individual characteristics (see Appendix Stata codes 3.1, 3.2, and 3.3 related to the 1991, 2001, and 2011 origin-destination matrices, respectively, for further details).

---

[2] Unique codes used by the Italian national institute of statistics to register the territorial administrative units (i.e., municipalities, provinces, and regions).

In so doing, we ended up with 391 283 records for the 1991 matrix, 435 279 records for the 2001 matrix, and 538 620 records for the 2011 matrix. Before appending the data we had to take into account administrative variations occurred in Italy during the 30 years under analysis, such as the establishment of new territorial units and the suppression of others. Indeed, in each of the three sample years the Italian territory was organized as follows:

- 8 100 municipalities divided between 93 provinces in 1991.
- 8 101 municipalities divided between 103 provinces in 2001.
- 8 092 municipalities divided between 110 provinces in 2011.

To coherently append the data:

- We replaced the 1991 and 2001 *Istat* codes of those municipalities that have changed their province of belonging during the period of analysis with the 2011 *Istat* codes by following the connection table provided by Appendix Table A.
- We replaced the 1991 and 2001 *Istat* codes of those municipalities that have merged by 2011 with the 2011 *Istat* codes by following the connection table provided by Appendix Table B.
- We replaced the 2011 and 2001 *Istat* codes of those municipalities that have splitted since 1991 with the 1991 *Istat* codes by following the connection table provided by Appendix Table C.

Then, we collapsed again all observations by the municipality-to-municipality unique code, we appended the data, and we filled the longitudinal structure of our dataset in order to obtain three observations for every origin-destination pair. In so doing, we ended up with a strongly balanced *Dataset_A* of 2 219 379 records describing, for each sample year, 739 793 commuting patterns among 8 084 municipalities divided into 110 provinces.

Finally, by using the *Codici Comuni italiani_*1 *gennaio* 2011*.xls* file from the 2011 unzipped folder, we linked our core origin-destination dataset with a set of time-invariant municipality characteristics and string variables (useful for labeling the various *Istat* codes) by the municipality *Istat* code. The list of variables obtained from *Dataset_A* are described in *Panel A* of Table 3.1.

3.3.2 Dataset_B

The 1991 and 2001 general industry and services censuses at the national level can be downloaded from (Istat, 2014), while the 2011 census at the regional level can be downloaded from (Istat, 2019b). After appending the 2011 data from the 20 regions, the three “xls” files contain information on the number of people employed in every *Ateco* economic activity at the municipality level. Due to the different data sources and to variations in the *Ateco* classification used in Italy during the 30 years under analysis, the three “xls” files are organized as follows:

- *Ateco*_1991.*xls*: data file of 222 *Ateco* codes (3 digits) classified by the 1991 *Ateco* classification. It describes the location of jobs across 8 100[3] municipalities for the 17 976 801 workers surveyed on the occasion of the 1991 census[4].
- *Ateco*_2001.*xls*: data file of 222 *Ateco* codes (3 digits) classified by the 1991 *Ateco* classification. It describes the location of jobs across 8 101[3] municipalities for the 19 410 556 workers surveyed on the occasion of the 2001 census[4].
- *Ateco*_2011.*xls*: data file of 85 *Ateco* codes (2 digits) classified by the 2007 *Ateco* classification. It describes the location of jobs across 8 092 municipalities for the 19 946 950 workers surveyed on the occasion of the 2011 census.

To coherently append the data:

- We merged the 1991, 2001, and 2011 *Ateco* codes by following a custom *Ateco* classification provided by Appendix Table D.
- We replaced the 1991 and 2001 *Istat* codes of those municipalities that have merged by 2011 with the 2011 *Istat* codes by following the connection table provided by Appendix Table B.
- We replaced the 2011 and 2001 *Istat* codes of those municipalities that have splitted since 1991 with the 1991 *Istat* codes by following the connection table provided by Appendix Table C.

Then, we collapsed all observations by the municipality *Istat* code and we appended the data. In so doing, we ended up with a strongly balanced *Dataset_B* of 24 252 records and 70 *Ateco* codes (2 digits) describing, for each sample year, the location of jobs across 8 084 municipalities divided into 110 provinces. The list of variables obtained from *Dataset_B* are described in *Panel B* of Table 3.1.

3.3.3 Dataset_C

The 1991 and 2001 general population and housing censuses can be downloaded from (Istat, 2014), while the 2011 census can be downloaded from (Istat, 2019a). The three “xls” files contain information on the population and the local labour market of belonging of each municipality. Before appending the data we had to take into account the same administrative variations occurred in Italy during the 30 years under analysis previously described. Hence, to coherently append the data:

- We replaced the 1991 and 2001 *Istat* codes of those municipalities that have changed their province of belonging during the period of analysis with the 2011 *Istat* codes by following the connection table provided by Appendix Table A.

---

[3] The raw data files have 8 101 and 8 102 municipalities, respectively. We dropped *Comano Terme* (*Istat* code: 022228) because it is a copy of *Lomaso* (*Istat* code: 022107). Indeed, *Comano Terme* will be establish only in 2010 (see Appendix Table B for further details).

[4] Despite the different number of municipalities, the 1991 and 2001 *Istat* codes of the raw data files are already reported with the 2011 *Istat* codes; hence, the connection table provided by Appendix Table A is not necessary in this case.

- We replaced the 1991 and 2001 *Istat* codes of those municipalities that have merged by 2011 with the 2011 *Istat* codes by following the connection table provided by Appendix Table B.
- We replaced the 2011 and 2001 *Istat* codes of those municipalities that have splitted since 1991 with the 1991 *Istat* codes by following the connection table provided by Appendix Table C.

Then, we collapsed all observations by the municipality *Istat* code and we appended the data. In so doing, we ended up with a strongly balanced *Dataset_C* of 24 252 records describing, for each sample year, the population and the local labour market of belonging of 8 084 municipalities divided into 110 provinces. The list of variables obtained from *Dataset_C* are described in *Panel C* of Table 3.1.

3.3.4 Dataset_D

The origin-destination distance matrices at the regional level are provided as zipped files by (Istat, 2019c). After downloading all 20 of them, we extracted from each unzipped folder the "txt" file containing 5 comma separated variables describing the distances in meters and journey times in minutes from all the municipalities of a region to all the Italian municipalities[5].

Note that the origin-destination distance matrices of *Sicily* and *Sardinia* regions (the two major islands) report only the distances between municipalities located within the same region. As regards the remaining minor islands, a separate "xls" file named *Dist_porti.xls* (still provided by (Istat, 2019c)) reports only the distances between the island and the main port of the Italian peninsula[6].

After having reorganized and cleaned the "txt" file of each region (see Appendix Stata code 3.4 for further details), we appended the data from the 20 regions and we ended up with a *Dataset_D* of 53 580 588 records describing the distances in meters and journey times in minutes between all Italian municipalities. The list of variables obtained from *Dataset_D* are described in *Panel D* of Table 3.1.

3.3.5 Dataset

To obtain the dataset presented in this data article:

- We merged both *Dataset_B* and *Dataset_C* with *Dataset_A* twice: first, by the year of observation and the municipality of origin i; and second, by the year of observation and the municipality of destination j.

---

[5] Data were obtained by using a commercial road graph (2013 *TomTom MultiNet*) and by considering the 2013 city hall location as the municipality's centroid. The calculations were carried out through *GIS* software by taking into account the average driving speed of each road type (e.g., urban roads, inter-urban roads, ring roads, highways).

[6] Distances from *Monte Isola* (*Istat* code: 017111) and *Campione d'Italia* (*Istat* code: 013040) are missing because there are no road connections in the commercial road graph used for calculations.

- We merged *Dataset_D* with *Dataset_A* by the municipality-to-municipality unique code.

Finally, due to the reasons previously explained in Section 3.3.4, we dropped the 9 231 origin-destination pairs for which the distances in meters and journey times in minutes are missing. In so doing, we ended up with a strongly balanced dataset of 2 210 148 observations and 177 variables describing, for each sample year, 736 716 commuting patterns among 8 060 municipalities divided into 110 provinces.

3.4 Value of the Data

- The dataset provides rich information on municipality-to-municipality commuting patterns in Italy over the 1991, 2001, and 2011 censuses.
- The core origin-destination dataset on the number of workers moving between municipalities, or within the same municipality, has been linked with further municipality covariates on jobs location, population, and the distances in meters and journey times in minutes between all municipalities.
- The data presented here are freely available online. However, they require some tedious work to organize. This data article brings the information together and converts the data into a user-friendly format.
- The dataset allows applied researchers who are interested in analysing the changing shape of urban systems to study the connection between increasing commuting patterns and the structural transformation of the economy.
- The dataset can be employed in urban, regional, and transport economics; it can be updated and extended with additional data sources to answer to various research questions.

3.5 Appendix

Listing 3.1: Stata commands for the 1991 origin-destination commuting matrix

```
**Destring grouped variables**

*1)Province of origin i*
generate code_prov_i=substr(v1,1,3)
*2)Municipality of origin i*
generate code_muni_i=substr(v1,4,3)

*3)Province of destination j*
generate code_prov_j=substr(v1,12,3)
*4)Municipality of destination j*
generate code_muni_j=substr(v1,15,3)

*5)Number of people commuting between ij*
generate individuals_ij=substr(v1,18,12)
destring individuals_ij , replace force

*6)Gender*
generate code_gender=substr(v1,7,1)
generate gender=""
replace gender="male" if code_gender=="1"
replace gender="female" if code_gender=="2"
destring code_gender , replace

*7)Status*
generate code_status=substr(v1,9,1)
generate status=""
replace status="student" if code_status=="1"
replace status="worker" if code_status =="2"
destring code_status , replace

*8)Means of transport*
generate code_transport=substr(v1,8,1)
generate transport=""
replace transport="onfoot-byke-other" if code_transport=="1"
replace transport="train-tram-subway" if code_transport=="2"
replace transport="bus" if code_transport=="3"
replace transport="car driver" if code_transport=="4"
replace transport="car passenger" if code_transport=="5"
replace transport="motorcycle" if code_transport=="6"
destring code_transport , replace

*9)Departure time*
generate code_departure=substr(v1,10,1)
generate departure=""
```

```
replace departure=”<7.15am” if code_departure==”1”
replace departure=”>7.15am & <8.14am” if code_departure==”2”
replace departure=”>8.15am & <9.14am” if code_departure==”3”
replace departure=”>9.15am” if code_departure==”4”
destring code_departure, replace

*10)Travel time*
generate code_travel=substr(v1,11,1)
generate travel=””
replace travel=”<15m” if code_travel==”1”
replace travel=”>16m & <30m” if code_travel==”2”
replace travel=”>31m & <60m” if code_travel==”3”
replace travel=”>60m” if code_travel==”4”
destring code_travel, replace

----------------------------------------------------------------------
**Municipality-to-municipality code**
----------------------------------------------------------------------

*Unique origin code (6 digits)*
generate idcode_i=code_prov_i+code_muni_i
*Unique destination code (6 digits)*
generate idcode_j=code_prov_j+code_muni_j
*Unique origin-destination code (12 digits)*
generate idcode_ij=idcode_i+idcode_j

*Year and id*
generate year=1991
egen id=group(idcode_ij)

----------------------------------------------------------------------
**Drop observations**
----------------------------------------------------------------------

*Drop students*
drop if code_status==1
*Drop commuters abroad*
drop if code_prov_j==”203” | code_prov_j==”215” | ///
code_prov_j==”216” | code_prov_j==”224” | ///
code_prov_j==”229” | code_prov_j==”236” | ///
code_prov_j==”241” | code_prov_j==”246”
*Drop municipality that no longer exists*
drop if idcode_j==”022008”

----------------------------------------------------------------------
**Collapse observations**
----------------------------------------------------------------------

*Collapse by id*
collapse (firstnm) year idcode_ij ///
code_prov_i code_muni_i idcode_i ///
```

```
code_prov_j code_muni_j idcode_j ///
(sum) individuals_ij , by(id)
```

Listing 3.2: Stata commands for the 2001 origin-destination commuting matrix

```
**Destring grouped variables**

*1)Province of origin i*
generate code_prov_i=substr(v1,1,3)
*2)Municipality of origin i*
generate code_muni_i=substr(v1,5,3)

*3)Province of destination j*
generate code_prov_j=substr(v1,15,3)
*4)Municipality of destination j*
generate code_muni_j=substr(v1,19,3)

*5)Number of people commuting between ij*
generate individuals_ij=substr(v1,36,8)
destring individuals_ij , replace force

*6)Gender*
generate code_gender=substr(v1,9,1)
generate gender=””
replace gender=”male” if code_gender==”1”
replace gender=”female” if code_gender==”2”
destring code_gender, replace

*7)Status*
generate code_status=substr(v1,11,1)
generate status=””
replace status=”student” if code_status==”1”
replace status=”worker” if code_status ==”2”
destring code_status, replace

*8)Means of transport*
generate code_transport=substr(v1,29,2)
generate transport=””
replace transport=”train” if code_transport==”01”
replace transport=”tram” if code_transport==”02”
replace transport=”subway” if code_transport==”03”
replace transport=”city bus” if code_transport==”04”
replace transport=”intercity bus” if code_transport==”05”
replace transport=”school bus” if code_transport==”06”
replace transport=”car driver” if code_transport==”07”
replace transport=”car passenger” if code_transport==”08”
replace transport=”motorcycle” if code_transport==”09”
replace transport=”onfoot-byke-other” if code_transport==”10”
destring code_transport, replace
```

```
*9)Departure time*
generate code_departure=substr(v1,32,1)
generate departure=””
replace departure=”<7.15am” if code_departure==”1”
replace departure=”>7.15am & <8.14am” if code_departure==”2”
replace departure=”>8.15am & <9.14am” if code_departure==”3”
replace departure=”>9.15am” if code_departure==”4”
destring code_departure, replace

*10)Travel time*
generate code_travel=substr(v1,34,1)
generate travel=””
replace travel=”<15m” if code_travel==”1”
replace travel=”>16m & <30m” if code_travel==”2”
replace travel=”>31m & <60m” if code_travel==”3”
replace travel=”>60m” if code_travel==”4”
destring code_travel, replace

*11)Type of destination*
generate code_destination=substr(v1,13,1)
generate destination=””
replace destination=”same municipality” if code_destination==”1”
replace destination=”other municipality” if code_destination==”2”
replace destination=”abroad” if code_destination==”3”
destring code_destination, replace

*12)Foreign destinations*
generate code_state_j=substr(v1,23,3)

*13)Last wednesday travel*
generate code_wednesday=substr(v1,27,1)
generate wednesday=””
replace wednesday=”no” if code_wednesday==”0”
replace wednesday=”yes” if code_wednesday==”1”
destring code_wednesday, replace
```

```
**Municipality-to-municipality code**
```

```
*Unique origin code (6 digits)*
generate idcode_i=code_prov_i+code_muni_i
*Unique destination code (6 digits)*
generate idcode_j=code_prov_j+code_muni_j
*Unique origin-destination code (12 digits)*
generate idcode_ij=idcode_i+idcode_j

*Year and id*
generate year=2001
egen id=group(idcode_ij)
```

```
**Drop observations**

*Drop students*
drop if code_status==1
*Drop commuters abroad*
drop if code_destination==3

**Collapse observations**

*Collapse by id*
collapse (firstnm) year idcode_ij ///
code_prov_i code_muni_i idcode_i ///
code_prov_j code_muni_j idcode_j ///
(sum) individuals_ij , by(id)
```

Listing 3.3: Stata commands for the 2011 origin-destination commuting matrix

```
**Destring grouped variables**

*1)Province of origin i*
generate code_prov_i=substr(v1,5,3)
*2)Municipality of origin i*
generate code_muni_i=substr(v1,9,3)

*3)Province of destination j*
generate code_prov_j=substr(v1,20,3)
*4)Municipality of destination j*
generate code_muni_j=substr(v1,24,3)

*5)Number of people commuting between ij*
generate individuals_ij=substr(v1,51,10)
destring individuals_ij , replace force

*6)Gender*
generate code_gender=substr(v1,14,1)
generate gender=””
replace gender=”male” if code_gender==”1”
replace gender=”female” if code_gender==”2”
destring code_gender, replace

*7)Status*
generate code_status=substr(v1,16,1)
generate status=””
replace status=”student” if code_status==”1”
```

```
replace status=”worker” if code_status ==”2”
destring code_status , replace

*8)Means of transport*
generate code_transport=substr(v1,32,2)
generate transport=””
replace transport=”train” if code_transport==”01”
replace transport=”tram” if code_transport==”02”
replace transport=”subway” if code_transport==”03”
replace transport=”city bus” if code_transport==”04”
replace transport=”intercity bus” if code_transport==”05”
replace transport=”school bus” if code_transport==”06”
replace transport=”car driver” if code_transport==”07”
replace transport=”car passenger” if code_transport==”08”
replace transport=”motorcycle” if code_transport==”09”
replace transport=”byke” if code_transport==”10”
replace transport=”other” if code_transport==”11”
replace transport=”onfoot” if code_transport==”12”
destring code_transport , replace

*9)Departure time*
generate code_departure=substr(v1,35,1)
generate departure=””
replace departure=”<7.15am” if code_departure==”1”
replace departure=”>7.15am & <8.14am” if code_departure==”2”
replace departure=”>8.15am & <9.14am” if code_departure==”3”
replace departure=”>9.15am” if code_departure==”4”
destring code_departure , replace

*10)Travel time*
generate code_travel=substr(v1,37,1)
generate travel=””
replace travel=”<15m” if code_travel==”1”
replace travel=”>16m & <30m” if code_travel==”2”
replace travel=”>31m & <60m” if code_travel==”3”
replace travel=”>60m” if code_travel==”4”
destring code_travel , replace

*11)Type of destination*
generate code_destination=substr(v1,18,1)
generate destination=””
replace destination=”same municipality” if code_destination==”1”
replace destination=”other municipality” if code_destination==”2”
replace destination=”abroad” if code_destination==”3”
destring code_destination , replace

*12)Foreign destinations*
generate code_state_j=substr(v1,28,3)

*13)Type of cohabitation*
generate code_cohabitation=substr(v1,3,1)
```

```
generate cohabitation=””
replace cohabitation=”family” if code_cohabitation==”1”
replace cohabitation=”cohabitation” if code_cohabitation==”2”
destring code_cohabitation , replace

*14)Type of record*
generate code_record=substr(v1,1,1)

*15)Number of estimated people moving between ij*
generate estimated_individuals_ij=substr(v1,39,12)
replace estimated_individuals_ij=”” if estimated_individuals_ij==”
ND   ”
destring estimated_individuals_ij , replace force
replace estimated_individuals_ij=0 if missing(estimated_individuals_ij)

--------------------------------------------------------------------
**Municipality-to-municipality code**
--------------------------------------------------------------------

*Unique origin code (6 digits)*
generate idcode_i=code_prov_i+code_muni_i
*Unique destination code (6 digits)*
generate idcode_j=code_prov_j+code_muni_j
*Unique origin-destination code (12 digits)*
generate idcode_ij=idcode_i+idcode_j

*Year and id*
generate year=2011
egen id=group(idcode_ij)

--------------------------------------------------------------------
**Drop observations**
--------------------------------------------------------------------

*Drop students*
drop if code_status==1
*Drop commuters abroad*
drop if code_destination==3
*Drop records of type L*
drop if code_record==”L”

--------------------------------------------------------------------
**Collapse observations**
--------------------------------------------------------------------

*Collapse by id*
collapse (firstnm) year idcode_ij ///
code_prov_i code_muni_i idcode_i ///
code_prov_j code_muni_j idcode_j ///
(sum) individuals_ij , by(id)
```

Listing 3.4: Stata commands for the origin-destination distance matrices

```
**Municipality−to−municipality code**

*Unique origin code (6 digits)*
generate i=substr(Destinazione,1,length(Destinazione)−3)
generate zeroi=”00” if length(i)==4
replace zeroi=”0” if length(i)==5
generate idcode_i=zeroi+i

*Unique destination code (6 digits)*
generate j=substr(Origine,1,length(Origine)−3)
generate zeroj=”00” if length(j)==4
replace zeroj=”0” if length(j)==5
generate idcode_j=zeroj+j

*Unique origin−destination code (12 digits)*
generate idcode_ij=idcode_i+idcode_j
sort idcode_ij

**Destring variables**

*Destring distance in metres *
destring Total_Mete, generate(dist_meters_ij) dpcomma
format %10.2f dist_meters_ij

*Destring journey time in minutes*
destring Total_Minu, generate(dist_minutes_ij) dpcomma
format %10.2f dist_minutes_ij

**Drop and Order variables**

*Drop*
drop Name Origine Destinazione Total_Minu Total_Mete ///
     i j zeroi zeroj idcode_i idcode_j
*Order*
order idcode_ij dist_meters_ij dist_minutes_ij
```

Table A: *Istat* codes connection for municipalities that have changed their province of belonging, 1991–2011

#	*Municipality*	*idcode_*1991[a]	*idcode_*2001[a]	*idcode_*2011[a]
Municipalities from *Nuoro* to *Cagliari*				
1	Escalaplano	091020	091020	092110
2	Escolca	091021	091021	092111
3	Esterzili	091022	091022	092112
4	Gergei	091030	091030	092113
5	Isili	091034	091034	092114
6	Nuragus	091052	091052	092115
7	Nurallao	091053	091053	092116
8	Nurri	091054	091054	092117
9	Orroli	091065	091065	092118
10	Sadali	091074	091074	092119
11	Serri	091080	091080	092120
12	Seulo	091082	091082	092121
13	Villanova Tulo	091102	091102	092122
Municipalities from *Nuoro* to *Oristano*				
1	Bosa	091013	091013	095079
2	Flussio	091023	091023	095080
3	Genoni	091029	091029	095081
4	Laconi	091036	091036	095082
5	Magomadas	091045	091045	095083
6	Modolo	091048	091048	095084
7	Montresta	091049	091049	095085
8	Sagama	091075	091075	095086
9	Suni	091087	091087	095087
10	Tinnura	091092	091092	095088
Municipalities from *Vercelli* to *Biella*				
1	Ailoche	002001		096001
2	Andorno Micca	002005		096002
3	Benna	002010		096003
4	Biella	002012		096004
5	Bioglio	002013		096005
6	Borriana	002018		096006
7	Brusnengo	002020		096007
8	Callabiana	002022		096008
9	Camandona	002023		096009
10	Camburzano	002024		096010
11	Campiglia Cervo	002026		096011
12	Candelo	002027		096012
13	Caprile	002028		096013
14	Casapinta	002034		096014
15	Castelletto Cervo	002036		096015
16	Cavaglià	002037		096016
17	Cerreto Castello	002039		096017

Continued on next page

Table A – continued from previous page

#	*Municipality*	*idcode*_1991[a]	*idcode*_2001[a]	*idcode*_2011[a]
18	Cerrione	002040		096018
19	Coggiola	002044		096019
20	Cossato	002046		096020
21	Crevacuore	002050		096021
22	Crosa	002051		096022
23	Curino	002053		096023
24	Donato	002055		096024
25	Dorzano	002056		096025
26	Gaglianico	002060		096026
27	Gifflenga	002063		096027
28	Graglia	002064		096028
29	Lessona	002069		096029
30	Magnano	002073		096030
31	Massazza	002074		096031
32	Masserano	002075		096032
33	Mezzana Mortigliengo	002076		096033
34	Miagliano	002077		096034
35	Mongrando	002080		096035
36	Mosso Santa Maria[b]	002081	096036	
37	Mottalciata	002083		096037
38	Muzzano	002084		096038
39	Netro	002085		096039
40	Occhieppo Inferiore	002086		096040
41	Occhieppo Superiore	002087		096041
42	Pettinengo	002092		096042
43	Piatto	002094		096043
44	Piedicavallo	002095		096044
45	Pistolesa[b]	002098	096045	
46	Pollone	002099		096046
47	Ponderano	002100		096047
48	Portula	002101		096048
49	Pralungo	002103		096049
50	Pray	002105		096050
51	Quaregna	002106		096051
52	Quittengo	002109		096052
53	Ronco Biellese	002117		096053
54	Roppolo	002119		096054
55	Rosazza	002120		096055
56	Sagliano Micca	002124		096056
57	Sala Biellese	002125		096057
58	Salussola	002129		096058
59	Sandigliano	002130		096059
60	San Paolo Cervo	002132		096060
61	Selve Marcone	002136		096061
62	Soprana	002138		096062
63	Sordevolo	002139		096063
64	Sostegno	002140		096064

Continued on next page

Table A – continued from previous page

#	*Municipality*	*idcode*_1991[a]	*idcode*_2001[a]	*idcode*_2011[a]
65	Strona	002141		096065
66	Tavigliano	002143		096066
67	Ternengo	002144		096067
68	Tollegno	002145		096068
69	Torrazzo	002146		096069
70	Trivero	002149		096070
71	Valdengo	002151		096071
72	Vallanzengo	002153		096072
73	Valle Mosso	002154		096073
74	Valle San Nicolao	002155		096074
75	Veglio	002157		096075
76	Verrone	002159		096076
77	Vigliano Biellese	002160		096077
78	Villa del Bosco	002161		096078
79	Villanova Biellese	002162		096079
80	Viverone	002165		096080
81	Zimone	002167		096081
82	Zubiena	002168		096082
83	Zumaglia	002169		096083
Municipalities from *Bergamo* and *Como* to *Lecco*				
1	Abbadia Lariana	013001		097001
2	Airuno	013002		097002
3	Annone di Brianza	013008		097003
4	Ballabio	013014		097004
5	Barzago	013016		097005
6	Barzanò	013017		097006
7	Barzio	013018		097007
8	Bellano	013020		097008
9	Bosisio Parini	013027		097009
10	Brivio	013031		097010
11	Bulciago	013033		097011
12	Calco	013039		097012
13	Casargo	013049		097015
14	Casatenovo	013051		097016
15	Cassago Brianza	013054		097017
16	Cassina Valsassina	013056		097018
17	Castello di Brianza	013057		097019
18	Cernusco Lombardone	013066		097020
19	Cesana Brianza	013067		097021
20	Civate	013069		097022
21	Colico	013072		097023
22	Colle Brianza	013073		097024
23	Cortenova	013078		097025
24	Costa Masnaga	013079		097026
25	Crandola Valsassina	013080		097027
26	Cremella	013081		097028

Continued on next page

Table A – continued from previous page

#	*Municipality*	*idcode*_1991[a]	*idcode*_2001[a]	*idcode*_2011[a]
27	Cremeno	013082		097029
28	Dervio	013086		097030
29	Dolzago	013088		097031
30	Dorio	013091		097032
31	Ello	013094		097033
32	Esino Lario	013096		097035
33	Galbiate	013103		097036
34	Garbagnate Monastero	013104		097037
35	Garlate	013105		097038
36	Imbersago	013115		097039
37	Introbio	013116		097040
38	Introzzo	013117		097041
39	Lecco	013124		097042
40	Lierna	013127		097043
41	Lomagna	013132		097044
42	Malgrate	013140		097045
43	Mandello del Lario	013141		097046
44	Margno	013142		097047
45	Merate	013146		097048
46	Missaglia	013149		097049
47	Moggio	013150		097050
48	Molteno	013151		097051
49	Monticello Brianza	013156		097054
50	Morterone	013158		097055
51	Nibionno	013162		097056
52	Oggiono	013164		097057
53	Olgiate Molgora	013166		097058
54	Olginate	013167		097059
55	Oliveto Lario	013168		097060
56	Osnago	013171		097061
57	Paderno d'Adda	013173		097062
58	Pagnona	013174		097063
59	Parlasco	013176		097064
60	Pasturo	013177		097065
61	Perego	013180		097066
62	Perledo	013181		097067
63	Pescate	013182		097068
64	Premana	013190		097069
65	Primaluna	013191		097070
66	Robbiate	013196		097071
67	Rogeno	013198		097072
68	Rovagnate	013200		097073
69	Santa Maria Hoè	013209		097074
70	Sirone	013213		097075
71	Sirtori	013214		097076
72	Sueglio	013219		097077
73	Suello	013220		097078

Continued on next page

Table A – continued from previous page

#	*Municipality*	*idcode*_1991[a]	*idcode*_2001[a]	*idcode*_2011[a]
74	Taceno	013221		097079
75	Tremenico	013224		097081
76	Valgreghentino	013230		097082
77	Valmadrera	013231		097083
78	Varenna	013235		097084
79	Vendrogno	013237		097085
80	Verderio Inferiore	013240		097087
81	Verderio Superiore	013241		097088
82	Vestreno	013243		097089
83	Viganò	013244		097090
84	Montevecchia	013247		097053
85	Calolziocorte	016045		097013
86	Carenno	016054		097014
87	Erve	016095		097034
88	Monte Marenzo	016138		097052
89	Torre de' Busi	016215		097080
90	Vercurago	016231		097086
Municipalities from *Milano* to *Lodi*				
1	Abbadia Cerreto	015001		098001
2	Bertonico	015020		098002
3	Boffalora d'Adda	015025		098003
4	Borghetto Lodigiano	015028		098004
5	Borgo San Giovanni	015029		098005
6	Brembio	015031		098006
7	Camairago	015043		098007
8	Casaletto Lodigiano	015052		098008
9	Casalmaiocco	015053		098009
10	Casalpusterlengo	015054		098010
11	Caselle Landi	015056		098011
12	Caselle Lurani	015057		098012
13	Castelnuovo Bocca d'Adda	015063		098013
14	Castiglione d'Adda	015064		098014
15	Castiraga Vidardo	015065		098015
16	Cavacurta	015066		098016
17	Cavenago d'Adda	015067		098017
18	Cervignano d'Adda	015073		098018
19	Codogno	015079		098019
20	Comazzo	015083		098020
21	Cornegliano Laudense	015089		098021
22	Corno Giovine	015090		098022
23	Cornovecchio	015091		098023
24	Corte Palasio	015094		098024
25	Crespiatica	015095		098025
26	Fombio	015102		098026
27	Galgagnano	015104		098027
28	Graffignana	015109		098028

Continued on next page

Table A – continued from previous page

#	*Municipality*	*idcode*_1991[a]	*idcode*_2001[a]	*idcode*_2011[a]
29	Guardamiglio	015111		098029
30	Livraga	015124		098030
31	Lodi	015126		098031
32	Lodi Vecchio	015127		098032
33	Maccastorna	015128		098033
34	Mairago	015132		098034
35	Maleo	015133		098035
36	Marudo	015135		098036
37	Massalengo	015137		098037
38	Meleti	015141		098038
39	Merlino	015143		098039
40	Montanaso Lombardo	015148		098040
41	Mulazzano	015153		098041
42	Orio Litta	015160		098042
43	Ospedaletto Lodigiano	015162		098043
44	Ossago Lodigiano	015163		098044
45	Pieve Fissiraga	015174		098045
46	Salerano sul Lambro	015190		098046
47	San Fiorano	015193		098047
48	San Martino in Strada	015196		098048
49	San Rocco al Porto	015197		098049
50	Sant'Angelo Lodigiano	015198		098050
51	Santo Stefano Lodigiano	015199		098051
52	Secugnago	015203		098052
53	Senna Lodigiana	015207		098053
54	Somaglia	015214		098054
55	Sordio	015215		098055
56	Terranova dei Passerini	015218		098057
57	Turano Lodigiano	015225		098058
58	Valera Fratta	015228		098059
59	Villanova del Sillaro	015238		098060
60	Tavazzano con Villavesco	015240		098056
61	Zelo Buon Persico	015245		098061
Municipalities from *Forlì* and *Pesaro e Urbino* to *Rimini*				
1	Bellaria-Igea Marina	040002		099001
2	Cattolica	040006		099002
3	Coriano	040010		099003
4	Gemmano	040017		099004
5	Misano Adriatico	040021		099005
6	Mondaino	040023		099006
7	Monte Colombo	040024		099007
8	Montefiore Conca	040025		099008
9	Montegridolfo	040026		099009
10	Montescudo	040027		099010
11	Morciano di Romagna	040029		099011
12	Poggio Berni	040030		099012

Continued on next page

Table A – continued from previous page

#	*Municipality*	*idcode*_1991[a]	*idcode*_2001[a]	*idcode*_2011[a]
13	Riccione	040034		099013
14	Rimini	040035		099014
15	Saludecio	040038		099015
16	San Clemente	040039		099016
17	San Giovanni in Marignano	040040		099017
18	Santarcangelo di Romagna	040042		099018
19	Torriana	040048		099019
20	Verucchio	040051		099020
21	Casteldelci	041011	041011	099021
22	Maiolo	041024	041024	099022
23	Novafeltria	041039	041039	099023
24	Pennabilli	041042	041042	099024
25	San Leo	041053	041053	099025
26	Sant'Agata Feltria	041055	041055	099026
27	Talamello	041063	041063	099027
Municipalities from *Firenze* to *Prato*				
1	Cantagallo	048007		100001
2	Carmignano	048009		100002
3	Montemurlo	048029		100003
4	Prato	048034		100005
5	Vaiano	048047		100006
6	Vernio	048048		100007
7	Poggio a Caiano	048051		100004
Municipalities from *Catanzaro* to *Crotone*				
1	Belvedere di Spinello	079010		101001
2	Caccuri	079015		101002
3	Carfizzi	079019		101003
4	Casabona	079021		101004
5	Castelsilano	079022		101005
6	Cerenzia	079026		101006
7	Cirò	079031		101007
8	Cirò Marina	079032		101008
9	Cotronei	079035		101009
10	Crotone	079037		101010
11	Crucoli	079038		101011
12	Cutro	079040		101012
13	Isola di Capo Rizzuto	079064		101013
14	Melissa	079075		101014
15	Mesoraca	079076		101015
16	Pallagorio	079090		101016
17	Petilia Policastro	079093		101017
18	Roccabernarda	079102		101018
19	Rocca di Neto	079103		101019
20	San Mauro Marchesato	079111		101020
21	San Nicola dell'Alto	079113		101021
22	Santa Severina	079119		101022

Continued on next page

Table A – continued from previous page

#	*Municipality*	*idcode*_1991[a]	*idcode*_2001[a]	*idcode*_2011[a]
23	Savelli	079124		101023
24	Scandale	079125		101024
25	Strongoli	079145		101025
26	Umbriatico	079150		101026
27	Verzino	079154		101027
Municipalities from *Catanzaro* to *Vibo Valentia*				
1	Acquaro	079001		102001
2	Arena	079006		102002
3	Briatico	079013		102003
4	Brognaturo	079014		102004
5	Capistrano	079016		102005
6	Cessaniti	079028		102006
7	Dasà	079041		102007
8	Dinami	079044		102008
9	Drapia	079045		102009
10	Fabrizia	079046		102010
11	Filadelfia	079049		102011
12	Filandari	079050		102012
13	Filogaso	079051		102013
14	Francavilla Angitola	079053		102014
15	Francica	079054		102015
16	Gerocarne	079057		102016
17	Ionadi	079062		102017
18	Joppolo	079066		102018
19	Limbadi	079067		102019
20	Maierato	079070		102020
21	Mileto	079078		102021
22	Mongiana	079079		102022
23	Monterosso Calabro	079082		102023
24	Nardodipace	079084		102024
25	Nicotera	079086		102025
26	Parghelia	079091		102026
27	Pizzo	079097		102027
28	Pizzoni	079098		102028
29	Polia	079100		102029
30	Ricadi	079101		102030
31	Rombiolo	079104		102031
32	San Calogero	079106		102032
33	San Costantino Calabro	079107		102033
34	San Gregorio d'Ippona	079109		102034
35	San Nicola da Crissa	079112		102035
36	Sant'Onofrio	079121		102036
37	Serra San Bruno	079128		102037
38	Simbario	079132		102038
39	Sorianello	079135		102039
40	Soriano Calabro	079136		102040

Continued on next page

Table A – continued from previous page

#	*Municipality*	*idcode*_1991[a]	*idcode*_2001[a]	*idcode*_2011[a]
41	Spadola	079140		102041
42	Spilinga	079141		102042
43	Stefanaconi	079144		102043
44	Tropea	079149		102044
45	Vallelonga	079152		102045
46	Vazzano	079153		102046
47	Vibo Valentia	079155		102047
48	Zaccanopoli	079156		102048
49	Zambrone	079158		102049
50	Zungri	079159		102050
Municipalities from *Novara* to *Verbano-Cusio-Ossola*				
1	Antrona Schieranco	003003		103001
2	Anzola d'Ossola	003004		103002
3	Arizzano	003005		103003
4	Arola	003007		103004
5	Aurano	003009		103005
6	Baceno	003010		103006
7	Bannio Anzino	003011		103007
8	Baveno	003013		103008
9	Bee	003014		103009
10	Belgirate	003015		103010
11	Beura-Cardezza	003017		103011
12	Bognanco	003020		103012
13	Brovello-Carpugnino	003028		103013
14	Calasca-Castiglione	003029		103014
15	Cambiasca	003031		103015
16	Cannero Riviera	003033		103016
17	Cannobio	003034		103017
18	Caprezzo	003035		103018
19	Casale Corte Cerro	003038		103019
20	Cavaglio-Spoccia	003046		103020
21	Ceppo Morelli	003048		103021
22	Cesara	003050		103022
23	Cossogno	003053		103023
24	Craveggia	003054		103024
25	Crevoladossola	003056		103025
26	Crodo	003057		103026
27	Cursolo-Orasso	003059		103027
28	Domodossola	003061		103028
29	Druogno	003063		103029
30	Falmenta	003064		103030
31	Formazza	003067		103031
32	Germagno	003072		103032
33	Ghiffa	003074		103033
34	Gignese	003075		103034
35	Gravellona Toce	003078		103035

Continued on next page

Table A – continued from previous page

#	*Municipality*	*idcode*_1991[a]	*idcode*_2001[a]	*idcode*_2011[a]
36	Gurro	003080		103036
37	Intragna	003081		103037
38	Loreglia	003085		103038
39	Macugnaga	003086		103039
40	Madonna del Sasso	003087		103040
41	Malesco	003089		103041
42	Masera	003092		103042
43	Massiola	003094		103043
44	Mergozzo	003096		103044
45	Miazzina	003099		103045
46	Montecrestese	003101		103046
47	Montescheno	003102		103047
48	Nonio	003105		103048
49	Oggebbio	003107		103049
50	Omegna	003110		103050
51	Ornavasso	003111		103051
52	Pallanzeno	003113		103052
53	Piedimulera	003117		103053
54	Pieve Vergonte	003118		103054
55	Premeno	003123		103055
56	Premia	003124		103056
57	Premosello-Chiovenda	003125		103057
58	Quarna Sopra	003126		103058
59	Quarna Sotto	003127		103059
60	Re	003128		103060
61	San Bernardino Verbano	003132		103061
62	Santa Maria Maggiore	003136		103062
63	Seppiana	003137		103063
64	Stresa	003142		103064
65	Toceno	003145		103065
66	Trarego Viggiona	003147		103066
67	Trasquera	003148		103067
68	Trontano	003150		103068
69	Valstrona	003151		103069
70	Vanzone con San Carlo	003152		103070
71	Varzo	003155		103071
72	Verbania	003156		103072
73	Viganella	003160		103073
74	Vignone	003161		103074
75	Villadossola	003162		103075
76	Villette	003163		103076
77	Vogogna	003165		103077
Municipalities from *Sassari* and *Nuoro* to *Olbia-Tempio*				
1	Aggius	090001	090001	104001
2	Alà dei Sardi	090002	090002	104003
3	Arzachena	090006	090006	104004

Continued on next page

Table A – continued from previous page

#	*Municipality*	*idcode*_1991[a]	*idcode*_2001[a]	*idcode*_2011[a]
4	Berchidda	090009	090009	104006
5	Bortigiadas	090014	090014	104007
6	Buddusò	090017	090017	104008
7	Calangianus	090021	090021	104010
8	La Maddalena	090035	090035	104012
9	Luogosanto	090036	090036	104014
10	Luras	090037	090037	104015
11	Monti	090041	090041	104016
12	Olbia	090047	090047	104017
13	Oschiri	090049	090049	104018
14	Palau	090054	090054	104020
15	Aglientu	090062	090062	104002
16	Santa Teresa Gallura	090063	090063	104022
17	Tempio Pausania	090070	090070	104025
18	Trinità d'Agultu e Vignola	090074	090074	104026
19	Telti	090080	090080	104024
20	Badesi	090081	090081	104005
21	Golfo Aranci	090083	090083	104011
22	Loiri Porto San Paolo	090084	090084	104013
23	Sant'Antonio di Gallura	090085	090085	104021
24	Padru[c]		090090	104019
25	Budoni	091014	091014	104009
26	San Teodoro	091076	091076	104023
Municipalities from *Nuoro* to *Ogliastra*				
1	Arzana	091002	091002	105001
2	Bari Sardo	091005	091005	105002
3	Baunei	091006	091006	105003
4	Elini	091019	091019	105005
5	Gairo	091026	091026	105006
6	Girasole	091031	091031	105007
7	Ilbono	091032	091032	105008
8	Jerzu	091035	091035	105009
9	Lanusei	091037	091037	105010
10	Loceri	091039	091039	105011
11	Lotzorai	091042	091042	105012
12	Osini	091069	091069	105013
13	Perdasdefogu	091072	091072	105014
14	Seui	091081	091081	105015
15	Talana	091088	091088	105016
16	Tertenia	091089	091089	105017
17	Tortolì	091095	091095	105018
18	Triei	091097	091097	105019
19	Ulassai	091098	091098	105020
20	Urzulei	091099	091099	105021
21	Ussassai	091100	091100	105022
22	Villagrande Strisaili	091101	091101	105023

Continued on next page

Table A – continued from previous page

#	*Municipality*	*idcode*_1991[a]	*idcode*_2001[a]	*idcode*_2011[a]
23	Cardedu	091103	091103	105004
	Municipalities from *Cagliari* to *Medio Campidano*			
1	Arbus	092001	092001	106001
2	Barumini	092006	092006	106002
3	Collinas	092014	092014	106003
4	Furtei	092022	092022	106004
5	Genuri	092023	092023	106005
6	Gesturi	092025	092025	106006
7	Gonnosfanadiga	092029	092029	106007
8	Guspini	092032	092032	106008
9	Las Plassas	092034	092034	106009
10	Lunamatrona	092035	092035	106010
11	Pabillonis	092045	092045	106011
12	Pauli Arbarei	092046	092046	106012
13	Samassi	092052	092052	106013
14	San Gavino Monreale	092055	092055	106014
15	Sanluri	092057	092057	106015
16	Sardara	092065	092065	106016
17	Segariu	092067	092067	106017
18	Serramanna	092072	092072	106018
19	Serrenti	092073	092073	106019
20	Setzu	092076	092076	106020
21	Siddi	092077	092077	106021
22	Tuili	092086	092086	106022
23	Turri	092087	092087	106023
24	Ussaramanna	092089	092089	106024
25	Villacidro	092092	092092	106025
26	Villamar	092093	092093	106026
27	Villanovaforru	092095	092095	106027
28	Villanovafranca	092096	092096	106028
	Municipalities from *Cagliari* to *Carbonia-Iglesias*			
1	Buggerru	092007	092007	107001
2	Calasetta	092010	092010	107002
3	Carbonia	092012	092012	107003
4	Carloforte	092013	092013	107004
5	Domusnovas	092019	092019	107005
6	Fluminimaggiore	092021	092021	107006
7	Giba	092026	092026	107007
8	Gonnesa	092028	092028	107008
9	Iglesias	092033	092033	107009
10	Musei	092040	092040	107011
11	Narcao	092041	092041	107012
12	Nuxis	092043	092043	107013
13	Perdaxius	092047	092047	107014
14	Portoscuso	092049	092049	107016
15	San Giovanni Suergiu	092056	092056	107017

Continued on next page

Table A – continued from previous page

#	*Municipality*	*idcode_1991*[a]	*idcode_2001*[a]	*idcode_2011*[a]
16	Santadi	092060	092060	107018
17	Sant'Anna Arresi	092062	092062	107019
18	Sant'Antioco	092063	092063	107020
19	Tratalias	092085	092085	107021
20	Villamassargia	092094	092094	107022
21	Masainas	092103	092103	107010
22	Villaperuccio	092104	092104	107023
23	Piscinas	092107	092107	107015
Municipalities from *Milano* to *Monza e della Brianza*				
1	Agrate Brianza	015003	015003	108001
2	Aicurzio	015004	015004	108002
3	Albiate	015006	015006	108003
4	Arcore	015008	015008	108004
5	Barlassina	015013	015013	108005
6	Bellusco	015017	015017	108006
7	Bernareggio	015018	015018	108007
8	Besana in Brianza	015021	015021	108008
9	Biassono	015023	015023	108009
10	Bovisio-Masciago	015030	015030	108010
11	Briosco	015033	015033	108011
12	Brugherio	015034	015034	108012
13	Burago di Molgora	015037	015037	108013
14	Busnago	015039	015039	108051
15	Camparada	015045	015045	108014
16	Caponago	015047	015047	108052
17	Carate Brianza	015048	015048	108015
18	Carnate	015049	015049	108016
19	Cavenago di Brianza	015068	015068	108017
20	Ceriano Laghetto	015069	015069	108018
21	Cesano Maderno	015075	015075	108019
22	Cogliate	015080	015080	108020
23	Concorezzo	015084	015084	108021
24	Cornate d'Adda	015088	015088	108053
25	Correzzana	015092	015092	108022
26	Desio	015100	015100	108023
27	Giussano	015107	015107	108024
28	Lazzate	015117	015117	108025
29	Lentate sul Seveso	015119	015119	108054
30	Lesmo	015120	015120	108026
31	Limbiate	015121	015121	108027
32	Lissone	015123	015123	108028
33	Macherio	015129	015129	108029
34	Meda	015138	015138	108030
35	Mezzago	015145	015145	108031
36	Misinto	015147	015147	108032
37	Monza	015149	015149	108033

Continued on next page

Table A – continued from previous page

#	*Municipality*	*idcode*_1991[a]	*idcode*_2001[a]	*idcode*_2011[a]
38	Muggiò	015152	015152	108034
39	Nova Milanese	015156	015156	108035
40	Ornago	015161	015161	108036
41	Renate	015180	015180	108037
42	Roncello	015186	015186	108055
43	Ronco Briantino	015187	015187	108038
44	Seregno	015208	015208	108039
45	Seveso	015212	015212	108040
46	Sovico	015216	015216	108041
47	Sulbiate	015217	015217	108042
48	Triuggio	015223	015223	108043
49	Usmate Velate	015227	015227	108044
50	Varedo	015231	015231	108045
51	Vedano al Lambro	015232	015232	108046
52	Veduggio con Colzano	015233	015233	108047
53	Verano Brianza	015234	015234	108048
54	Villasanta	015239	015239	108049
55	Vimercate	015241	015241	108050
Municipalities from *Ascoli Piceno* to *Fermo*				
1	Altidona	044003	044003	109001
2	Amandola	044004	044004	109002
3	Belmonte Piceno	044008	044008	109003
4	Campofilone	044009	044009	109004
5	Falerone	044018	044018	109005
6	Fermo	044019	044019	109006
7	Francavilla d'Ete	044022	044022	109007
8	Grottazzolina	044024	044024	109008
9	Lapedona	044025	044025	109009
10	Magliano di Tenna	044026	044026	109010
11	Massa Fermana	044028	044028	109011
12	Monsampietro Morico	044030	044030	109012
13	Montappone	044033	044033	109013
14	Montefalcone Appennino	044035	044035	109014
15	Montefortino	044037	044037	109015
16	Monte Giberto	044039	044039	109016
17	Montegiorgio	044040	044040	109017
18	Montegranaro	044041	044041	109018
19	Monteleone di Fermo	044042	044042	109019
20	Montelparo	044043	044043	109020
21	Monte Rinaldo	044046	044046	109021
22	Monterubbiano	044047	044047	109022
23	Monte San Pietrangeli	044048	044048	109023
24	Monte Urano	044049	044049	109024
25	Monte Vidon Combatte	044050	044050	109025
26	Monte Vidon Corrado	044051	044051	109026
27	Montottone	044052	044052	109027

Continued on next page

Table A – continued from previous page

#	*Municipality*	*idcode_*1991[a]	*idcode_*2001[a]	*idcode_*2011[a]
28	Moresco	044053	044053	109028
29	Ortezzano	044055	044055	109029
30	Pedaso	044057	044057	109030
31	Petritoli	044058	044058	109031
32	Ponzano di Fermo	044059	044059	109032
33	Porto San Giorgio	044060	044060	109033
34	Porto Sant'Elpidio	044061	044061	109034
35	Rapagnano	044062	044062	109035
36	Santa Vittoria in Matenano	044067	044067	109036
37	Sant'Elpidio a Mare	044068	044068	109037
38	Servigliano	044069	044069	109038
39	Smerillo	044070	044070	109039
40	Torre San Patrizio	044072	044072	109040
Municipalities from *Bari* and *Foggia* to *Barletta-Andria-Trani*				
1	Margherita di Savoia	071030	071030	110005
2	San Ferdinando di Puglia	071045	071045	110007
3	Trinitapoli	071057	071057	110010
4	Andria	072005	072005	110001
5	Barletta	072007	072007	110002
6	Bisceglie	072009	072009	110003
7	Canosa di Puglia	072013	072013	110004
8	Minervino Murge	072026	072026	110006
9	Spinazzola	072042	072042	110008
10	Trani	072045	072045	110009

[a] The same *Istat* codes connection are applied to both *idcode_i* and *idcode_j* variables.

[b] The *idcode_*2011 is missing because these municipalities have merged in the 1999 (see Table for further details).

[c] The *idcode_*1991 is missing because this municipality was established in the 1996 (see Table for further details).

Source: Authors' own elaboration, supported by Storia dei Comuni (2019).

Table B: *Istat* codes connection for merged municipalities, 1991–2011

1991		2001		2011	
Municipality	*idcode_1991*	*Municipality*	*idcode_2001*	*Municipality*	*idcode_2011*
Mosso Santa Maria	002081	Mosso	096084	Mosso	096084
Pistolesa	002098				
Colcavagno	005043	Montiglio Monferrato	005121	Montiglio Monferrato	005121
Montiglio	005078				
Scandeluzza	005102				
Consiglio di Rumo	013076	Consiglio di Rumo	013076	Gravedona ed Uniti	013249
Germasino	013108	Germasino	013108		
Gravedona	013112	Gravedona	013112		
Sant'Abbondio	013208	Sant'Abbondio	013208	San Siro	013248
Santa Maria Rezzonico	013210	Santa Maria Rezzonico	013210		
Bleggio Inferiore	022016	Bleggio Inferiore	022016	Comano Terme	022228
Lomaso	022107	Lomaso	022107		
Bezzecca	022014	Bezzecca	022014	Ledro	022229
Concei	022065	Concei	022065		
Molina di Ledro	022119	Molina di Ledro	022119		
Pieve di Ledro	022141	Pieve di Ledro	022141		
Tiarno di Sopra	022197	Tiarno di Sopra	022197		
Tiarno di Sotto	022198	Tiarno di Sotto	022198		
Carrara San Giorgio	028024	Due Carrare	028106	Due Carrare	028106
Carrara Santo Stefano	028025				
Contarina	029016	Porto Viro	029052	Porto Viro	029052
Donada	029020				
Campolongo al Torre	030017	Campolongo al Torre	030017	Campolongo Tapogliano	030138
Tapogliano	030115	Tapogliano	030115		

Source: Authors' own elaboration, supported by Storia dei Comuni (2019).

Table C: *Istat* codes connection for splitted municipalities, 1991–2011

2011		2001		1991	
Municipality	*idcode*_2011	*Municipality*	*idcode*_2001	*Municipality*	*idcode*_1991
Bollate	015027	Bollate	015027	Bollate	015027
Baranzate	015250				
Venezia	027042	Venezia	027042	Venezia	027042
Cavallino-Treporti	027044	Cavallino-Treporti	027044		
Roma	58091	Roma	58091	Roma	058091
Fiumicino	058120	Fiumicino	058120		
Guidonia Montecelio	058047	Guidonia Montecelio	058047	Guidonia Montecelio	058047
Mentana	058059	Mentana	058059	Mentana	058059
Fonte Nuova	058122	Fonte Nuova	058122		
Taranto	073027	Taranto	073027	Taranto	073027
Statte	073029	Statte	073029		
Cagliari	092009	Cagliari	092009	Cagliari	092009
Monserrato	092109	Monserrato	092109		
Buddusò	104008	Buddusò	104008	Buddusò	090017
Padru	104019	Padru	104019		

Source: Authors' own elaboration, supported by Storia dei Comuni (2019).

Table D: *Ateco* codes connection, 1991–2011

1991 *Ateco* classification	2007 *Ateco* classification	Custom *Ateco* classification
Ateco_011	Ateco_01	*ateco_01_02*
Ateco_012	Ateco_02	
Ateco_013		
Ateco_014		
Ateco_015		
Ateco_020		
Ateco_050	Ateco_03	*ateco_03*
Ateco_101	Ateco_05	*ateco_05*
Ateco_102		
Ateco_111	Ateco_06	*ateco_06*
Ateco_120	Ateco_07	*ateco_07*
Ateco_131		
Ateco_132		
Ateco_103	Ateco_08	*ateco_08*
Ateco_141		
Ateco_142		
Ateco_143		
Ateco_144		
Ateco_145		
Ateco_112	Ateco_09	*ateco_09*
Ateco_151	Ateco_10	*ateco_10*
Ateco_152		
Ateco_153		
Ateco_154		
Ateco_155		
Ateco_156		
Ateco_157		
Ateco_158		
Ateco_159	Ateco_11	*ateco_11*
Ateco_160	Ateco_12	*ateco_12*
Ateco_171	Ateco_13	*ateco_13*
Ateco_172		
Ateco_173		
Ateco_174		
Ateco_175		
Ateco_176		
Ateco_177		
Ateco_181	Ateco_14	*ateco_14*
Ateco_182		
Ateco_183		
Ateco_191	Ateco_15	*ateco_15*
Ateco_192		
Ateco_193		

Continued on next page

Table D – continued from previous page

1991 *Ateco* classification	2007 *Ateco* classification	Custom *Ateco* classification
Ateco_201	Ateco_16	*ateco_16*
Ateco_202		
Ateco_203		
Ateco_204		
Ateco_205		
Ateco_211	Ateco_17	*ateco_17*
Ateco_212		
Ateco_222	Ateco_18	*ateco_18*
Ateco_223		
Ateco_231	Ateco_19	*ateco_19*
Ateco_232		
Ateco_241	Ateco_20	*ateco_20*
Ateco_242		
Ateco_243		
Ateco_245		
Ateco_246		
Ateco_247		
Ateco_244	Ateco_21	*ateco_21*
Ateco_251	Ateco_22	*ateco_22*
Ateco_252		
Ateco_261	Ateco_23	*ateco_23*
Ateco_262		
Ateco_263		
Ateco_264		
Ateco_265		
Ateco_266		
Ateco_267		
Ateco_268		
Ateco_233	Ateco_24	*ateco_24*
Ateco_271		
Ateco_272		
Ateco_273		
Ateco_274		
Ateco_275		
Ateco_281	Ateco_25	*ateco_25*
Ateco_282		
Ateco_283		
Ateco_284		
Ateco_285		
Ateco_286		
Ateco_287		
Ateco_296		
Ateco_322	Ateco_26	*ateco_26*
Ateco_323		

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Table D – continued from previous page

1991 *Ateco* classification	2007 *Ateco* classification	Custom *Ateco* classification
Ateco_332 Ateco_334 Ateco_335		
Ateco_297 Ateco_311 Ateco_312 Ateco_313 Ateco_314 Ateco_315 Ateco_316 Ateco_321	Ateco_27	*ateco_27*
Ateco_291 Ateco_292 Ateco_293 Ateco_294 Ateco_295 Ateco_300	Ateco_28	*ateco_28*
Ateco_341 Ateco_342 Ateco_343	Ateco_29	*ateco_29*
Ateco_351 Ateco_352 Ateco_353 Ateco_354 Ateco_355	Ateco_30	*ateco_30*
Ateco_361	Ateco_31	*ateco_31*
Ateco_331 Ateco_362 Ateco_363 Ateco_364 Ateco_365 Ateco_366	Ateco_32	*ateco_32*
Ateco_333	Ateco_33	*ateco_33*
Ateco_401 Ateco_402 Ateco_403	Ateco_35	*ateco_35*
Ateco_371 Ateco_372 Ateco_410 Ateco_900	Ateco_36 Ateco_37 Ateco_38 Ateco_39	*ateco_36_37_38_39*
Ateco_451 Ateco_452 Ateco_454 Ateco_455	Ateco_41 Ateco_42 Ateco_43	*ateco_41_42_43*

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Table D – continued from previous page

1991 *Ateco* classification	2007 *Ateco* classification	Custom *Ateco* classification
Ateco_453		
Ateco_501 Ateco_502 Ateco_503 Ateco_504	Ateco_45	*ateco_45*
Ateco_511 Ateco_512 Ateco_513 Ateco_514 Ateco_515 Ateco_516 Ateco_517	Ateco_46	*ateco_46*
Ateco_505 Ateco_521 Ateco_522 Ateco_523 Ateco_524 Ateco_525 Ateco_526	Ateco_47	*ateco_47*
Ateco_601 Ateco_602 Ateco_603	Ateco_49	*ateco_49*
Ateco_611 Ateco_612	Ateco_50	*ateco_50*
Ateco_621 Ateco_622 Ateco_623	Ateco_51	*ateco_51*
Ateco_631 Ateco_632 Ateco_634	Ateco_52	*ateco_52*
Ateco_641	Ateco_53	*ateco_53*
Ateco_551 Ateco_552	Ateco_55	*ateco_55*
Ateco_553 Ateco_554 Ateco_555	Ateco_56	*ateco_56*
Ateco_221	Ateco_58	*ateco_58*
Ateco_921 Ateco_922 Ateco_923	Ateco_59 Ateco_60	*ateco_59_60*
Ateco_642	Ateco_61	*ateco_61*
Ateco_721 Ateco_722 Ateco_726	Ateco_62	*ateco_62*

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Table D – continued from previous page

1991 *Ateco* classification	2007 *Ateco* classification	Custom *Ateco* classification
Ateco_723 Ateco_724 Ateco_924	Ateco_63	*ateco_63*
Ateco_651 Ateco_652	Ateco_64	*ateco_64*
Ateco_660	Ateco_65	*ateco_65*
Ateco_671 Ateco_672	Ateco_66	*ateco_66*
Ateco_701 Ateco_702 Ateco_703	Ateco_68	*ateco_68*
Ateco_741 Ateco_742 Ateco_743 Ateco_744 Ateco_748	Ateco_69 Ateco_70 Ateco_71 Ateco_73 Ateco_74	*ateco_69_70_71_73_74*
Ateco_731 Ateco_732	Ateco_72	*ateco_72*
Ateco_852	Ateco_75	*ateco_75*
Ateco_711 Ateco_712 Ateco_713 Ateco_714	Ateco_77	*ateco_77*
Ateco_745	Ateco_78	*ateco_78*
Ateco_633	Ateco_79	*ateco_79*
Ateco_746	Ateco_80	*ateco_80*
Ateco_747	Ateco_81	*ateco_81*
Ateco_725	Ateco_82	*ateco_82*
Ateco_751 Ateco_752 Ateco_753	Ateco_84	*ateco_84*
Ateco_801 Ateco_802 Ateco_803 Ateco_804	Ateco_85	*ateco_85*
Ateco_851 Ateco_853	Ateco_86 Ateco_87 Ateco_88	*ateco_86_87_88*
Ateco_926 Ateco_927	Ateco_90 Ateco_92 Ateco_93	*ateco_90_92_93*
Ateco_925	Ateco_91	*ateco_91*

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Table D – continued from previous page

1991 *Ateco* classification	2007 *Ateco* classification	Custom *Ateco* classification
Ateco_911 Ateco_912 Ateco_913 Ateco_930	Ateco_94	*ateco_94*
Ateco_527	Ateco_95	*ateco_95*
Ateco_950	Ateco_96	*ateco_96*
Ateco_990[a]		

[a] We excluded the Ateco_990 because no individuals were employed in this economic activity in each sample year.

Source: Authors' own elaboration based on Istat (2015a) and Istat (2015b).

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