Economic Modelling 44 (2014) S68–S76

Contents lists available at ScienceDirect

Economic Modelling

journal homepage: www.elsevier.com/locate/ecmod

Temporary speed limit changes: An econometric estimation of the effects of the Spanish Energy Efficiency and Saving Plan

José I. Castillo-Manzano [a,*], Mercedes Castro-Nuño [a], Diego J. Pedregal-Tercero [b]

[a] University of Seville, Spain
[b] University of Castilla-La Mancha, Spain

ARTICLE INFO

Article history:
Accepted 31 January 2014

Keywords:
Fuel consumption
Road safety
Speed management policy
Unobserved component models

ABSTRACT

Nowadays, speeding is one of the most relevant problems for traffic safety and most resistant to change in motorized countries. The key instruments in Speed Management Policy are speed limits. This road safety strategy is often established or changed, in order to save fuel during periods of rising prices. However, the relationship between speed limits and traffic accidents, is a topic widely discussed by researchers, and there seems to be some consensus about "speed kills." By applying advanced time series models of unobserved components, our study investigates the impact of a temporary reduction of maximum speed limits, implemented in Spain in 2011, in terms of fuel consumption and fatalities. Our analysis shows that this measure caused a positive effect, although with a limited statistical significance, on fuel consumption and a discrete reduction in road mortality.

1. Introduction

The speed of road transport has contributed to countries' economic development and has increased wellbeing and the quality of life because of travel time savings, which, according to Metz (2008), helps generate productivity gains and reduce opportunity costs in terms of user time. Nevertheless, speed also has very adverse impacts in the form of energy consumption, air pollution, noise emissions, and, above all, road traffic accidents as pointed out by Kremers et al. (2002). Nowadays, excessive and inappropriate speed[1] is one of the biggest road safety problems (Wegman and Aarts, 2006), for both rich and highly motorized (Elvik, 2010) and developing countries (Afukaar, 2003). Despite speeding being a widespread issue and everybody being convinced that "speed kills" (GRSP, 2008), it is widely tolerated and, in the words of Elvik (2010:1092): "one of the road safety problems most resistant to change".

For all these reasons, most governments regard speeding as a priority within the road safety strategies, such as Vision Zero in Sweden, Sustainable Safety in the Netherlands and Safe System in Australia, and a range of tools are applied for developing an effective Speed Management Policy (GRSP, 2008), from road engineering treatment to the setting of maximum speed limits (see e.g., Bolderdijk et al., 2011; Elvik and Vaa, 2004; Feng Ng and Small, 2012).

Although an appropriate combination of measures is required (Elvik, 2012), the key tool for speed management, and the most widely addressed, is speed limit (Ritchey and Nicholson-Crotty, 2011). There are some roads in motorized countries where no speed limits are in force (i.e., German Autobahns), but the need for legal speed limits on all types of roads is very widely recognized and commonly legitimated by the fact that drivers' choices of speed may not always be perfectly rational from a social perspective (Elvik, 2012; Jørgensen and Polak, 1993) and may be strongly influenced by how fast others are driving (Haglund and Åberg, 2000).

In this paper, we analyze a recent change to maximum speed limits allowed on free-public and toll-private dual carriageways and motorways in Spain during a few months in 2011, which was put in place with the primary objective of obtaining savings in fuel consumption.

Speed limit laws have existed in Spain since the mid-nineteen-seventies and the speeding problem has been reflected in Spanish active traffic safety policies developed during recent years (December 2007 and June 2010 Penal Code Reforms; penalty points system-based driving license in 2006; the 2005–2008 and 2011–2020 Strategic Road Safety Plans). However, the most unforeseen strategy may have been the reduction in the maximum speed limits allowed on dual carriageways and motorways, which was reduced from 120 km/h to 110 km/h from the 7th of March 2011 to the 30th of June 2011 for automobiles and motorcycles. This measure was taken at a time of political instability in oil producing countries during the first quarter of 2011, known as the "Arab Spring", and which entailed a steep hike in the price of oil (around USD 125 per barrel). Therefore, in the local context of a serious economic crisis in Spain and with the aim of reducing fuel consumption, the

* Corresponding author at: Department of Economic Analysis and Political Economy, University of Seville, Spain. Tel.: +34 954 55 67 27.
E-mail addresses: jignacio@us.es (J.I. Castillo-Manzano), mercas@us.es (M. Castro-Nuño), diego.pedregal@uclm.es (D.J. Pedregal-Tercero).

[1] According to ECMT (2006), excessive speed is a speed over the legal speed limit and inappropriate speed is a speed much too high for the road, and the weather and congestion conditions, but within the legal speed limit. Excess speed covers both terms.

http://dx.doi.org/10.1016/j.econmod.2014.01.032
0264-9993/

government adopted a package of measures included in the so-called Energy Efficiency and Saving Intensification Plan (2008–2011), as part of which this reduction in speed limits was implemented.

Our goal is to analyze the impact of this temporary change in the Spanish speed limits, measured by road fatalities and fuel consumption, for the whole national road network. Although the speed limit reduction was valid only for dual carriageways and motorways, our aim is to determine its full impact, taking into account the consequent traffic transfer between different types of alternative roads (secondary). Changes in speed limits may have effects that extend beyond the roads that are affected, such as speeds being generalized (Richter et al., 2004) and traffic transferring to and police enforcement on other roads (Lave and Elias, 1994) which, in the opinion of these authors, might lead to an increase in top-end limits having a neutral or even positive effect on the number of road fatalities in the road network.

In order to isolate the impact of the provisional reduction in speed limits, we use a method based on advanced time series treatment, the Unobserved Component Model, of the discrete linear time transfer function type, with multiple explanatory variables. In the line of other preceding studies, such as Balkin and Ord (2001) in the U.S. and Johansson (1996) in Sweden, this methodology answers the need stated by authors such as Dee and Sela (2003) and Shafi and Gentilello (2007) of pursuing findings that control potential confounding factors and eliminate the biases that may be due to unobserved or specific aspects of traffic safety, such as other simultaneous policies implemented. For the purpose of comparison and as a benchmark, ARIMA models with exogenous variables are also included (Box et al., 1994).

The paper is structured in the following way: after this introduction, Section 2 lays out a brief review of literature on speed limit effects; Section 3 explains the empirical framework; the findings are stated and discussed in Section 4 and the conclusions and resulting policy implications are analyzed in Section 5. Finally, we include a methodological annex in Section 6, and the references.

2. Literature review

Since they became widespread at the beginning of the nineteen-seventies (Elvik and Vaa, 2004) speed limit strategies appear to have been linked not only to the goals of traffic safety, such as controlling speeding and reducing road accidents, but have also very frequently formed part of broader policies with environmental, health or economic purposes, such as reductions in fuel consumption for less foreign energy dependence during times of increased gasoline prices or reducing Greenhouse Gas (GHG) emissions, and road safety issues seem to have been afforded secondary importance. However, the relationship between speed limits and traffic safety has been widely addressed by researchers worldwide, especially in the U.S. (Albalate and Bel, 2012; Dee and Sela, 2003; Friedman et al., 2009; Lave, 1985; Retting and Teoh, 2008). Since the initial estimates obtained by Solomon (1964), there has been a degree of consensus on speed having a significant effect (with certain causality) on road safety, in the sense that both accident incidence and accident severity are expected to increase with higher speed limits (Ashenfelter and Greenstone, 2004).

How changes in speed limits affect actual driven speeds and the consequent estimation of their effects on road accidents is a controversial topic addressed from a wide range of focuses and approaches. Many of the studies examined the influence of absolute speed on accident rates (Kloeden et al., 2001), either at individual vehicle level or at average road section level (the Power Model by Nilsson, 1982, 2004 and its evaluations made by Elvik, 2009; Elvik et al., 2004; Hauer and Boneson, 2008 are well-known). Both types were founded on an exponential function and a power function between speed and accidents (prevalent in the literature) and recent validations have shown that the effect on rural roads is relatively greater than on urban roads (SWOV, 2012).

Other studies emphasized the influence of speed dispersion on the risk of a crash (with the first studies conducted by Cirillo (1968) and Solomon (1964), and modern reformulations by Kloeden et al. (2001) and Lave (1985)) finding that large speed differences between vehicles (speed variance) increase the likelihood of an accident. In addition, drivers driving much faster than the average driver have a higher accident risk ("variance kills", Dee and Sela, 2003); although it is not yet evident that this is also the case for the slower driver, and neither has any clear relationship been established to date to quantify the effect of speed differences and the crash involvement rate.

In general terms, the evidence seems to confirm the negative/positive impact of raising/decreasing the speed limits on average speed and consequently on road accidents. Research, such as Elvik et al.'s (2004) points to the average speed varying in the same direction as the change in the speed limit on roads affected by the change, although approximately 25% less in magnitude.

In conclusion, the exact relationship between speed and crash rate seems to depend on a large number of different factors and, as pointed out by authors like Ritchey and Nicholson-Crotty (2011, 331): "…despite years of research, there is still no clear consensus in the literature on the impact that speed limit laws have on traffic fatalities".

Neither does there seem to be any agreement on mechanisms for gasoline prices affecting speed limit compliance. The findings of Blomquist (1984), Goodwin et al. (2004) and Peltzman (1975) show that vehicle speeds decrease with higher gasoline prices. However, Burger and Kaffine (2009) have recently found the opposite relationship and rejected the hypothesis that drivers reduce speeds when gasoline prices are high. There are only a limited number of empirical studies on how speed limits specifically affect health, although some results obtained indirectly suggest that higher speed limits might have adverse health effects (Currie & Walker, 2011).

From a methodological point of view (see the meta-analyses and reviews by Aarts and Van Schagen (2006); Elvik et al. (2004); Finch et al. (1994); McCarthy (2001); and Wilmot and Khanal (1999)), existing research on speed limits generally employ before–after analysis, a case-control approach, univariate classification procedures, regression analysis or ARIMA time-series models. Multivariate models are rarely used. Consequently there is often a lack of correction for common statistical problems in time series (e.g., serial correlation).

3. Empirical framework

The variables used to evaluate the effect of the changes in speed limits in Spain (all measured on a monthly basis and are used on a logarithmic scale in later models, except binary type variables) can be divided into three groups (see Table 1).

A) Endogenous variables: fatalities in road accidents (Fatal in Table 1) and gasoline and diesel consumption for transport (Consumption). In order to use consistent time series that were as long as possible, we used the definition of deaths within the first 24 h after the accident, instead of the Vienna Convention definition (30 days after the accident). The available time series span from January 1995 to August 2012 (Source: Spanish National Statistics Institute, INE; and Spanish Road Traffic Directorate General, DGT).
B) Dummy exogenous variables: an ample set to estimate a number of intervention variables and outlier effects seen in the data. The most important, with their definitions, are:
   b.1) Speed: takes into account the change in speed limits on highways (from the 7th of March 2011 to the 30th of June 2011). Several options have been tried out empirically, but the final version is one step over the whole period with a value of 75% in the first month, in order to take into account the fact that change took place after the first week in March.

Table 1
Estimation results.

	Unobserved component models		ARIMA models	
	Fatal	Consumption	Fatal	Consumption
Speed	−0.091**	−0.017*	−0.099**	−0.017*
Price	−0.053**	−0.029***	−0.045**	−0.031***
ASI	2.027***	1.481***	1.862***	1.498***
Easter	0.018	0.008	0.003	0.008
Trading	−0.009***	0.006***	−0.008***	0.006***
Leap		0.030***		0.034***
PPS	−0.188***		−0.155***	
PPS denominator	−0.876***		−0.789***	
NOV2007 (Penal Code)	−0.233***		−0.191**	
DEC2007 (Penal Code)	−0.130***		−0.102***	
JAN2006	0.158**		0.183**	
SEP2000		0.078***		0.083***
OCT2000		−0.079***		−0.078***
Trend	1.16×10^{-5}	1.17×10^{-10}		
Slope	9.62×10^{-8}	3.94×10^{-8}		
Seasonal	0	1.32×10^{-7}		
Irregular	5.51×10^{-3}	2.23×10^{-4}		
MA1			−0.820***	−0.814***
MA12			−0.713***	−0.614***
Q(4)	6.073	4.075	4.569	7.268
Q(8)	12.698	6.635	8.077	12.583
Q(12)	14.734	9.455	14.328	16.563
Q(24)	20.390	16.290	19.561	21.728
Bera–Jarque	0.238	1.257	1.183	1.053
	(0.888)	(0.534)	(0.553)	(0.591)
H	0.761	0.982	0.992	0.996
	(0.278)	(0.944)	(0.976)	(0.986)
Reduction	40 fatalities	148,374 metric tons	44 fatalities	147,229 metric tons
	8.24%	1.55%	9.06%	1.58%

Items are described in Section 3: speed is a dummy that takes into account the analyzed change in Spanish speed limits; price is the price of gas consumption approximated by the Brent oil price in Euros; ASI is the Activity Synthetic Index used as an approximation of Spanish GDP; Easter is a dummy variable for the Spanish Holy Week; trading is a dummy for the number of trading days in a month; leap is a dummy variable to take into account the effect of 29-day Februaries; PPS and Penal Code are referred to two legal changes respectively: the Penalty Point System driving license (denominator when is modeled as a transitory change), and the Spanish Penal Code Reform (DEC2007 when it came into force and NOV2007 because its effects started to be felt earlier).
One, two and three asterisks indicate statistical significance at 10%, 5% and 1% levels, respectively. Trend, slope, seasonal and irregular stand for disturbance variances corresponding to each unobserved component. Q(p) are the Ljung-Box Q statistics for p lags. Bera–Jarque is a normality test (P-values in brackets). H is a variance ratio homoscedasticity test that compares the variance in the first and third parts of the sample (P-values in brackets).

b.2) 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. We have included it because it is a moving festival between March and April, and the proportion of days of the holidays in each month, changes along the years. Accordingly, the moving Easter festival variable is defined by assigning different weights to the days in question depending on the expected traffic density (these weights must add up to one). Maximum weights are assigned to Friday, Palm Sunday, Wednesday and Easter Sunday. Medium weights are assigned to the Saturday before Palm Sunday and Holy Thursday. Weights of zero are assigned to all other days.

b.3) Trading: the number of trading days in a month in excess of weekend days, assuming that in each week there should be 5 working days and two days at the weekend. For each month this variable takes a value that equals the number of working days minus 2.5 times the weekend days.

b.4) Leap: dummy variable to take into account the effect of 29-day Februaries.

b.5) Two legal changes: firstly, the introduction of the Penalty Points driving license system in 2006 (PPS; Castillo-Manzano et al., 2010), which may be modeled as a transitory change in accordance with Butler et al. (2006) and Farchi et al. (2007) on the Irish and Italian cases, respectively and Castillo-Manzano and Castro-Nuño (2012) for a worldwide meta-analysis. As the effect is considered transitory, a denominator is included in the model (see an explanation around Eq. (4) below; PPS denominator in Table 1).
Secondly, a dummy variable has been included to estimate the effects of the 2007 Spanish Penal Code reform (DEC2007). Although the reform came into effect in December 2007, its effects started to be felt earlier, in November 2007 (NOV2007), given the huge impact that the passing of the Bill through Parliament had in the media (Castillo-Manzano et al., 2011).

b.6) There are other outliers, often related to bad weather conditions (like JAN06) and other causes that have been detected by statistical tools (SEP2000 and OCT2000). In the last two cases this was perceived as being due to the truck drivers' and retailers' strike of October, 2000. The procedure followed to look for outliers of this type consisted of selecting the residuals out of four times standard deviation and including them as potential candidates in the models under different specifications (Level Shift, LS; Transitory Change, TC, as explained in the annex, or additive outliers, AO, for sudden changes that affect just one observation). The outliers are included in final models with the specification that provides the best fit when they result statistically significant.

C) Other exogenous variables: we assume that gasoline and diesel consumption and the number of fatalities depend on a set of common causes, of which the most important are gasoline prices (see e.g. Álvarez et al., 2011 for the impact of oil price changes on Spain) and the level of economic activity (economic cycle, see e.g., Castillo-Manzano et al., 2010; García-Ferrer et al., 2007). In short, see Albalate (2011) on the effect of this price on road safety outputs.

The price of gas consumption we use in this paper is approximated by the Brent oil price measured in Euros (Price in Table 1). The most frequent fuel price variable used by researchers in relation to traffic safety is the retail price for regular-grade gasoline/diesel prices (see Chi et al. (2010) for a review). In our case, although some statistics on gasoline and diesel consumption prices for transport were available, we preferred Brent prices because they represented a very good approximation and mainly because the time series is longer (see Fig. 1, beware that the correlation between Brent prices and gasoline and diesel prices are 0.97 and 0.98, respectively). Introducing Brent prices directly in the models, we eliminate two potential problems, namely: i) the multicollinearity induced by two price input variables in the same model, and ii) possible endogeneity between consumption and prices of gasoline/diesel, that could be avoided by introducing instrumental variable estimation in which an exceptional instrumental candidate would be, precisely, the Brent price. Then our model could be considered close to instrumental variable estimation.

Spanish economic cycle is approximated by Gross Domestic Product (GDP) measured by the Activity Synthetic Index (ASI) estimated by the Spanish Ministry of the Economy (http://serviciosweb.meh.es/apps/dgpe/default.aspx). Through this we intend to capture the entire change in road traffic in Spain. Evidently, we know that the best variable would be e.g., number of vehicles/km traveled, but as the appropriate monthly data are not available for our timeframe we have selected the GDP, which allows both individual traffic movements and freight road transport to be considered. Nevertheless, one of the most significant obstacles for short-term forecasts is the frequency with which the Spanish GDP is published (annually/quarterly). Therefore, we use the ASI index which is published monthly and, as the Spanish Ministry of Finance recognizes, shows a high correlation with the GDP and is a good indicator for seeing quick changes in the cycle.

Other macro-economic indicators usually used as proxies for traffic movements are: revenue, unemployment rate by e.g., Hermans et al. (2006), Holló et al. (2010), and Wiklund et al. (2012); disposable income (Neumayer, 2004); the index of industrial production (e.g., García-Ferrer et al., 2007 for Spain); GDP or GDP per capita (Noland, 2005). As Bergel-Hayat et al. (2013) explain, most of these use annual data and GDP might be at least a partial explanation for changes in road safety and better than other proxies.

Both endogenous variables (road fatalities and fuel consumption) are regarding to data from the entire Spanish road network, because as we have said, we want to capture the full impact of the temporary speed limit reduction. This circumstance is a constraint on the consideration of other exogenous variables (enforcement through sanctions or law violations, vehicle-km traveled) because there are no available monthly time-series suitable for our time-span. This limitation has been solved in some cases and we have used variables such as ASI (described above) as a proxy of traffic movements. Nevertheless, our study uses a much wider set of exogenous variables than previous studies on this topic, and we have also followed a strict statistical procedure to detect outliers (as we have explained) which adds rigor regarding any possible omitted variables.

The variable profile can be seen in Fig. 1. Vertical lines have been added in order to locate the narrow period of time where speed limit change took place. The time series for gasoline/diesel consumption and fatalities are much longer than the ASI variable. This will impose a constraint on the models where the latter variable is included, but the said constraint does not spoil the analysis since the main effect we want to measure is at the end of the sample.

Fig. 1 shows the relationship between consumption/prices of gasoline and diesel, and the level of economic activity; and also the reduction in the level of fatalities in Spain during the last three decades. The severity of the current economic crisis can also be clearly seen in Fig. 1, with a major drop in the ASI in 2008. Despite subsequently recovering slightly, it eventually flat lined.

Fig. 2 shows that the overall mean value of the number of fatalities per accident with fatalities reduces from a level value of 1.2 deaths per accident to less than 1.1.

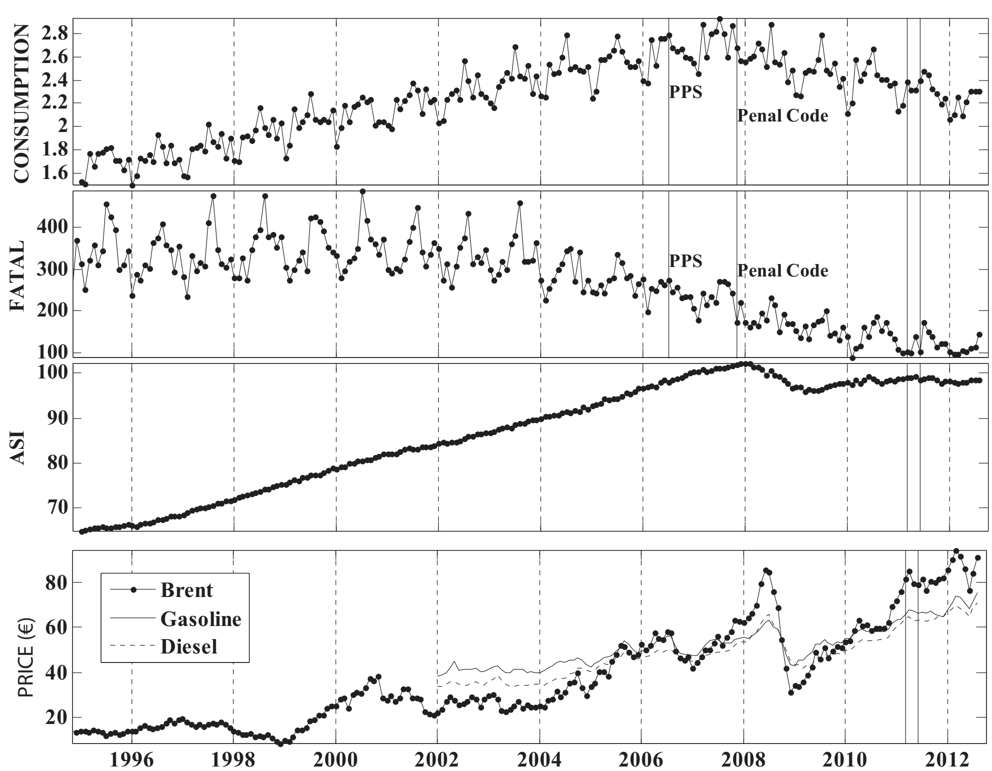

Fig. 1. Gasoline and diesel consumption in million metric tons in Spain (upper panel), number of road fatalities. Activity Synthetic Index and Brent oil price in Euros (lower panel). In the bottom panel gasoline and diesel prices are also shown for comparison purposes. Vertical solid lines mark the period during which speed limit modification took place. Vertical lines mark the time the Penalty Point System driving license came into force and the reform of the Penal Code.

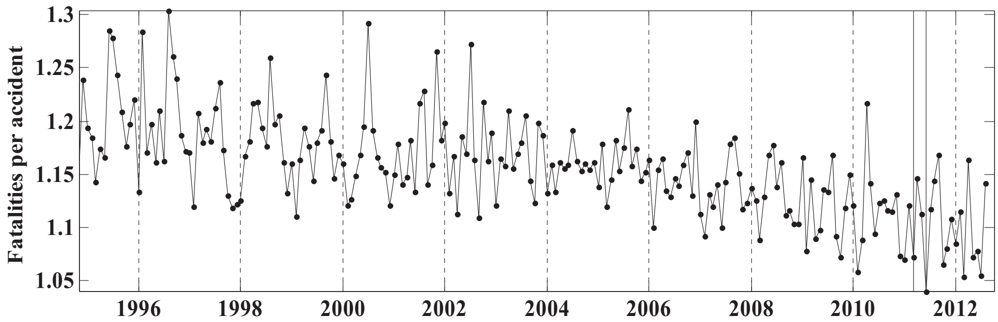

Fig. 2. Mean number of fatalities per accident with fatalities.

The models used in this paper are of the multivariate Unobserved Component (UC) Model class that allow for a time series to be broken down into economically meaningful, though unobserved, components, see Eq. (1).

$$z_t = T_t + S_t + \mathbf{DI}_t + v_t \tag{1}$$

where z_t, T_t, S_t and v_t denote the endogenous time series and trend, seasonal and irregular components, respectively. $\mathbf{DI}_t$ measures the effects of explanatory variables in matrix $\mathbf{I}_t$ through a linear regression model.

One appropriate set up in which the UC analysis may be carried out is the State Space (SS) framework, in which the dynamic system is split into two types of equations, i.e., State and Observation equations. Discrete-time, stochastic State Equations reflect all the dynamic behaviors of the system by relating the current value of the states to their past values as well as to the deterministic and stochastic inputs, while Observation Equations define how the state variables are related to the observed data (as a matter of fact, Eq. (1) is the observation equation of the UC model, see below). There are a number of different formulations of these vector–matrix equations, but the one favored here is as follows:

$$\begin{cases} \mathbf{x}_{t+1} = \Phi\mathbf{x}_t + \Gamma\mathbf{I}_t + \mathbf{w}_t : & \text{State Equations} \\ z_t = \mathbf{H}\mathbf{x}_t + \mathbf{DI}_t + v_t : & \text{Observation Equations} \end{cases} \tag{2}$$

where $\mathbf{x}_t$ is an n dimensional stochastic state vector; $\mathbf{I}_t$ is a k dimensional vector of dummy exogenous variables; $\mathbf{w}_t$ and v_t are an n and scalar dimensional vectors of Gaussian system disturbances, i.e., zero mean white noise inputs with covariance matrix $\mathbf{Q}$ and $\mathbf{R}$ and independent of each other; and Φ, Γ, $\mathbf{H}$ and $\mathbf{D}$ are the so called system matrices, some elements of which are known while others need to be estimated.

Given model (1), 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 as it minimizes the mean squared errors (MSE). An algorithm that is used in parallel with the KF but which is not as well-known in certain contexts is the fixed interval smoothing (FIS) algorithm, which allows for an operation similar to that of the KF but with a different information set.

The estimation of the unknown parameters in the system matrices Φ, Γ, $\mathbf{H}$, $\mathbf{D}$, $\mathbf{Q}$ and $\mathbf{R}$ may be tackled in several ways. Maximum likelihood (ML) is the most common because of its good theoretical properties. Under the Gaussian assumption, the log-likelihood function can be computed using the KF via 'prediction error decomposition' (see details in Harvey, 1989; Pedregal and Young, 2002).

The UC model in Eq. (1) fits naturally in the SS framework in Eq. (2), since the observation equations show the breakdown of the time series into its components, and the state equations specify the component dynamics. A description of the full SS system for a simplified case with just one input variable and some further technical details are discussed in the Methodological annex. This methodology is implemented in the MATLAB™ platform, in the SSpace toolbox (Pedregal and Taylor, 2012), which will subsequently be used for model estimation.

4. Results and discussion

Two UC models are estimated in order to measure the effect of speed limit reduction, one for each endogenous variable, namely fatalities (labeled as Fatal in Table 1) and gasoline and diesel consumption (Consumption). Due to the sample data restriction imposed by the ASI variable, the sample estimation starts in January 1995. As a benchmark, ARIMA models with the same structure as the UC models are also estimated in Table 1 in order to enable comparisons and confirm the robustness of the results. Standard identification procedures suggest an airline model (i.e., ARIMA$(0,1,1)\times(0,1,1)_{12}$, with estimated parameters in Table 1 named *MA1* and *MA12*), see Box et al. (1994). One simple way of looking at ARIMA models in the present context is to consider the ARIMA as a replacement for $T_t + S_t + v_t$ in Eq. (1).

Since both models include the effect of speed limit reduction on the endogenous variables, it is possible to rebuild the time series as would have been the case if the change had not taken place. In this way, it is possible to calculate the fatalities and consumption saved by the measure.

Several conclusions may be drawn from the models in Table 1:

- The results are robust to the methodology used, both the UC and the ARIMA models. Differences between models for the same time series are negligible, indicating that the results are very robust. One advantage of the UC models, however, is that unobserved components like trends and seasonals are estimated as an additional product of the process (see comments below and Fig. 4).
- There is a statistically significant effect of speed limits on the number of fatalities (at the 5% significance level), and also on gasoline consumption (but at the 10% significance level). However, the magnitude of the effect judged by the number of fatalities or metric tons of gasoline saved does not seem exceedingly great. In fact, regardless of statistical significance, point estimates imply that 40 fatalities (8.2% of fatalities in 4 months, 44 fatalities and 9.06% with ARIMA models) and 148,374 metric tons (1.55%,[2] 151,229 and 1.58%) were saved. Based on models in Table 1 and simulating the speed limit extended to the whole year, the effect would have been reductions of 137 fatalities and 500,245 metric tons. The differences between the two magnitudes are so large due to the first being estimated on the basis of total deaths on highways alone, while the second is with respect to overall consumption, both on highways and in urban areas, where the number of deaths is significantly lower. The effect can be examined in greater detail in Fig. 3.

[2] Since the model is log-linear with respect to the dummy variables, when the said variable is binary (only 0 s and 1 s) the percentage should be calculated as $[\exp(\textit{coefficient}) - 1]\times 100\,\%$. In the case of gasoline consumption this would mean a reduction of $[\exp(-0.017) - 1]\times 100\,\% = -1.69\,\%$. The difference from the 1.55% reported here is due to the first month, when the value of the dummy variable is not 1, but 0.75.

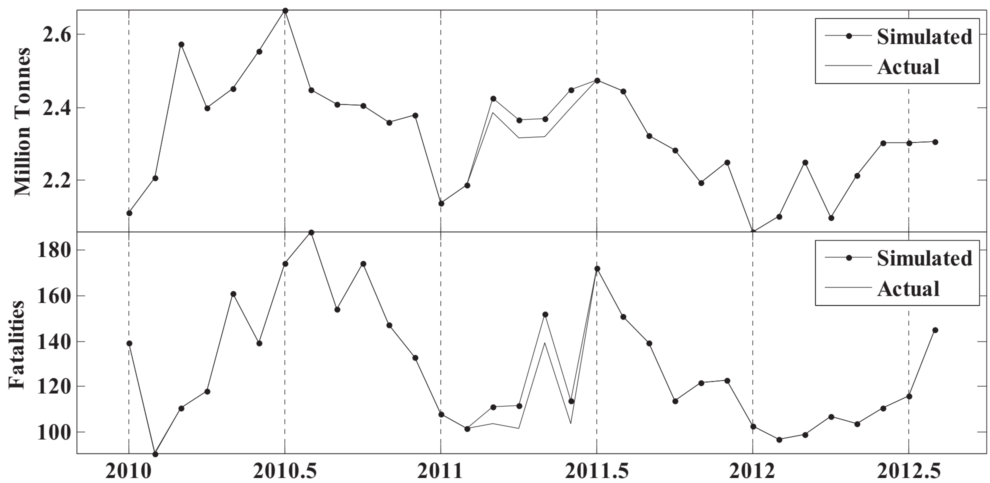

Fig. 3. Effect of speed limit reduction on fuel consumption and traffic fatalities measured by UC models.

- The oil price had a significant negative impact on consumption and fatalities. The level of economic activity had a greater effect on both endogenous variables. Their positive signs and high absolute values in the case of fatalities indicate that negative effects prevail over positive effects due to the greater numbers of journeys made during times of expansion in the period under study and, therefore, drivers being exposed to greater risks.
- One point that may seem somewhat surprising is that the Easter effect is not significant, contrary to the usual result reported in the literature (see e.g., Castillo-Manzano et al., 2010; García-Ferrer et al., 2007). Univariate models[3] of any kind with longer time series show that Easter is statistically significant, but that this effect disappears with shorter time series. This implies that this effect has lost its strength in recent times, showing a change of behavior during Easter holidays; perhaps more trips by low-cost carrier and fewer trips by car.
- The effect of trading days on consumption is positive, but negative on fatalities. In other words, the gasoline consumption is logically higher for weekdays because more trips are taken for business, work, and school…, but driving becomes more dangerous on weekends (more driving under influence of alcohol or drugs…), such as is shown by studies as Kanaan et al. (2009) for a specifically Spanish case.
- The legal changes considered in this study, namely the implementation of the Penalty Point System driving license in 2006 and the 2007 Penal Code reform, were only effective for fatalities, but clearly did not produce any detectable change in consumption.
- Both time series have a remarkably stable seasonal profile (see Fig. 4). This is coherent with the 0 coefficient obtained in Table 1 for the seasonal component disturbance, implying that this component is deterministic (after removing all the effects that may affect it, such as Easter, Trading… even the exogenous variables).
- From a statistical point-of-view, the models are correct, since the innovations do not show any serial dependence, gaussianity, or heteroscedasticity problems.

The estimated unobserved components for consumption are shown in Fig. 4 by way of example.

5. Conclusions

Faced with a specific issue, the high fuel prices in spring 2011 that were due to the political instability caused by the so-called “Arab Spring”, the Spanish Government implemented a serie of short-term measures as part of the National Energy Efficiency and Saving Plan (2008–2011). One of these measures was the temporary reduction of the maximum speed limits allowed on dual carriageways and motorways from 120 km/h to 110 km/h from the 7th of March 2011 to the 30th of June 2011.

Our analysis shows that this measure had a positive effect on the main variable it was intended to impact on: gasoline consumption, with an estimated 1.55% reduction, but that this was of little statistical significance (at 10%). This transitory energy saving strategy also managed to reduce the total number of deaths on highways in road accidents by 8%. However, this effect fell to 6.5% when calculated against the total number of road deaths on both highways and in urban areas during the period.

Our estimations differ from the forecasts given by the Spanish Government in the media: fuel reductions of 15% for gasoline and 11% for diesel were expected. Our conclusions are also different from IRTAD (2012) before–after analysis findings, which estimated an 8.4% fuel saving and a 30% reduction in the number of fatalities. A large number of these discrepancies could simply be the result of these other estimations mistakenly attributing part of the reduction occurred in Spain during the period under study to the reduction in the speed limit when they are in fact attributable simply to the effects of mobility reduction caused by the grave economic crisis. As a result of this, there was a noticeable reduction in fuel consumption and road fatalities, as Bel and Rosell (2012) stated was the case for air pollution in the Region of Catalonia. Moreover, both fuel consumption and fatalities were still reducing after the speed limit was released in June 2011, when the level of economic activity was leveled out and fuel prices were increasing (see Fig. 1).

In other respects, the steep fall in mobility due to the crisis can also be the explanation for our obtaining lower percentages than those found by prior researchers, such as Elvik and Vaa (2004), who, in their meta-analysis, determined a mean reduction of 15% in fatal accidents as a result of a reduction in maximum permitted speed limits.

Fig. 5 shows how far the government's goal was from a sensible assumption, as well as how optimistic estimates were reported by IRTAD.

In short, these results could be potentially biased by the real effects on overall mobility of the economic recession that began in 2008, because little research has been done that unequivocally explains this phenomenon with only 4–5 years of available observations. We think that the drop in the total number of traffic fatalities might be partially explained by the economic downturn but with an ambiguous net effect, since the reduction in crashes is the product of many different factors, including, but not limited to, the economic cycle (García-Ferrer et al., 2007), improved vehicle technology, shifts in driver behavior with respect to vehicle purchase, operating the vehicles and driving to improve fuel economy, progress in road infrastructure and medical care,

[3] Available from the authors upon request.

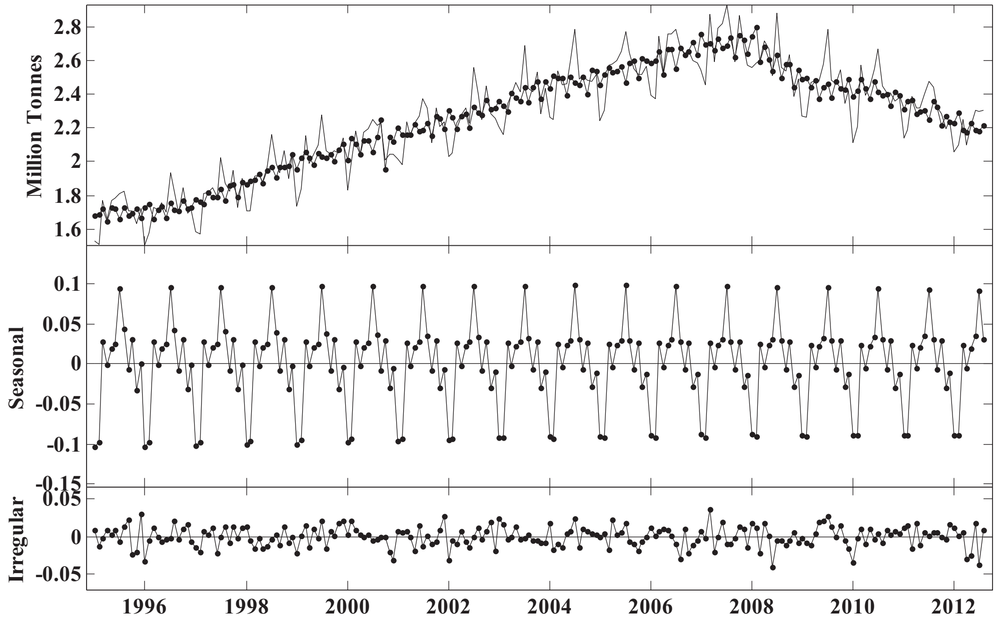

Fig. 4. Unobserved components of the fuel consumption model.

road safety policies, policing and law enforcement, etc. However, as Bergel-Hayat et al. (2013) state, this negative relationship is not obvious when considering short-term changes (with e.g., monthly data, as is our case), as the short-term changes might be detecting a different type of relationship between fatalities and economic growth. So we believe that much more research is necessary in the coming years. For the same reasons, the same approach could be applied in the case of fuel consumption (see Esteve and Tamarit, 2012).

If these supposed positive effects could be compared to the hypothetical costs of the measure, it is difficult to state that the bottom-line is clearly positive. The following should be highlighted among the many costs: those that arise from changing all the highway signage twice (which, according to the only estimations available in the press amount to 250,000 Euros for the stickers used on the 6000 speed limit signs that were affected); adapting the whole traffic fine and penalty system; expenditure resulting from advertising the measure and the loss of economic efficiency caused by slowing down journeys made by users.

To all this must be added to the generation of certain situations due to the fact that the measure was only applied to motorways. Given the economic crisis, many toll motorways, especially new ones (such as some in the arterial network around Madrid) saw reductions in their use to the point that some of the companies managing them went bankrupt. On many occasions drivers were forced to keep their speed to 110 km/h on new, half-empty roads.

In summary, the lessons that can be taken from the Spanish case indicate that applying such a measure as this for such a short period in time may obtain limited, although not insignificant, results in terms of lives and energy consumption saved. Nevertheless, it seems that long-term measures, which are generally incompatible with the haste required by the political cycle, are, unfortunately, those that should really be the basis of a true National Energy Efficiency and Saving Plan. In this context, it might be more appropriate to discuss the permanent implementation of Variable Speed Limits (VSL) reflecting road design characteristics and environment and traffic compositions, as widely used in the United States and safe European countries, such as Germany or United Kingdom.

Also, if the aims are to save fuel while driving, to reduce Spain's innate energy dependency and rationalize energy consumption, it might be more efficient to implement other alternative measures based on investments in energy saving in the sense of Zanin and Marra (2012), or that encourage road users to adopt a real structural

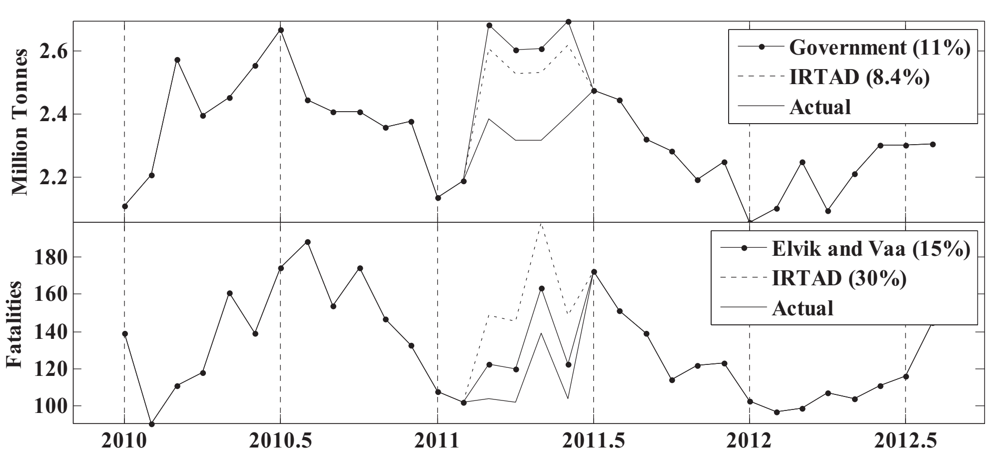

Fig. 5. Spanish government's goal and alternative estimates.

change in their behavior, such as stimulating the replacement of older vehicles on the road and their proper maintenance, and providing incentives for the use of electric vehicles.

6. Methodological annex

This annex shows a particular case of model (2) with the purpose of providing a clearer illustration of how the general model is set up in a State Space form. Eq. (A.1) includes a trend model in the first block, a trigonometric seasonal component in the second block and a single regression term in the third (see Harvey, 1989; Pedregal and Young, 2002).

$$\mathbf{x}_{t+1} = \begin{bmatrix} T \\ F \\ S_1 \\ S_1^* \\ S_2 \\ \vdots \\ f_1 \end{bmatrix}_{t+1} = \left[\begin{array}{cc|cccccc|c} 1 & 1 & 0 & 0 & 0 & \cdots & 0 \\ 0 & 1 & 0 & 0 & 0 & \cdots & 0 \\ \hline 0 & 0 & \cos\omega_1 & \sin\omega_1 & 0 & \cdots & 0 \\ 0 & 0 & -\sin\omega_1 & \cos\omega_1 & 0 & \cdots & 0 \\ 0 & 0 & 0 & 0 & \cos\omega_2 & \cdots & 0 \\ \vdots & \vdots & \vdots & \vdots & \vdots & \ddots & \vdots \\ \hline 0 & 0 & 0 & 0 & 0 & \cdots & -a_1 \end{array}\right] \mathbf{x}_t + \begin{bmatrix} 0 \\ 0 \\ \hline 0 \\ 0 \\ 0 \\ \vdots \\ \hline -a_1 b_1 \end{bmatrix} I_t + \begin{bmatrix} w_0 \\ w_0^* \\ w_1 \\ w_1^* \\ w_2 \\ \vdots \\ 0_1 \end{bmatrix}_t \tag{A.1}$$

$$z_t = T_t + S_t + f(\mathbf{I}_t) + v_t = [1 \; 0 | 1 \; 0 \; 1 \; 0 \cdots | 1]\mathbf{x}_t + b_1 I_t + v_t.$$

A comparison of systems (2) and (A.1) enables system matrices to be identified. New elements not necessary in the general formulation (2) appear in Eq. (A.1): F_t is the trend 'slope' or trend rate of change; S_{it} ($i = 1,2,\ldots, P/2$) are the seasonal harmonics of frequencies $\omega_i = 2\pi i/P$, whereby $S_t = \sum_i^{P/2} S_{it}$, with P being the fundamental frequency (12 observations per year in the case of monthly data with annual seasonality) and S_{it}^* (i=1,2,…,6) are additional blocks of states necessary for the definition of seasonal terms.

Transfer Function (TF) effect specification deserves further comment. All TFs considered here are of order one, since only outlier corrections are considered. The general formulation of a single TF is given in Eq. (A.2), where B is the lag operator, so that $B^m x_t = x_{t-m}$

$$f_{pt} = \frac{b_p}{\left(1 + a_p B\right)} I_{pt}. \tag{A.2}$$

For Transitory Change outliers (TC), $a_p < 0$, i.e., the effect disappears after some time. Additive outliers (AO) imply $a_p = 0$, i.e., the effect is observed in just one observation. Finally, Level Shifts (LS) means that $a_p = 1$, i.e., the effect is permanent.

The extension of system (A.2) to accommodate additional TF terms or linear regression terms is straightforward.

Acknowledgments

The authors would like to express their gratitude to Dirección General de Tráfico (Spanish Road Traffic Directorate General) for the human and financial resources that it provided for this study (grant reference: 0100DGT21354). The authors are also grateful to the editor of the journal, Prof. Stephen G. Hall, the Special Issue Editors, Prof. Lola Gadea and Cecilio Tamarit and the anonymous reviewers for their helpful comments.

References

Aarts, L., Van Schagen, I., 2006. Driving speed and the risk of road crashes: a review. Accid. Anal. Prev. 38, 215–224.
Afukaar, F.K., 2003. Speed control in developing countries: issues, challenges and opportunities in reducing road traffic injuries. Inj. Control. Saf. Promot. 10, 77–81.
Albalate, D., 2011. Shifting death to their alternatives: The case of toll motorways. J. Transp. Econ. Policy 45, 453–479.
Albalate, D., Bel, G., 2012. Speed limits laws in America: the role of geography, mobility and ideology. Transp. Res. A 46, 337–347.
Álvarez, L.J., Hurtado, S., Sánchez, I., Thomas, C., 2011. The impact of oil price changes on Spanish and euro area consumer price inflation. Econ. Model. 28, 422–431.
Ashenfelter, O., Greenstone, M., 2004. Using mandated speed limits to measure the value of a statistical life. J. Polit. Econ. 112, 226–267.
Balkin, S., Ord, J.K., 2001. Assessing the impact of speed-limit increases on fatal interstate crashes. J. Transp. Stat. 4, 1–26.
Bel, G., Rosell, J., 2012. Policy success or economic slowdown? Effects of the 80 km/h speed limit on air pollution in the Barcelona metropolitan area. Working Paper. , no 663. Fundación Cajas de Ahorro (FUNCAS), Spain.
Bergel-Hayat, R., Christoforou, Z., Ferriere, S., 2013. The impact of the economic crisis on road mortality: an exploratory approach for some countries in Europe. European Transport Conference. Association for European Transport (AET), Frankfurt.
Blomquist, G., 1984. The 55 m.p.h. speed limit and gasoline consumption. Resour. Energy 6, 21–39.
Bolderdijk, J.W., Knockaert, J., Steg, E.M., Verhoef, E.T., 2011. Effects of pay-as-you-drive vehicle insurance on young drivers' speed choice. Accid. Anal. Prev. 43, 1181–1186.
Box, G.E.P., Jenkins, G.M., Reinsel, G.C., 1994. Time Series Analysis Forecasting and Control, 3rd edition. Prentice-Hall, Englewood Cliffs.
Burger, N.E., Kaffine, D.T., 2009. Gas prices, traffic and freeway speeds in Los Angeles. Rev. Econ. Stat. 91, 652–657.
Butler, J.S., Burke, J.P., Healy, D.G., Stephens, M.M., McManus, F., McCormack, D., 2006. Trends in RTA related spinal injuries: the post penalty points era. Ir. J. Med. Sci. 175, 20–23.
Castillo-Manzano, 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, 1310–1319.
Castillo-Manzano, J.I., Castro-Nuño, M., Pedregal, D.J., 2011. Can fear of going to jail bring down the number of road accidents? The Spanish experience. J. Saf. Res. 42, 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. Transp. Policy 21, 191–201.
Chi, G., Cosby, A., Quddus, M., Gilbert, P., Levinson, D., 2010. Gasoline prices and traffic safety in Mississippi. J. Saf. Res. 41 (6), 493–500.
Cirillo, J.A., 1968. Interstate system accident research study II. Interim report II. Public Roads 35, 71–75.
Currie, J., Walker, R., 2011. Traffic congestion and infant health: evidence from EZPass. Am. Econ. J. Appl. Econ. 3, 65–90.
Dee, T.S., Sela, R.J., 2003. The fatality effects of highway speed limits by gender and age. Econ. Lett. 79, 401–408.
ECMT (European Conference of Ministers of Transport), 2006. Speed Management. Transport Research Centre of OECD. OECD Publishing, France.
Elvik, R., 2009. The power model of the relationship between speed and road safety: update and new analyses. TOI ReportInstitute of Transport Economics, Oslo. Norway.
Elvik, R., 2010. Why some road safety problems are more difficult to solve than others. Accid. Anal. Prev. 42, 1089–1096.
Elvik, R., 2012. Speed limits, enforcement and health consequences. Annu. Rev. Public Health 33, 225–238.
Elvik, R., Vaa, T., 2004. The Handbook of Road Safety Measures. Elsevier Science, Amsterdam.
Elvik, R., Christensen, P., Amundsen, A., 2004. Speed and road accidents. An evaluation of the power model. TOI ReportInstitute of Transport Economics, Oslo. Norway.
Esteve, V., Tamarit, C., 2012. Is there an environmental Kuznets curve for Spain? Fresh evidence from old data. Econ. Model. 29, 2696–2703.
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.
Feng Ng, Ch., Small, K.A., 2012. Trade-offs among free-flow speed, capacity, cost, and environmental footprint in highway design. Transportation. http://dx.doi.org/10.1007/s11116-012-9395-8.
Finch, D.J., Kompfner, P., Lockwood, C.R., Maycock, G., 1994. Speed, speed limits and crashes. Project Record S211G/RB/Project Report PR 58. Transport Research Laboratory TRL, Crowthorne, Berkshire. UK.
Friedman, L.S., Hedeker, D., Richter, E., 2009. Long-term effects of repealing the national maximum speed limit in the United States. Am. J. Public Health 99, 1626–1631.
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.
Goodwin, P., Dargay, J., Hanly, M., 2004. Elasticities of road traffic and fuel consumption with respect to price and income: a review. Transp. Rev. 24, 275–292.
GRSP (Global Road Safety Partnership), 2008. Speed Management: A Road Safety Manual for Decision-Makers and Practitioners (Geneva. Switzerland).
Haglund, M., Åberg, L., 2000. Speed choice in relation to speed limit and influences from other drivers. Transp. Res. F 3, 39–51.
Harvey, C., 1989. Forecasting Structural Time Series Models and the Kalman Filter. Cambridge University Press, Cambridge (Cambridge).
Hauer, E., Boneson, J.A., 2008. An empirical examination of the relationship between speed and road accidents. In: Harkey, D.L., et al. (Eds.), Accident Modification Factors for Traffic Engineering and ITS Improvements. Transportation Research Board (Report NCHRP-617).
Hermans, E., Wets, G., Van Den Bossche, F., 2006. Frequency and severity of Belgian road traffic accidents studied by state-space methods. J. Transp. Stat. 9, 63–75.

Holló, P., Eksler, V., Zukowska, J., 2010. Road safety performance indicators and their explanatory value: a critical view based on the experience of Central European countries. Saf. Sci. 48 (9), 1142–1150.
IRTAD (International Road Traffic Accidents Database), 2012. Annual Report 2011. OECD. ITF.
Johansson, P., 1996. Speed limitations and motorway casualties: a time series count data regression approach. Accid. Anal. Prev. 28, 73–87.
Jørgensen, F., Polak, J., 1993. The effect of personal characteristics on drivers' speed selection: an economic approach. J. Transp. Econ. Policy 27, 237–252.
Kalman, R.E., 1960. A new approach to linear filtering and prediction problems. ASME Trans. J. Basic Eng. 83, 95–108 (D).
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. Legal Med. 11, S333–S336.
Kloeden, C.N., Ponte, G., McLean, A.J., 2001. Travelling speed and the risk of crash involvement on rural roads. Report CR 204Australian Transport Safety Bureau ATSB, Civic Square, ACT.
Kremers, H., Nijkamp, P., Rietveld, P., 2002. A meta-analysis of price elasticities of transport demand in a general equilibrium framework. Econ. Model. 19, 463–485.
Lave, C., 1985. Speeding, coordination, and the 55 mph limit. Am. Econ. Rev. 75, 1159–1164.
Lave, C., Elias, P., 1994. Did the 65 mph speed limit save lives? Accid. Anal. Prev. 26, 49–62.
McCarthy, P., 2001. Effect of speed limits on speed distributions and highway safety: a survey of recent literature. Transp. Rev. 21, 31–50.
Metz, D., 2008. The myth of travel time saving. Transp. Rev. 28, 321–336.
Neumayer, E., 2004. Recessions lower (some) mortality rates: evidence from Germany. Soc. Sci. Med. 58, 1037–1047.
Nilsson, G., 1982. The effects of speed limits on traffic accidents in Sweden. Proceedings of the International Symposium on the Effects of Speed Limits on Traffic Accidents and Transport Energy Use, Dublin.
Nilsson, G., 2004. Traffic safety dimensions and the power model to describe the effect of speed on safety. Lund Bulletin, 221Lund Institute of Technology, Lund. Sweden.
Noland, R.B., 2005. Fuel economy and traffic fatalities: multivariate analysis of international data. Energy Policy 33, 2183–2190.
Pedregal, D.J., Taylor, C.J., 2012. SSpace: a flexible and general state space toolbox for MATLAB. In: Wang, L., Garnier, H. (Eds.), System Identification, Environmental Modelling, and Control System Design. Springer Verlag, London.
Pedregal, D.J., Young, P.C., 2002. Statistical approaches to modelling and forecasting time series. In: Clements, M.P., Hendry, D.F. (Eds.), A Companion to Economic Forecasting. Oxford Blackwell, pp. 69–104.
Peltzman, S., 1975. The effects of automobile safety regulations. J. Polit. Econ. 75, 677–725.
Retting, R.A., Teoh, E.R., 2008. Traffic speeds on interstates and freeways 10 years after repeal of national maximum speed limit. Traffic Inj. Prev. 9, 119–124.
Richter, E.D., Barach, P., Friedman, L., Krikler, S., Israeli, A., 2004. Raised speed limits, speed spillover, case-fatality rates, and road deaths in Israel: a 5-year follow-up. Am. J. Public Health 94, 568–574.
Ritchey, M., Nicholson-Crotty, S., 2011. Deterrence theory and the implementation of speed limits in the American States. Policy Stud. J. 39, 329–346.
Shafi, S., Gentilello, L., 2007. A nationwide speed limit $\leq$ 65 miles per hour will save thousands of lives. Am. J. Surg. 193, 719–722.
Solomon, D., 1964. Accidents on Main Rural Highways Related to Speed, Driver and Vehicle. Bureau of Public Roads, U.S. Department of Commerce, Washington D.C. U.S.
SWOV, 2012. The relationship between speed and crashes. Fact Sheet of April (Leidschendam, The Netherlands).
Wegman, F., Aarts, L. (Eds.), 2006. Advancing Sustainable Safety; National Road Safety Outlook for 2005–2020. SWOV, Leidschendam. The Netherlands.
Wiklund, M., Simonsson, L., Forsman, Å., 2012. Traffic safety and economic fluctuation: long-term and short-term analyses and a literature survey. Rapport 704AVTI The Swedish Road Administration, Sweden.
Wilmot, Ch.G., Khanal, M., 1999. Effect of speed limits on speed and safety: a review. Transp. Rev. 19, 315–329.
Zanin, L., Marra, G., 2012. Assessing the functional relationship between CO_2 emissions and economic development using an additive mixed model approach. Econ. Model. 29, 1328–1337.