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From legislation to compliance: The power of traffic law enforcement for the case study of Spain

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ABSTRACT

Using a dynamic transfer function model-based methodology, this study analyzes the joint influence of legislation changes, enforcement and compliance with driving regulations in terms of road fatalities in Spain during the 2005–2015 time period. Three robust econometric models demonstrate that two of the road safety law reforms recently implemented in Spain, the points-based driver's license and the toughening of the Penal Code, have had positive impacts, albeit with varying durations. Their impacts are also seen to have been reinforced by the application of a range of monitoring instruments to track compliance. The most effective of these include radar speed measuring devices, the mere presence of which has the desired deterrent effect irrespective of the positive proof that they might detect. However, lack of compliance with maximum alcohol limits seems to increase road fatalities, which suggests that a more complex preventive strategy needs to be developed through a combination of programmed actions. Lastly, the irreplaceable deterrence role of traffic police who enforce compliance with driving laws stands out, with the number of officers deployed being decisive.

1. Introduction

Traffic accidents cause over a million deaths per year worldwide, produce substantial economic costs for society, and generate a major public health problem (WHO, 2017). A great number of policies have therefore been developed by different levels of government and international organizations to reduce the accident rate. These policies stress each of the dimensions that affect driving and the likelihood of a crash (the road, the vehicle, the user) before, during, and after the accident (Haddon, 1980). Many are specifically directed at preventing, enforcing, and correcting individual driver behavior since, as is well known, most traffic accidents are caused by human error due to widespread noncompliance with traffic laws (Elvik et al., 2009).

Framed in this line, the purpose of this study is to examine the influence of changes to legislation, enforcement, and compliance with traffic regulations in terms of the number of road fatalities in Spain. The period chosen for the study is recent—2005-2015—and marked by the end of the economic growth cycle and the economic recession, which was especially hard-felt in Spain (Regidor et al., 2014). 2005 was specifically taken as the starting point as it marks a turning point in Spanish road safety. The coming into effect of the Directorate-General of Traffic's Strategic Plan for 2005–2008 (DGT, 2006) made road safety a political priority (Novoa et al., 2009; Pérez, 2009). This Plan strengthened existing legislative measures by making major changes to traffic laws, including the introduction of the points-based driver's license and the reform of the Penal Code. Measures to enforce compliance were also strengthened (Novoa et al., 2011b). To achieve our objective we use a robust econometric methodology based on dynamic transfer function models for the advanced treatment of time series.

This article is structured in the following way: after the introduction, Section 2 includes a review of both the international and Spanish literature on the topic. Next, the dataset and methodology are explained in Section 3. Section 4 sets out the results, which are subsequently discussed in Section 5. Section 6 addresses the main conclusions that derive from the research. Finally, a list of references is provided.

2. Literature review

One of the most-widespread strategies to raise compliance with traffic laws in developed countries is based on a combination of

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legislation (with differing degrees of severity) (see e.g., Castillo-Manzano et al., 2011, 2015), police monitoring-controls (see Tay, 2005), and punitive correction (see e.g., Basili et al., 2015; Bjørnskau and Elvik, 1992). Evidence indicates that these three road safety policy tools should be inseparable (Wegman, 1992) as the existence of traffic legislation does not *per se* ensure a reduction in risk behaviors (ETSC, 2011). Traffic laws should also be enforced by an effective traffic monitoring and control system (Mäkinen et al., 2003).

Coercive road safety measures have traditionally been based on the principles of the General Deterrence Theory (Bates et al., 2012) with the aim of increasing individual-social education, perceptions and awareness of the consequences of Unsafe Driving Actions (UDAs) (Allen et al., 2017; Fleiter et al., 2013; Watling and Leal, 2012). According to the General Deterrence Theory, individuals will be motivated to abstain from rule breaking if they perceive any subsequent sanction or punishment to be severe, unavoidable, and immediate. Therefore, to effectively encourage compliance with the law, sanctions need to be perceived by the public as unavoidable, severe, and swift (Homel, 1994, 2012). Nonetheless, it must be borne in mind that people's personalities influence their moral acceptance of coercive policies, which might reduce the effectiveness of these road safety efforts (Guttman, 2015).

The literature has broadly addressed the relationship between the application of law enforcement and compliance with road safety law (Davey and Freeman, 2011). In practice, the most widely implemented Traffic Law Enforcement (TLE) strategies to achieve deterrence and compliance with laws include, inter alia, police surveillance (Tay, 2005) and the application of formal penalty mechanisms (e.g., fines and jail sentences; see Blair and Knight, 2013; Goodwin et al., 2006). Surveillance is frequently used for recurrent UDAs, such as speeding (Castillo-Manzano et al., 2019; ETSC, 2016; Veisten et al., 2013) and driving while under the influence of alcohol (DUI) (Blais et al., 2015; Sanem et al., 2015).

There is a logical consensus that the key outcome used to evaluate TLE effectiveness is deterrence. The police prevent road users from committing violations by causing a fear of being detected and fined or receiving some other form of punishment. For this they use two processes which, despite being directed at different populations, are based on similar mechanisms (see, for example, Fleiter et al., 2013 for a broader analysis): specific deterrence (i.e., anyone detected breaking the law and punished is deterred from reoffending) and general deterrence (i.e., people, in general, are deterred from committing a violation without being detected). Compliance with the law through deterrence is complemented (and, ideally, replaced in the long term) by voluntary compliance based on moral adherence to the law, whether because the law is considered to be morally justified or because it is considered to be morally correct to comply with authority even when the law is controversial (Goldenbeld et al., 2013).

The model underlying this process is synthesized in Fig. 1, which shows all the corresponding phases, from legislation to the final objective of compliance, based on the deterrence mechanism introduced by TLE.

As can be observed in Fig. 1 and following Sanem et al. (2015), there are various elements, from legislation to compliance, that need to be coordinated to successfully raise awareness and induce a perception of being caught and sanctioned if laws are violated (Mäkinen et al., 2003; SWOV, 2016).

Legislation is seen as the reference framework for traffic planning and management and can influence users (basically drivers) in three ways (ETSC, 2011):

First, the legislation enforced by means of police monitoring, surveillance, and control activities (TLE) creates an *objective risk* (i.e., a real likelihood of being caught caused by the level of surveillance activities). This has an impact on drivers' perceptions of the possibility of traffic violations being detected depending to the intensity of TLE (i.e., a *subjective perception)*. Second, the application of complementary support measures (e.g., publicity campaigns, see Castillo-Manzano et al., 2012; or the existence of an efficient judicial-punitive system, see Factor, 2014; Redelmeier et al., 2003) can increase or reduce the subjective risk of detection and, to a great extent, determine the size of the effect that deterrence has on behavior (Mehmood, 2010; Stanojevĭ;c et al., 2013). Third, the effects of legislation can directly influence the behavior of some road users due to their moral attitude toward the legislation (Zaidel, 2002); essentially, they are aware of the need for laws and some kind of vehicle code to exist, and so comply voluntarily when they see other users abiding by the law (Zaal, 1994).

The legislation-TLE combination can have a significant effect on compliance with traffic rules, although it is also clear that non-compliance will probably continue to exist (see Zaidel, 2002). Legislation is the most evaluated intervention with the best outcomes, although, as Bendak (2005) and Castillo-Manzano et al. (2011) found, this positive effect seems to be limited in time. Two outcomes can be analyzed to assess the impact of TLE when considering the enforcement mechanism: change in road user behavior and attitudes (traffic violations) and effect on traffic accidents.

The impact of TLE on the number of traffic accidents has been investigated by different studies, although, as Stanojević et al. (2013) state, there is mixed evidence as to its efficacy for reducing accidents. Some of these studies (e.g., Hakkert et al., 2001; Makowsky and Stratmann, 2011) found that TLE activities and/or fines had some positive effects on road accident reduction, while others (Fell et al., 2014; Tarko, 2008) did not find any statistical significance for enforcement measures. This difference in findings has led authors such as Elvik (2001) to argue that all relevant costs and benefits should be taken into account when evaluating TLE effectiveness.

Considering TLE effects on different traffic law violations, a very recent exhaustive meta-analytic review by Theofilatos et al. (2017), developed in the framework of the SafetyCube European Commission supported Horizon 2020 project, addresses the effectiveness of TLE by referring to the most studied research topics. For example, with respect to speeding, a recent systematic literature review by Botteghi et al. (2017) concludes a positive impact of speed control measures in general, as they reduce accident frequency and the proportion of drivers exceeding speed limits. In addition, several meta-analyses such as De Ceunynck (2017) and Høye (2014) show that the presence of, or an increase in, specific speed control measures such as section control and fixed speed cameras leads to compliance with speed limit laws.

Regarding enforcement of restrictions on alcohol consumption while driving, meta-analyses by Erke et al. (2009) and Macaluso et al. (2017) evaluate the effectiveness of well-known control measures, such as BAC (Blood Alcohol Content) limits laws, applied in combination with enforcement measures, such as DUI checkpoints and random or selective breath tests. Both found that there is a broad deterrence effect on drivers who commit these kinds of offences that leads to a statistically significant reduction in fatal accidents in general and in alcohol-related accidents in particular. Notwithstanding, other meta-analyses such as Elvik et al. (2009) reported more limited results, with a non-significant deterrence effect on young drivers and even an increase in fatal accidents. Furthermore, the decrease in mean BAC observed by Živković et al. (2013) for the case of Serbia was not statistically significant. Theofilatos et al. (2017) believe that these discrepancies could be explained by the difficulty of isolating the effect of alcohol-related laws from time trends and other confounding variables, and the fact that DUI control procedures may vary among countries (and, therefore, among the analyzed studies).

With respect to enforcement to diminish seatbelt violations, the systematic review by Alfonsi et al. (2017) observes that seatbelt legislation and related enforcement activities are effective for improving the behavior of road users, with a 21% increase in seatbelt usage during the enforcement period and 15% subsequently. More specifically, Dinh-Zarr et al. (2001) and Nichols et al. (2014), show that increasing the number of police officers on patrol and increasing fine levels, respectively, result in higher rates of seatbelt use.

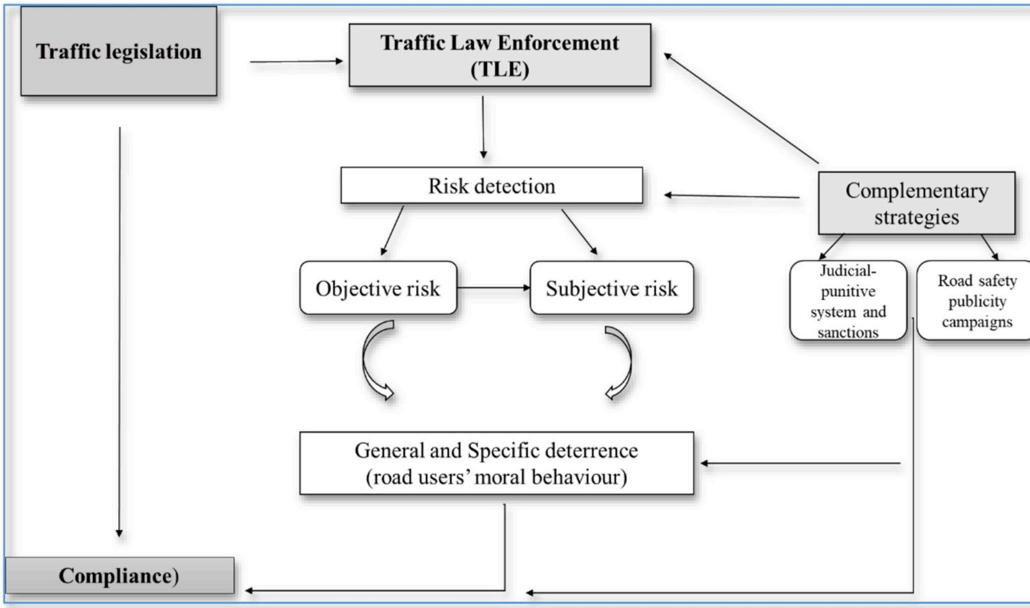

Fig. 1. Mechanisms for traffic law compliance through introduced by TLE. Source: Prepared by authors based on Mäkinen et al. (2003).

Regarding enforcement activities in relation to recurrent distractions such as, for example, cell phone use while driving, evidence to date seems to show that implementing laws and increasing enforcement have had no clear effect. The meta-analysis by Theofilatos (2017) showed a mixed impact on drivers' intention toward cell phone use and on observed cell phone use, as there are positive effects in absolute numbers—but with no statistical evaluation—and nonsignificant and even negative effects. This author therefore concludes that the topic needs further investigation.

Notwithstanding, there would seem to be a degree of consensus that legislation needs to be accompanied by adequate TLE and other complementary measures if it is to be effective over time (Åberg, 1998; Castillo-Manzano et al., 2011; ETSC, 2016) and prevent a perverse compensatory behavior, namely the "*Peltzman effect*"[1] (Benedettini and Nicita, 2012; Peltzman, 1975).

The academic literature has also analyzed the three previously mentioned cornerstones of road safety in the Spanish case: legislation, TLE, and compliance with the law. With regard to legislation, a number of different road safety laws have been passed in Spain in recent years (Albalate et al., 2013; López-Ruiz et al., 2014), with the main measures being the 2007 reform of the Penal Code to impose tougher penalties for traffic violations (Castillo-Manzano et al., 2011; Novoa et al., 2011a) and, especially, the highly scrutinized implementation of the points-based driver's license in 2006 (Aparicio Izquierdo et al., 2011; Castillo-Manzano et al., 2010; Novoa et al., 2010; Pulido et al., 2010). However, as previously explained, the real effectiveness of legislative measures to reduce traffic accidents is clearly influenced by the subsequent degree of police control and surveillance, and individual compliance.

With regard to behavior and detected violations, Ayuso et al. (2010) studied reckless behavior and driver distraction in both administrative and speeding-related traffic violations in Spain and analyzed their influence on accident likelihood by crash severity. More specifically, they found that combinations of traffic violations in a crash lead to higher estimated average costs and are associated with a greater likelihood of a fatal accident occurrence compared to cases in which there are no traffic violations. Consequently, penalizations imposed for traffic violations do not necessarily address the total economic cost of accidents.

Lastly, other studies such as Aparicio Izquierdo et al. (2013) and Dadashova et al. (2016) have related several of the above-mentioned cornerstones of road safety for the 1990–2004 and 2000–2011 periods, respectively, analyzing some of the previously indicated relevant legislative changes in combination with surveillance measures. In net terms, Aparicio Izquierdo et al. (2013) find evidence for a significant reduction in traffic accidents because effective police surveillance and improvements to both vehicles and roads can counterbalance the influence of factors such as risk exposure, speed, and aging vehicle stock. Dadashova et al. (2016) show that increased rates of driver behavior surveillance (such as alcohol controls, speed checks, suspended driver licenses) have generally led to improved road safety indicators and a decrease in the number of fatal accidents.

The current paper addresses the impact of traffic regulation measures, TLE, and violations on traffic fatalities for the case study of Spain during a more recent period and uses a methodological focus based on dynamic transfer function models. In addition, a comprehensive bibliographical review has enabled our results to be corroborated by previous studies. The objective has been to conduct the fullest study possible and jointly test Legislation, TLE, and Compliance to obtain robust coefficients for the measurement of the net effects of the fundamental processes included in Fig. 1.

3. Data and methodology

The endogenous variable is the number of fatalities recorded monthly during the 2005–2015 period on intercity roads in all Spanish national territory excepting the Basque Country and Catalonia, as the Civil Guard's traffic task force is responsible for TLE data in all regions except these two.

Following Fig. 1, the explanatory or exogenous variables can be classified into three groups: legislation, TLE, and compliance.

a) Road safety legislation-related variables during the period under

[1] The effect frequently referred to as the "Peltzman effect" was first described by the economist S. Peltzman in 1975 as a risk compensation-related phenomenon that explains the unintended consequences of health care interventions in general and road safety regulations in particular. The hypothesis is that individuals react to safety laws by increasing other risky driving behaviors such as, for example, a driver who wears his seatbelt but has a sense of security that leads him/her to believe that speeding is not dangerous.

study: the implementation of the points-based driver's license (Aparicio Izquierdo et al., 2011; Castillo-Manzano et al., 2010; Novoa et al., 2010) and Penal Code reform (Aparicio Izquierdo et al., 2011; Castillo-Manzano et al., 2011).

b) TLE-related variables: speed controls (Aparicio Izquierdo et al., 2013), breath tests (Dadashova et al., 2016), number of traffic police deployed (Aparicio Izquierdo et al., 2013) and their productivity.

c) Variables for the degree of driver compliance with traffic laws. The monitored violations for which noncompliance is analyzed in this paper are alcohol- and speed-related as, according to the European Commission (2008), estimates for 2004 attribute 30% of road deaths in the EU to speed, both too low and too high, while 25% are attributed to driving under the effects of alcohol. In addition, according to Lardelli-Claret et al. (2003), speeding and alcohol consumption before driving are the main driver-dependent risk factors for causing a vehicle collision in Spain.

Two other exogenous variables have also been included to capture the evolution of economic activity. These are, specifically, Fuel Consumption (Dadashova et al., 2016), used as a proxy of the economic cycle (also an indication of the country's level of motorization) and Workdays (Castillo-Manzano et al., 2011), used to measure the ratio between the number of workdays and weekend days per month.

Table 1 gives the full list of the variables considered, their definitions and their descriptive statistics. All variables are monthly.

According to Lavrenz et al. (2018), little use has been made of time series models in traffic safety research due to a combination of problems with data collection and researchers' and practitioners' limited knowledge of appropriate methods. As a novelty, transfer function models (Box et al., 2016; García-Ferrer et al., 2007; Castillo-Manzano et al., 2010, 2011) have been used. Their use is still limited in this field, as is demonstrated by the fact that they are not included in the thorough survey conducted by Lavrenz et al. (2018). However, they have been chosen due to the main advantages of dynamic transfer function models over other methodologies, namely, they provide parametrically efficient fully dynamic specifications of input-output relationships, allow for autocorrelated noises, and enable automatic identification procedures based on information criteria (see below; Young, 2011).

Transfer function models can actually be understood as fully dynamic extensions of linear regression models. The general formula for dynamic transfer models can be written as (1), below:

$$\Delta^d \Delta_{12}^D y_t = \alpha + \sum_{i=1}^{k} \frac{b_i}{1 + a_i B} \Delta^d \Delta_{12}^D x_{it} + \sum_{j=1}^{m} \frac{w_j(B)}{\delta_j(B)} \Delta^d \Delta_{12}^D z_{jt} + \frac{\theta_q(B)\Theta_Q(B^{12})}{\phi_p(B)\Phi_P(B^{12})} e_t \tag{1}$$

In this equation y_t is an endogenous variable (fatalities on intercity roads); x_{it} $(i = 1,2,...,k)$ are the set of dummy variables; z_{jt} $(j = 1,2,...,m)$ are the continuous exogenous variables; e_t is white noise with zero mean, constant variance and no serial correlation; B is the delay operator, where $B^l x_t = x_{t-l}$; $\Delta = 1 - B$ is the difference operator; $\Delta_{12} = 1 - B^{12}$ is the seasonal difference operator; α is a constant; b_i y a_i $(i = 1,2,...,k)$ are constants; $w_j(B)$ is the numerator of the dynamic model that relates each of the exogenous variables to the endogenous variable, i.e., $w_j(B) = (w_0 + w_1B + ... + w_jB^j)$; $\delta_j(B)$ is the denominator of the same dynamic model, i.e., $\delta_j(B) = (1 + \delta_1 B + ... + \delta_j B^j)$; the last summand is the stationary and reversible ARMA noise model which contains different order, regular and seasonal polynomials in the delay operator, i.e., $\phi_p(B) = (1 + \phi_1 B + ... + \phi_p B^p)$, $\theta_q(B) = (1 + \theta_1 B + ... + \theta_q B^q)$, $\Phi_P(B^{12}) = (1 + \Phi_1 B^{12} + ... + \Phi_P B^{12P})$ y $\Theta_Q(B^{12}) = (1 + \Theta_1 B^{12} + ... + \Theta_Q B^Q)$.

One important aspect of the model construction process is to identify the orders of the polynomials in the noise model (p, P, q, Q) and that affect the continuous exogenous variables $(w_j(B)/\delta_j(B))$. In this study, identification was achieved by minimizing the Schwarz Bayesian Information Criterion (SBC) for a set of alternative models. SBC weight model adjustment is done by penalizing the objective function by the

Table 1
Variables considered.

Group	Name	Definition	Mean	Std. Dev.	Min.	Max.
Road safety outcome	Fatalities	No. of traffic fatalities on intercity roads in Spain excluding the Basque Country and Catalonia (1)	130.44	56.63	51	282
Legislation	Points license	Dummy variable that captures the effect of the introduction of the points-based driver's license in July 2006 (2)	0.08	0.09	0	1
	Penal Code	Dummy variable for the Penal Code reform of December 2007	0.73	0.44	0	1
TLE	Speed controls (thousands)	No. of vehicles subjected to speed tests using radar equipment (mobile) on intercity roads (3)	2267	433.53	1494	3185
	Breath tests (thousands)	Total no. of breath tests administered on intercity roads	438.84	104.11	228.81	683.66
	No. police officers (thousands)	Total no. of Civil Guard Traffic Task Force officers deployed on intercity roads	105.17	12.95	73.21	140.44
	Police officers Productivity	Total no. of controls (including breath tests and speed checks) per number of Civil Guard officers deployed	25.93	4.85	17.30	39.55
Compliance	DUI (alcohol) violations (%)	Percentage of positive breath test results per total no. of breath tests administered	1.91	0.43	1.27	3.12
	Speed violations (%)	Percentage of positive speeding violation detections per total no. of vehicles subjected to speed controls	3.20	0.67	2.00	4.91
Economic activity	Fuel (million tonnes)	Total domestic transport sector fuel consumption (gas and diesel)	2.39	0.24	1.88	2.92
	Workdays (days)	Variable defined as the no. of workdays minus weekend days x 2½	0.00	2.66	−5.00	3.00

(1) Series provided by the Spanish Directorate General of Traffic in accordance with the Vienna Convention, which considers fatalities that occur during a period of 30 days following the accident. (2) The Points-Based Driver's License variable is modeled as a transitory change, as indicated by Butler et al. (2006) for Ireland, and De Paola et al. (2013) and Farchi et al. (2007) for Italy. (3) The Speed Control variable only quantifies controls conducted by radars mounted on Civil Guard Traffic Task Force vehicles. Controls using permanent roadside radar equipment are therefore excluded.

Table 2
Results of transfer function estimations.

Independent Variables		Model I *Legislation and TLE*	Model II *Legislation, TLE and Compliance*	Model III *Legislation, TLE Productivity and Compliance*
Legislation	Points license (numerator, $\boldsymbol{b_i}$)	−0.166** (0.076)	−0.199** (0.091)	−0.189** (0.085)
	Points license (denominator, $\boldsymbol{a_i}$)	−0.802*** (0.129)	−0.851*** (0.082)	−0.854*** (0.073)
	Penal Code reform ($\boldsymbol{b_i}$, $\boldsymbol{a_i} = 1$)	−0.118** (0.043)	−0.148*** (0.051)	−0.205*** (0.054)
TLE	No. police officers deployed	−0.191** (0.090)	−0.372*** (0.113)	
	Breath tests	−0.066* (0.038)		
	Speed controls	−0.201** (0.091)		
	Productivity of police officers			−0.121* (0.066)
Compliance	Alcohol violations (%)		0.161** (0.075)	0.128** (0.061)
	Speeding violations (%)		−0.087 (0.162)	−0.042 (0.182)
Economic Activity	Fuel	0.513*** (0.201)	0.699*** (0.255)	0.701*** (0.263)
	Workdays	−0.009*** (0.002)	−0.006* (0.003)	−0.009** (0.004)
MA(12)		0.473*** (0.094)	0.473*** (0.097)	0.414*** (0.101)
Constant		−0.089*** (0.018)	−0.089*** (0.019)	−0.075*** (0.016)
Q(4)		5.081	5.392	2.611
Q(12)		7.716	9.054	10.092
Q(24)		25.091	30.443	26.759
Jarque-Bera		3.135 (0.208)	3.682 (0.158)	2.915 (0.233)
KSL		0.069 (0.226)	0.057 (0.432)	0.061 (0.366)
H		0.702 (0.203)	0.725 (0.385)	0.704 (0.378)

Note: One, two, and three asterisks indicate parameter significance at 10%, 5%, and 1%, respectively.

number of parameters to include only the parameters that cause a significant improvement to the objective function.

The identification process yields the following model (2):

$$\Delta_{12} y_t = \alpha + \sum_{i=1}^{k} \frac{b_i}{1 + a_i B} \Delta_{12} x_{it} + \sum_{j=1}^{m} w_j \Delta_{12} z_{jt} + (1 + \Theta_1 B^{12}) e_t \quad (2)$$

The model can be said to only contain a seasonal difference. The transfer functions with continuous variables are in reality linear regression terms and the noise model is an MA(1) with monthly seasons.

The dummy variable effects in (2) require further explanation. When x_{it} is taken as a dummy variable with a value of 1 at time t and 0 elsewhere, the first order transfer functions affecting the dummy variables in (2) may behave in several ways, depending on the value of a_i:

- Additive ($a_i = 0$): Depending on the sign of b_i, there is a sudden positive or negative effect at time t.
- Transitory change ($-1 < a_i < 0$): There is a sudden effect at time t that tends gradually toward zero. The effect may be positive or negative depending on the sign of b_i.
- Permanent step ($a_i = -1$): There is a sudden effect at time t that subsequently remains at the new level. The effect may be positive or negative depending on the sign of b_i.

When the general specification for dummy variables was estimated with the data, the introduction of the points license came out naturally as a transitory effect, while changes in penal code resulted in a permanent step (see results section).

It is well known that there may potentially be multi-collinearity problems with multiple input models like (2). Variance Inflation Factor (VIF) is a widely used measure for testing for this problem (Gareth et al., 2017) and provides an idea of how much the variance of a coefficient is increased due to collinearity with the rest of inputs. These values are functions of the coefficients of determination (R-squared) calculated by estimating regressions for each of the input variables on all the other input variables. Severe problems of collinearity are found when VIF is above 10, while values above five indicate mild problems.

4. Results

The obtained results are given in Table 2. An interannual difference was applied to all the variables to stabilize the time series mean. Log transformation was also applied to the continuous exogenous and endogenous variables, allowing the estimated coefficients to be directly interpreted as elasticities, i.e., estimated coefficients can be interpreted as the annual percentage variation of fatalities when the annual variation of the corresponding exogenous variable is 1%. The correct interpretation of the dummy variable coefficients is that a one-unit variation implies an *exp(coefficient)-1 percent* percentage variation of the endogenous variable.

Three models have been developed to analyze the transition from legislation to compliance depending on each of the cornerstones of road safety. The models are the result of a complex process to find useful models with sensible interpretations that are at the same time correct from a statistical point-of-view.

The first model examines whether surveillance and enforcement of traffic violations, using either specific (radar speed controls and breath tests) or generic (no. of Civil Guard officers deployed for TLE purposes) measures, have any effect on reducing the number of traffic fatalities bearing in mind the implemented legislative changes.

In addition to the legislation applied and the TLE activities in the previous model (taking only the no. of officers deployed as an indicator), the second model includes the influence of compliance with traffic laws on alcohol and speed limits on the number of traffic fatalities. Noncompliance is measured as the percentage of detected violations over all controls and tests.

Finally, the third model is a variant of the preceding model with TLE measured by the productivity of the officers deployed.

The absence of residual autocorrelation, Gaussianity, and homoscedasticity of residuals in the diagnostic tests reported in Table 2 proves the models' correctness from the statistical point-of-view. One final but important test in this context is for the absence of any relevant collinearity problems among the input variables. Table 3 shows the VIF coefficients of all the continuous inputs considered in this paper (second column) and the specific VIF coefficients for each model reported in Table 2.[2] The second column (VIF Overall) shows collinearity for all of the variables with the sole exception of fuel consumption (as all VIF coefficients are above 10). However, these problems virtually disappear in the three models considered, although Model 3 presents a minor problem with one coefficient, which is approaching five. This is due to these collinearity problems being explicitly considered in the specification process.

[2] Dummy variables are not tested for collinearity as there is no point in calculating VIF coefficients for dummies.

Table 3
VIF coefficients.

Variables	VIF Overall	VIF Model 1	VIF Model 2	VIF Model 3
No. of police officers	13.957	1.171	1.354	
Breath tests	11.022	1.305		
Speed controls	68.508	2.488		
Police officer productivity	105.153			4.934
Alcohol violations (%)	14.453		1.208	1.714
Speeding violations (%)	35.947		2.518	4.266
Fuel	2.823	2.291	2.481	2.165

5. Discussion

The following can be deduced from the results in Table 2:

First, changes to legislation play an important role in road safety in all three models. In other words, the implementation of the previously mentioned road safety legal reforms (introduction of the points-based driver's license in 2006 and reform of the Penal Code in 2007) have had positive and statistically significant effects on fatalities on intercity roads. Other studies in the same line, conducted on both the international scale (Dionne et al., 2011; Zambon et al., 2007) and for the specific case of Spain (see Aparicio Izquierdo et al., 2011; Dadashova et al., 2016; Novoa et al., 2010) agree on the positive effects of the implementation of the points-based driver's license. The changes to the Penal Code can also be seen to have had a favorable and significant impact, thus corroborating the prior literature (Aparicio Izquierdo et al., 2011; Castillo-Manzano et al., 2011). Notwithstanding, in the case of the points-based driver's license our results show that the effects of the reform were not permanent but only lasted for a limited amount of time, disappearing completely after either 17 months (according to Model I) or 22 months (according to Models II and III). Other authors found similar evidence for this, including Castillo-Manzano et al. (2010) for Spain, and Castillo-Manzano and Castro-Nuño (2012) and Farchi et al. (2007), among others, on the international scale.

Second, with respect to TLE, all the enforcement instruments, whether specific, such as speed controls and breath tests, or general, measured by the number of police officers deployed, were significantly associated with reductions in road fatalities (Models I and II). This would suggest that there is a deterrence effect.

As can be seen in Model I, the significance of the speed controls variable indicates that these are a TLE measure that improves road safety. The values of the coefficients in Table 2 (interpreted as elasticities) also seem to suggest that the number of vehicles checked is more strongly related to a reduction in fatalities than the number of breath tests (as Dadashova et al., 2016 also indicate for Spain) and that it has almost the same effect as the number of police officers deployed. However, other studies find the opposite: that breath tests are more effective than speed controls (Tay, 2005).

Moreover, it should be highlighted that the number of police officers deployed results in a greater reduction in the number of road deaths than the number of checks and controls conducted by these police officers (see models II and III). This is an indication of the greater importance that police officers themselves have than the specific controls that each of these can perform. This clearly confirms the deterrence effect that Civil Guard officers have, as stated in the prior literature in reference to the effectiveness of visible enforcement by police officers (Redelmeier et al., 2003; Tay, 2005). Furthermore, the fact that the reform of the Penal Code has a more enduring effect than the points-based driver's license (see above) also shows that legislation to increase sanctions reinforces TLE without the need to deploy any extra resources, as there is a sum of the two effects.

Our finding that productivity is associated with a reduction in fatalities provides a strong argument for productivity being further pursued and developed, and made a high priority policy option in new national road safety programs. However, the variable's lesser significance (at 10%) in Model III, compared to No. Police Officers Deployed in Models I (5%) and II (1%) demonstrates that the human factor is irreplaceable. In other words, the goal has to be the maximum productivity of the human resources deployed but, once this has been achieved, the number of officers cannot be reduced, as this would undermine said greater productivity.

Third, the compliance variables (Models II and III) show that noncompliance with laws on alcohol limits increases the number of traffic fatalities (while speeding violations do not have any effect on road safety). This clearly justifies both campaigns to prevent violations of this type and the associated fines, despite the recurring debate about whether raising money is the primary consideration when levying fines (see Tay, 2010). This idea may be supported by earlier findings by Castillo-Manzano et al. (2017) that point to high socio-cultural alcohol tolerance in European countries such as Spain in conjunction with the traditional higher drinking patterns.

Noncompliance with speed limits has no statistically significant effect on road traffic accidents (Models II and III), contrary to what is stated for the Spanish case in Aparicio Izquierdo et al. (2013). With respect to the number of traffic fatalities, our result contrasts with the above-commented efficacy of speed limits, which probably reflects the fact that just conducting speed checks is effective, without any need to take into account the number of positive detections.

Lastly, in all three models, economic activity and greater numbers of vehicles on the road measured by fuel consumption increase the number of traffic fatalities. This result is widely confirmed by the prior literature (Ahmad and Greene, 2005; Grabowski and Morrisey, 2006), which demonstrates the coherence of the methodology used. An increase in fatalities is also generally observed on weekends. In other words, the effect of workdays is negative for fatalities, which would indicate that there are greater numbers of traffic accidents on weekends due to UDAs (see Kanaan et al., 2009). This can undoubtedly be attributed to certain risk groups, such as young drivers, making a greater use of cars for their trips and journeys on nonworkdays.

6. Conclusions

This paper analyzes the different effects that the widest set of variables studied to date has on road safety in Spain. The three dimensions examined are the impact of legislation, Traffic Law Enforcement, and lastly, compliance with road safety laws. First, a broad review was conducted of analyses of these three dimensions in the prior literature. This justifies the complementary nature of the three dimensions (see Mäkinen et al., 2003) and, therefore, the need for them to be studied jointly in order to obtain the best possible net impacts of their cross effects.

Three full econometric advanced time series models have been used to test these three strategies for a broad period that takes in both the economic crisis that began in Spain toward the end of 2007 and significantly affected TLE funding and the beginning of the subsequent recovery. In short, a period of abrupt economic changes which, according to our results (see results for the Fuel variable in Table 2), had a significant effect on road safety.

In all three models, the two road safety legal reforms implemented during the period under study, the points-based driver's license and the toughening of the Penal Code were all significantly related to a reduction in fatalities on intercity roads, which suggests that safer road behavior may have been achieved through deterrence. However, whereas the effects of the first change to the law were observed to be transitory and to last under two years, the effects of the second, the reform of the Penal Code, persisted over time.

Surveillance of violations, through breath tests and speed detection radars, and the number of police officers deployed, have a deterrence effect and reduce road traffic fatalities. In addition, in line with other studies that have highlighted the effectiveness of speed enforcement for improving road safety (Botteghi et al., 2017; De Waard and Rooijers, 1994; Soole et al., 2013), our results show that speed controls by radar appear to be the most effective of all the different types of surveillance methods for road fatalities. This is good news for countries with tight budgets—as was the case in Spain during the analyzed period—given their lower per-unit cost compared to breath tests.

However, the statistical significance of the coefficient that measures the influence of speed controls by radar contrasts with the lack of significance of the coefficient associated with noncompliance with speed limits. This, perhaps, reflects the fact that the mere existence of radars might the desired effect, irrespective of the number of violations detected. This would also provide an empirical basis for initiating a discussion in Spain about, for example, a prudent relaxation of maximum speed limits from 120 to 130 km per hour (approx. 75 to 80 mph) on certain more advanced sections of highways and freeways when traffic and weather conditions allow (through the implementation of Variable or Dynamic Speed Limits). This is actively being called for by some sectors (according to RACE, The Royal Automobile Club of Spain, 80% of drivers would support a measure of this type: https://www.race.es/notas-de-prensa/el-80-de-los-conductores-espanoles-estan-a-favor-de-subir-los-limites-de-velocidad). In this context, the results of our paper would also indicate that raising the speed limits should be accompanied by the installing of radars to monitor speed along any such sections.

On the other hand, noncompliance with traffic laws governing alcohol consumption seems to increase the number of traffic fatalities. This should come as no surprise in a country like Spain, where there is a greater social tolerance of alcohol consumption (see Castillo-Manzano et al., 2017, 2018). However, other cases should also be considered, such as some Scandinavian countries where drunk-driving is also associated with a large share of road fatalities but there is a lower tolerance of drinking and driving (see e.g., Gustafsson and Forsman, 2013 for Sweden, and Legrand et al., 2014 for Finland). Therefore, compared to speed violations, where the effort can be put into strengthening deterrence measures, the strategy for reducing violations for exceeding the alcohol limit must be more substantial and complex. In this regard, the solution might be to put the stress on prevention (with, e.g., educational publicity campaigns targeted at specific risk groups such as novice drivers), and reinforcing control policies and surveillance activities.

Lastly, our results underscore the irreplaceable role of human resources in reducing the number of traffic fatalities. Human resources are an indispensable component that enables the implemented strategies to achieve their full effectiveness through legislation. In addition, the value (and significance) of the coefficient for police officers over that for their productivity, measured by numbers of reported violations, highlight the work done by law enforcement, not only with respect to punishment but also deterrence and raising intercity road users' awareness by their mere presence.

To summarize, all these conclusions jointly demonstrate that, if the aim is to optimize road safety results, there must be a joined-up approach based on these three dimensions: Traffic Legislation + Traffic Law Enforcement + Compliance. Therefore, it is essential for investments to be made in these strategies to combat road accidents. Hill et al. (2017), Wagenaar et al. (2005) and Aparicio Izquierdo et al. (2013) all arrived at the same conclusion and, in the case of the last of these studies, specifically for the number of police officers deployed and breath test variables for the Spanish case, although for a period prior to the legislative reforms considered in the present study. Furthermore, as stated, the present study takes in the years of severe economic crisis that affected the Spanish economy from the end of 2007 on, when these instruments were subjected to cutbacks, which, as the statistics for recent years would seem to suggest, may have exacerbated the accident rate (Castro-Nuño et al., 2018; DGT, 2018).

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Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.tranpol.2018.12.009.

References

Åberg, L., 1998. Traffic rules and traffic safety. Saf. Sci. 29 (3), 205–215.
Ahmad, S., Greene, D., 2005. Effect of fuel economy on automobile safety: a reexamination. Transport. Res. Rec. J. Transport. Res. Board 1941, 1–7.
Albalate, D., Fernández, L., Yarygina, A., 2013. The road against fatalities: infrastructure spending vs. regulation? Accid. Anal. Prev. 59, 227–239.
Alfonsi, R., Meta, E., Ammari, A., 2017. Seatbelt Law and Enforcement, European Road Safety Decision Support System, Developed by the H2020 Project SafetyCube. Retrieved from. www.roadsafety-dss.eu, Accessed date: 6 December 2018.
Allen, S., Murphy, K., Bates, L., 2017. What drives compliance? The effect of deterrence and shame emotions on young drivers' compliance with road laws. Polic. Soc. 27 (8), 884–898.
Aparicio Izquierdo, F., Arenas Ramírez, B., Mira McWilliams, J.M., Páez Ayuso, J., 2011. The endurance of the effects of the penalty point system in Spain three years after. Main influencing factors. Accid. Anal. Prev. 43, 911–922.
Aparicio Izquierdo, F., Arenas Ramírez, B., Bernardos Rodríguez, E., 2013. The interurban DRAG-Spain model: the main factors of influence on road accidents in Spain. Res. Transport. Econ. 37, 57–65.
Ayuso, M., Guillén, M., Alcañiz, M., 2010. The impact of traffic violations on the estimated cost of traffic accidents with victims. Accid. Anal. Prev. 42 (2), 709–717.
Basili, M., Belloc, F., Nicita, A., 2015. Group attitude and hybrid sanctions: microeconometric evidence from traffic law. Transport Res. A-Pol. 78, 325–336.
Bates, L., Soole, D., Watson, B., 2012. The effectiveness of traffic policing in reducing traffic crashes. In: Policing and Security in Practice. Palgrave Macmillan, London, pp. 90–109.
Bendak, S., 2005. Seat belt utilization in Saudi Arabia and its impact on road accident injuries. Accid. Anal. Prev. 37 (2), 367–371.
Benedettini, S., Nicita, A., 2012. The costs of avoiding accidents: selective compliance and the 'Peltzman effect' in Italy. Int. Rev. Law Econ. 32 (2), 256–270.
Bjørnskau, T., Elvik, R., 1992. Can road traffic law enforcement permanently reduce the number of accidents? Accid. Anal. Prev. 24 (5), 507–520.
Blair, R.D., Knight, T., 2013. Compliance with corporate policy: an economic approach. Manag. Decis. Econ. 34 (7–8), 529–537.
Blais, É., Bellavance, F., Marcil, A., Carnis, L., 2015. Effects of introducing an administrative 0.5% blood alcohol concentration limit on law enforcement patterns and alcohol-related collisions in Canada. Accid. Anal. Prev. 82, 101–111.
Botteghi, G., Theofilatos, A., Macaluso, G., 2017. Speeding: General Police Enforcement, Speeding, European Road Safety Decision Support System, Developed by the H2020 Project SafetyCube. Retrieved from. www.roadsafety-dss.eu, Accessed date: 6 December 2018.
Box, G.E.P., Jenkins, G.M., Reinsel, G.C., Ljung, G.M., 2016. Time Series Analysis, Forecasting and Control, fifth ed. Wiley and Sons, Hoboken, New Jersey.
Butler, J.S., Burke, J.P., Healy, D.G., Stephens, M.M., Mc Manus, F., Mc Cormack, D., O'Byrne, J.M., Poynton, A.R., 2006. Trends in RTA related spinal injuries: the post penalty points era. Ir. J. Med. Sci. 175 (1), 20. https://doi.org/10.1007/BF03168994.
Castillo-Manzano, J.I., Castro-Nuño, M., Pedregal, D.J., 2010. An econometric analysis of the effects of the penalty points system driver's license in Spain. Accid. Anal. Prev. 42 (4), 1310–1319.
Castillo-Manzano, J.I., Castro-Nuño, M., Pedregal, D.J., 2011. Can fear of going to jail reduce the number of road fatalities? The Spanish experience. J. Saf. Res. 42 (3), 223–228.

Castillo-Manzano, J.I., Castro-Nuño, M., 2012. Driving licenses based on points systems: efficient road safety strategy or latest fashion in global transport policy? A worldwide meta-analysis. Transport Pol. 21, 191–201.
Castillo-Manzano, J.I., Castro-Nuño, M., Pedregal, D.J., 2012. How many lives can bloody and shocking road safety advertising save? The case of Spain. Transport. Res. F Traffic Psychol. Behav. 15 (2), 174–187.
Castillo-Manzano, J.I., Castro-Nuño, M., Fageda, X., 2015. Are traffic violators criminals? Searching for answers in the experiences of European countries. Transport Pol. 38, 86–94.
Castillo-Manzano, J.I., Castro-Nuño, M., Fageda, X., López-Valpuesta, L., 2017. An assessment of the effects of alcohol consumption and prevention policies on traffic fatality rates in the enlarged EU. Time for zero alcohol tolerance? Transport. Res. F Traffic Psychol. Behav. 50, 38–49.
Castillo-Manzano, J.I., Castro-Nuño, M., López-Valpuesta, L., Vassallo, F.V., 2018. 2018 An assessment of road traffic accidents in Spain: the role of tourism. Curr. Issues Tourism. https://doi.org/10.1080/13683500.1548581.
Castillo-Manzano, J.I., Castro-Nuño, M., Lopez-Valpuesta, L., Vassallo, F.V., 2019. The complex relationship between increases to speed limits and traffic fatalities: evidence from a meta-analysis. Saf. Sci. 111, 287–297.
Castro-Nuño, M., Castillo-Manzano, J.I., Fageda, X., 2018. The role of road safety in a sustainable urban mobility: an econometric assessment of the Spanish NUTS-3 case. Int. J. Sustain. Transport. 12 (3), 205–217.
Dadashova, B., Arenas-Ramírez, B., Mira-McWilliams, J., Aparicio-Izquierdo, F., 2016. Methodological development for selection of significant predictors explaining fatal road accidents. Accid. Anal. Prev. 90, 82–94.
Davey, J.D., Freeman, J.E., 2011. Improving road safety through deterrence-based initiatives: a review of research. Sultan Qaboos Univ. Med. J. 11 (1), 29–37.
De Ceunynck, T., 2017. Installation of Section Control & Speed Cameras, European Road Safety Decision Support System, Developed by the H2020 Project SafetyCube. Retrieved from. www.roadsafety-dss.eu, Accessed date: 6 December 2018.
De Paola, M., Scoppa, V., Falcone, M., 2013. The deterrent effects of the penalty points system for driving offences: a regression discontinuity approach. Empir. Econ. 45 (2), 965–985.
De Waard, D., Rooijers, T., 1994. An experimental study to evaluate the effectiveness of different methods and intensities of law enforcement on driving speed on motorways. Accid. Anal. Prev. 26 (6), 751–765.
Dinh-Zarr, T.B., Sleet, D.A., Shults, R.A., Zaza, S., Elder, R.W., Nichols, J.L., Task Force on Community Preventive Services, 2001. Reviews of evidence regarding interventions to increase the use of safety belts. Am. J. Prev. Med. 21 (4), 48–65.
Dionne, G., Pinquet, J., Maurice, M., Vanasse, Ch, 2011. Incentive mechanisms for safe driving: a comparative analysis with dynamic data. Rev. Econ. Stat. 93, 218–227.
Dirección General de Tráfico (DGT), 2006. Plan Estratégico de Seguridad Vial 2005–2008. Plan de Acciones Estratégicas Claves 2005–2008. Ministerio del Interior, Madrid.
Dirección General de Tráfico (DGT), 2018. Balance de seguridad vial para 2017. Ministerio del Interior. Madrid. Accessible at. http://www.dgt.es/Galerias/prensa/2018/01/NP-Balance-DGT-siniestralidad-vial-2017.pdf.
Elvik, R., 2001. Cost-benefit Analysis of Police Enforcement. Report ESCAPE Project, Working Paper. VTT, Helsinki.
Elvik, R., Vaa, T., Hoye, A., Sorensen, M. (Eds.), 2009. The Handbook of Road Safety Measures. Emerald Group Publishing.
Erke, A., Goldenbeld, C., Vaa, T., 2009. The effects of drink-driving checkpoints on crashes-A meta-analysis. Accid. Anal. Prev. 41 (5), 914–923.
European Commission, 2008. Commission Staff Working Document Accompanying the Proposal for a Directive of the European Parliament and of the Council Facilitating Cross-border Enforcement in the Field of Road Safety. Brussels, SEC (2008) 351/352.
European Transport Safety Council (ETSC), 2011. Traffic Law Enforcement across the EU Tackling the Three Main Killers on Europe's Roads. Brussels. Accessible at. http://archive.etsc.eu/documents/Final_Traffic_Law_Enforcement_in_the_EU.pdf.
European Transport Safety Council (ETSC), 2016. How Traffic Law Enforcement Can Contribute to Safer Roads (PIN Flash 31). Brussels. Accessible at. https://etsc.eu/how-traffic-law-enforcement-can-contribute-to-safer-roads-pin-flash-31/.
Factor, R., 2014. The effect of traffic tickets on road traffic crashes. Accid. Anal. Prev. 64, 86–91.
Farchi, S., Chini, F., Rossi, P.G., Camilloni, L., Borgia, P., Guasticchi, G., 2007. Evaluation of the health effects of the new driving penalty point system in the Lazio Region, Italy, 2001–4. Inj. Prev. 13, 60–64.
Fell, J.C., Waehrer, G., Voas, R.B., Auld-Owens, A., Carr, K., Pell, K., 2014. Effects of enforcement intensity on alcohol impaired driving crashes. Accid. Anal. Prev. 73, 181–186.
Fleiter, J.J., Watson, B.C., Lennon, A.J., 2013. Effective punishment experiences: the need for a more comprehensive approach to conceptualising behavioural punishers and reinforcers in a road safety context. In: Psychology of Punishment: New Research. Nova Science Publishers, pp. 1–30.
García-Ferrer, A., De Juan, A., Poncela, P., 2007. The relationship between road traffic accidents and real economic activity in Spain: common cycles and health issues. Health Econ. 16, 603–626.
Gareth, J., Witten, D., Hastie, T., Tibshirani, R., 2017. An Introduction to Statistical Learning, eighth ed. Springer Science + Business Media, New York.
Goodwin, A.H., Wells, J.K., Foss, R.D., Williams, A.F., 2006. Encouraging compliance with graduated driver licensing restrictions. J. Saf. Res. 37 (4), 343–351.
Goldenbeld, C., Mesken, J., van Schagen, I., 2013. The Effect of Severity and Type of Traffic Penalties on Car Drivers'. SWOV Institute for Road Safety Research, The Netherlands Report 2013-12.
Grabowski, D.C., Morrisey, M.A., 2006. Do higher gasoline taxes save lives? Econ. Lett. 90 (1), 51–55.
Gustafsson, S., Forsman, Å., 2013. Alcohol- and drug-related fatal accidents in Sweden: where do they occur? In: Paper Presented at 16th Road Safety on Four Continents Conference Beijing, China 15-17 May 2013, Accessible at: http://www.diva-portal.org/smash/get/diva2:750331/FULLTEXT03.pdf.
Guttman, N., 2015. Persuasive appeals in road safety communication campaigns: theoretical frameworks and practical implications from the analysis of a decade of road safety campaign materials. Accid. Anal. Prev. 84, 153–164.
Haddon Jr., W., 1980. Advances in the epidemiology of injuries as a basis for public policy. Publ. Health Rep. 95 (5), 411–421.
Hakkert, A.S., Gitelman, V., Cohen, A., Doveh, E., Umansky, T., 2001. The evaluation of effects on driver behaviour and accidents of concentrated general enforcement on interurban roads in Israel. Accid. Anal. Prev. 33, 43–63.
Hill, S.R., Vale, L., Hunter, D., Henderson, E., Oluboyede, Y., 2017. Economic evaluations of alcohol prevention interventions: is the evidence sufficient? A review of methodological challenges. Health Pol. 121 (12), 1249–1262.
Homel, R., 1994. Drink-driving law enforcement and the legal blood alcohol limit in New South Wales. Accid. Anal. Prev. 26 (2), 147–155.
Homel, R., 2012. Policing and Punishing the Drinking Driver: a Study of General and Specific Deterrence. Springer Science & Business Media.
Høye, A., 2014. Speed cameras, section control, and kangaroo jumps-a meta-analysis. Accid. Anal. Prev. 73, 200–208.
Kanaan, A., Huertas, P., Santiago, A., Sánchez, J.A., Martínez, P., 2009. Incidence of different health factors and their influence on traffic accidents in the province of Madrid, Spain. Leg. Med. 11, S333–S336.
Lardelli-Claret, P., de Dios Luna-Del-Castillo, J., Jiménez-Moleón, J.J., Rueda-Domínguez, T., García-Martín, M., Femia-Marzo, P., Bueno-Cavanillas, A., 2003. Association of main driver-dependent risk factors with the risk of causing a vehicle collision in Spain, 1990–1999. Ann. Epidemiol. 13 (7), 509–517.
Lavrenz, S.M., Vlahogianni, E.I., Gkritza, K., Ke, Y., 2018. Time series modeling in traffic safety research. Accid. Anal. Prev. 117, 368–380.
Legrand, S.A., Gjerde, H., Isalberti, C., Van der Linden, T., Lillsunde, P., Dias, M.J., Gustafsson, S., Ceder, G., Verstraete, A.G., 2014. Prevalence of alcohol, illicit drugs and psychoactive medicines in killed drivers in four European countries. Int. J. Inj. Contr. Saf. Promot. 21 (1), 17–28.
López-Ruiz, M., Martínez, J.M., Pérez, K., Novoa, A.M., Tobías, A., Benavides, F.G., 2014. Impact of road safety interventions on traffic-related occupational injuries in Spain, 2004–2010. Accid. Anal. Prev. 66, 114–119.
Macaluso, G., Theofilatos, A., Botteghi, G., Ziakopoulos, A., 2017. Law and Enforcement: Random and Selective Breath Tests, European Road Safety Decision Support System, Developed by the H2020 Project SafetyCube. Retrieved from. www.roadsafetydss.eu, Accessed date: 6 December 2018.
Mäkinen, T., Zaidel, D.M., Andersson, G., Biecheler-Fretel, M.B., Christ, R., Cauzard, J.P., Nilsson, G., 2003. Traffic Enforcement in Europe: Effects, Measures, Needs and Future. Final Report of the ESCAPE (Enhanced Safety Coming from Appropriate Police Enforcement) Consortium. Accessible at: http://virtual.vtt.fi/virtual/proj6/escape/escape_d10.pdf.
Makowsky, M.D., Stratmann, T., 2011. More tickets, fewer accidents: how cash-strapped towns make for safer roads. J. Law Econ. 54 (4), 863–888.
Mehmood, A., 2010. An integrated approach to evaluate policies for controlling traffic law violations. Accid. Anal. Prev. 42, 427–436.
Nichols, J.L., Tippetts, A.S., Fell, J.C., Eichelberger, A.H., Haseltine, P.W., 2014. The effects of primary enforcement laws and fine levels on seat belt usage in the United States. Traffic Inj. Prev. 15 (6), 640–644.
Novoa, A.M., Pérez, K., Borrell, C., 2009. Efectividad de las intervenciones de seguridad vial basadas en la evidencia: una revisión de la literatura. Gac. Sanit. 23 (6) 553.e1–553.e14.
Novoa, A.M., Pérez, K., Santamarina-Rubio, E., Marí-Dell'Olmo, M., Ferrando, J., Peiró, R., Tobías, A., Zori, P., Borrell, C., 2010. Impact of the penalty points system on road traffic injuries in Spain: a time-series study. Am. J. Public Health 100, 2220–2227.
Novoa, A.M., Pérez, K., Santamariña-Rubio, E., Borrell, C., 2011a. Effect on road traffic injuries of criminalizing road traffic offences: a time-series study. Bull. World Health Organ. 89, 422–431.
Novoa, A.M., Pérez, K., Santamariña-Rubio, E., Marí-Dell'Olmo, M., Rogelio Cozar, R., Ferrando, J., Peiró, R., Tobías, A., Zori, P., Borrell, C., 2011b. Road safety in the political agenda: the impact on road traffic injuries. J. Epidemiol. Community Health 65, 218–225.
Peltzman, S., 1975. The effects of automobile safety regulation. J. Polit. Econ. 83 (4), 677–725.
Pérez, K., 2009. Rojo, amarillo y ¿verde?: La seguridad vial en España en la primera década del siglo XXI. Gac. Sanit. 23 (5), 359–361.
Pulido, J., Lardelli, P., De La Fuente, L., Flores, V.M., Vallejo, F., Regidor, E., 2010. Impact of the demerit point system on road mortality in Spain. J. Epidemiol. Community Health 64, 274–276.
Redelmeier, D.A., Tibshirani, R.J., Evans, L., 2003. Traffic-law enforcement and risk of death from motor-vehicle crashes: case-crossover study. Lancet 361 (9376), 2177–2182.
Regidor, E., Barrio, G., Bravo, M.J., De la Fuente, L., 2014. Has health in Spain been declining since the economic crisis? J. Epidemiol. Community Health 68, 280–282.
Sanem, J.R., Erickson, D.J., Rutledge, P.C., Lenk, K.M., Nelson, T.F., Jones-Webb, R., Toomey, T.L., 2015. Association between alcohol-impaired driving enforcement-related strategies and alcohol-impaired driving. Accid. Anal. Prev. 78, 104–109.
Soole, D.W., Watson, B.C., Fleiter, J.J., 2013. Effects of average speed enforcement on speed compliance and crashes: A review of the literature. Accid. Anal. Prev 54, 46–56.
Stanojević, P., Jovanović, D., Lajunen, T., 2013. Influence of traffic enforcement on the attitudes and behavior of drivers. Accid. Anal. Prev. 52, 29–38.
SWOV, 2016. Police Traffic Enforcement Fact Sheet. Institute for road traffic research,

The Netherlands Accessible at: https://www.swov.nl/rapport/Factsheets/UK/FS_Police_traffic_enforcement.pdf.
Tarko, A., 2008. Can enforcement and education affect speed on county roads? In: Paper Presented at Transportation Research Board 87thAnnual Meeting, January 2008. Transportation Research Board, Washington, DC.
Tay, R., 2005. General and specific deterrent effects of traffic enforcement: do we have to catch offenders to reduce crashes? J. Transport Econ. Pol. 39 (2), 209–224.
Tay, R., 2010. Speed cameras improving safety or raising revenue? J. Transport Econ. Pol. 44 (2), 247–257.
Theofilatos, A., 2017. Law and Enforcement - Distraction: Laws and Enforcement against Mobile Phone Use while Driving, European Road Safety Decision Support System, Developed by the H2020 Project SafetyCube. Retrieved from. www.roadsafety-dss.eu, Accessed date: 6 December 2018.
Theofilatos, A., Aigner-Breuss, E., Kaiser, S., Alfonsi, R., Braun, E., Eichhorn, A., 2017. Identification and Safety Effects of Road User Related Measures. Deliverable 4.2 of the H2020 Project SafetyCube. Accessible at: https://hal.archives-ouvertes.fr/hal-01575215/document.
Veisten, K., Stefan, C., Winkelbauer, M., 2013. Standing in cost-benefit analysis of road safety measures: a case of speed enforcement vs. speed change. Transport Pol. 30, 269–274.
Wagenaar, A.C., Toomey, T.L., Erickson, D.J., 2005. Complying with the minimum drinking age: effects of enforcement and training interventions. Alcohol Clin. Exp. Res. 29 (2), 255–262.
Watling, Ch N., Leal, N.L., 2012. Exploring perceived legitimacy of traffic law enforcement. In: ACRS 2012 National Conference. Menzies Sydney Hotel, Sydney, NSW 9-10 August 2012.
Wegman, F.C.M., 1992. Legislation, Regulation and Enforcement to Improve Road Safety in Developing Countries. Contribution to the World Bank Seminar on Road Safety, Washington.
World Health Organization (WHO), 2017. Save LIVES - a Road Safety Technical Package. Geneva. Accessible at: www.who.int/violence_injury_prevention/publications/road_traffic/save-lives-package/en/.
Young, P.C. (Ed.), 2011. Recursive Estimation and Time-series Analysis. Springer-Verlag, Berlin - Heidelberg.
Zaal, D., 1994. Traffic Law Enforcement: a Review of the Literature. Monash University accident Research Centre Report Document no. 53. Australia.
Zaidel, D.M., 2002. The Impact of Enforcement on Accidents. ESCAPE Project. Deliverable 3. Technical Research Centre of Finland (VTT). Finland. Accessible at: http://virtual.vtt.fi/virtual/proj6/escape/escape_d3.pdf.
Zambon, F., Fedeli, U., Visentin, C., Marchesan, M., Avossa, F., Brocco, S., Spolaore, P., 2007. Evidence-based policy on road safety: the effect of the demerit points system on seat belt use and health outcomes. J. Epidemiol. Community Health 61 (10), 877–881.
Živković, V., Nikolić, S., Lukić, V., Živadinović, N., Babić, D., 2013. The effects of a new traffic safety law in the Republic of Serbia on driving under the influence of alcohol. Accid. Anal. Prev. 53, 161–165.