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An econometric analysis of the effects of the penalty points system driver's license in Spain

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ABSTRACT

This article seeks to quantify the effects of the penalty points system driver's license during the 18-month period following its coming into force. This is achieved by means of univariate and multivariate unobserved component models set up in a state space framework estimated using maximum likelihood. A detailed intervention analysis is carried out in order to test for the effects and their duration of the introduction of the penalty points system driver's license in Spain. Other variables, mainly indicators of the level of economic activity in Spain, are also considered. Among the main effects, we can mention an average reduction of almost 12.6% in the number of deaths in highway accidents. It would take at least 2 years for that effect to disappear. For the rest of the safety indicator variables (vehicle occupants injured in highway accidents and vehicle occupants injured in accidents built-up areas) the effects disappeared 1 year after the law coming into force.

1. Introduction

Over recent decades, road accidents have become one of the main causes of fatalities and morbidity, both on an international level and in some Mediterranean countries, including Spain (Page, 2001; Gras et al., 2007; Nasrullah et al., 2008). In terms of risk indicators (OECD, IRTAD, 2009), 3823 people died on Spanish roads in 2007, which is equivalent to 8.6 deaths per 100,000 inhabitants. According to the same source, Spain is on a par with Italy, behind Portugal (9.2), Belgium (10.1) and Greece (14.9), but a long way in front of European leaders such as the Netherlands (4.3), Great Britain (5.0) and France (7.5). The ratio of road user fatalities per 100,000 motor vehicles in Spain for the same year was thirteen, which is lower than that of other countries in Europe such as Greece (24) and Portugal (18); but significantly higher than the nine in France and Germany.

The higher accident rate on roads in Spain during the 1980s compared to its neighbors and other countries with similar rates of vehicle ownership is a widely studied topic in the academic literature. Frequent analyses are made of Spanish road traffic series, either treated individually using a variety of techniques (García-Ferrer et al., 2007) or compared to those of other countries (Lassarre, 2001; Page, 2001). Studies on more specific aspects are also prevalent, such as on the incidence of accidents in certain types of vehicles (see Arenas et al., 2009); accidents that have occurred with drivers under the influence of psychoactive substances such as illicit or medicinal drugs (Carpenter, 2004); seatbelt use (Gras et al., 2007); or the attitude of some groups of potentially high risk drivers as far as road accidents are concerned, such as young people (Ramos et al., 2008).

The huge economic and social cost of deaths, disabilities and injuries, has been estimated by López Bastida et al. (2004) at 1.35% of Spain's Gross National Product. With a view to minimizing this economic problem of primary importance (Peden et al., 2004), Spanish governments have implemented a range of preventive and corrective strategies, especially after the 2005–2008 Road Safety Strategic Plan was passed. The major road safety policies that have been devised are OECD (2008): the creation of the National Road Safety Observatory, the introduction of surveillance devices with greater monitoring of speeding and alcohol or drugs use, obligatory seatbelt use, obligatory crash helmet use for motorcycle drivers, infrastructure improvement programs, waves of shock campaigns in the media and the enforcement of offenses through legal reforms of the penalties envisaged and the implementation of a penalty points system driver's license.[1]

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[1] A summary of all these measures can be found on the Spanish General Directorate of Road Traffic (DGT) website (www.dgt.es). This is the Spanish Traffic Authority, which is dependent on the Ministry of Home Affairs.

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Recent studies all point toward the human component as the explanatory factor in most accidents (Stanton and Salmon, 2009; Medina et al., 2004). Consequently, of all these initiatives, penalty points systems (PPS) are particularly recommended by a number of institutions involved in road safety (see Global Road Safety Partnership, 2008 on an international level, and RACC, 2007 in Spain) to modify and penalize repeated inappropriate behavior behind the wheel[2].

Spain was one of the last countries in the European Union to implement the PPS.[3] Passed by Law 17/2005 of July 19, 2005, use of the system came into force on July 1, 2006. With its application the DGT aimed, on the one hand, to ensure compliance with the goal set by the European Commission for 2001–2010 of a 50% reduction in the number of deaths in road accidents (European Commission, 2002), and, naturally, on the other hand, to reduce the traditionally high road accident rates recorded in Spain (DGT, 2008).

In general terms, the PPS is a system through which road safety authorities assign a point to every driver who commits a traffic violation. The point is either positive or negative depending on the country and how serious the offense is. Thus, when the total number of points added or subtracted reaches the permitted limit, the driver's license is suspended or revoked. Systems based on the accumulation of points (demerit points system: DPS) are applied in Japan and in non-European Anglo-Saxon countries (several US states, Canada, Australia and New Zealand), and in the north of Europe (United Kingdom, Ireland, Denmark, Norway and Germany), for instance, while in the south of Europe (in France and Italy, for example) it is more frequent to subtract points from the initial credit issued to every driver.

The Spanish PPS issues an initial number of points (generally 12) that are progressively used up as violations are committed.[4] The system defines three groups of drivers: professional drivers, novice drivers (with licenses or permits under 3 years old) and all remaining drivers. Points are subtracted from the individual's administrative driving license, not from the type of permit or license for the vehicle that he/she is driving at the time the violation is committed. In addition, there is a bonus of a maximum of five points for drivers who have never been penalized for serious or very serious offenses. Drivers who exhaust their credit are obliged to attend a rehabilitation and re-education course.

Table 1 shows the most recent PPS effectiveness analyses for different countries based on a variety of techniques and the main conclusions.

As Nolén and Östlin (2008) stated, there is at least one study for every country where the PPS has been implemented. Nevertheless, there are some question marks regarding the assessment of the effects of these systems. On the one hand, from a methodological perspective, these studies are frequently based on a comparative analysis of statistical series, as Table 1 shows. In the opinion of Mohammed and Labuschagne (2008), very little is known of the effects of the PPS on road safety, because it is difficult to assess these systems. On the other hand, there is no consensus in the literature on the duration of the positive impact of the PPS (see Montoro and Roca, 2007 vs. Farchi et al., 2007, for example).[5]

In the case of Spain, preliminary literature shows that the PPS has been welcomed by public opinion[6] (Montoro and Roca, 2007; Lijarcio et al., 2008; Montoro et al., 2008; Ramos et al., 2008). Moreover, a 14.6% reduction in mortality from road accidents is usually attributed to the PPS (RACC, 2007; DGT, 2007) by a simple statistical comparison, even though the same sources confirm that the reduction was most evident between July 2006 and January 2007, with a decline in the effect of the system being noted after that date. Nevertheless, according to Roca and Tortosa (2008), the majority of these studies have only considered the way that the number of accidents and/or victims has evolved without any methodological support and without isolating the influence of other relevant factors, which is what this article aims to do.

This article goes beyond a simple descriptive view of the introduction of the PPS driver's license in Spain. We use an econometric model to estimate the quantitative impact of this reform on the main safety indicators for road accidents in Spain. The model is based on unobserved component models with added linear transfer function effects to model relationships with explanatory variables. There are several recent transportation studies that use similar approaches, either in motor vehicle accident analysis (see e.g., García-Ferrer et al., 2007) or port governance (see Castillo-Manzano et al., 2008, 2009). Compared to alternative approaches, our approach presents at least three major features. Firstly, it allows us to carry out a dynamic analysis that exploits the time series structure of the series of accidents on highways and in built-up areas (versus alternative studies that follow a comparative static approach). Secondly, we take an agnostic approach insofar as we do not need to make any assumptions regarding the nature of the different components in the series.

Finally, to avoid spurious or confusing effects that might blur the impact of the PPS (see Engström et al., 2003), we can easily control for variables that might have influenced Spanish traffic accidents in the time period analyzed, such as the level of economic activity, the rate of vehicle utilization and other specific events, including general bad weather conditions or strikes by truck drivers and other variables that are explained in the following data section. The use of multivariate models allows us to estimate the log-term effect of the June 1992 legal change that made seatbelt use mandatory, for example.

In short, the goal of this article is to evaluate the effectiveness of the PPS in Spain and the way its effects have developed over time. We therefore analyze if the effects only exist in the very short term (Farchi et al., 2007), or whether is it possible for the effects to last more than 6 months, as stated in other studies (see Montoro and Roca, 2007; Zambon et al., 2008). In other words, the purpose of this analysis is to discover whether the application of the penalty points system license does really represent a turning point in the history of Spanish road safety.

This article is organized as follows. Section 2 sets out the data, Section 3 establishes the methodology used, Section 4 presents the empirical results and, finally, Section 5 presents the conclusions of the study.

[2] Basili and Nicita (2005), Roca and Tortosa (2008) and SWOV (2005) detail the changes that this policy aims to encourage in driver behavior, grouping the possible effects of the tool into four categories: the signaling/selection effect, the frightening or deterrence effect (aiming to reduce recidivism and multiple offenders), the leniency effect and the correction effect.

[3] See Nolén and Östlin (2008) for the chronological details of the introduction of this measure in all EU member-states.

[4] Ultimately, they can reach a maximum of 15. The driver will lose 2, 3, 4 or 6 points depending on the seriousness of the offense committed, although it is possible to lose a maximum of 8 points on a single day if various offenses are accumulated.

[5] As suggested by Roca and Tortosa (2008), the differences in the duration of the results could be due to the differences in the models used and, especially, to the introduction of other complementary measures by governments. It is therefore necessary to control for the maximum number of variables possible, as our methodology approach proposes to do.

[6] Despite the fact that a high degree of social consensus has been achieved regarding the positive qualities of the PPS, its coming into force has been controversial, too. Within a year of its application, associations like *Automovilistas Europeos Asociados* (AEA, Associated European Automobile Drivers) and some media outlets had reservations about its weaknesses. For instance, in Spain, points are a requirement for continuing to hold a driver's license, not a penalty. This nuance allows tourists (59 million in 2007) to drive with impunity in Spain, while Spanish drivers suffer the consequences of their behavior in all European countries thanks to what is called the "computer registry of foreign offenders".

Table 1
An overview of recent studies on driving licenses based on points system.

Authors	Place	Type of method	Main conclusion
Bartl and Stummvoll (2000)	Austria	Systematic collection and description and qualitative analysis of experts	A 19% crash reduction resulted from the combined introduction of a PPS and a lower alcohol limit for novice drivers.
Basili and Nicita (2005)	An hypothetic country	Utility functions	The introduction of a DPS should increase general deterrence by increasing compliance by non-deterred agents. However, these effects are not quantified.
Bourgeon and Picard (2007)	An hypothetic country	Social welfare maximization	There is no quantification.
Butler et al. (2006)	The Republic of Ireland	Statistical analysis using a two-factor analysis of variance	Early evidence suggested a reduction in road traffic accident (RTA)-related mortality and a reduction in RTA-related spinal injuries. The first year of penalty points saw a fall in RTA deaths from 409 to 328; however, in the second year, the number of RTA deaths increased to 365.
Chen et al. (1995)	British Columbia	Logistic regression	The results showed a consistent increase in post-period accidents per driver, with increasing pre-period numbers for both crashes and convictions.
Deshapriya and Iwase (1996)	Japan	Time series analysis	Joint study of several legal interventions intended to deter drunk driving. There is no quantification.
Diamantopoulou et al. (1997)	Victoria (Australia)	Multivariate statistical models	The number of emergency room visits was 12% lower than during the previous year. The number of hospital admissions was 16% lower, and a 4% reduction was also observed in the number of deaths (although this last result did not achieve sufficient statistical relevance).
Farchi et al. (2007)	The Lazio Region (Italy)	Poisson models	The emergency room visit rate ratio (RR) was 0.87; the hospital admission RR was 0.87. The death RR was 0.93. However, the effect was lower than expected, and it decreased over time.
Gebers and Peck (2003)	California (USA)	A multiple linear regression analysis	A canonical correlation approach considering subsequent accident and citation rates simultaneously produced a 14.9% improvement in classification accuracy or “hit rate” for identifying accident-involved drivers.
Hauer et al. (1991)	Ontario, Toronto (Canada)	Multiple regression	The authors conclude that by using a multivariate statistical model to identify those drivers who are most likely to have an accident in the near future, one can do substantially better than by using a DPS in which points are assigned to offenses on the basis of their perceived seriousness.
Healy et al. (2004)	The Republic of Ireland	A retrospective statistical analysis	In the first 6 months of system use, there were 140 deaths, compared to 208 in the previous year. In the second 6 months under observation, the initial reduction was not maintained.
Hussain et al. (2006)	The Republic of Ireland	A comparative assessment of data	The number of maxillofacial surgery operations decreased by 61% during the PPS’s first year of application.
Lenehan et al. (2005)	The Republic of Ireland	A prospective study of data	There was a 37% reduction of the number of admissions per traffic accident at the emergency room once the system came into force.
Masten and Peck (2004)	California (USA)	Meta-analysis techniques	Of the driver improvement interventions studied, license suspension/revocation was by far the most effective treatment for both crashes and violations.
Meewes and Weissbrodt (1992)	Germany	Time sequence analysis	A general preventive effect was demonstrated in the first year after the implementation of a special DPS, with decreases in crash involvement of about 5% seen in the target group or parts of it.
Nallet et al. (2008)	France	Multiple correspondence analysis	The correspondence analysis has shown how danger, penalties and offenses were linked in the mental representation of the course-takers.
Elvik et al. (1997) cited by Nolén and Östlin (2008)	Six EU countries	A descriptive analysis of several studies	A PPS reduces the traffic accidents by about 12% and the injuries by about 17% on average.

Table 1(*Continued*).

Authors	Place	Type of method	Main conclusion
Poli de Figueiredo et al. (2001)	Brazil	An empirical analysis of data	There was an overall 21.3% reduction in the number of accidents and a 24.7% reduction in the number of immediate deaths. Motor vehicle accident-related emergency room admissions decreased by 33.2%.
Redelmeier et al. (2003)	Ontario, Toronto (Canada)	A case-crossover study	The risk of a fatal crash in the month after a conviction was about 35% lower than in a comparable month with no conviction for the same driver. The benefit lessened substantially by the time 2 months had passed and was not significant at 3–4 months. The benefit was greater for speeding violations with penalty points than for speeding violations without points.
Simpson et al. (2002)	Great Britain	A questionnaire survey and empirical analysis of data	The results of a new PPS for novice drivers did not lead to a significant decrease in crashes in the first year and led only to a slight change in the second. There was a decrease in the percentage of drivers (from 4.8 to 4.5) offending in their second year of post-test driving after the legislation was introduced.
Wong et al. (2008)	Hong Kong	A multinomial logit model	Increases in point penalties and the assessment of a fine had a marked positive effect on deterring red light violations (both at the 1% level of significance).
Zambon et al. (2008)	The Veneto Region, Italy	Poisson regression	The introduction of the DPS associated with heavy fines led to a positive effect on seatbelt use increase, both in the short and in the long term.

2. The data

The data used to measure the effects of the PPS in Spain can be divided into three groups:

1. Safety indicator variables: There are four monthly variables relating to accident rates, namely the number of deaths in highway accidents, deaths in accidents in built-up areas, vehicle occupants injured in highway accidents, and vehicle occupants injured in accidents built-up areas. In order to use consistent time series for as long as possible, we used the definition of death as occurring within 24 h of the accident as opposed to the Vienna Convention definition (within the following 30 days). The available time series spans from January 1980 to December 2007 INE (2009).[7]
2. Dummy explanatory variables: There is an ample set of variables included in models intended to estimate a number of intervention variables and outlier effects seen in the data. The most important of these in the remainder of the paper are, with their definitions:
   a. PPS: Penalty points system driver's license, which came into force in July 2006. Two specifications are searched for to test whether the system causes a permanent change (i.e. a level shift or LS from the point of view of intervention analysis) or a transitory change (TC, i.e. a sudden change that tends to disappear in time).
   b. Easter: Traffic campaigns around this vacation period are especially intense in Spain. In fact, authorities launch special police operations to minimize problems on the roads. Such operations usually start on the weekend before Good Friday and finish on the Monday after Easter Sunday (this is the so-called 'Easter effect' in the time series literature, although strictly speaking, it refers to some specific days during the Holy Week period). Accordingly, the movable Easter festival variable is defined by assigning different weights to the days in question depending on expected traffic density (such weights must add up to one). Maximum weights are assigned to Good Friday, Palm Sunday, Holy Wednesday and Easter Sunday. Medium weights are assigned to the Saturday before Palm Sunday and Holy Thursday. Weights of zero are assigned to the remaining days.
   c. Trading: The number of trading days in a month. This variable was also considered in modeling IPI and gasoline and diesel consumption.
   d. Law 92: Any level shift due to a legal change introduced in June 1992.
   e. There are other outliers, often related to bad weather conditions (for example Jan 84 and Jan 06), strikes by truck drivers (Oct 2005) and other causes that have been detected by statistical tools. The procedure for finding outliers of this type consists of considering the residuals that are outside four times standard deviation and including them as potential candidates for analysis with differently specified models (LS, TC as explained above, or additive outliers, AO, for sudden changes that affect just one observation). When they are statistically

[7] All data is primary data (http://www.ine.es/). Although the DGT has recent data available (up to the first months of 2009), the series presents two difficulties. First, the data only considers fatalities in road accidents, whereby only one of the four safety indicator variables used in our study is included. In addition, the series uses the Vienna Convention definition (death within a period of 30 days following the accident), an interval for which homogeneous data only exists after 1993. This is in contrast to the series which was finally used, for which data from 1980 is available. We were consequently forced to conclude our analysis in December 2007.

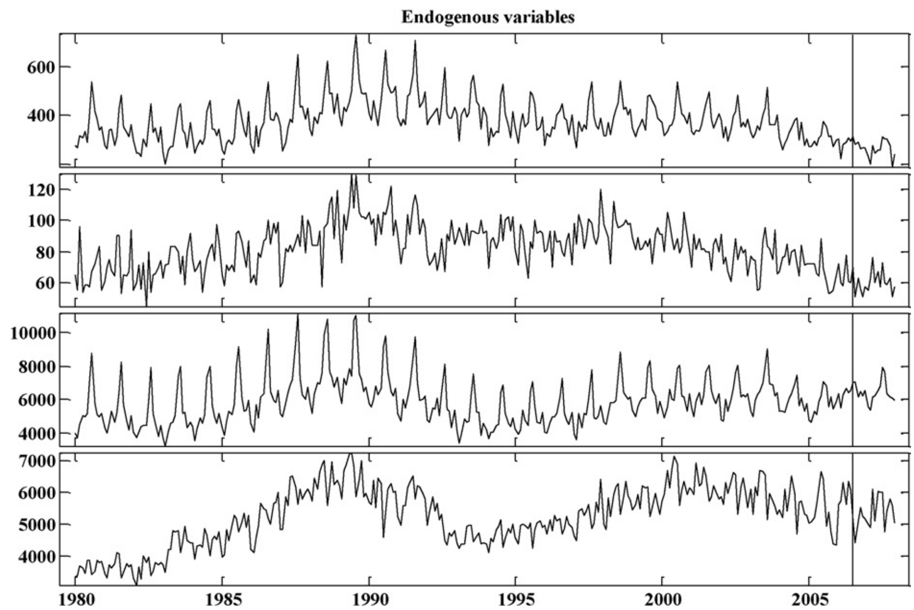

Fig. 1. Safety indicator variables from January 1980 to December 2008. From top to bottom: the number of deaths in highway accidents, deaths in accidents in built-up areas, vehicle occupants injured in highway accidents, and vehicle occupants injured in accidents built-up areas. The vertical line indicates July 2006, the month in which the PPS license was introduced.

significant, the outliers are included in final models with the specification that provides the best fit.

3. Other explanatory variables: Part of the literature argues that both the rate of vehicle utilization and the level of economic activity are important determinants of the number of road accidents (García-Ferrer et al., 2007). In this article, economic activity is represented by the Industrial Production Index (IPI) and the degree of vehicle utilization by the consumption of gasoline and diesel for transport.

Other variables have been included in the literature (see e.g., García-Ferrer et al., 2007), such as vehicle stock; the aggregate length of highways in kilometers; weather conditions; police activity; the age and physical condition of automobiles. It is clear that such variables have an influence on our safety indicator variables, but the lack of monthly data, as well as the high degree of correlation with the variables included in our models, made these other variables not particularly relevant given our specific objective of testing the effect of the introduction of the PPS driver's license in Spain.

Fig. 1 shows the safety indicator variables. Common features are observed in all of these, such as the existence of long-term trends, two long-term cycles with maximums around 1989 and 1999, and a marked seasonal pattern, especially for highway series, mainly due to vacation periods. At first sight, the PPS license does not seem to have drastically changed the long-term behavior that can be seen in the time series, since fatalities on highways and in built-up areas were already falling at a reasonable rate at the time of its introduction, while the number of victims was actually increasing.

The shape of the explanatory variables is shown in Fig. 2. Once again, long-term trends, long cycles (especially in IPI) similar to the cycles in the safety indicator variables, and marked seasonal patterns are easily distinguishable. There are other calendar effects on these time series not visible upon simple inspection which will be included in the models and are statistically significant, namely the influence of Easter, and trading day effects. The Easter variable for gasoline and diesel consumption matches the definition of the Easter variable above, but the Easter variable for IPI gives equal weight to the 4 days of Holy Week (from Holy Thursday to Easter Sunday).

3. General methodology

The basic model is of the unobserved component model class known as the Basic Structural Model (Harvey, 1989), which decomposes a set of time series into unobserved but meaningful components from an economic point of view (mainly trend, seasonal, and irregular). The model has to be multivariate and may be written as in Eq. (1):

$$\mathbf{z}_t = \mathbf{T}_t + \mathbf{S}_t + f(\mathbf{I}_t) + \mathbf{v}_t \quad (1)$$

$\mathbf{z}_t$, $\mathbf{T}_t$, $\mathbf{S}_t$ and $\mathbf{v}_t$ denote the m dimensional output time series and trend, seasonal and irregular components, respectively. $f(\mathbf{I}_t)$ measures the effects of explanatory variables in matrix $\mathbf{I}_t$ through a general function $f(\bullet)$. $\mathbf{z}_t$ will typically be a vector composed of one of the safety indicators, gasoline consumption and the IPI series. Eq. (1) is in fact a set of observation equations in a state space (SS) system, which has to be completed using the standard transition or state equations. The state equations qualify the dynamic behavior of the components, and a full model may be built via block concatenation of the individual components (see details in Harvey, 1989; Pedregal and Young, 2002 and Appendix A for the specific formulation used in this paper).

A key issue in this article, essential to carrying out the intervention analysis necessary to test the impact of the PPS license on driving behavior, is the question of how to model the relationship between output models and intervention variable inputs (dummy type). In this case, Eq. (1) has been expanded to include linear transfer function (TF) models, which is the usual way to handle these types of variables. The particular model used in later examples is a first-order transfer function model shown in Eq. (2) for one output variable, where I_{it} (i = 1, 2, . . ., k) are a set of impulse variables appropriately defined in order to perform the intervention analysis, ω_i and a_i (i = 1,2, . . ., k) are a set of parameters to be estimated,

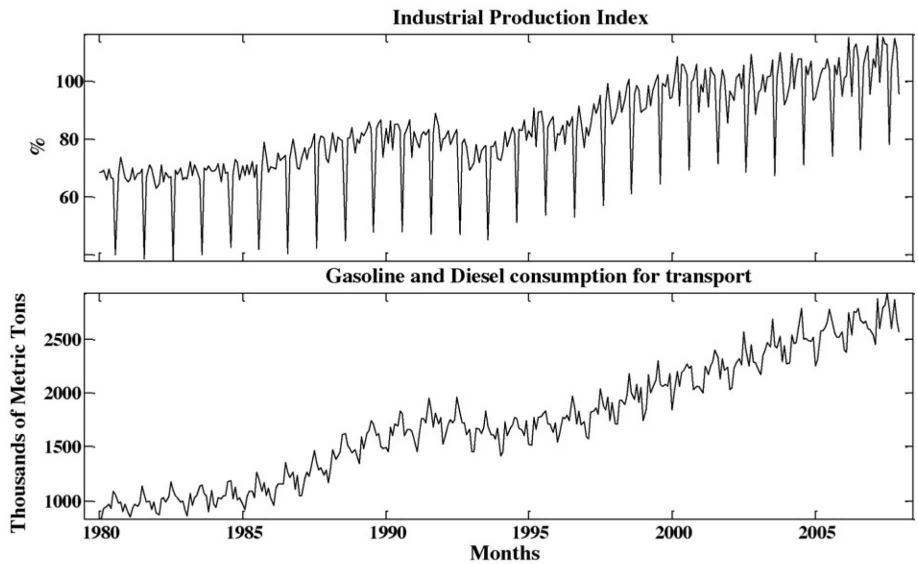

Fig. 2. Explanatory economic variables from January 1980 to December 2008.

and B is the lag operator, so that $B^m x_t = x_{t-m}$.

$$z_{j,t} = T_{j,t} + S_{j,t} + \sum_{i=1}^{k} \frac{\omega_i}{(1 + a_i B)} I_{i,t} + v_{j,t} \quad (2)$$

Given an overall SS system (see the Appendix A), the well-known Kalman filter (KF, Kalman, 1960) produces the optimal estimates of the first- and second-order moments (mean and covariance) of the state vector, conditional on all the data in a sample in the sense of minimizing the mean squared errors (MSEs). An algorithm that is used in parallel with the KF but is not as well-known in certain contexts is the fixed interval smoothing (FIS, Bryson and Ho, 1969) algorithm, which allows for an operation similar to that of the KF, but based on all the information available in the sample.

The application of the recursive KF/FIS algorithms requires knowledge of all the system matrixes. This is not usually possible, but there are a number of possible ways of handling this estimation problem; the maximum likelihood (ML) method is the most common in the time domain because of its sound theoretical properties. Under the Gaussian assumption, the log-likelihood function can be computed using the KF via 'prediction error decomposition' (Schweppe, 1965; Harvey, 1989). As all these algorithms are well known and discussed in detail in other sources, we will not pursue the topic further (see e.g., Bryson and Ho, 1969; Young, 1984; Harvey, 1989; Koopman, 1993; Young et al., 1999; Durbin and Koopman, 2001; Pedregal and Young, 2002).

4. Models and results

Two types of model were developed within the previous framework: (1) univariate models with a single output and a set of dummy variables to take into account all the relevant events on which the univariate time series may depend ($\mathbf{z}_t$ is just one of the safety indicators); and (2) multivariate models that are an expanded version of their univariate counterparts, in which IPI and gasoline consumption are also included (i.e. $\mathbf{z}_t$ is one of the safety indicators, IPI and gasoline consumption). All models were run on the MATLAB™ platform with code developed by the authors.

Table 2

Estimation results for univariate models with intervention variables. σ^2 stands for the innovations variance; $Q(12)$ and $Q(24)$ are the Ljung-Box Q statistics for 12 and 24 lags, respectively; Bera-Jarque is a normality test (P-values in parenthesis); H is a variance ratio homocedasticity test (P-values in parenthesis).

	Deaths in highway accidents		Deaths in built-up areas		Injured in highway accidents		Injured in built-up areas	
	LS	TC	LS	TC	LS	TC	LS	TC
PPS	−0.157***	−0.182***	−0.014	0.087	−0.081*	−0.153***	−0.121***	−0.172***
a_i	–	−0.915***	–	0.746*	–	−0.551**	–	−0.578***
Easter	0.063***	0.064***	0.028	0.027	0.053***	0.053***	−0.009	−0.009
Trading	−0.007***	−0.007***	−0.002	−0.002	−0.006***	−0.007***	−0.002**	−0.002**
Law 92	−0.147***	−0.154***	−0.020	−0.022	−0.187***	−0.188***	−0.152***	−0.155***
Jan 84 (AO)	0.145**	0.136*			0.125***	0.128***	0.099**	0.095**
Nov 93 (AO)					−0.137***	−0.136***	–	–
Jan 06 (AO)					0.167***	0.167***	–	–
Jan 06 (TC)							0.205***	0.222***
Oct 05 (TC)							−0.244***	−0.233***
Jul 90 (AO)							−0.336***	−0.340***
$\sigma^2 \times 1000$	6.185	6.108	16.954	16.884	3.047	2.958	2.355	2.288
Q (12)	4.726	5.773	10.708	9.982	10.476	10.491	6.695	6.904
Q (24)	10.630	11.126	18.525	18.924	25.111	26.759	19.144	19.845
Bera-Jarque	0.631 (0.729)	0.788 (0.674)	0.237 (0.888)	0.329 (0.848)	0.249 (0.883)	0.249 (0.883)	0.568 (0.753)	0.514 (0.773)
H	0.858 (0.236)	0.824 (0.182)	0.794 (0.141)	0.781 (0.124)	0.795 (0.142)	0.714 (0.058)	0.881 (0.277)	0.790 (0.135)

* Indicates coefficient significance at the 10% levels.

** Indicates coefficient significance at the 5% levels.

*** Indicates coefficient significance at the 1% levels.

Table 3
Estimation results for the first equation of multivariate models with intervention variables. σ^2 stands for the innovations variance; $Q(12)$ and $Q(24)$ are the Ljung-Box Q statistics for 12 and 24 lags, respectively; Bera-Jarque is a normality test (P-values in parenthesis); H is a variance ratio homocedasticity test (P-values in parenthesis).

	Deaths in highway accidents		Deaths in built-up areas		Injured in highway accidents		Injured in built-up areas	
	LS	TC	LS	TC	LS	TC	LS	TC
PPS	−0.126***	−0.163***	−0.027	0.038	−0.097***	−0.156***	−0.111***	−0.160***
a_i	–	−0.860***	–	0.258	–	−0.599***	–	−0.527***
Easter	0.068***	0.067***	0.035	0.037	0.052***	0.054***	−0.011	−0.012
Trading	−0.007***	−0.007***	−0.001	−0.001	−0.007***	−0.007***	−0.002***	−0.002**
Law 92	−0.120***	−0.102***	0.047	0.013	−0.136***	−0.137***	−0.128***	−0.134***
Jan 84 (AO)	0.124*	0.136**			0.115***	0.111***	0.081**	0.072*
Nov 93 (AO)					−0.138***	−0.139***	–	–
Jan 06 (AO)					0.167***	0.170***	–	–
Jan 06 (TC)							0.180***	0.202***
Oct 05 (TC)							−0.249***	−0.234***
Jul 90 (AO)							−0.345***	−0.348***
$\sigma^2 \times 1000$	5.767	5.759	15.781	15.556	2.860	2.746	2.274	2.203
Q(12)	6.057	8.643	10.893	14.255	7.915	9.030	8.495	7.778
Q(24)	12.674	16.776	18.792	24.008	24.500	24.786	20.291	20.304
Bera-Jarque	1.311 (0.519)	2.248 (0.325)	0.995 (0.608)	1.082 (0.582)	0.197 (0.906)	0.011 (0.995)	0.641 (0.726)	0.850 (0.654)
H	0.789 (0.134)	0.747 (0.087)	0.926 (0.359)	0.872 (0.262)	0.821 (0.179)	0.709 (0.054)	0.916 (0.340)	0.811 (0.164)

* Indicates coefficient significance at the 10% levels.
** Indicates coefficient significance at the 5% levels.
*** Indicates coefficient significance at the 1% levels.

The models are estimated under logarithmical transformation, implying that the coefficients affecting the relationship between explanatory variables and safety indicators (parameters ω_i in Eq. (2) above or in matrix **D** in Appendix A) may be interpreted as elasticities (i.e. the percentage change experienced by a safety indicator variable when one of the explanatory variables increases by 1% and all others remain constant).

4.1. Univariate models

To be correct, the eight univariate models considered in this article correspond to model (1), with one safety indicator variable and the intervention variables defined in Section 2. The models correspond to each of the four accident variables with two possible specifications for the PPS license variable: a level shift and a transitory change.

Table 2 shows the estimated parameters of the intervention variables and of each model, where the coefficients may be interpreted as percentage changes or elasticities. Additional tests for outliers were carried out after each estimate and subsequently included in the model. Outliers corresponding to January 1984 and January 2006 are attributable to especially difficult weather conditions.[8]

All models seem appropriate from the point of view of diagnostics checking, as is demonstrated towards the bottom of Table 2. The residuals are Gaussian according to the Jarque-Bera test, are homoscedastic according to the ratio of variances test (H test in Table 2), and would seem to have no serial correlation problems according to the Ljung-Box Q tests. It is remarkable that all the tests are not rejected statistically by a wide margin, with the only exception of heteroskedasticity being found in injuries sustained on highways. The P-value in this case was 5.8%, with 12.4% being the next lowest P-value.

The introduction of a PPS license in Spain had a clear effect on the safety indicators. However, the intensity varied depending on the indicator. Judging strictly by the fit or the residual variance of the models, the effect of the PPS was transitory in all cases, rather than causing a permanent change, with the exception of vehicle occupants injured in built-up areas, where no effect at all was detected. This is in line with some other references (e.g., Montoro et al., 2008; Ramos et al., 2008; Montoro and Roca, 2007), although the intensity and duration of the effect differs from these references. The PPS license had an initial impact in July 2006 of 18.2 and 15.3% for deaths and vehicle occupants injured on highways, respectively,[9] and of 17.2% for vehicle occupants injured in built-up areas, but the effect declined and disappeared after 40.9 and 11 months, respectively.

As expected, the Easter effect was only significant for highway accidents.

The legal change introduced in June 1992 caused an important permanent reduction in traffic accidents of about 15% in the case of fatalities on highways and vehicle occupants injured in built-up areas and of almost 19% in the case of vehicle occupants injured on highways.

The fact that the model for deaths in built-up areas is not related to any of the dummy variables (and the residuals show the greatest variance of all) is truly remarkable. This implies that this is a time series that obeys very different factors to those that rule the other accident variables; even components that cannot be observed are unable to fit the signal as well as in the rest of the cases because of the irregular behavior of fatalities in built-up areas.

4.2. Multivariate models

Multivariate models include one safety indicator in turn, together with the IPI and gasoline and diesel consumption for transport. The model consists of three equations of type (1) or (A.1)–(A.2) in Appendix A, in which the unobserved components (trend, seasonal and irregular) are assumed to correlate. The estimated results for the first equation are presented in Table 3 in the same format as for Table 2.

[8] For instance, according to newspaper libraries, the rain, snow, and icy cold gales that blew in from Europe and affected Spain during the last weekend of January 2006 not only caused the major collapse of air traffic, but also had a significant effect on the roads. This effect accounted for more than 15 mountain passes being closed, more than 30 highways being closed and traffic being restricted on about the same number of highways, almost 200 points of the highway system subject to mandatory tire chain use, and 150 km of traffic congestion in Madrid.

[9] See Table 2, parameters PPS in columns "Deaths in highway accidents" and "Injured in highway accidents".

Table 4
Diagnostics checking of equation corresponding to IPI and gas consumption in model for deaths highway accidents.

	IPI		Gasoline and diesel consumption for transport	
	LS	TC	LS	TC
$\sigma^2 \times 1000$	0.583	0.585	0.482	0.481
Q(12)	10.512	9.252	5.128	5.232
Q(24)	27.125	28.091	26.244	26.122
Bera-Jarque	3.401 (0.182)	2.652 (0.265)	1.013 (0.602)	0.647 (0.723)
H	0.796 (0.145)	0.794 (0.142)	0.832 (0.197)	0.815 (0.171)

The outliers found for the IPI series were the influence of Easter, trading day effects and a transitory change due to the events of September 1992. The outliers in gasoline consumption were connected with Easter and trading day effects; there was also a transitory change in February 1988 and an additive outlier in October 2000.

If we compare Table 3 with Table 2, the conclusions are clear. There are improvements in terms of residual properties, and the levels of variance are lower in all cases, implying that the levels of economic activity and vehicle utilization represent variables that are relevant in explaining accidents. The rest of the conclusions taken from Table 2 are again seen in Table 3, with the exception of some changes in the estimate of some of the important effects taking place in the series. Particularly, the June 1992 legal change now has a lesser impact in all cases (ranging from 10 to 13.7%); the same occurs with the introduction of the PPS license. In particular, there was no effect detected on injured in built-up areas and significant transitory effects in the rest of time series. The PPS license produces an initial impact in July 2006 of 16.3 and 15.6% for deaths and injured people on highways, respectively, and of 16% for injured people in built-up areas, but the effect declined and disappeared after 24.9, and 11 months, respectively. Apart from significance of estimation differences between these and the univariate models in strict statistical terms, the multivariate models represent a more full and robust specification and hence will be considered our final estimates.

Table 4 shows diagnostics checking for the two additional variables in the model corresponding to fatalities on highways. Differences between the specifications of the PPS as a permanent and transitory change are very small, in terms of fit and test diagnostics. In all cases, the Ljung-Box independence test indicates no problems with autocorrelations; the Gaussianity Bera-Jarque tests show that the Gaussianity assumption cannot be rejected by a very wide margin (the lowest *P*-value is 79.4%); and the *H* variance ratio tests show no problem of heteroskedasticity (the lowest *P*-value is 14.2%).

5. Conclusions

The question of the possible positive effects of the introduction of penalty points system driver's licenses (in its two varieties: PPS and DPS) is a topic that has generated a notable amount of academic literature in recent years. After conducting a survey of the main results obtained, this work focuses on the case of Spain. The coming into force of the PPS in the summer of 2006 represented the latest attempt on the part of the Spanish government to put an end to Spain's status as one of the European countries with the highest rates of road accidents.

After a descriptive analysis of the system's characteristics, a solid methodology is offered that allows us to study its effects, producing robust and individualized results for the different safety indicator variables, including the effects of the PPS during the first 18 months it was in force. This methodology consists of estimating univariate and multivariate unobserved component models set up in a state space framework estimated by maximum likelihood and enhanced by a detailed intervention analysis and the inclusion of other relevant variables. The Kalman filter and smoothing algorithms provide the means to estimate the required effects and the unobserved components (trend, seasonal and irregular components). The different phases of the methodology used allow corrections to be made for any possible effects of the legal change through the introduction of a series of factors that determine the dynamics of the dependent variables (Easter effects, possible inclement weather, other relevant legal changes, etc.), and explanatory variables, such as the rate of vehicle utilization and the level of economic activity. With regard to the last two, the results and the tests on residuals show the usefulness of their inclusion since, despite the fact that univariate estimates have almost the same quality as multivariate estimates, there are some improvements in terms of residual properties and their variance, which is smaller in all cases (see Table 4).

In addition, the proposed methodology can easily be extrapolated to other countries, allowing comparisons and the corroboration of the results obtained.

Regarding the results, the significant impact that the introduction of the PPS has had on three of the four safety indicator variables must be underlined: the number of fatalities in highway accidents, vehicle occupants injured in highway accidents, and vehicle occupants injured in accidents in built-up areas. Nevertheless, certain signs, such as the better fit and the residual variance of the TC models compared to the LS models, point to the hypothesis that the PPS effect is certainly transitory.

However, the effects have lasted much longer than previous studies have indicated in their discussion of the reduction in the number of deaths in highway accidents. Should the reduction pace of the first 18 months be maintained, it would take at least 2 years for them to disappear. For the rest of the safety indicator variables (vehicle occupants injured in highway accidents, and vehicle occupants injured in accidents built-up areas) the effects disappeared 1 year after the law coming into force. Even for these variables, the effects lasted longer than 6 months, coinciding with the information included in Montoro and Roca (2007) and Zambon et al. (2008), and in opposition to the thesis of Farchi et al. (2007).

In addition, the initially positive shock reduced the three significant safety indicator variables between 15.6 and 16.3% (see Table 3), with no meaningful differences observed between deaths and injured occupants.

The LS models may be consider that the coefficients of the level shift models are the average effect of the PPS license during the first 18 months of its implementation, especially with regard to deaths in highway accidents, which effect lasts 24 months. In this sense, the PPS license led to a 12.6% average reduction in the number of deaths, i.e. an effect somewhat inferior to the 14.6 in other studies (RACC, 2007; DGT, 2007).

Another relevant conclusion of this article is the confirmation, fifteen-and-a-half years after its implementation, that the legal change introduced in June 1992 whereby seatbelts became mandatory for automobile occupants was a turning point in the evolution of the number of road accidents in Spain. In particular, we can observe that at the very least (that is, taking the coefficients of the multivariate models; see Table 3), the June 1992 legal change led to a 12–13% reduction in the figures for the three safety indicator variables mentioned above. These results are consistent with previous literature (see García-Ferrer et al., 2007 and Lardelli-Claret et al., 2006 for Spain; see Cummings et al., 2003 and Harvey and Durbin, 1986 for international viewpoints).

Finally, it is worth underlining that the fourth dependent variable, the number of fatalities in built-up areas is not related to any of the dummy variables, including the two legal changes analyzed (PPS and seatbelt regulation). Therefore, we face a problem that requires a change of attitude among Spanish policy-makers, who will have to seek specific solutions.

To conclude, everything would seem to indicate that the feeling of social euphoria, initially induced by the government and widely disseminated among the media,[10] which suggested that the coming into force of the PPS represented a triumph in the history of accident prevention in Spain, is well-founded. However, it is more than probable that the majority of these effects are transitory; the effect on the number of vehicle occupants injured in accidents on highways and in built-up areas at least, which prevents us from feeling fully triumphant; ongoing efforts must be made to address this grave issue.

Appendix A.

The Basic Structural Model proposed in this paper for the analysis of the PPS is of the form in Eq. (A.1), equivalent to Eq. (1) in the main text (for further information see Harvey, 1989; Pedregal and Young, 2002):

$$\mathbf{z}_t = \mathbf{T}_t + \mathbf{S}_t + f(\mathbf{I}_t) + \mathbf{v}_t \tag{A.1}$$

The components, together with their dynamic specification can be expressed in compact form as Eq. (A.2):

$$\begin{cases} \mathbf{x}_{t+1} = \mathbf{\Phi x}_t + \Gamma \mathbf{I}_t + \mathbf{E w}_t : & \text{Transition Equations} \\ \mathbf{z}_t = \mathbf{H x}_t + \mathbf{D I}_t + \mathbf{v}_t : & \text{Observation Equations} \end{cases} \tag{A.2}$$

Here, $\mathbf{z}_t$ denote the m dimensional output time series; $\mathbf{I}_t$ stands for a k dimensional vector of explanatory variables; $\mathbf{x}_t$ is the state vector, that is composed mainly by the unobserved components (trend and seasonal components); $\mathbf{w}_t$ and $\mathbf{v}_t$ are two sets of Gaussian noises serially and mutually independent, with covariance matrices $\mathbf{Q}$ and $\mathbf{R}$ respectively; and $\mathbf{\Phi}$, $\mathbf{\Gamma}$, $\mathbf{E}$, $\mathbf{H}$ and $\mathbf{D}$ are matrices of coefficients of appropriate dimensions.

As an illustration, consider the case of a single output (one of the safety indicator variables) model with no explanatory variables. The corresponding model is given in Eq. (A.3):

$$\mathbf{x}_{t+1} = \begin{pmatrix} T \\ T^* \\ S_1 \\ S_1^* \\ \vdots \\ S_6 \\ S_6^* \end{pmatrix}_{t+1} = \begin{pmatrix} 1 & 1 & 0 & 0 & \cdots & 0 & 0 \\ 0 & 1 & 0 & 0 & \cdots & 0 & 0 \\ 0 & 0 & \cos\omega_1 & \sin\omega_1 & \cdots & 0 & 0 \\ 0 & 0 & -\sin\omega_1 & \cos\omega_1 & \cdots & 0 & 0 \\ \vdots & \vdots & \vdots & \vdots & \ddots & \vdots & \vdots \\ 0 & 0 & 0 & 0 & \cdots & \cos\omega_6 & \sin\omega_6 \\ 0 & 0 & 0 & 0 & \cdots & -\sin\omega_6 & \cos\omega_6 \end{pmatrix} \begin{pmatrix} T \\ T^* \\ S_1 \\ S_1^* \\ \vdots \\ S_6 \\ S_6^* \end{pmatrix}_t + \begin{pmatrix} w_0 \\ w_0^* \\ w_1 \\ w_1^* \\ \vdots \\ w_6 \\ w_6^* \end{pmatrix}_t$$
$$z_t = (1 \quad 0 \mid 1 \quad 0 \quad \cdots \quad 1 \quad 0)\mathbf{x}_t + v_t \tag{A.3}$$

In this model $\omega_j = 2\pi j/12$; and $Var(w_j) = Var(w_j^*)$ for $j = 1, 2, \ldots, 6$, but $Var(w_j) \neq Var(w_j)$ for any $h \neq j : j, h = 1, 2, \ldots, 6$. It is straightforward to identify the system matrices, according to Eq. (A.2). The trend is the first element in the state vector (T_t) and the seasonal component is $\sum_{k-1}^{6} S_{k,t}$.

Multivariate models can be specified by extending the state, noise, and output vectors accordingly; replacing any 1 and 0 by corresponding identity and zero-block matrices of m dimension; and substituting the cosine and sine terms by diagonal matrices of cosine and sine terms of dimension m.

The SS form of the linear transfer functions used to model the relation with explanatory variables in Eq. (2) in the main text is given by Eq. (A.4):

$$\begin{cases} x_{t+1} = -a_i x_t - a_i \omega_i I_{i,t} : & \text{Transition Equations} \\ z_t = x_t + \omega_i I_{i,t} : & \text{Observation Equations} \end{cases} \tag{A.4}$$

The TF by itself may model transitory changes (TC) in the time series (with $a_i < 0$); additive outliers (AO) may be modeled by setting $a_i = 0$; level shifts (LS) may be included by constraining $a_i = 1$.

If we define $I_{i,t}$ as any other arbitrary variable and set $a_i = 0$, other possibilities appear, like the influence of Easter, trading day effects, etc. Ramps are also possible if we set $a_i = 0$ and define $I_{i,t}$ as a time index instead of an impulse.

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[10] This topic has generated endless hours of discussion in news programs aired by public and private television stations, the effects of the PPS being regarded favorably in most cases. Viewers have had the opportunity to get to know new celebrities, such as the driver who was the first to lose all his points, the driver who lost the greatest number of points for a single offense, and even the driver who was the first to be legally deprived of his driver's license.

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