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THE SPEED LIMITS DEBATE: IS EFFECTIVE A TEMPORARY CHANGE? THE CASE OF SPAIN.

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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. The costs associated with this temporary change seem to explain the discrepancies between these estimates and the forecasts that initially held the Spanish government.

Keywords: Speed Management Policy, speed limits, road safety, fuel consumption, Unobserved Components Models.

JEL Codes: C320, I180, R410.

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1. INTRODUCTION.

Over the past 50 years, citizens in motorized countries have benefited from the manufacture of vehicles capable of ever increasing speeds (ECMT, 2006). 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 (GRSP, 2008); this, 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, uncontrolled urban growth and, above all, road traffic accidents (with negative effects on casualties and economic damage) as pointed out by ECMT (2006). Nowadays, *excessive* and *inappropriate* speed¹ is one of the biggest road safety problems (Elvik, 2010b; Wegman & Aarts, 2006), for both rich and highly motorized countries (Elvik, 2010a) and developing countries (Afukaar, 2003). However, 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 (2010a), "*one of the road safety problems most resistant to change*".

Most governments regard speeding as a priority in the context of road safety strategies, such as *Vision Zero* in Sweden, *Sustainable Safety* in the Netherlands and *Safe System* in Australia, where a range of tools are applied for developing an effective *Speed Management Policy* (GRSP, 2008). However, the key tool for speed management, and that which has been most widely addressed in the literature for decades, is *speed limits* (Ritchey & Nicholson-Crotty, 2011). And, despite the fact that there are some roads in motorized countries where no speed limits (i.e., German Autobahns) are in force, 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 (in Elvik, 2012) and may be strongly influenced by how fast others are driving (Haglund & Åberg, 2000).

Following ERSO (2006) and SWOV (2010), speed limits must also be *safe* and *credible*, reflecting the road design characteristics and environment and traffic composition. A number of research studies have been carried out on the implementation and effectiveness of the so-called Variable Speed Limits (VSL) or Dynamic Speed Limits, widely used in United States

¹ According to ECMT (2006) terminology, we can define *excessive speed* as a speed over the legal speed limit and *inappropriate speed* as 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, both excessive speed and inappropriate speed.

and other safe European countries, such as Germany or UK, to warn drivers to adjust their speed according to the specific road situation.

Since they became widespread at the beginning of the nineteen-seventies (Elvik & 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 also very frequently form 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 and reducing GHG emissions and their health costs.

After an overview of the academic literature (see the meta-analyses and the reviews by Aarts & Van Schagen, 2006; Elvik, et al., 2004; Finch et al., 1994; McCarthy, 2001; Wilmot & Khanal, 1999), we find that governments may initially use speed limit laws with economic goals for saving gasoline and diesel consumption with road safety as a secondary objective. However, the relationship between speed limits and traffic safety is an issue that has been widely addressed by researchers worldwide, especially in the U.S. (Albalade & Bel, 2012; Dee & Sela, 2003; Forester et al., 1984; Friedman et al., 2009; Lave, 1985; Retting & Teoh, 2008). There are also studies for European countries (Burns et al., 2001; Johansson, 1996; Peltola, 2000; Richter et al., 2004), for Australia (Sliogeris, 1992) and, more recently, for Asia (He et al., 2012; Wong et al., 2005) and Africa (Afukaar, 2003).

Since the initial estimates obtained by Solomon (1964), there has been a degree of consensus on speed having a significant effect on road safety (with certain causality according to Elvik, 2012) in the sense that both accident incidence and accident severity are expected to increase with higher speed limits (Ashenfelter & Greenstone, 2004). However, “...*despite years of research, there is still no clear consensus in the literature on the impact that speed limit laws have on traffic fatalities*” as pointed out by Ritchey & Nicholson-Crotty (2011).

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: the influence of the individual speed chosen by the driver on the risk of a crash (well-known are the *Power Model*² by Nilsson, 1982, 2004 and its evaluations made by Elvik et al., 2004; Elvik, 2009; Hauer & Boneson, 2008); the influence of speed differences³ on the risk of a

² The original Power Model introduced by Nilsson (1982), explains the relationship between speed and crash rate as a power function: the crash rate increases more quickly when the speed increases and vice versa. For example, a 5% drop in mean speed caused by a reduction in the speed limits would lead to a 20% fall in fatal accidents and a 10% fall in accidents with injuries. Subsequent validations showed that the effect on rural roads was relatively greater than on urban roads (SWOV, 2012).

³ According to this approach, large speed differences between vehicles (speed variance) increases the likelihood of an accident. In addition, drivers driving much faster than the average driver have a higher accident risk

crash (with the first studies conducted by Solomon, 1964 and Cirillo, 1968, and the modern reformulations by Lave, 1985 and Kloeden et al., 2001).

Bearing in mind all the foregoing considerations, we understand that this paper helps to shed light on this controversy. To be more specific, we analyze a recent temporary change to maximum speed limits allowed on free-public and toll-private dual carriageways and motorways in Spain between the months of March and June, 2011, which was put in place with the primary objective of obtaining savings in fuel consumption. This lowering of speed limits was the most striking measure in the so-called *Energy Efficiency and Saving Plan* passed by the Spanish Government to counteract the effects that the high price of oil was having on the weakened Spanish economy at that time.

This analysis is appropriate in as much as, firstly, although speed limit laws have existed in Spain since the mid-nineteen-seventies, to date there has still been no evaluation of their effects, neither of the actual driven speed, or on traffic safety, or in terms of fuel consumption or environmental impact.

Secondly, despite the short period of time that it was in force, only three and a half months, limiting speed like this resulted in intense debate in Spain on the pertinence and real effectiveness of speed limits: in public opinion, between environmental associations, accident victims' associations, and vehicle manufacturers and in all the media. The core question that surrounded this debate and that this paper attempts to answer is whether it is worth changing a country's speed limits temporarily with the major costs this entails in order to save fuel.

To shed light on this debate, this study analyzes the impact of limited changes in the Spanish speed limits measured by road accident indicators and fuel consumption. In order to isolate the impact of the provisional reduction in speed limits, a method based on advanced time series models was used, of the discrete linear time transfer function type, with multiple explanatory variables. In the line of other preceding studies, such as Balkin & Ord (2001) in the U.S. and Johansson (1996) in Sweden, this methodology answers the need stated by Dee & Sela (2003) and Shafi & 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.

The paper is structured in the following way: following this introduction, Section 2 explains the data, variables and methodology used; the findings are stated and discussed in

(“variance kills” as stated by Dee & Sela, 2003); 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 (ERSO, 2006).

Section 3 and the conclusions and resulting policy implications are analyzed in Section 4. Finally, we include the references.

2. DATA AND METHODS.

The data used to measure the effect of the changes in speed limits in Spain can be divided into three groups that will be used later in the estimated models.

A) Endogenous variables: namely fatalities in road accidents (FATAL in later table) 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 hours after the accident, instead of the Vienna Convention definition (30 days after the accident). The available time series span from January 1998 to August 2012 (Source: Spanish National Statistics Institute (INE) and DGT).

B) Dummy exogenous variables: The most important, with their definitions, are:

b.1) SPEED: takes into account the change in speed limits on highways (from 7th March 2011 to 30th 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 enforcement took place after the first week in March.

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. 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).

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 will 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. Secondly, a dummy variable has been included to

estimate the effects of the 2007 Spanish Penal Code reform. To be more precise, although the reform came into effect in December 2007, its effects started to be felt earlier, in November 2007 (NOV07), given the huge impact that the passing of the Bill through Parliament had on 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 (September and October 2000). 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 (LS, TC as explained above 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 and the level of economic activity (or economic cycle or income, see e.g., Castillo-Manzano et al., 2010 and García-Ferrer et al., 2007). The price of gas consumption used in this paper is approximated by the Brent oil price measured in Euros (variable PRICE in table). 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. Income is approximated by economic activity in the Spanish economy, measured by the Activity Synthetic Index (ASI) estimated by the Spanish Ministry of the Economy (<http://serviciosweb.meh.es/apps/dgpe/default.aspx>).

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

$$z_t = T_t + S_t + \mathbf{DI}_t + v_t \quad (1)$$

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 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 behavior 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, equation (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:

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

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 $\mathbf{\Phi}$, $\mathbf{\Gamma}$, \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 $\mathbf{\Phi}$, $\mathbf{\Gamma}$, \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 unobserved components model in equation (1) fits naturally in the SS framework in equation (2), since the observation equations show the breakdown of the time series into its components, and the state equations specify the components dynamics. A description of the

full SS system for a simplified case with just one input variable is shown in equation (3) (see Harvey (1989), Pedregal and Young (2002)).

$$\mathbf{x}_{t+1} = \begin{bmatrix} T \\ F \\ S_1 \\ S_1^* \\ S_2 \\ \vdots \\ f_1 \end{bmatrix}_{t+1} = \begin{bmatrix} 1 & 1 & 0 & 0 & 0 & \cdots & 0 \\ 0 & 1 & 0 & 0 & 0 & \cdots & 0 \\ \hline 0 & 0 & \cos \omega_1 & \sin \omega_1 & 0 & \cdots & 0 \\ 0 & 0 & -\sin \omega_1 & \cos \omega_1 & 0 & \cdots & 0 \\ 0 & 0 & 0 & 0 & \cos \omega_2 & \cdots & 0 \\ \vdots & \vdots & \vdots & \vdots & \vdots & \ddots & \vdots \\ \hline 0 & 0 & 0 & 0 & 0 & \cdots & -a_1 \end{bmatrix} \mathbf{x}_t + \begin{bmatrix} 0 \\ 0 \\ 0 \\ 0 \\ 0 \\ \vdots \\ -a_1 b_1 \end{bmatrix} + I_t + \begin{bmatrix} w_0 \\ w_0^* \\ w_1 \\ w_1^* \\ w_2 \\ \vdots \\ 0 \end{bmatrix}_t \quad (3)$$

$$z_t = T_t + S_t + f_t + v_t = \begin{bmatrix} 0 & 1 & 0 & 1 & 0 & \cdots & 1 \end{bmatrix} \mathbf{x}_t + b_1 I_t + v_t$$

A comparison of systems (2) and (3) enables system matrices to be identified. New elements other than the previous ones appear in equation (3): F_t is the trend ‘slope’ or trend rate of change; S_{it} ($i=1,2,\dots,P/2$) are the seasonal harmonics of frequencies $\omega_i = 2\pi i/P$, whereby $S_t = \sum_{i=1}^{P/2} S_{it}$, with P being the fundamental frequency (12 observations per year in the case of monthly data with annual seasonality); S_{it}^* ($i=1,2,\dots,6$) are additional blocks of states necessary for the definition of seasonal terms.

TF effect specification deserves further comment. All TF considered here are of order one, since only outlier corrections are considered. The general formulation of a single TF is given in equation (4), where B is the lag operator, so that $B^m x_t = x_{t-m}$.

$$f_{pt} = \frac{b_p}{1 + a_p B} \mathbf{1}_{pt} \quad (4)$$

For Transitory Change outliers (TC), $a_p < 0$, i.e., the effect disappears after some time. Additive outliers (AO) implies $a_p = 0$, 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 (3) to accommodate additional TF terms or linear regression terms is straightforward. This methodology is implemented in the MATLABTM platform, in the SSpace toolbox (Pedregal and Taylor, 2012), which will subsequently be used for model estimation.

3. RESULTS AND DISCUSSION.

Two models are estimated in order to measure the effect of speed limit enforcement, 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.

	<i>FATAL</i>	<i>CONSUMPTION</i>
SPEED	-0.091**	-0.017*
PRICE	-0.053**	-0.029***
ASI	2.027***	1.481***
EASTER	0.018	0.008
TRADING	-0.009***	0.006***
LEAP		0.030***
PPS	-0.188***	
PPS Denominator	-0.876***	
NOV2007 (Penal Code)	-0.233***	
DEC2007 (Penal Code)	-0.130***	
JAN2006	0.158**	
SEP2000		0.078***
OCT2000		-0.079***
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}
Q(4)	6.073	4.075
Q(8)	12.698	6.635
Q(12)	14.734	9.455
Q(24)	20.390	16.290
Bera-Jarque	0.238 (0.888)	1.257 (0.534)
H	0.761 (0.139)	0.982 (0.472)
REDUCTION	40 fatalities 8.24%	148,374 metric tonnes 1.55%

Table 1. Estimation results. 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 homoskedasticity test that compares the variance in the first and third parts of the sample (P-values in brackets).

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

- 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 fatalities or metric tonnes 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) and

148,374 metric tonnes (1.55%⁴) 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 tonnes. 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 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 indicates 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 and García-Ferrer et al., 2007).
- The effect of trading days on consumption is positive, but negative on fatalities. In other words, there are more fatalities on weekends but less gasoline consumption because driving becomes more dangerous on weekends, which is perfectly logical.
- 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.
- From a statistical point-of-view, the models are correct, since the innovations do not show any serial dependence, gaussianity, or heteroscedasticity problems.

4. CONCLUSIONS.

Faced with a specific issue, the high fuel prices in spring 2011 that were due to a great extent to the political instability caused by the so-called “Arab Spring”, the Spanish Government implemented a series of short-term measures as part of the National Energy Efficiency and Saving Plan (2008-2011). Without doubt the most striking and controversial of these measures was to temporarily reduce the maximum speed limits allowed on dual

⁴ Since the model is log-linear with respect to the dummy variables, when said variable is binary (only 0s and 1s) the percentage should be calculated as $\beta_{xp} \times \text{Coefficient}_t \times 100\%$. In the case of gasoline consumption this would mean a reduction of $\beta_{xp} \times 0.017 \times 100\% = -1.69\%$. 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.

carriageways and motorways from 120 km/h to 110 km/h from 7th March 2011 to 30th 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 greatly from the forecasts given by the Spanish Government in the media. According to these, the government expected fuel reductions of 15% for gasoline and 11% for diesel. Our conclusions are also very 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 fuel consumption reduction and the accidents that 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 & Rosel (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.

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 & 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.

In fact, if these supposed benefits are compared to the real 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 6,000 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.

In conclusion, the lessons that can be taken from the Spanish case seem to indicate that applying such an aggressive measure as this for such a short period in time is not profitable,

as the overheads generated by its application end up swallowing up any profits, which are directly proportionate to the time that the measure is in place. For this reason it seems that long-term measures that are generally incompatible with the haste required by the political cycle (the decisions were taken just a few months prior to the general elections in Spain) are, unfortunately, those that should really be the basis of a true National Energy Efficiency and Saving Plan. If the aims are to save fuel while driving, to reduce Spain's innate energy dependency and rationalize energy consumption, it may be more efficient and productive to implement other alternative measures that encourage road users to adopt a real structural 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.

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