PLANNING TRAFFIC SURVEILLANCE IN SPAIN: HOW TO OPTIMIZE THE MANAGEMENT OF POLICE RESOURCES TO REDUCE ROAD FATALITIES

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Abstract

Although traffic police enforcement is widely recognized as a key action in the road safety field, it can be a costly policy to implement. In addition, governments often impose budget constraints that can limit the resources available for activities such as law enforcement and surveillance. To evaluate the impact of human traffic control resource planning on traffic fatalities on Spanish NUTS-3 region interurban roads, this paper uses an econometric model to investigate the performance of police enforcement intensity by focusing on two crucial traffic law infractions (i.e., speeding and drunk driving). After controlling for a range of economic, demographic, climate, and risk exposure variables, results highlight the relevance of visible, human, and in-person traffic law enforcement through regular vehicle patrols for reducing traffic crashes, with a non-significant effect of automatic enforcement. Our findings have important implications for traffic police resource management regarding the effective maintenance of patrol cars and plans to digitalize and automatize police administrative tasks and procedures.

Keywords: law enforcement, surveillance, traffic police management, human police resource planning, road fatalities, NUTS-3 regions.

Research highlights

- Police surveillance is a key road safety tool but is costly to implement and manage

- Investigates impact of policing enforcement intensity on traffic fatalities in Spain

- Focuses on police surveillance of main traffic law violations: speeding and DUI

- Highlights role of visible human enforcement vs limited effect of automatic resources

- Study needed of how automatization/digitalization affect allocation of human assets

1. Introduction

Road crashes represent both a significant task for public health management and one of the most ambitious targets addressed by the United Nations 2030 Agenda for Sustainable Development (UN, 2021). Considering the road safety policy framework, traffic law, police enforcement, and surveillance are primary tools that help manage road safety and are a top concern for many traffic departments in high-income countries to encourage road users' norm compliance (Urie et al., 2016). These activities may have numerous benefits for road transportation and safety management as part of a so-called "Safe System" (Michael et al., 2021). By monitoring traffic flow, police can enhance the efficiency of traffic by identifying bottlenecks or high-risk or congestion areas, and saving time for road users (Lou et al., 2011). These activities can also help authorities identify traffic violation and collision behavior patterns that can be used as information to develop targeted interventions through education campaigns or changes in road infrastructure (Walter et al., 2011). From a safety perspective, although traffic enforcement intensification may contribute to significantly reducing crash rates derived from traffic violations, the impact of these efforts on the severity of collisions is not conclusive (Blais and Dupont, 2005; Mäkinen et al., 2003).

One of the most effective ways to enhance traffic police enforcement is through the use of technology and automated systems (Li et al., 2020) (e.g., the use of speed cameras and red-light cameras has been shown to reduce speeding and other dangerous behaviors and can help police officers to identify and apprehend offenders quickly; see Truelove et al., 2023). However, on its own, the use of technology seems to fall short (Sam et al., 2022) and the presence of police officers remains an essential component for effective enforcement (Beaton et al., 2022) to detect unsafe driving practices, poor road design, or inadequate signage, or to respond to complex changing traffic circumstances with a deeper understanding of the local environment (Alrejjal et al., 2022). The necessary presence of human enforcement with the use of uniformed police officers is particularly irreplaceable in certain areas of traffic policing such as driver distraction, seatbelt use, and random breath testing (see Tudor-Owen, 2021 on the 'Blue Shirt' effect of traffic policing).

The literature on the study of the effectiveness of traffic police enforcement performance in general is extensive and mainly focuses on the application of Data Envelopment Analysis (see, for, example, Antić et al., 2020; Mozaffari et al., 2021; Verma and Gavirneni, 2006; Wu et al., 2010) or Multicriteria Decision methods (Adler et al., 2014; Martins & Garcez, 2021). This extends to the evaluation of the efficiency of public road safety management in general (Alper et al., 2015; Chang et al., 2020). Nevertheless, academic research does not seem to have given the same priority to the investigation of traffic police human resource planning in Europe (ETSC, 1999), probably due to the complexity of traffic law regulations and the specific professional skills for enforcement planning that the subsequent deterrence process requires. Consequently, traffic law violations traditionally compete with other forms of crime (robberies, murders, gender violence, environmental issues…) that also demand police attention (Hunt et al., 2019). This has made traffic law enforcement unattractive and in many European countries, the allocation of policing resources for traffic surveillance is under-prioritized and does not keep pace with the growing traffic volumes (ETSC, 2016).

The optimal allocation of traffic policing resources is critical for managing road safety (Adler et al., 2012), especially when there is a limited public budgetary framework (Adler et al., 2014), and this sparks an intense debate on more appropriate strategies for deploying officers (Tay, 2005) that are most likely based on predictive crash analytics (Redelmeier et al., 2003; Rosenfeld et al., 2017) and risk-based approaches (Elvik et al., 2012; Santhiapillai and Ratnayake, 2022).

The current paper addresses this field by assessing econometrically how effective the management of the resources used by traffic police is for accident-related fatalities on Spanish interurban roads. For this, we highlight the different roles played by human and material means and analyze the intensity of the resources applied to police enforcement and surveillance in the academic literature. To our knowledge, the number of previous studies on policing performance in Spain is extremely small and they mainly focus on police activities in general (Benito et al., 2021; Díez-Ticio and Mancebon, 2002) and the efficiency with which the responsibilities of the municipal police are executed in matters of public and urban road safety (García-Sánchez, 2009; 2013)[1].

In addition, the study covers a time period of 15 years, which is greater than that used in other international studies on this topic (Yannis et al., 2008). Furthermore, our geographic focus is regional, as some preceding studies on enforcement resources recommend (Braga et al., 2019; Kuo et al., 2013). The literature on the impact of traffic police enforcement has predominantly been conducted by evaluating aggregated data for large areas (i.e., national level), and demonstrating, in general terms, that a proactive policy leads to a dissuasion effect that seems to be inversely correlated with both crashes and traffic offenses (Bates et al., 2012; Rezapour et al., 2017; Tay, 2005). This is also the case in Spain, the object of our case study (Castillo-Manzano et al., 2019; Dadashova et al., 2014; Villalbí and Pérez, 2006). Nevertheless, road safety analyses with regional approaches are fully justified (Castro-Nuño and Arévalo-Quijada, 2018), although less frequent for exploring traffic law enforcement effectiveness (Hakkert et al., 2001; Stanojević et al., 2013; Yannis et al., 2007; 2008). This is especially true in Spain, where, to our knowledge, a gap exists that our paper aims to fill by introducing a spatial approach to examine the optimal allocation of traffic policing resources for NUTS-3 (Eurostat nomenclature of territorial units for statistics) regions (provinces).

In summary, scholars have widely addressed how limited resources for policing in general tend to be allocated by government departments according to the efficiency of police performance (Kratooski and Das, 2002; Wu et al., 2010). However, as noted by Hakkert et al. (2001) and Hakkert and Gitelman (2005), the daily tasks of traffic police officers have not been extensively studied by the academic literature. The pertinence of our study would, therefore, be supported by this, and road safety evidence, especially that related to enforcement intensity, could be used as a reference to design and plan the traffic police enforcement system (Adler et al., 2012).

The paper is organized as follows. Section 2 presents data and methodology. In Section 3, we discuss the results derived from our model. Section 4 briefly concludes the paper and indicates some future directions of research. Finally, Section 5 presents some lessons that have been learned.

2. Data and methodology

[1] Three police forces exist in Spain: 1. *Policía Nacional* (National Police), which deals with more serious crimes in all Spanish regions in collaboration with three Autonomous Community police authorities in their respective regions, i.e., the Basque Country (*Ertzaintza*), Catalonia (*Mossos d'Esquadra*), and Navarre (*Policía Foral*). 2. *Guardia Civil* (Civil Guard), with responsibility for law enforcement and highway and road patrol, except in the Basque Country, Catalonia, and Navarre, where this is the responsibility of their own above-mentioned regional police forces. 3. *Policía Municipal* (Local/Municipal Police force), organized at the municipal level in towns and cities of 5,000 or more inhabitants. This force collaborates with the National Police and deals with matters such as urban traffic management within the town/city space, parking, monitoring public demonstrations, guarding municipal buildings, and enforcing bylaws.

In Spain, Traffic Law Enforcement (TLE) tasks and surveillance on interurban roads are the responsibility of the Civil Guard Traffic Task Force (hereafter, CGTF) in the whole of Spanish national territory except the Basque Country and Catalonia. In these two regions, there is a decentralization of the TLE to their own regional traffic police forces (Castillo-Manzano et al., 2022), the *Ertzaintza* and *Mossos d'Esquadra*, respectively. As a result, our dataset has been constructed for a sample of 43 of the total number of 52 Spanish NUTS-3 regions or provinces as we exclude provinces in the Basque Country and Catalonia, and also Ceuta and Melilla (Spanish territories located in the North of Africa, whose small size could distort our analysis). Note that the province of Navarre is included in our sample as TLE was managed jointly by the CGTF and the regional traffic police (i.e., the *Policía Foral*) during our timeframe[2]. The CGTF has over 140 detachments in these 43 regions that depend on the Spanish State Government and are responsible for some specific highways in each of the NUTS-3 units. Notwithstanding, they can also be called upon to carry out surveillance on other roads, even in other NUTS-3 units, when some special operations that involve a high level of mobility so require. These include vacation periods, for example, and some sporting events (the road cycling Tour of Spain and the Spanish Motorcycle Gran Prix, among others).

The study period is from 2005 (the year in which the Strategic Road Safety Plan 2005-2008 came into force to align Spanish road safety policy with EU objectives) to 2019 (the year preceding the outbreak of the recent COVID-19 pandemic). As we stated in the Introduction Section, this broad time period of 15 years is one of the strengths of our study since it allows us to cover different legislative reforms implemented in Spain in terms of road safety, such as the introduction of the points-based driver's license in July 2006 or the Penal Code reform in December 2007 (Castillo Manzano et al., 2011).

We apply a country fixed effects model that allows us to consider any omitted constant variable that correlates with the explanatory variables. The panel data have been econometrically treated with the STATA package using a model that follows expression (1) and takes NUTS-3 region (province) i during period t in the expression (1):

$$\mathrm{Ln}\ (E\ [Y_{it}]) = \alpha + \beta_k X_{it} + \gamma_k Z_{it} + \lambda_k W_{it} + \nu \mathrm{Year}_t + \delta_i \mathrm{NUTS3\text{-}Region}_i + \varepsilon_{it,} \quad (1)$$

where Y_{it} is the endogenous road safety variable, namely the number of road traffic accidents/road traffic fatalities on interurban roads (within 30 days of the accident, as per the Vienna Convention). As explained below, following previous and recent studies on road safety such as Albalate and Fageda (2021) and Sánchez-González et al. (2021), total figures have been chosen instead of per capita variables as the total population was used as the exposure variable.

[2] Responsibility for TLE was transferred exclusively to the Navarre regional police force on July 1, 2023.

Regarding explanatory variables, as Table 1 shows, our model considers a set of different vectors relating to Spanish NUTS-3 regions (provinces) inspired by recent studies on traffic safety and TLE. Specifically:

- X_{it} contains a vector of the province's economic and demographic attributes that scholars believe may influence road safety. These are: unemployment rate (Casado-Sanz et al., 2019; Naqvi et al., 2023), mean age of population (Albalate and Fageda, 2019; Castro-Nuño and López-Valpuesta, 2023), and population density (Besharati et al., 2021; Chen et al., 2023);
- Z_{it}: a vector that refers to TLE and surveillance activities carried out by the CGTF (whose impact on road safety derived from intensity and productivity is analyzed in the current paper) according to statistical data provided by the official source (CGTF). This vector has been used in previous studies such as Feng et al. (2020) and Rezapour et al. (2018).
- W_{it}: a vector that represents mobility and meteorological variables related to traffic fuel consumption[3] (as in Antoniou et al., 2016; Maulidar et al., 2022; Suphanchaimat et al., 2019) and weather conditions (as explored in Albalate and Bel-Piñana, 2019; Sánchez-González et al., 2018, among others).

Note that X_{it} and W_{it} act as control variables and $Year_t$ is an annual time trend that controls for the common trend in all the provinces in the dataset. Finally, $NUTS\text{-}3Region_{it}$ are fixed effects per province and ε_{it} is a mean-zero random error.

Table 1. Description of the Variables (in Spanish NUTS-3 regions, excluding the Basque Country and Catalonia) and their descriptive statistics

Variable	Definition (for each Spanish NUTS-3 region or province)	Sources and websites (where available)	Mean	Std Dev	Max	Min
Endogenous variable						
Fatalities	Number of traffic fatalities recorded on interurban roads (within 30 days of the accident)	Spanish Directorate General of Traffic (https://www.dgt.es/.galleries/downloads/dgt-en-cifras/publicaciones/Series_Historicas_Accidentes_30_dias/Series-Historicas-Accidentes-30-dias-2021.xlsx)	**36.97**	**26.91**	**200**	**3**

[3] We have used this variable as a proxy of mobility due to the lack of data on vehicle miles traveled for our sample.

Exogenous variables by category						
TLE and surveillance variables						
Speed Control	Number of vehicles subjected to speed tests using CGTF radar equipment (stationary and mobile)[4] (in log form)	Civil Guard Traffic Task Force (data provided by source)	**13.01**	**0.72**	**15.42**	**10.74**
Alcohol Control	Number of breath tests administered by CGTF (in tens of thousands)		**12.60**	**9.11**	**63.49**	**1.30**
Officers	Number of CGTF officers deployed (annual mean) (in log form)		**7.65**	**0.41**	**9.21**	**6.68**
Infraction Reports/Officers	Number of violations detected by CGTF per CGTF officer		**21.42**	**6.22**	**40.06**	**8.11**
Hours/Officers	Mean time devoted to surveillance tasks (Number of hours per CGTF officer)		**7.74**	**0.39**	**9.58**	**5.72**
Km/Vehicles	Number of km traveled by CGTF per number of vehicles used by CGTF		**226.85**	**36.02**	**422.33**	**150.14**
Economic and demographic variables						
Unemployment	Unemployment rate (in percentage) in the fourth trimester of each year	Spanish National Statistical Institute (https://www.ine.es/dynt3/inebase/es/index.htm?padre=996&capsel=997)	**17.73**	**8.03**	**42.3**	**2.88**
Mean age	Population mean age in number of years	Spanish National Statistical Institute (https://www.ine.es/jaxiT3/Tabla.htm?t=3199&L=0)	**42.98**	**3.02**	**50.93**	**36.9**
Population Density	Population per km^2	Eurostat (https://data.europa.eu/data/datasets/gngfvpqmfu5n6akvxqkpw?locale=en)	**112.98**	**154.32**	**839.7**	**8.7**
Population (exposure variable)	Number of inhabitants on January 1 each year	Spanish National Statistical Institute (https://www.ine.es/jaxiT3/Tabla.htm?t=2852&L=0)	**851185.7**	**1007848**	**6,663,394**	**88,600**
Mobility and meteorological variables						
Transport fuel consumption per capita	Tonnes of transport sector fuel consumption (gas and diesel) per capita (in log form)	Spanish Ministry for the Ecological	**-0.36**	**0.28**	**0.36**	**-0.93**

[4] The Speed Control variable only quantifies controls conducted by radar mounted on Civil Guard Traffic Task Force vehicles. Controls using permanent roadside radar equipment are therefore excluded.

		Transition and the Demographic Challenge (https://www.cores.es/en/estadisticas)				
Rainfall	Mean rainfall (in millimeters)	Spanish State Meteorological Agency (data provided by source)	**514.76**	**305.31**	**1,883.7**	**58.6**
Minimum Temperature	Mean minimum temperature (in tenths of a degree C)		**101.96**	**36.60**	**194.7**	**27.4**
Maximum Temperature	Mean maximum temperature (in tenths of a degree C)		**211.83**	**26.48**	**275.3**	**153.7**
Linear time trend						
Time Trend		Prepared by authors	**2012**	**4.32**	**2019**	**2005**

A panel data model averaged by population has been estimated assuming a negative binomial distribution. Fixed effects have been included to conform with the Hausman Test results (see Table 2) and these also serve to correct any possible endogeneity issues triggered by time-invariant unobserved factors. The inclusion of province-fixed effects is a common approach when working with panel data in road traffic evaluations (Castillo-Manzano et al., 2020).

The only way to address the other possible source of endogeneity, based on simultaneity, would be that, when an exceptional increase occurs in road deaths in any given province, the local traffic policy in the province would respond flexibly with an increase in Traffic Police resources. It would be more implausible to assume the opposite; that a fall in the mortality rate would be met with a reduction in traffic police resources, due to the inflexibility of low short-term supply.

Be that as it may, the first case is unlikely in our case study, due to the unique features of the CGTF. As has been explained above, the CGTF depends on the Spanish State Government alone and is completely independent of the governments with direct powers in the NUTS-3 regions (i.e., local, provincial, and regional governments), which have absolutely no power over the CGTF. Thus, the territorial supply of traffic police resources is essentially governed by historical considerations and factors related to the hybrid police force's management type, as the force is military by nature (with ranks such as general, colonel, captain, and lieutenant). There is also a rigid network of territorial facilities including the so-called "police barracks" in every province with a specific quota of traffic officers. Traffic officers are also civil servants and have the right to a tenured position in a specific area, which means that their transfer to another NUTS-3 area is rather inflexible in the short term.

We have opted for a negative binomial distribution, as is regularly the case in the prior literature that analyzes road safety determinants (see, for example, Albalate et al., 2013 among many other applications). However, in our case, this is also justified by the non-normal distribution of the variables (see the results of the Doornik-Hansen test in Table 2).

A negative binomial distribution has been preferred to a Poisson as the variance of the Fatalities variable is nearly 20 times greater than the mean (724.17 versus 36.97, see Table 1). As statistical theory states, the mean and the variance are the same in a Poisson distribution. In our case, the distribution of the Fatalities variable displays some signs of overdispersion, corroborated by the results of the Cameron and Trivedi equidispersion test (see Table 2).

This result is not unusual: as Khattak et al. (2021) maintain, overdispersion is an extremely common feature in crash data, whereby it is advisable to use a negative binomial estimation for crash count rather than a Poisson as it relaxes the equal mean-variance equality constraint of Poisson regression. In any event, results are very robust to the use of Poisson estimation and even improve substantially (Poisson estimation available from authors upon request).

The test results in Table 2 also show that the dataset is heteroscedastic and autocorrelated (see the results of Greene's modified Wald test and Wooldridge test in Table 2), so the model has been estimated with standard errors robust to heteroscedasticity and assuming an AR (1) correlation in the error term, as is usual in analyses of Spanish provinces (Castillo-Manzano et al., 2021). The low VIF values (maximum 4.86; average 2.93) indicate that there are no significant correlation/multicollinearity issues. The VIF values are significantly lower than the rule-of-thumb recommendation in econometrics textbooks, which is below 10 (see Hair et al., 2013). Finally, the Levin-Lin-Chu unit root test shows that the dependent variable does not present any stationarity problems.

3. Discussion of Results

Table 2 gives the estimation results for the global model presented in the previous section. An estimation with only the main explanatory variables and an estimation with the main explanatory variables and province fixed effects are included as a robustness check. Our results can be observed to be quite robust in both of the proposed estimations.

The results in Table 2 are consistent with the previous road safety academic literature. Beginning with the explanatory variables not associated with enforcement, a negative relationship can be observed between road fatalities and economic activity measured by the unemployment rate (in line with Wegman et al., 2017). This indicates that, with a similar level of economic development among all Spanish provinces, those with less economic activity, and therefore a higher unemployment rate, would have lower deaths on interurban roads.

In addition, the positive relationship between the population mean age and fatalities could be indirect confirmation that elderly drivers are linked to a greater risk of being involved in more severe collisions (Braver & Trempel, 2004).

Table 2. Estimation results (panel data model, population-averaged with negative binomial distribution and logarithmic link)

Exogenous Variables	Endogenous variable: Fatalities		
Speed Control	0.0141 (0.0234)	0.0024 (0.0244)	0.0055 (0.0469)
Alcohol Control	-0.0043 (0.0022)*	-0.0041 (0.0020)**	-0.0140 (0.0037)***
Officers	-0.3978 (0.1184)***	-0.3615 (0.1164)***	-0.4964 (0.1260)***
Infraction Reports/Officers	-0.0044 (0.0024)*	-0.0065 (0.0023)***	-0.0116 (0.0034)***
Hours/Officers	-0.0502 (0.0290)*	-0.0532 (0.0297)*	-0.0927 (0.0450)**
Km/Vehicles	-0.0014 (0.0007)**	-0.0014 (0.0008)*	-0.0002 (0.0007)
Unemployment	-0.0191 (0.0040)***	-0.0253 (0.0025)***	-0.0232 (0.0035)***
Mean age	0.0415 (0.0239)*	-	-
Population Density	0.0008 (0.0011)	-	-
Transport fuel consumption per capita	0.4264 (0.1931)**	-	-
Rainfall	0.00012 (0.0006)*	-	-
Minimum Temperature	-0.0017 (0.0023)	-	-
Maximum Temperature	0.0024 (0.0021)	-	-
Time Trend	-0.0885 (0.0069)***	-0.0794 (0.0048)***	-0.0761 (0.0053)***
Province fixed effects	Yes	Yes	No
Autocorrelation structure	AR(1)		
Hausman specification test (Ho: the preferred model is random effects)	139.56***	154.89***	154.89***
Doornik-Hansen test – multivariable normality (Ho: the dependent variable is normally distributed)	2486.495***	2486.495***	2486.495***
Cameron and Trivedi test – overdispersion (Ho: equidispersion)	0.0362***	0.0575***	0.0575***
Levin-Lin-Chu test – nonstationarity (Ho: nonstationarity I(1) behavior)	-1.05696***	-1.05696***	-1.05696***
Greene's modified Wald test – heteroscedasticity (Ho: constant variance)	430.55***	393.16***	338.77***

Wooldridge test – autocorrelation (Ho: no first-order correlation)	8.575***	13.706***	13.706***
Wald test – joint significance (Ho: no joint significance of the independent variables)	4791.98***	268.79***	1302.46***
Max VIF/Mean VIF – multicollinearity	4.86/2.93	2.69/1.79	2.69/1.79
No. observations	645	645	645
No. NUTS-3 regions (provinces)	43	43	43

Note: Standard errors in brackets robust to heteroscedasticity. Statistical significance at 1 percent (***), 5 percent (**), and 10 percent (*).

It can likewise be concluded that the greater the movement of vehicles on highways, measured by fuel consumption (Dadashova et al., 2016), the higher the mortality rate due to greater risk exposure. The same is true for adverse weather conditions due to rain, which demonstrates a higher impact on traffic fatalities on interurban roads (Jung et al., 2014). Lastly, the time trend points to a favorable evolution of Spanish road safety over time since 2005. This was to be expected as Spain was one of the countries that recorded the fastest and most notable progression in compliance with the commitment to reduce road mortality by 50%, as established by the European Union in the third European Road Safety Program 2003-2010 (Castillo-Manzano et al., 2014).

Focusing on the goal of the present work and observing the traffic policing-related variables in Table 2, we find a broad set of results on the impact of TLE and surveillance on both instrument choice and the level of resource management.

Considering the different traffic policing instruments, this paper estimates the two main controls conducted by the CGTF, specifically, speed controls and breath tests. Our model's results enable us to test the suitability of the human factor vs. task automatization to maximize the positive effect of enforcement on drivers' risk-taking. In other words, breath tests conducted by officers in person reduce the road accident rate, whereas patrol car-mounted speed controls of which road users are generally unaware have no effect. Following on with this same idea of the irreplaceability of the human factor, the significance of the number of CGTF officers must be emphasized.

In other respects, the results on traffic policing management also show the positive effects of optimizing the use of human and material traffic policing resources on crash deterrence, which is similar to the result obtained by Basilio et al. (2021) for crime prevention. The positive effect of the vehicle use indicator is especially noteworthy (see Km/Vehicles variable), which is compelling for the efficient maintenance management of vehicles in order to maximize their up-time on the road. Other significant results, albeit at only 10% in this case, are the reported traffic infractions per officer ratio (Infraction Reports/Officers variable) and the time devoted to specific enforcement tasks per officer (Hours/Officers variable).

Taken together, these results suggest that the visible presence of traffic police officers and their vehicles conducting controls not only increases the possibility of apprehending offenders (Tay, 2005) but that it might also have a halo effect on drivers (Walter et al., 2011). This would have a greater deterrent effect on incompliance behaviors than the simple fact of being surveilled automatically when driving by a radar that might also be camouflaged, which would result in the deterrent effect being squandered.

4. Concluding remarks

Road crashes constitute both a significant task for public health management and one of the most ambitious targets addressed by the United Nations 2030 Agenda for Sustainable Development. Two of the main tools that authorities can use to tackle this safety and public health issue are traffic law enforcement and police surveillance, although their impact on the severity of collisions is not fully conclusive.

This paper uses a panel data model to investigate the impact on fatalities of traffic law enforcement management and surveillance intensity on interurban roads with a sample based on the 43 Spanish NUTS-3 regions and for a time period of 15 years (2005-2019), which is greater than that used in other international studies on this topic. In addition, economic, demographic, climate, and risk exposure variables have been included in the model as control variables.

Our results reinforce the essential role of visible, human, in-person enforcement based on constantly moving vehicle patrols to combat traffic collisions (in line with other researchers such as Sam, 2022) with, for example, breath test controls, and highlight the non-significant effect of automatic enforcement through radar speed control (Fisa et al., 2022). Furthermore, although it seems that there might be a limited margin for the automatization of surveillance and enforcement tasks, our findings would justify opening up future research lines to evaluate the influence and success of any plan to digitalize and automatize bureaucratic tasks and administrative procedures that the traffic police must conduct and also for good health and occupational hazard prevention policies, bearing in mind the very demanding work environment in which police force tasks are executed (Van Thielen et al, 2018). The end goal in both cases would be to maximize the time that officers are actively and effectively devoting their time to the surveillance and sanctioning of traffic violation behaviors. These issues would lead to a future exploration of the impact on the allocation of police resources after recent challenges derived from enforcement automatization and digitalization phenomena such as the introduction of Artificial Intelligence tools (see Raja et al., 2023) and the application of traffic rules for automated vehicles (Bhuiyan et al., 2023). This might also be complementary to another future research line that assesses the efficiency of traffic police force performance at the regional level using other techniques such as Data Envelopment Analysis methodology, to close the existing gap in Spain.

5. Lessons learned

The outcomes of this research provide insights into the limits associated with the automatization of police surveillance and enforcement tasks and the need to maximize the time that officers actively devote to the surveillance of traffic violation behaviors in the line explored by other researchers such as Lum et al. (2017) and Singh et al. (2020). Moreover, some managerial implications are offered with the provision of efficient patrol car technical maintenance, plans to digitalize and automatize bureaucratic tasks and administrative procedures, and officer health and occupational hazard policies.

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