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An assessment of the safety effects of the French speed camera program

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ABSTRACT

This article presents the results of an evaluation of the speed camera program implemented in France in November 2003. The effects of this program on traffic casualties were estimated using interrupted time-series analyses. Various parametizations were attempted in order to capture changes in the constant and the slope of our traffic injury series. Results of the study reveal significant decreases in both fatal and non-fatal traffic injuries on the whole road network following deployment of the speed camera program. The fatality rate per 100,000 vehicles fell by 21% whereas the decrease in non-fatal traffic injuries displayed a decay function: a 26.2% reduction was recorded in the first month but dropped to 0.8% for the last observation of the series.

1. Introduction

Speeding is one of the leading causes of traffic injuries. Between 30 and 50% of all fatal crashes are speed-related (WHO, 2004). In order to prevent speed limit violations, numerous countries have implemented speed camera programs (Blais and Dupont, 2005; Wilson et al., 2011). In their systematic review, Pilkington and Kinra (2005) report that: (1) all but one study found evidence that speed cameras were effective in reducing average speeds and (2) all studies reported decreases in fatal as well as non-fatal traffic crashes.

Some studies have also investigated specific issues related to automated speed enforcement programs (ASEP) (see Cameron and Delaney (2006) for a synthesis about specific effects according to specific speed camera programs). It is well documented that compared to the localized effect of visible cameras on speeds and crashes, hidden cameras produce general effects on all the roads of a traffic network (Keall et al., 2001, 2002). Evidence from the British–Columbia program in Canada, also suggests that the impact of an enforcement program on speeds is greater when a fine is imposed as compared to just sending a warning letter (Chen et al., 2000).

There is nonetheless little knowledge about the long-term effect of introducing an ASEP or about the functional form of its relation to traffic crashes. Most previous studies used rather short time periods and conducted simple before-and-after comparisons or modeled the effect of the program as a step function (Chen et al., 2000, 2002; Keall et al., 2001, 2002; Perez et al., 2007; Retting and Farmer, 2003). Using such an approach rests on the questionable assumption that introducing a speed camera program will produce an immediate and permanent change in the constant of the series of crashes. This approach is also limited since it gives relatively little guidance about the optimal allocation of resources to speed enforcement (Tay, 2005; Elvik, 2011).

These previous observations echo those found in two recent studies. First, in a Cochrane review of speed enforcement detection devices based on 35 studies, Wilson et al. (2011) reported that it was difficult to either estimate the overall magnitude or the significance of the effects of speed camera programs on traffic casualties. Studies integrating relevant confounding factors and based on lengthy follow-up periods are needed (Wilson et al., 2011). Second, Elvik (2011) developed an accident modification function to describe the functional form of the relationship between traffic law enforcement by police officers and a decrease in crashes. Based on 63 data points found in 13 studies, it appears that the relationship between accidents and enforcement is best expressed as a logarithmic or inverse function.

Using the case of the French ASEP, the following study attempts to estimate the effect of this program on traffic injuries and fatalities using a seven-year follow-up period. Attempting to model the effect of the ASEP using different functions will shed light on the long-term effect of the French ASEP and also on the relationship between the number of citations issued by speed cameras and relative decreases in crashes. This article is organized as follows: this section presents the characteristics of the French ASEP. Section 2

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describes the methodology used while the last two sections present and discuss the results.

1.1. The French context

Before implementation of the ASEP, France's traffic fatality rate was higher than that of several OECD countries. In 2000 for instance, its traffic fatality rate was 13.6 per 100,000 population in comparison to 9.1, 7.7 and 6.7 for Germany, Finland and Sweden, respectively. The OECD average stood at 11.6 (Australian Transport Safety Bureau, 2008). For the same period, according to the *Observatoire national interministériel de la sécurité routière* (ONISR), speed limit violations were a major concern for French authorities. Over 60% of all recorded speeds exceeded the prescribed speed limits: 40% by more than 10 km/h, 5% by more than 30 km/h (ONISR, 2006).

Part of the problem was the lack of effective enforcement. A survey conducted by the ONISR (2006) showed that one could exceed the speed limit by 10 km/h for a period of 2000 h before being arrested. The arrest risk in Denmark, for instance, was 75 times greater. In order to improve the situation, President Chirac announced, in July of 2002, that traffic safety was among the top priorities of his next five-year term. A few weeks later, three distinct traffic safety measures were announced: (1) implementation of the ASEP, (2) increased severity of penalties for traffic violations and (3) creation of new traffic offenses. In the period between Chirac's announcement and the effective introduction of the ASEP, print and visual media provided wide and positive coverage of the new policy (Carnis, 2011).

1.2. Program description and strategy

The first photo radar devices were installed in November 2003 after a trial period (between March and November 2003). Since then, roughly 500 radar devices have been installed each year. By 2010, more than 2,756 speed cameras — 1,823 fixed devices and 933 mobile ones — were operating throughout the public road and highway network (Carnis, 2011). Warning signs alert drivers to the presence of fixed photo radars but not to mobile ones and controls are conducted in unmarked police vehicles.[1] Fixed devices are generally installed close to "black spots", or near areas experiencing high levels of speed limit violations whereas location of the mobile radars used in various speed enforcement contexts will depend on police officers' knowledge and strategy.

The ASEP can be considered as a combination of general and specific deterrence, since fixed photo radars should dissuade potential offenders from speeding whereas mobile devices should deter those who are caught and penalized. The expected effectiveness of the ASEP rests on three basic principles of deterrence theory (Gibbs, 1979). The first invokes the certainty of punishment, which is the probability of being detected and sentenced for a speed limit violation. Building a credible ASEP means gridding the road network with enough speed cameras to yield a high probability of detection and punishment. The second principle is swift punishment. The fine is sent to the car owner in less than 8 days following detection of the offense and demerit points are then added to the driver's record. The third principle concerns the severity of punishment. Accordingly, the amount fined and the demerit points added are proportional to the speed excess (Carnis, 2008, 2011).

1.3. Prior investigations of the French ASEP

Implementation of the ASEP led to a radical increase in traffic citations issued for speed limit violations. Respectively, 110,000 and 502,000 citations were issued per month before-and-after the introduction of the program. More than 87% of all citations are now issued by speed cameras (Carnis, 2008). Estimates of average speeds show a marked drop since 2002: the average was 90.5 km/h in the first quarter of 2002 and 81.6 km/h in the third quarter of 2007. Significant reductions have also been observed in the proportion of speeding vehicles. The rate of infringements of more than 10 km/h over the speed limit decreased by 56% for private cars and by more than 33% and 36%, respectively, for motorcycles and trucks (ONISR, 2006).

A first evaluation concluded that the ASEP was responsible for 75% of the decrease in traffic fatalities for the 2002–2005 period (ONISR, 2006). This estimate should be considered with caution since it is based on a rough application of Nilsson's formula (Nilsson, 2004).[2] The variation in the mean traffic speed is not necessarily related to introduction of the ASEP and a short time period was considered. Furthermore, it appears that the formula is sensitive to the road environment. In a recent study, Cameron and Elvik (2010) show that Nilsson's power model does not appear to be directly applicable to traffic speed change on urban arterial roads.

Further studies investigating the long-term effect of the ASEP are required, with special emphasis on the form of the relationship between the introduction of the program and its evolution through time (Carnis, 2008). Such studies are especially relevant since the French Government plans to further increase the number of photo radar devices in use to 4500 by 2012, in order to lower the number of traffic fatalities to about 3000, which would represent a reduction of 15% in comparison to 2010 (when 3499 fatalities were recorded).

2. Method

2.1. Data

Data on traffic injuries come from the *Fichier national des accidents corporels de la circulation*, a national database managed by the ONISR, which contains information about traffic crashes and injuries. The ONISR defines a crash as an event in which damages are caused by a moving vehicle. The database contains the essential information gathered at the crash scene by police officers. The police officer on duty at the scene of a crash must fill up a *Bulletin d'Analyse d'Accident Corporel de la Circulation* (BAAC): a report detailing the main characteristics of the crash scene, vehicles and victims. Data on the French vehicle fleet are published by the *Comité des constructeurs français d'automobiles* (CCFA).[3]

2.2. Variables under analysis

2.2.1. Dependent variables

In the present study, the effect of the ASEP is estimated based on two dependent variables. The first dependent variable is the number of non-fatal traffic injuries per 100,000 registered vehicles (property-damage-only crashes are excluded from this category).

[1] Following the proposition of a ministerial committee, gradual removal of warning signs has been in effect since the second half of 2011.

[2] Nilsson developed a power model to estimate the relationship between changes in speeds and variations in traffic crashes at various level of injury severity (Nilsson, 2004). If the speed limit decreases, the crash risk is reduced as well as the level of injury severity. As summarized by Cameron and Elvik (2010: 1908), "(i)ncreases in fatal crashes are related to the 4th power of the increase in speed mean, increases in serious casualty crashes (those involving death or serious injuries) according to the 3rd power, and increases in casualty crashes (those involving death or any injury) according to the 2nd power".

[3] Data on traffic injuries are published in the ONISR annual report and can be found online at www.ladocumentationfrancaise.fr (last accessed 30 July 2012). Data on vehicles are available online at: http://www.unionroutiere.fr/wp-content/uploads/2012/04/chapitre-2_vehicules-faits-et-chiffres-2011.pdf (last accessed 17 April 2012).

Non-fatal traffic injuries are defined as injuries which required some kind of medical attention (either hospitalization or treatments by a health professional). The non-fatal traffic injuries registered also had to (1) take place either on a public road or on a private road open to public circulation, and (2) involve at least one motor vehicle. The second dependent variable is the number of traffic fatalities per 100,000 registered vehicles. In the present study, traffic fatalities are defined as deaths occurring within 30 days of a crash.

Since the ASEP grids the entire French road network, France's whole territory was used as the spatial unit of analysis. Using such an approach allows one to estimate the overall impact of the ASEP on traffic injuries and fatalities. All rates were aggregated on a monthly basis. Data were available from January 1999 to December 2010 ($N = 144$).

2.2.2. Independent variables

The independent variables of interest are those associated with the introduction of the ASEP. The first, "Intervention", is a dichotomous variable and refers to the introduction of the program. Units in the pre-intervention period are coded 0 (January 1999–October 2003) while those in the post-intervention period are coded 1 (November 2003–December 2010). This first variable allows us to estimate changes in the constant of the series. The second, "Time after the Intervention", is a continuous variable counting the number of months after the Intervention at time *t*, coded 0 before the program and (Time-58) after introduction of the program.[4] This variable estimates changes in the slope of the series. In keeping with Elvik (2011) work, the following functions were considered for "Time after the intervention variable".[5]

1. Linear ($Y = b_0 + b_1 \cdot t$)
2. Logarithmic ($Y = b_0 + b_1 \cdot \ln(t)$)
3. Inverse ($Y = b_0 + (b_1/t)$)
4. Quadratic ($Y = b_0 + b_1 \cdot t + b_2 \cdot t^2$)
5. Power ($Y = b_0 * t^{b1}$)
6. Exponential ($Y = b_0 * e^{b1 \cdot t}$)

where b_0 is the constant of the equation, b_n represents a regression coefficient, t stands for "*time*" and "ln" for the natural logarithm transformation.

Finally, another dichotomous variable was introduced into the model. In July 2002, President Chirac declared that traffic safety had become a national priority and, a few weeks later, installation of the ASEP on the French road network was announced. Values from July 2002 to December 2010 were coded 1 and otherwise, 0. The creation of this variable makes it possible to account for the impact of media coverage leading up to introduction of the ASEP (Carnis, 2011). This variable also accounts for deterrent effects that could have been initiated by the announcement of the ASEP.[6]

2.2.3. Control variables

A second set of independent variables is included to overcome internal validity threats associated with seasonality and history. On one hand, 11 dummy variables were created to account for monthly variations in the volume of traffic injuries ($K-1$: reference category = December). On the other hand, a trend variable, called "Time", was created. "Time" is a continuous variable indicating the time in months at time *t* from the start of the observation period (January 1999 through December 2010). "Time" controls for potential confounding factors that could be associated with a general decline in traffic injuries before introduction of the ASEP.

2.3. Statistical analysis

In the first place, averages of the different traffic injury variables were calculated for the pre-and-post intervention periods. In the second place, interrupted time-series analyses were conducted using the autoregressive, integrated, moving average (ARIMA) intervention time-series models (Box et al., 2008; Yaffee and McGee, 2000). Interrupted time-series analysis is particularly well suited to determine whether the introduction of one intervention at a specific point in time is associated with changes in the behavior of a time-series (Biglan et al., 2000; Shadish et al., 2002).

Typical regression based on the ordinary least-square principle rests on a set of assumptions regarding the distribution of the residuals: they must be normally distributed, independent, random and of constant variance (Lewis-Beck, 1980). The typical consequence of positive autocorrelations is that estimated standard errors are biased low, leading to an overestimation of the statistical significance of an estimated intervention effect (Biglan et al., 2000). Unlike linear regression, the ARIMA model can take into account autocorrelations between units of analysis.

Since each time series has a unique structure, ARIMA models are developed using a three-stage iterative process: (1) identification, (2) estimation and (3) diagnostic (Box et al., 2008; Yaffee and McGee, 2000). Identification involves analyzing autocorrelation and partial autocorrelation matrices to identify, on one hand, sources of non-stationarity in the series (stochastic or deterministic) and, on the other hand, autoregressive and moving average parameters.[7] The predictive validity of these parameters is then evaluated in the estimation stage. As each series exhibited seasonality, seasonal parameters were first identified and error terms were then re-inspected to identify other lags with significant Q-statistics. In the diagnostic stage, error terms were plotted to make sure that they followed a white noise process. In all models, Q-statistics are not significant, error terms are normally distributed and the homoskedasticity assumption is respected.

Once an ARIMA model is identified, independent variables can be introduced on the right side of the equation. Since various functions were attempted for the time-after-intervention variable and since dependent variables were sometimes transformed in their

[4] The number of citations issued by speed cameras was also considered in preliminary analyses. The variable was however withdrawn from the models for two reasons. First, it displays multicollinearity with the time-after-intervention variable. Second, when the time-after-intervention term was removed from the model, the number of citations was positively associated with the non-fatal traffic injury rate. This result suggests that the effect of the ASEP is likely to be best understood in terms of "time-after-intervention" rather than in terms of allocated resources. Lastly analyses were conducted to estimate the relationship between citations issued by speed cameras and fatal and non-fatal traffic injury rates for the intervention period only. No relationships reached statistical significance.

[5] Analyses were conducted with the Trend Module in SPSS 20. In order to obtain estimates for the exponential and power functions, the latest were transformed into their equivalent additive forms. The power function was expressed by ($\ln(Y) = \ln(b_0) + b_1 \ln(t)$) and the exponential function was expressed by ($\ln(Y) = \ln(b_0) + b_1 t$). The transformation of Y into its natural logarithmic value also explains the large variations observed in the estimates about the effect of the ASEP on fatal and non-fatal traffic injuries (see Tables 2 and 3).

[6] Other preventive measures were implemented between January 1999 and December 2010: (1) increased sanctions for not fastening the seat belt in March 2003; (2) increased sanctions for driving while impaired by alcohol in July 2003; (3) increased sanctions for speed limit violations over 50 km/h in December 2004 and in January 2006; and (4) red light cameras in July 2009. All these measures were expressed by dichotomous variables (units in the pre-intervention period were coded 0 and those in the post-intervention period were coded 1). However, they were all withdrawn from the models since they were not statistically associated with the dependent variables ($p > 0.10$).

[7] Both series displayed a deterministic trend. The trend variable, called "Time", also allowed us to achieve stationarity in both models.

Table 1
Monthly averages in fatal and non-fatal traffic injuries before and after introduction of the ASEP.

	Period 1 (P1): November 1999–October 2003	Period 2 (P2): November 2003–October 2008	Period 3 (P3): November 2003–October 2010	Percentage change	
				P1 vs. P2	P1 vs. P3
Traffic fatalities	642.98	412.78	393.96	−35.8%	−38.7%
Non-fatal traffic injuries	12,074.52	8,767.55	8,376.15	−27.4%	−30.6%
Traffic fatalities per 100,000 vehicles	1.86	1.13	1.07	−39.3%	−42.5%
Non-fatal traffic injuries per 100,000 vehicles	34.98	24.03	22.81	−31.3%	−34.8%

natural logarithmic expression, the MAPE (Maximum Absolute Percentage Error) and the stationary r^2 were used as goodness-of-fit measures. Models with the lowest MAPE and the highest stationarity r^2 were deemed the most robust.

3. Results

3.1. Descriptive results

Comparisons in the average counts and monthly average of traffic injuries per 100,000 registered vehicles for the pre-intervention (Period 1) and the post-intervention periods (see Periods 2 and 3) are displayed in Table 1. Periods were balanced in order to, on one hand, control for months where higher volumes of traffic injuries are recorded and, on the other hand, to determine whether the improvement in the road toll might be related to the general recession that began in Fall of 2008.

Between periods 1 and 2, the volume of fatal and non-fatal traffic injuries respectively fell by 35.8% and 27.4%. Declines are even greater when traffic injuries are divided by the number of registered vehicles, showing that the decrease was partially obscured by the growth in the French vehicle fleet. In fact, traffic fatalities per 100,000 vehicles dropped by more than 39.3% following introduction of the ASEP while a 31.3% diminution is observed for non-fatal injuries per 100,000 vehicles. Results are quite similar when one compares periods 1 and 3, suggesting that the recession was not responsible for the decline in fatal and non-fatal traffic injury rates.

Despite the large decreases observed in fatal and non-fatal traffic injuries following introduction of the French ASEP, one could argue that other factors could be associated with this improvement (for instance, increase in the gasoline price). In fact, Fig. 1 shows that the downward trends in fatal as well as in non-fatal traffic injuries per 100,000 vehicles started before introduction of the ASEP.

3.2. Results of the interrupted time series analyses

An ARIMA intervention time-series analysis overcomes the shortcomings previously highlighted by controlling for autocorrelation between residuals, previous trends and other relevant control variables. Tables 2 and 3 presents results from interrupted time series analyses. Results are displayed for all functions attempted for the time-after-intervention variable. Since goodness-of-fit values were similar in all models, those for which the intervention variables had the greatest predictive validity were selected to compute fatal and non-fatal injuries prevented by the ASEP and Chirac's announcement (Section 3.3).

3.2.1. Effect of the ASEP on traffic fatalities per 100,000 vehicles

Three main results come out of Table 2. First, introduction of the ASEP is associated with a significant decrease in traffic fatalities per 100,000 registered vehicles in five out of six models. Regardless of its form, the "time-after-intervention" term is not significant, suggesting that introduction of the ASEP produced an immediate and permanent effect on the constant of the series. Second, Chirac's announcement is associated with a significant decline in traffic fatalities in all six models. Finally, in all six models, coefficients for the Time variable indicate that the downward trend in traffic fatalities started before the ASEP was introduced.

3.2.2. Effect of the ASEP on non-fatal traffic injuries per 100,000 vehicles

Effects of the ASEP on non-fatal traffic injuries are not as evident as those observed on traffic fatalities (Table 3). First, following Chirac's announcement, significant decreases are observed in five

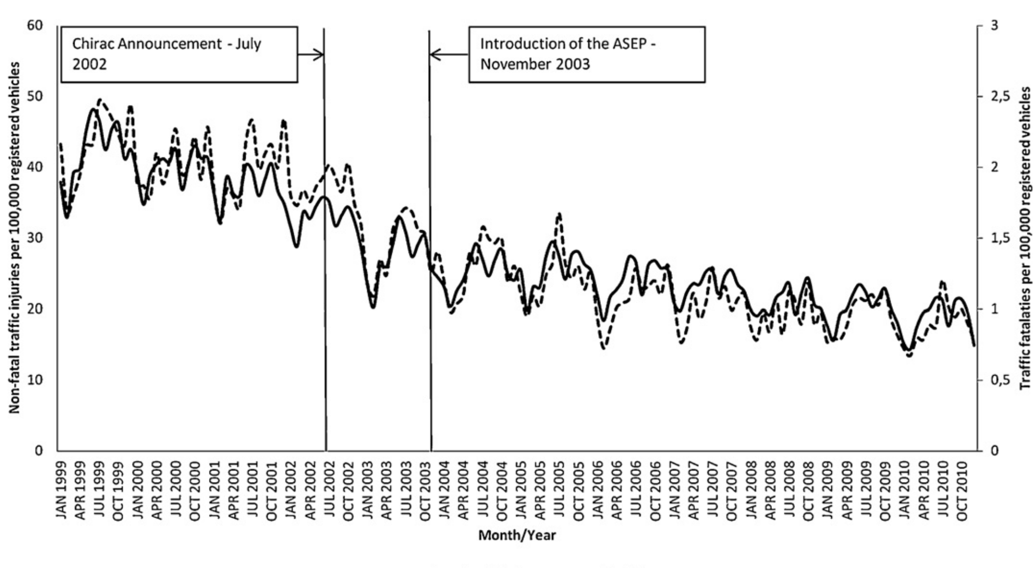

Fig. 1. Trends in fatal and non-fatal traffic injuries per 100,000 registered vehicles between January 1999 and December.

Table 2
Effect of the ASEP on traffic fatalities per 100,000 registered vehicles.

	Linear		Logarithmic		Inverse		Quadratic		Power		Exponential	
	β	S.E.	β	S.E.	β	S.E.	β	S.E.	β	S.E.	β	S.E.
AR1 parameter	0.21^{*}	0.09	0.21^{*}	0.09	0.21^{*}	0.09	0.19	0.09	0.21^{*}	0.09	0.21^{*}	0.09
Constant	2.31^{**}	0.05	2.29^{**}	0.05	2.30^{**}	0.04	2.31^{**}	0.05	0.88^{**}	0.03	0.86^{**}	0.04
Chirac announcement (July 2002)	-0.28^{**}	0.06	-0.31^{**}	0.05	-0.30^{**}	0.04	-0.28^{**}	0.06	-0.16^{**}	0.04	-0.19^{**}	0.05
Intervention -Introduction of the ASEP (November 2003)	-0.20^{**}	0.05	-0.20^{**}	0.08	-0.20^{**}	0.05	-0.17^{**}	0.06	−0.08	0.05	-0.13^{**}	0.04
Time × intervention	0.001	0.002	−0.003	0.03	−0.02	0.13	−0.00003	0.00003	−0.02	0.02	−0.002	0.001
Time (Trend)	-0.01^{**}	0.002	-0.01^{**}	0.001	-0.01^{**}	0.001	-0.01^{**}	0.002	-0.004^{**}	0.001	-0.003^{**}	0.001
Goodness-of-fit												
Stationary r^2	95.3%		95.3%		95.3%		95.4%		95.1%		95.1%	
MAPE	6.57		6.60		6.60		6.48		6.16		6.14	
Test for autocorrelation												
Q (lag 1)	0.05; $p = 0.83$		0.05; $p = 0.83$		0.05; $p = 0.83$		0.03; $p = 0.86$		0.07; $p = 0.80$		0.06; $p = 0.81$	
Q (lag 12)	8.73; $p = 0.73$		8.78; $p = 0.72$		8.87; $p = 0.71$		9.01; $p = 0.70$		8.30; $p = 0.76$		8.30; $p = 0.76$	

All models contain 11 dummy variables to control for monthly variations in the rates of fatal and non-fatal traffic injuries. A linear expression of the "time-after-intervention" variable is included in the quadratic model.
* $p < 0.05$.
** $p < 0.01$.
*** $p < 0.10$

Table 3
Effect of the ASEP on non-fatal traffic injuries per 100,000 vehicles.

	Linear		Logarithmic		Inverse		Quadratic		Power		Exponential	
	β	S.E.	β	S.E.	β	S.E.	β	S.E.	β	S.E.	β	S.E.
AR1 parameter	0.47^{**}	0.08	0.48^{**}	0.08	0.59^{**}	0.09	0.42^{**}	0.08	0.41	0.09	0.51^{**}	0.08
AR2 parameter	–	–	–	–	0.22^{*}	0.09	–	–	–	–	–	–
Constant	43.50^{**}	0.76	42.50^{**}	0.66	40.81^{**}	1.17	43.68^{**}	0.70	3.78^{**}	0.02	3.78^{**}	0.03
Chirac announcement (July 2002)	-2.86^{**}	0.95	-4.52^{**}	1.08	−2.16	1.32	-2.98^{**}	0.88	-0.11^{**}	0.03	-0.97^{*}	0.04
Intervention – introduction of the ASEP (November 2003)	−0.66	0.75	-4.22^{**}	1.08	−0.93	1.89	-1.79^{*}	0.83	-0.12^{**}	0.04	−0.02	0.03
Time × intervention	0.13^{**}	0.03	1.93^{**}	0.46	−1.49	2.04	-0.001^{**}	0.0001	0.06^{**}	0.02	0.002^{***}	0.001
Time (Trend)	-0.23^{*}	0.03	-0.18^{**}	0.02	-0.15^{**}	0.03	-0.23^{**}	0.02	-0.12^{**}	0.04	-0.01^{**}	0.001
Goodness-of-fit												
Stationary r^2	97.9%		97.8%		97.7%		98.0%		97.6%		97.4%	
MAPE	3.45		3.52		3.58		3.66		3.35		3.45	
Test for autocorrelation												
Q (lag 1)	0.03; $p = 0.87$		0.03; $p = 0.86$		0.08; $p = 0.78$		0.01; $p = 0.99$		0.05; $p = 0.82$		0.002; $p = 0.96$	
Q (lag 12)	10.86; $p = 0.54$		8.47; $p = 0.0.74$		15.77; $p = 0.20$		11.15; $p = 0.52$		16.61; $p = 0.17$		16.66; $p = 0.16$	

All models contain 11 dummy variables to control for monthly variations in the rates of fatal and non-fatal traffic injuries. A linear expression of the "time-after-intervention" variable is included in the quadratic model.
* $p < 0.05$.
** $p < 0.01$.
*** $p < 0.10$

out of six models. Second, introduction of the ASEP produced additional declines only in models where the time-after-intervention variable is either expressed as a logarithmic, quadratic or power function. In these three models, the time-after-intervention coefficient is significant and positive, suggesting that the deterrent effect of the ASEP follows a decay function. It means that the effect of the measure fades away through time despite the addition of speed cameras during the post-intervention period.[8]

3.3. Fatal and non-fatal injuries prevented by Chirac's announcement and the ASEP

The estimates found in Tables 2 and 3 can be used to compute the number of non-fatal and fatal traffic injuries prevented as of December 2010. Formula 1 was used to compute the monthly rates of traffic injuries per 100,000 vehicles "with and without" the presidential announcement and the speed camera program. The same procedure was performed to determine injuries saved by Chirac's announcement by itself. Computing differences for each month between the rates "with and without" the ASEP permits to calculate the total number of injuries saved.

Formula 1 Parameters used to estimate number of fatal and non-fatal traffic injuries prevented by the ASEP

$$Y_{\text{(with intervention)}} = b_0 + b_1 \times x_1 + b_2 \times x_2 + b_3 \times x_3 + b_4 \times x_4 + b_5 \times x_5$$
$$Y_{\text{(without the intervention)}} = a + b_1 \times x_1 + b_5 \times x_5$$
$$\text{Absolute difference} = Y_{\text{(without the intervention)}} - Y_{\text{(with intervention)}}$$
$$\text{Relative percent change} = (\text{absolute difference}/Y_{\text{(without the intervention)}})*100$$

b_0 = Constant
b_n = Coefficient
x_1 = TREND
x_2 = Chirac's announcement
x_3 = ASEP
x_4 = Time-after-Intervention
x_5 = Dummy for a given month

Estimates obtained with the linear model (Table 2) were used to compute the number of fatalities avoided since Chirac's

[8] Additional analyses were conducted to make sure the effects of the ASEP and Chirac's announcement were not due to the recession (that started around October 2008) or to an unbalanced research design. Analyses were conducted, considering this time, the same months in the before-and-after periods. Similarly, analyses were realized with the series ending in October 2008. Regardless of the time periods used, estimates remained unchanged.

Table 4
Non-fatal and fatal traffic injuries prevented by the presidential announcement and the introduction of the Automated Speed Enforcement Program (ASEP).

Interventions/outcomes	Average injuries per 100,000 vehicles avoided per month	Average injuries avoided per month	Total injuries avoided	Change in relative percentage
Presidential announcement only (July 2002–October 2003)				
Non-fatal traffic injuries	4.52 [2.36; 6.88]	1598 [1,044; 2,151]	25,566 [16,704; 34,428]	−13.3% [−8.7; −17.9]
Traffic fatalities	0.28 [0.16; 0.40]	99 [57; 141]	1584 [905; 2263]	−12.1% [−6.9; −17.3]
Chirac announcement + automated speed enforcement program (November 2003–December 2010)				
Non-fatal traffic injuries	1.99 [+0.17; 14.16]	724 [+72; 1520]	62,259 [+6,172; 130,692]	−7.3% [+1.8; −16.5]
Fatal traffic injuries	0.48 [0.26; 0.70]	177 [96; 258]	15,193 [8230; 22,157]	−20.7% [−11.3; −30.3]

Note: Results in parentheses represent the lower and the upper bound of the estimates (95% CI). For the period combining the effects of Chirac's announcement and the introduction of the automated speed enforcement program, change in relative percentage was obtained by dividing the effects of both measures by the constant of the model. Addition symbols mean that there were more injuries with than without the ASEP.

announcement and the introduction of the ASEP (see Fig. 3a for a comparison between predicted and observed values). Since none of the time-after-intervention variables were significant, they were not considered in the computation. Based on our results, it is estimated that the presidential announcement led to a 12.1% decline in the fatal traffic injury rate. About 99 fatalities were avoided on average per month, for a total of 1,584 for the 16-month period (Table 4). The introduction of the ASEP was associated with an additional 9.9% in traffic fatalities (or 20.7% when effects of both measures are combined). On average, results indicate that 177 fatalities were prevented per month between November 2003 and December 2010 (for a total of 15,193 for the whole period).

Computing the number of non-fatal traffic injuries prevented by the ASEP and Chirac's announcement was more tedious since goodness-of-fit values were excellent in all models. Significant relationships between the ASEP and non-fatal traffic injuries were however only observed in the logarithmic, quadratic and power models. Using Formula 1, estimates were attempted with the three sets of results. In all cases, the estimate for the time-after-intervention variable caused problems, since the introduction of the ASEP was associated with more injuries when the upper bound of the interval was considered. The logarithmic function of the time-after-intervention variable produced the most coherent results (see Fig. 3b in appendix for a comparison between predicted and observed values). Chirac's announcement was associated with a 13.3% decrease in non-fatal traffic injuries per 100,000 vehicles, which is the equivalent of 1,598 non-fatal injuries avoided per month (a total of 25,566 for the 16-month period) (Table 4). On average, an additional 7.3% decrease in non-fatal traffic injuries occurred when the ASEP was implemented. Since the logarithmic function of the time-after-intervention variable is significant, the effect decays over time. In fact, the change in relative percentage was 26.2% at the beginning of the intervention period (November 2003) while it falls to 0.79% at the end of the period (December 2010). If the upper bound limit is used to compute the number of non-fatal traffic injuries saved by the ASEP, one can conclude that the preventive effect of the ASEP ended around May 2006 (see Fig. 2 below).

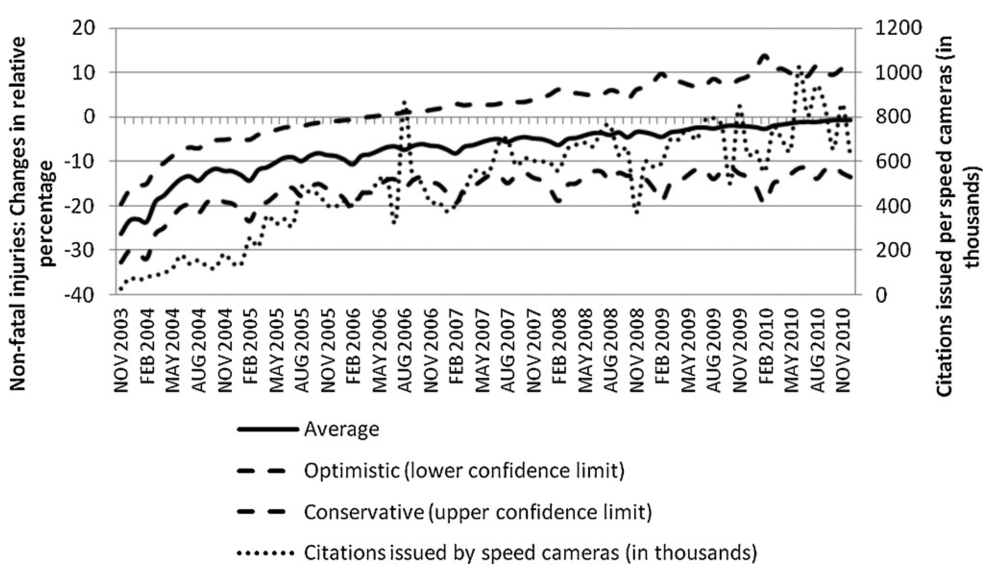

Fig. 2. Relative percentage changes in the rate of non-fatal traffic injuries per 100,000 vehicles and the number of citations issued by speed cameras per month, November 2003–December 2010. *Note*: Negative values represent decreases while positive values are associated with increases in non-fatal traffic injuries. The highest values are those associated with the most pronounced increases or decreases.

4. Discussion

Results from our statistical models show that the introduction of the ASEP played a significant role in reducing the French road toll. Between November 2003 and December 2010, our estimates suggest that about 15,193 fatalities and 62,259 non-fatal injuries were prevented by the ASEP. These figures are nonetheless less optimistic than those presented by the ONISR (2006), which suggest that at least 88% of the decline in fatalities was associated with the program between 2003 and 2005 (5,446 of the 6,189 avoided fatalities). For the same period, our estimates suggest that about 72.7% of the decrease is attributable to the ASEP (4,498 of the 6,189 fatalities prevented). These estimates must however be interpreted with caution. Besides other prevention measures, a linear trend and seasonality, other factors, not considered in our models, may have influenced trends in traffic injuries (gasoline price and alcohol consumption). Another French study concluded that during the last decade, about 11% of the decline in serious and fatal traffic injuries (car occupants and pedestrians) was related to the introduction of vehicles with improved safety standards (Page et al., 2011).

The present results also have several implications for authorities seeking to optimize the deployment of their ASEP and use it as a central road safety measure. First, as reported in other studies, the introduction of a speed camera program is generally followed by a significant decline in traffic casualties. This is actually the case with the French ASEP, where a 21% decrease in the traffic fatality rate was observed following its introduction.

Second, the effect on fatal injuries is stable and lasts throughout the whole experimental period, suggesting that the success of the program is not solely associated with the number of citations issued by the photo radar devices in function. Although adding speed cameras may be crucial to maintain the effect of the ASEP, other dimensions—such as the intensity of the program (the tight gridding of the whole road network); the high detection capacity of each device (fixed devices operate full time); the credibility of the sanction (almost 70% of all detected violations are sanctioned)—could be associated with the success of the program.

Third, for fatal traffic injuries, the effect of the program is characterized by the law of diminishing marginal returns (Kirzner, 1963). Additional inputs in terms of speed cameras did not translate into proportional decreases in fatal traffic injuries. As highlighted previously, the preventive effect remains constant at about 21%. One can however suppose that adding devices was necessary to maintain the effect of the ASEP.

Fourth, Fig. 2 highlights the importance of attempting various parametizations when assessing road safety programs. When expressed in relative percentage changes, reductions in non-fatal traffic injuries make it possible to conceptualize the deterrent effect of the ASEP as a decay function. This observation suggests that the ASEP produced an immediate general deterrent effect that tends to dissipate over time. The ASEP was associated with a 26.2% decrease in the rate of non-fatal traffic injuries in its first month of activity. After one year, the ASEP lost about half of its effect, since the decrease was on the order of 12.1% for November 2004. Declines in non-fatal traffic injuries were respectively 3.5% and 0.8% for December of 2008 and 2010. To understand this decay function, additional studies that consider driver characteristics and causes of crashes are needed. Some drivers involved in crashes may not be sensitive to the treat of punishment or to punishment itself (Piquero and Paternoster, 1998). On one hand, motorcyclists can sometimes avoid punishment since speed cameras do not detect them (they are still over-represented in traffic injuries). On the other hand, there is no formal agreement between the French and other European authorities to make sure foreign drivers pay their fine to the French authorities. In such situations, the citation cannot generate its specific deterrent effect. And it may also be that traffic crashes may now be associated with causes that cannot be managed by the ASEP. Distracted driving (cell phone use and texting while driving) and motorcycles passing between vehicles when overtaking are some examples (ONISR, 2010).

Finally, these results also call for multifaceted interventions to generate further improvements, especially for non-fatal traffic injuries. Measures targeting the vehicle and the physical environment could effectively support the ASEP (Runyan, 2003). Engineering schemes incorporating vertical deflections such as speed bumps and cushions have proven to be effective in preventing traffic casualties and could be used to complement speed cameras (Mountain et al., 2005). Moreover, speed adaptation via in-car devices offers another promising solution. Positive outcomes were associated with speed management systems incorporating an advisory feature and other systems that enforce current speed limits and automatically limit speed in critical conditions (slippery roads, poor visibility) (Sergerie, 2005; Turetschek, 2005).

5. Conclusion

The objectives of this study were to estimate the general effect of the French ASEP on traffic casualties and to model its effect using various parametizations. Results indicate that the French ASEP played a major role in improving safe driving, despite the decaying effect observed for non-fatal traffic injuries. Choosing to evaluate the general effect of the ASEP necessarily left some questions unanswered. First, it was not possible to differentiate between local, spillover and migration effects. Similarly, halo effects are not documented.

Second, available information on traffic casualties was quite general. It was therefore not possible to create a control series (e.g. alcohol-related casualties) and avoid all threats that could be related to history (Shadish et al., 2002). The presence of such biases is quite unlikely in light of the positive results reported in previous systematic reviews (Blais and Dupont, 2005; Pilkington and Kinra, 2005; Wilson et al., 2011).

Third, traffic injury rates were not broken down according to drivers' age and gender. Little is known about whether or not drivers' responses to the ASEP vary with regard to these characteristics. Additional studies are required to investigate the aforementioned issues.

Conflict of interest

None.

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Appendix A.

Comparisons between observed and predicted values

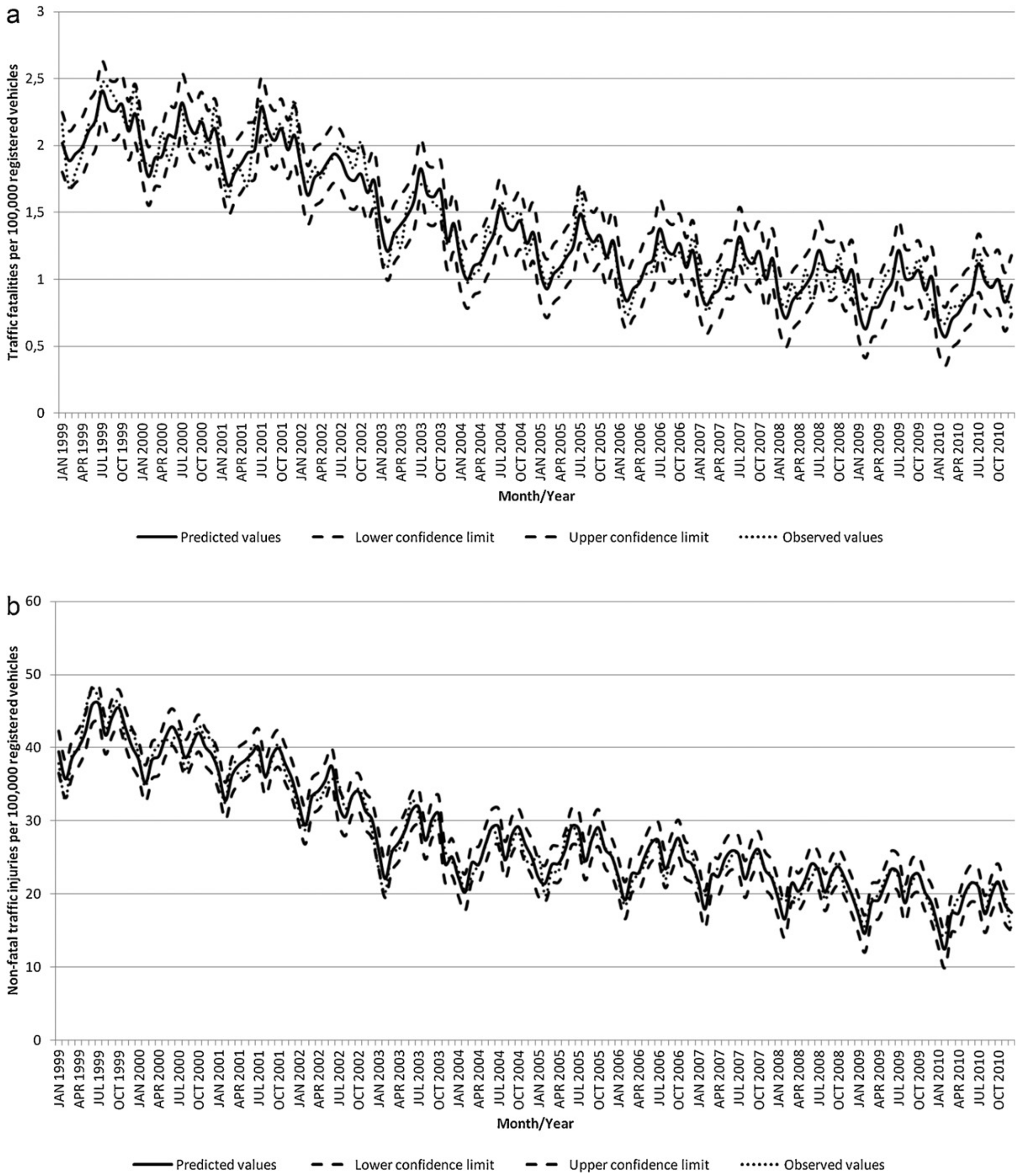

Fig. 3. (a) Comparison between observed and predicted values for traffic fatalities per 100,000 registered vehicles. (b) Comparison between predicted and observed values for non-fatal traffic injuries per 100,000 registered vehicles.

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