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Spot speed cameras in a series - Effects on speed and traffic safety

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ABSTRACT

Reduced speeds and increased speed compliance are crucial for achieving increased road traffic safety, cutting across most Safe System interventions. Speed cameras have been shown to be effective in increasing speed compliance and reducing the number of fatalities and seriously injured. The speed cameras system in Sweden is different compared to many other countries, spot speed cameras are almost always placed in series along a road stretch. The aim of this study is to investigate the effects of this system on mean speeds, speed compliance, and on the number of fatalities and seriously injured. Including 20 years of data, the study applies before-after analysis to 361 speed measurement spots, and Empirical Bayes before-after analysis with control to crash outcomes on 202 road sections.

The results show a mean speed decrease of 3.5 km/h for all vehicles and road sections, 7.9 km/h at cameras and 3.0 km/h between cameras. Furthermore, follow-up measurements showed that the effects were maintained long-term. Speed compliance increased 16 %-units, 42 %-units at cameras and 13 %-units between cameras. Though larger effects can be seen at cameras, there are still substantial effects on the enforced road sections between cameras. The cameras had an average effect of 38.6 % on decreasing fatalities and may also suggest a decrease for seriously injured, though not statistically significant. This study also shows that for roads that received both a decreased speed limit from 90 to 80 km/h and speed cameras, the mean speeds were reduced by additionally 3.6 km/h compared to roads with unchanged limits of 90 km/h. The combined effect on fatalities and seriously injured was a reduction by 61.6 % and 33.4 %.

In conclusion, the Swedish strategy with spot speed cameras in a series led to an increased speed compliance and a comprehensive reduction in mean speeds and of the number of fatalities.

1. Introduction

Speed management is at the core of a Safe System approach for road traffic, cutting across most Safe System interventions. A Safe System employs three main strategies to eliminate fatalities and serious injuries due to road crashes: reduced risk exposure, reduced risk levels, and increased protection from harmful impact forces in the event of a crash. Reducing the speed of traffic increases the reaction distance so that you have greater opportunities to avoid a crash, and lowers the impact force in the event of a crash, which makes the injuries less severe. Even small changes in driving speeds can have a substantial effect on road safety. As a rough estimate, a 10 % decrease in mean speed leads to 20 % decrease in injury crashes and a 40 % decrease in fatal crashes (OECD/ITF, 2018, based on Elvik, 2013). Therefore, managing and controlling speed is at the center of developing a Safe System. In addition to protecting road users from death or serious injury, the objective of managing speed is to create a sustainable society with livable cities and increased health, security, and equity.

In advance of the Third Ministerial Conference on Global Road Safety 2020, an Academic Expert Group on road safety developed nine recommendations to advise on priority directions following the first Decade of Action (The Swedish Transport Administration, 2020). These recommendations are based on the introduction of Agenda 2030 and the Sustainable Development Goals (SDGs). One of the group's recommendations addresses speed compliance *(#7): Zero Speeding.* This highlights that excessive speeds is a major problem in most countries and therefore a main challenge for all governments. In Sweden, it has been estimated that if all drivers complied with the speed limits, the number of fatalities would be reduced by 20–25 % (Vadeby, 2023). To increase speed compliance and reduce mean speeds, increased enforcement is a common measure and many countries have now implemented automated enforcement of speed limits. These camera-based enforcement systems are either spot speed cameras where the speed compliance is enforced at a specific spot or section control where a speed limit is enforced

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automatically in terms of average speed travelled over a section of road.

Earlier studies have investigated the effects of spot cameras as well as section control and found that both spot speed cameras and section control is effective in reducing mean speeds, P85 and speed variations between vehicles, Soole et al. (2013). In many of the studies referred to in Soole et al. (2013), the decrease in P85 was greater than the decrease in mean speed which suggests a change in the shape of the speed distribution. In Vadeby and Forsman (2017), the speed distribution before and after the installation of speed cameras in Sweden was investigated. Comparing the change in the speed distributions at and between cameras, the change was more pronounced at camera sites and for high speeds, meaning that there was a larger displacement of the speed distribution towards lower speeds at cameras than between cameras. However, both at and between cameras a more upright shape of the speed distribution was shown after speed cameras were installed.

Gains et al. (2005) studied the effects on vehicle speed following the introduction of spot speed cameras in the UK and found that the mean speed decreased by 3.7 km/h (6 %) and P85 by 5.0 km/h (7 %). Moreover, the number of speeding offences decreased by 30 % and the proportion of serious offences (more than 24 km/h over the speed limit) decreased by 43 %. Shin et al. (2009) studied the effects of spot speed cameras on a freeway (SR 101) in Arizona and found that mean speed decreased by 14.5 km/h (11.9 %), while P75 decreased by 17.7 km/h (14.7 %) and P25 by 10.1 km/h (9 %), illustrating a change in the shape of the speed distribution. Montella et al. (2015) analysed the effects of section control on the Italian motorway (A56) and reported that the mean speed decreased by 8 km/h (10 %), P85 by 14 %, the proportion of speeding offences by 45 percentage points, and the standard deviation by 26 %.

Previous studies have also measured the effects of spot speed cameras and section control on the number of accidents as well as the number of fatal and non-fatal injuries. Carnis and Blais (2013) reported that fatality rates decreased by 21 % on the whole road network in France following the deployment of the French spot speed camera program. However, it remains unclear how much other traffic safety improvements (e.g., safer vehicles) contributed to this reduction. Li et al. (2013, 2016) evaluated 771 spot speed camera sites in England over nine years. Comparing Empirical Bayes (EB) and Propensity Score Matching (PSM) methods, they recorded reductions in personal injury collisions per kilometer of 23.3 % and 25.9 %, respectively. Furthermore, they found larger reductions close to the cameras (largest within 200 m, but only slightly lower within 200–500 m), as well as no evidence of accident migration. Høye (2014) performed a *meta*-analysis of 15 spot speed camera studies and four section control studies. Spot speed cameras were found to reduce the number of fatal crashes by 51 %, though this result may be affected by regression-to-the-mean effects. The total number of crashes was reduced by about 20 %, with the effect declining with the distance to the camera. Section control was found to reduce killed or seriously injured (KSI) crashes by 56 % and the total number of crashes by 30 %. The analysis also showed that kangaroo driving (excessive braking and acceleration) does occur but does not appear to adversely affect the speed or number of crashes.

Thus, the literature provides strong evidence for the effectiveness of both spot speed cameras and section control in reducing mean speeds and injuries, as well as increasing speed compliance (see e.g., Li et al., 2020, for a more comprehensive literature review). In Sweden, there is a national goal that the number of fatalities should be reduced by 50 % and the number of seriously injured by 25 % during the period 2020–2030. Increased speed compliance has been identified as one of the most important areas to achieve these traffic safety goals. Previous studies have shown that speed compliance on the Swedish national road network is low – only about 50 percent of drivers adhere to the speed limit (Greijer and Nyfjäll, 2020). Therefore, there is a large potential in increasing speed compliance. Since 2006, the Swedish Transport Administration and the Police have been installing a system of fixed digital speed cameras to monitor speed compliance.

The speed cameras system in Sweden is different compared to many other countries. In Sweden, spot speed cameras are almost always placed in series along a road stretch. This means that when effects of speed cameras are studied, we refer both to effects close to individual cameras and effects between cameras, as well as effects on the whole road section. On average, the distance between speed cameras is about 5 km. All cameras are placed visibly, and the speed limit is well signposted before the cameras so that everyone can drive legally. The cameras measure the speed of the vehicle using radar and only takes pictures when someone drives faster than the speed limit. In December 2022 about 2 400 speed cameras were installed on the Swedish state road network covering about 6 000 km of roads. Many of the cameras are installed on rural roads with speed limits of 70, 80, or 90 km/h, though other speed limits (50 km/h in particular) can also be quite common. A prevalent strategy in Sweden for roads with speed limit 90 km/h has been to lower the limit to 80 km/h following the introduction of speed cameras.

1.1. Aim

The aim of this study is to investigate the effects of spot speed cameras set in a series on mean speeds, speed compliance, and on the number of fatalities and seriously injured. Furthermore, three sub-aims are to; (1) compare speed effects at and between cameras, (2) investigate if short-term mean speed decreases are maintained long-term, and (3) evaluate the combined effect of introducing cameras and lowering the speed limit to 80 km/h on roads with speed limit 90 km/h.

2. Methods

2.1. Speed definitions

Effects of speed cameras are studied both close to individual cameras, between cameras and for the whole road section. The measurement's locations are defined as:

- **At camera** – within 250 m before or after the camera in your direction of travel.
- **Between cameras** – more than 250 m after the previous and before the next camera, but within 10 km, in your direction of travel.

Considering that the average length between two cameras in one direction is 5 km, a total effect for a road section is calculated by weighting the effect at camera with 10 % (500 m of 5 km, ± 250 m) and the effect between cameras by 90 %. This weighting is motivated by results from earlier studies which confirms that the effects decline with increasing distance from the cameras and that a distance of ± 250 m is reasonable to represent the effect at cameras (Swedish Road Administration, 2009; Vadeby and Howard, 2022).

2.2. Speed data

Speed data from two applications of speed measurements were used in the study. The data are briefly described below. For a more detailed description see Vadeby and Howard (2022).

1. **Data from national speed measurements.** These data were collected during 2002–2017 and during the summer semester (April–September). The same spots are measured every 4th year and only spots where a measurement was done both before and after a speed camera was installed are included in the analysis. At each spot and year, data were collected during 2–4 days. This dataset includes roads with speed limits of 50, 70 and 90 km/h as well as roads where the speed limit changed from 90 to 80 km/h. The data considered are hourly mean speeds and hourly traffic volumes for each vehicle type.
2. **Targeted speed measurements.** These data were collected on roads that received speed cameras during 2019–2021. Speed

measurements were done during the summer semester. At each site and on each measurement occasion, the speeds of passing vehicles were recorded for one week, both before and after a speed camera was installed. In general, speeds were measured about one month before the speed camera was installed and one year after. This dataset includes roads with speed limits of 70, 80 and 90 km/h. The data considered are speeds from individual vehicles, allowing for calculation of both mean speeds and speed compliance.

Speeds of all vehicles were considered in the analyses and results are reported separately for personal cars, trucks with trailers and all vehicles. In general, the speed measurements are conducted on straight road stretches with a visibility distance above 300 m. Speed data were collected using pneumatic tubes stretched across the road. For both data sets, speed data from all vehicles were studied. However, the roads in question have no congestion, with mostly free speed conditions, and the differences between all vehicles and free speed vehicles are small. The geographical distribution of measurement locations is shown in Fig. 1 and the number of measurement locations per speed limit and at and between cameras for the national and targeted data sets are shown in Table 1. For the road sections with an unchanged speed limit of 50, 70, 80 or 90 km/h, 44 of the 310 measurement locations are located at the

Table 1
The number of measurement locations per speed limit for the two data sets: national and targeted.

Speed limit (km/h) and location	National speed measurements	Targeted speed measurements	Total
50, at cameras	3	–	3
50, between cameras	15	–	15
70, at cameras	7	5	12
70, between cameras	41	7	48
80, at cameras	–	5	5
80, between cameras	–	23	23
90, at cameras	11	13	24
90, between cameras	137	43	180
Total unchanged speed limit	**214**	**96**	**310**
90–80, at cameras	4	–	4
90–80, between cameras	47	–	47
Total changed speed limit	**51**	**–**	**51**
Total	**265**	**96**	**361**

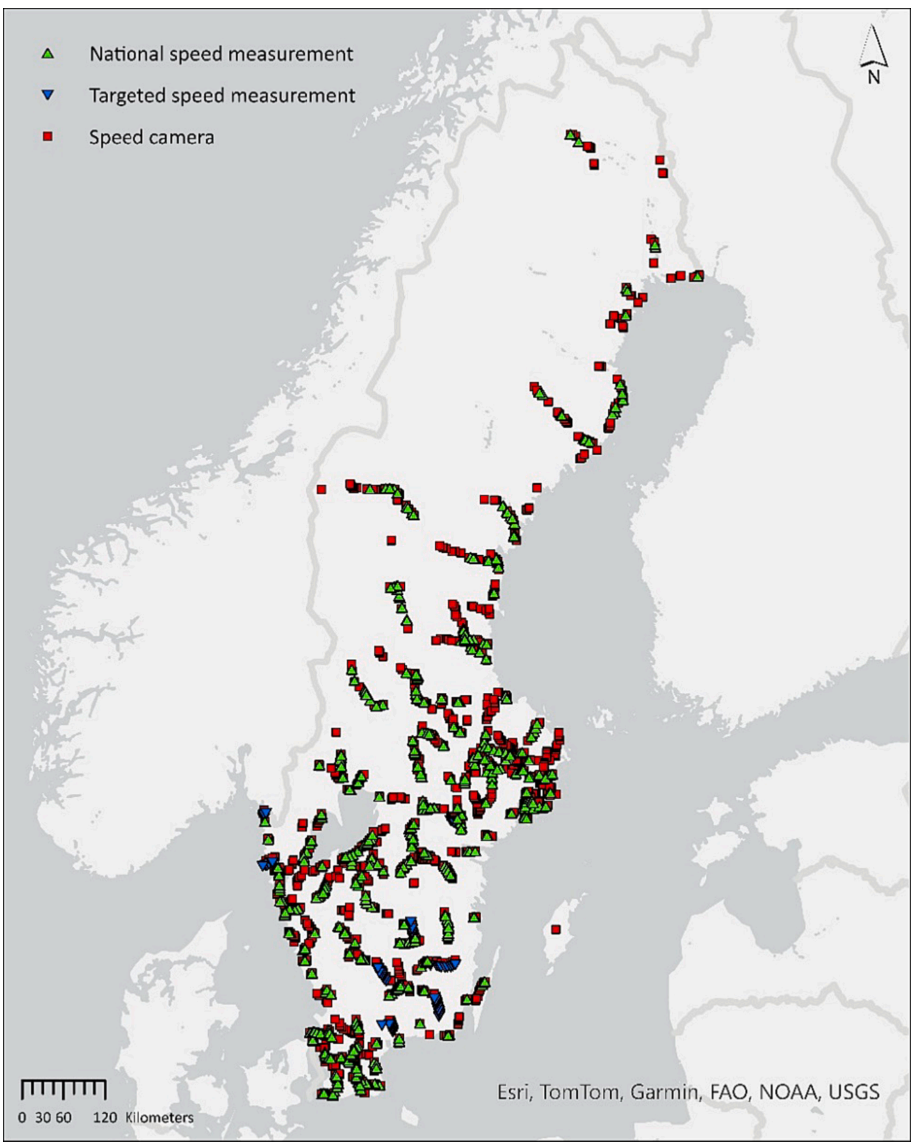

Fig. 1. Speed measurement points and cameras.

camera sites and 266 between camera sites.

2.3. Speed analyses

The parameters considered are mean speed and speed compliance. Separate estimates are calculated for three categories of vehicles: all vehicle types, personal cars, and trucks with trailers. The data from the national measurements are based on hourly mean speeds and the data from the targeted measurements are speed data from individual vehicles. Therefore, speed compliance was only studied based on data from the targeted measurements. The estimates are first calculated separately for the two data sets since the data originally were collected and analysed at separate years.

For the targeted speed measurements, the mean speed, v_i, is estimated for each measurement spot, $i = 1, \ldots, m_{target}$, as:

$$\hat{v}_i = \frac{\sum_j v_{ij}}{\sum_i n_i} \tag{1}$$

where

v_{ij} = speed of vehicle j at measurement spot i.

n_i = number of vehicles at measurement spot i.

For the national speed measurements, where only hourly mean speeds are available, the mean speed, v_i, is estimated for each measurement spot $i = 1, \ldots, m_{national}$ as:

$$\hat{v}_i = \frac{\sum_k n_{ik}\mu_{ik}}{\sum_k n_{ik}} \tag{2}$$

where

μ_{ik} = mean speed for hour k at measurement spot i.

n_{ik} = number of vehicles for hour k at measurement spot i.

For both data sets, the mean speed, V_k, for each speed limit, $k = 50, 70, 80, 90$ and $90–80$ km/h, is calculated as:

$$\hat{V}_k = \frac{\sum_{i=1}^{m_k} w_i \hat{v}_i}{\sum_{i=1}^{m_k} w_i} \tag{3}$$

where

m_k = the number of measurement spots at each speed limit k.

w_i = the number of vehicles per time unit at measurement spot i.

Speed compliance is defined as the proportion of vehicle mileage at or below the speed limit, and is calculated as:

$$x = Q_0/Q, \tag{4}$$

where Q_0 is the total vehicle mileage of vehicles travelling at or below the speed limit and Q is the total vehicle mileage. These calculations need data from individual vehicles and, therefore, data from the targeted speed measurements are used to calculate speed compliance.

Because the same points are studied in the before- and after-period, pairwise differences are used to study changes in the mean speed and speed compliance per speed limit, which reduces the statistical uncertainty. To calculate an average change in the mean speed for the various speed limits, these pairwise differences are weighted by the average hourly traffic flow at each point. Confidence intervals with an approximate confidence level of 0.95 have been calculated based on the normal distribution assumption and the central limit value theorem, see Casella and Berger (1990).

To achieve a general estimate based on the two data sets, data from the different studies are combined, where each study is assumed to carry equal weight. The results from the two data sets are combined in the following way:

1. **A common estimate per speed limit, at camera and between cameras.** The results per speed limit are calculated as:
   - 50 km/h – only based on the national speed measurements
   - 70 km/h – mean of national and targeted measurements
   - 80 km/h – only based on the targeted measurements
   - 90 km/h – mean of national and targeted measurements.
2. **An estimate per speed limit** is calculated by weighting the effect at camera with 10 % (500 m of 5 km) and the effect between cameras by 90 %, i.e.,

$$\textit{Total effect} = 0.1^*(\textit{effect at camera}) + 0.9^*(\textit{effect between cameras}). \tag{5}$$

3. **An estimate for all roads and speed limits** is calculated by weighting together the estimates per speed limit based on traffic volumes (Table 2).

2.4. Long-term effects on speed

To follow up long-term effects, the mean speed at all measurement sites that have had repeated follow-up measurements are studied. This limits the data to the national speed measurements since the targeted measurements only have one after-measurement. Only sites with an unchanged speed limit of 50, 70 or 90 km/h and with three follow-up measurements are included. In total, data from 85 measurement sites meet the above criteria and are used to study long-term effects. On average, there are 3–4 years between the measurements at each site and the average measurement year for the before-period is 2005 and for the three after-measurements 2008, 2012 and 2016.

2.5. Crash data and road section selection

To analyze the effects speed cameras had on the number of fatalities and seriously injured, Police recorded crash data for 2003–2018 were obtained from the Swedish national crash database Strada (Swedish Traffic Accident Data Acquisition). The police are required to record all road traffic accidents involving personal injury occurring on the Swedish road network. The information recorded includes any fatalities or seriously injured, and the GPS-coordinates of where the crash occurred. Who is seriously injured is determined by the police at the scene according to the definition: "…a person who has sustained a fracture, crush, tear, serious cut, concussion or internal injury". Furthermore, the definition extends to persons with other injuries if they are expected to be admitted to hospital.

To determine if a crash occurred on a road section with speed cameras, data for 2003–2018 were obtained from the Swedish national road database NVDB. This data includes road speed limits and Annual Average Daily Traffic (AADT, measured in axel pairs), as well as camera positions, installation and (possible) deinstallation dates. Speed cameras in Sweden are almost always placed in a series and through the NVDB data it was possible to identify 275 road sections where speed cameras were installed during a specific year in the time-period 2003–2018. To further identify speed camera road sections suitable for before-after analysis based on yearly observations, the following inclusion criteria were applied:

- No major changes to the road section (e.g., change of speed limit or rebuilding) at least one year before and one year after camera

Table 2
Proportion of vehicles in 2021 on roads with speed cameras per speed limit. Source: Swedish Transport Administration.

Speed limit (km/h)	Proportion traffic volume
50*	17 %
70	30 %
80	44 %
90**	8 %

* representing roads with 40, 50 and 60 km/h. ** representing roads with 90 and 100 km/h.

Table 3
Summarized data for all road sections included in the before-after analysis.

Speed limit (km/h)	N	Total length (km)	Mean length (km)	Total traffic volume before (miljon axel-pair-km)	Total traffic volume after (miljon axel-pair-km)
50	13	12	0.9	91	141
60	2	1	0.6	6	6
70	31	163	5.3	1 694	3 630
80	27	159	5.9	909	1 095
90	91	1 149	12.6	8 826	19 356
100	1	16	15.7	112	153
110	2	46	23.0	229	151
All above	**167**	**1 546**	**9.3**	**11 866**	**24 532**
90–80	35	264	7.5	2 801	4 092
Control	1 540	1 179	0.8	11 112	17 753

installation. That is, at least one before observation and one after observation for the road section.

- One predominant speed limit on the entire road section (shorter stretches on the road section where the speed limit varied were allowed).
- No previous camera system on the road section (road sections which had an older camera system that was upgraded to the current system were excluded).

Of the initial 275 road sections, 167 matched the criteria above. These 167 road sections, where the speed limit remained unchanged for one or more years both before and after camera installation form the basis for the study. In addition, 35 road sections where the speed was lowered from 90 to 80 km/h when the cameras were installed are studied separately.

To control for other changes during 2003–2018 that might affect fatality and injury outcomes (e.g., safer vehicles), 1 540 road sections with speed limits 50, 70 or 90 km/h that did not receive cameras were selected. These were chosen to match the camera road sections as closely as possible on average in terms of road width (average of 8.8 m for both datasets) and AADT (average of 4 493 vehicles for the camera sections and 6 128 vehicles for the control sections). These two parameters are important because they largely govern how the rural road sections in Sweden are designed. Thus, rural road sections with similar width and AADT share similar features. Though the camera sections have a slightly lower AADT on average, the average vehicle type proportions are almost identical – about 87 % cars/light vehicles and 13 % trucks/heavy vehicles for both datasets.

The speed limits 50, 70, 90 km/h were specifically chosen for the control because they represent most of the camera road sections and have a high likelihood of remaining unchanged during the studied time period. Because the before- and after periods vary for the different speed camera road sections, these were averaged to determine a before- and after period for the control road sections of 2003–2008 and 2010–2018, respectively. Further details on road section selection are available in Vadeby and Howard (2022).

Data for all included road sections are summarized in Table 3. The road sections are illustrated in Fig. 2.

2.6. Empirical Bayes analysis of fatalities and seriously injured

The before-after analysis of fatalities and seriously injured is based on the Empirical Bayes method for estimating safety (e.g., Hauer et al., 2002) with a control dataset to account for trend. The basis for the method is that, to account for regression effects, the recorded number of occurrences (fatalities/seriously injured) are weighted together with the expected number of occurrences. In this study, the method is adapted to the data available in Sweden and modified to calculate one overall effect by weighting together the results from each individual road section. Traffic volumes are used as weights to address that the camera installation years and lengths of the before/after periods differ between the road sections. This, combined with only including unchanged road sections and controlling for general trend (see below), should mitigate possible heterogeneities of effects caused by the study's long time span.

The adjusted (weighted) number of fatalities or seriously injured per road section before camera installation is calculated as:

$$X_{Adj} = vX_{Exp} + (1 - v)X_{Obs} \tag{6}$$

where, X_{Exp}, is the number of occurrences one would normally expect for a road section of its type and, X_{Obs}, is the actual number of occurrences recorded. The weighting factor, v, is calculated through the expected number of occurrences and the dispersion parameter, φ, as

$$v = \frac{1}{1 + X_{Exp}/\varphi}. \tag{7}$$

The expected number of fatalities and seriously injured in this study are partly based on empirical data from the evaluation of new speed limits (Vadeby and Björketun, 2015), and partly on compilations previously made based on accident statistics from Strada, see Vadeby and Howard (2022) for a detailed description. These apply approximately to the time periods being studied. The dispersion parameter was estimated from the 1 540 control road sections (moment estimation assuming a negative binomial distribution).

The camera effect is determined by calculating the fatality/seriously injured ratios before and after. For road section i let.

x_i = the observed (or adjusted) number of fatalities/seriously injured in the before period.

y_i = the observed number of fatalities/seriously injured in the after period.

c_i = traffic volume in the before period (AADT*road section length*365*number of years).

d_i = traffic volume in the after period (AADT*road section length*365*number of years).

The fatality/seriously injured ratios before and after, Q_B *and* Q_A, are calculated as

$$Q_B = \frac{\sum_i x_i}{\sum_i c_i} \tag{8}$$

and

$$Q_A = \frac{\sum_i y_i}{\sum_i d_i}. \tag{9}$$

The percentage change after camera installation is then given by

$$\frac{Q_A}{Q_B} - 1 = \frac{\sum_i c_i}{\sum_i d_i} * \frac{\sum_i y_i}{\sum_i x_i} - 1. \tag{10}$$

When x_i are adjusted for regression effects the corresponding ratio is denoted by $\widetilde{Q}_B$. Calculating the before- and after ratio (denoted by K_B and K_A) for the control road sections analogously, the overall effect is

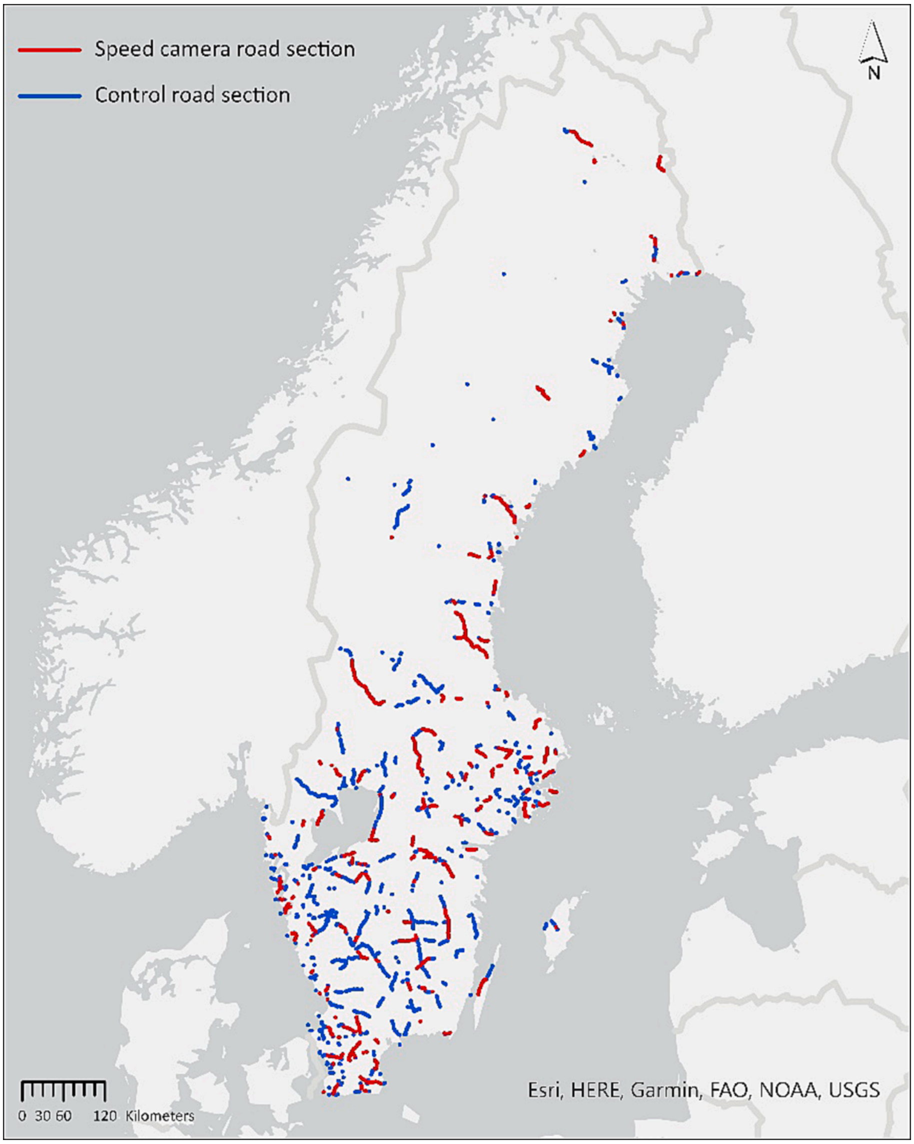

Fig. 2. Speed camera road sections.

given by

$$Effect = 1 - \frac{Q_A \Big/ \widetilde{Q}_B}{K_A / K_B}. \tag{11}$$

Note that the effect is formulated as the expected relative decrease in fatalities/seriously injured and, therefore, a larger value means a larger reduction.

The confidence interval for the effect is approximated by assuming a normal distribution, where the mean and variance are calculated through Taylor expansion. That is, if the sums $X = \sum_i x_i$ and $Y = \sum_i y_i$ are Poisson distributed, independent, and the traffic volume is constant, the mean and variance of the effect can be approximated by applying the formulas below (e.g., Stuart and Ord, 1994)

$$E\left(\frac{Y}{X}\right) = \frac{E(Y)}{E(X)} + \frac{V(X)E(Y)}{E(X)^3}$$

$$V\left(\frac{Y}{X}\right) = \frac{V(Y)}{E(X)^2} + \frac{E(Y)^2 V(X)}{E(X)^4}. \tag{12}$$

2.7. Speed and crashes – Exponential model

As a comparison to the analyses based on crash statistics from Strada an estimate of changes in crash risk is calculated via the Exponential model. The aim is to estimate how a change in mean speed affects the outcome of the number of fatalities and seriously injured. The Exponential model describes the relationship between a speed change and accidents using an exponential function:

$$\frac{y_A}{y_B} = e^{\beta(v_A - v_B)} \tag{13}$$

where y_B and y_A are the number of fatalities or seriously injured before and after the speed change, v_B and v_A are the mean speed before and after the speed change, and β is a coefficient estimated for seriously injured in Elvik (2014) and for fatalities in Elvik et al. (2019). The coefficients used in this study are $\beta = 0.08$ (SE = 0.003) for fatalities and $\beta = 0.06$ (SE = 0.004) for seriously injured.

3. Results

The effects of spot speed cameras in a series on speed as well as on fatalities and seriously injured are presented below. Additionally, based

Table 4
Mean speed (km/h) for all vehicles before and after speed cameras were installed, at cameras and between cameras. All speed limits (50, 70, 80 and 90 km/h). 95 % confidence interval.

Category	No of sites	Before (km/h)	After (km/h)	Change (95 % CI)
All vehicles, at camera	44	75.6	67.7	−7.9 ± 2.3
All vehicles, between cameras	266	75.6	72.6	−3.0 ± 0.7
All vehicles, total effect	**310**	**75.6**	**72.1**	**−3.5 ± 0.6**

Table 5
Mean speed (km/h) for all vehicles before and after speed cameras were installed per speed limit (50, 70, 80 and 90 km/h) and on roads with changed speed limit 90–80 km/h.

Category	No of sites	Before (km/h)	After (km/h)	Change (95 % CI)
All vehicles, 50 km/h	18	55.0	52.5	−2.6 ± 1.7
All vehicles, 70 km/h	60	73.7	70.2	−3.5 ± 1.4
All vehicles, 80 km/h	28	83.4	79.5	−3.9 ± 0.9
All vehicles, 90 km/h	204	90.1	87.1	−3.0 ± 0.3
All vehicles, 90–80 km/h	51	86.9	79.7	−7.1 ± 1.3

on the estimated speed changes, the change in fatalities and seriously injured is estimated using the Exponential model.

3.1. Mean speeds

Table 4 shows mean speeds before and after speed cameras were installed as well as the change for all speed limits combined, i.e., the total effect on the entire road network with speed cameras in Sweden. Considering all vehicles on the whole road section (total effect), the mean speed was reduced by 3.5 km/h. At cameras the reduction was 7.9 km/h and between cameras it was 3.0 km/h. Results for passenger cars and trucks with trailers are provided in Annex 1.

In Table 5, mean speeds before and after speed cameras were installed as well as the change per speed limit are shown. On roads with speed limit 50, 70, 80, and 90 km/h, the mean speed decreased by 2.6, 3.5, 3.9 and 3.0 km/h, respectively. Mean speed changes for cars and trucks with trailers are provided in Annex 1. The changes in mean speed are smaller for trucks with trailers, that in Sweden have a maximum speed limit of 80 km/h. For roads that received both a decreased speed limit from 90 to 80 km/h and speed cameras, the mean speeds decreased additionally by 3.6 km/h compared to roads where the speed limit remained unchanged at 90 km/h during the study period. The change for these roads was −7.1 km/h.

3.2. Speed compliance

Table 6 shows speed compliance before and after speed cameras were installed as well as the change for all speed limits (70, 80 and 90 km/h) combined. These calculations need data from individual vehicles and, therefore, only data from the targeted speed measurements are used for these calculations. Considering all vehicles on the whole road section (total effect), speed compliance increased almost 16 %-units. At cameras the increase was 41.6 %-units and between cameras it was 13.1 %-units. Results for passenger cars and trucks with trailers are provided in Annex 1.

Table 7
Speed compliance (%) for all vehicles before and after speed cameras were installed per speed limit (70, 80 and 90 km/h).

Category	No of sites	Before (%)	After (%)	Change (95 % CI)
All vehicles, 70 km/h	12	34.9	46.7	11.8 ± 3.7
All vehicles, 80 km/h	28	41.8	61.3	19.5 ± 2.6
All vehicles, 90 km/h	56	55.3	67.1	11.7 ± 1.6

In Table 7, speed compliance before and after speed cameras were installed as well as the change per speed limit is shown. On roads with speed limits of 70, 80 and 90 km/h, speed compliance increased by 11.8, 19.5 and 11.7 %-units, respectively. Changes for cars and trucks with trailers are provided in Annex 1.

3.3. Long-term effects on speed

The results regarding long-term effects on speed are shown in Table 8. At cameras, the mean speed decreased by 6.1 km/h when the cameras were installed (after 1) and remained basically unchanged (−0.2, −0.1, not significant) between the three consecutive after-measurements. Between cameras, the decrease was 3.2 km/h between the before and the first after-measurement and essentially unchanged (−0.3, not significant) between the three after-measurements. The results show that the lower mean speed on roads with traffic safety cameras was maintained during the studied period.

It can be noted that the mean speed before the introduction of speed camera is higher **between** cameras than **at** cameras. This is because the speed limit is higher between cameras at the studied measurement sites.

3.4. Fatalities and seriously injured

The observed, expected and adjusted fatality ratios are presented in Table 9. Note that some of the speed limit categories contain very few road sections. Therefore, comparisons between speed limits should be made with caution. Table 10 presents the ratios for persons seriously injured. In general, the data suggest that there has been a larger reduction in fatalities compared to seriously injured.

Incorporating the results from the control road sections, Table 11 presents the camera effects for all speed limits combined and for 90–80 separately. The data for all speed limits show that the cameras have had an average effect of 38.6 % on decreasing fatalities. The data may also suggest a decrease for seriously injured, though the recorded 15.2 % is not statistically significant. For 90–80, the effects are larger than for all speed limits and statistically significant for both fatalities and seriously injured, at 61.6 % and 33.4 % respectively.

Table 6
Speed compliance (%) for all vehicles before and after speed cameras were installed, at cameras and between cameras. Speed limits 70, 80 and 90 km/h. 95 % confidence interval.

Category	No of sites	Before (%)	After (%)	Change (95 % CI)
All vehicles, at camera	23	39.8	81.4	41.6 ± 3.1
All vehicles, between cameras	73	40.7	53.7	13.1 ± 2.1
All vehicles, total effect	**96**	**40.6**	**56.5**	**15.9 ± 1.9**

Table 8
Long-term mean speed effects of speed cameras. Measurements at camera, between cameras and total. N = 85.

Camera location	No of sites	Mean speed (km/h)				Difference (km/h)		
		Before	After 1	After 2	After 3	After 1 − Before (SD)	After 2 − After 1 (SD)	After 3 − After 2 (SD)
At	12	69.8	63.8	63.6	63.5	−6.1 (1.3)	−0.2 (0.5)	−0.1 (0.9)
Between	73	74.9	71.7	71.5	71.1	−3.2(0.3)	−0.3 (0.4)	−0.3 (0.3)
Total	**85**	**74.1**	**70.4**	**70.2**	**69.9**	**−3.6 (0.4)**	**−0.3 (0.3)**	**−0.3 (0.3)**

Table 9
Average number of fatalities per 100 million axel pair kilometers.

Speed Limit (km/h)	N	Total km	Observed Q_B	Expected Q_B	Adjusted $\widetilde{Q}_B$	Observed Q_A	$Q_A/\widetilde{Q}_B$-1
50	13	12	2.20	0.40	1.44	0.00	−100 %
60	2	1	0.00	0.55	0.21	0.00	−100 %
70	31	163	1.06	0.80	0.99	0.36	−64 %
80	27	159	0.55	0.40	0.44	0.27	−37 %
90	91	1149	1.26	0.70	1.16	0.51	−56 %
100	1	16	0.00	0.50	0.13	0.65	392 %
110	2	46	0.00	0.50	0.13	0.00	−100 %
All above	**167**	**1546**	**1.15**	**0.68**	**1.05**	**0.47**	**−55 %**
90–80	35	264	1.21	0.70	1.13	0.32	−72 %

3.5. Empirical Bayes sensitivity analysis

Two sources of uncertainty when applying the Empirical Bayes methodology are if the expected values for the number of fatalities or seriously injured (used to calculate Q_B and, in turn, $\widetilde{Q}_B$) and the dispersion parameter (φ) accurately capture the road network studied. To show how changes to these parameters influence the results, the camera effects are plotted for different percentage changes in Figs. 3 and 4. The flat curves show that the method used in this study is robust to errors in these parameters. The largest effect changes are seen when changing the expected values for fatalities, all speed limits. However, even in this case, a −25 % or 25 % value change still only results in a −3.8 or 2.3 percentage point effect change.

3.6. Speed and crashes - Exponential model

By means of the Exponential model (Elvik, 2014, Elvik et al., 2019), an estimate of how many fatalities and seriously injured that can be saved are calculated. The exponential model uses the difference in mean speed between the after- and before-period to estimate effects on the number of killed and seriously injured. The mean speed change used in the model are presented in Table 4. The results show that according to the Exponential model and the average speed changes calculated in the present study, the number of fatalities is reduced by 24 % and severely injured by 19 %, see Table 12.

4. Discussion

This study sought to investigate the effects of spot speed cameras set in a series on mean speeds, speed compliance, and on the number of fatalities and seriously injured. The results show an increased speed compliance and a comprehensive reduction in mean speeds and in the number of fatalities.

One advantage with the present study is the scope. Regarding speed measurements, speeds have been measured at 361 different spots on camera enforced roads distributed all over Sweden in two different studies together spanning 20 years. The same goes for the traffic safety effects regarding fatalities and seriously injured. Camera enforced road sections distributed across Sweden were included. In total, 167 road sections with unchanged speed limits and an additional 35 road sections

Table 10
Average number of seriously injured per 100 million axel pair kilometers.

Speed Limit (km/h)	N	Total km	Observed Q_B	Expected Q_B	Adjusted $\widetilde{Q}_B$	Observed Q_A	$Q_A/\widetilde{Q}_B$-1
50	13	12	15.37	5.50	13.86	9.95	−28 %
60	2	1	16.75	3.60	14.52	0.00	−100 %
70	31	163	9.21	5.00	8.69	4.77	−45 %
80	27	159	3.08	3.00	2.91	1.64	−43 %
90	91	1149	4.45	3.00	4.42	2.69	−39 %
100	1	16	0.90	3.00	1.07	1.31	22 %
110	2	46	1.75	3.00	1.83	1.33	−28 %
All above	**167**	**1546**	**5.03**	**3.31**	**4.91**	**2.97**	**−39 %**
90–80	35	264	4.39	3.00	4.37	2.08	−52 %

Table 11
Effects on fatalities and seriously injured.

Category	N	Total km	$Q_A/\widetilde{Q}_B$	K_A/K_B	Effect $1-\left(Q_A/\widetilde{Q}_B\right)/(K_A/K_B)$	CI 95 %
Fatalities, all speed limits	167	1546	0.45	0.73	38.6 %	± 25.2 %
Seriously injured, all speed limits	167	1546	0.61	0.71	15.2 %	± 15.6 %
Fatalities, 90–80	35	264	0.28	0.73	61.6 %	± 17.5 %
Seriously injured, 90–80	35	264	0.48	0.71	33.4 %	± 13.7 %

Note. Effects refer to speed camera effects for categories “all speed limits” and combined speed camera and speed limit reduction effects for categories “90–80”.

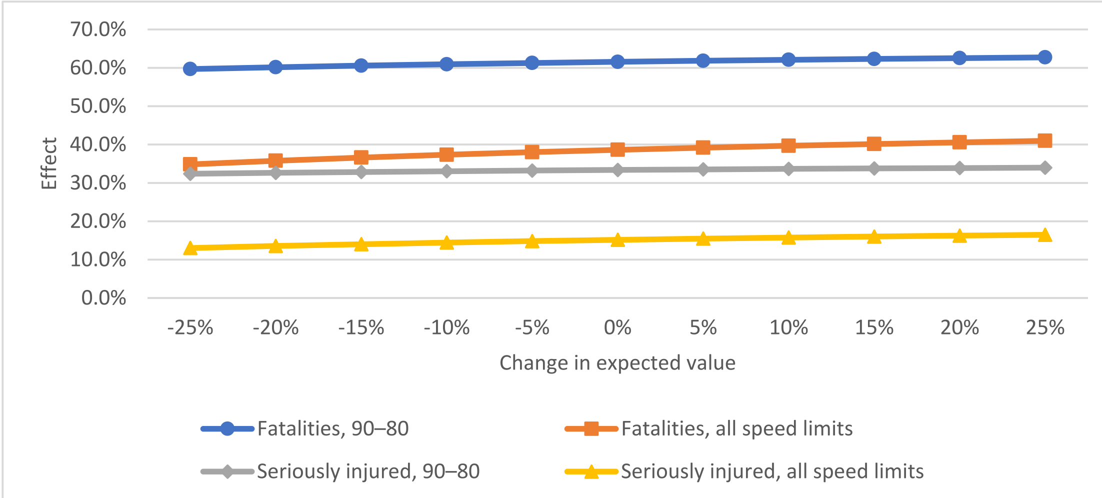

Fig. 3. Effect results for different changes in the expected value.

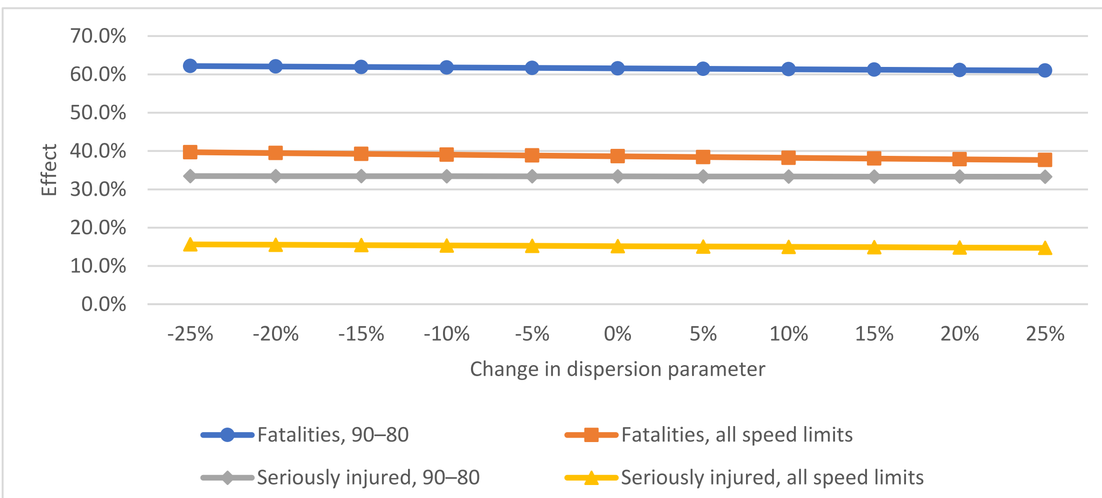

Fig. 4. Effect results for different changes in the dispersion parameter.

Table 12
Estimated effects (relative reduction) of speed cameras on the number of fatalities and seriously injured according to the Exponential model (Elvik, 2014, Elvik et al., 2019).

Category	Effect (relative reduction)	CI 95 %
Fatalities	24 %	±4 %
Seriously injured	19 %	±3 %

where the speed limit was lowered from 90 to 80 km/h are studied over 16 years. To control for other changes that might affect fatality and injury outcomes during these 16 years a control data set consisting of 1 540 road sections with speed limits 50, 70 or 90 km/h that did not receive cameras were also included in the study.

The strategy used by Sweden with spot speed cameras in a series is different compared to strategies in most other countries where it is more common to use either spot speed cameras or section control. However, the results from this study seem to harmonise with previous studies. Regarding mean speed changes, a decrease of 3.5 km/h for all vehicles and all road sections was found, 7.9 km/h at cameras and 3.0 km/h between cameras. Mean speed reduction varied slightly depending on the speed limit where 80 km/h saw the largest reductions at 3.9 km/h. Speed compliance increased 16 %-units, 42 %-units at cameras and 13 %-units between cameras. Again, the speed limit of 80 km/h saw the largest improvement with a 20 %-unit increase. Previous studies from the UK evaluating spot speed cameras found that the mean speed decreased by 3.7 km/h (Gains et al., 2005), on a freeway in Arizona mean speed decreased by 14.5 km/h (Shin et al., 2009) while Montella et al. (2015) analysed the effects of section control in Italy and reported that the mean speed decreased by 8 km/h. An earlier Swedish study where the effect of 700 speed cameras were evaluated showed that they decreased the mean speed by 3.6 km/h (Swedish Road Administration, 2009).

Though larger effects can be seen at cameras, there are still substantial effects on the enforced road sections between cameras. This means that, between the cameras, the drivers do not compensate for the decreased speed at cameras. Earlier studies in Sweden, Vadeby and Forsman (2017), have shown that the change of the speed distribution was more pronounced at camera sites and for high speeds, but both at and between cameras the speed distribution was shifted towards lower speeds and a more upright shape of the speed distribution was shown after speed cameras were installed.

The cameras have had an average effect of 38.6 % on decreasing fatalities and may also suggest a decrease for seriously injured, though not statistically significant. Comparing these results to previous studies, a *meta*-analysis of 15 spot speed camera studies and four section control studies showed that spot speed cameras were found to reduce the number of fatal crashes by 51 %, with the effect declining with the distance to the camera (Høye, 2014). Section control was found to reduce killed or seriously injured (KSI) crashes by 56 %. Note, however, that the former result may be influenced by regression-to-the-mean effects and that comparisons between the number of persons and crashes is not one-to-one.

A prevalent strategy in Sweden for roads with speed limit 90 km/h has been to lower the limit to 80 km/h following the introduction of speed cameras. This study shows that for roads that have received both a decreased speed limit from 90 to 80 km/h and speed cameras, the mean speeds were reduced by additionally 3.6 km/h compared to roads where the speed limit remained unchanged 90 km/h, with a total reduction of 7.1 km/h. These results show the combined effect of the two measures and are in line with previous results from an evaluation of new speed limits where it was shown that the mean speed decreased by 3.3 km/h when the speed limit was lowered from 90 to 80 km/h (Vadeby and Forsman, 2014). The combined effect is also evident when fatalities and seriously injured are studied. This study shows that the combined effect on fatalities and seriously injured was a reduction by 61.6 % and 33.4 %, respectively, compared to 38.6 % and 15.2 % on roads where the speed limit remained unchanged.

The estimated effects on fatalities and seriously injured based on the Empirical Bayes methodology was compared to estimates obtained by the Exponential model. The Exponential model uses the difference in mean speed between the after- and before-period to estimate effects on the number of killed and seriously injured. The results from the Exponential model showed somewhat lower effects on fatalities compared to the EB-study (a reduction of 24 % to 39 %), but the confidence intervals are wide and the differences are not statistically significant.

Regarding limitations to the study, the speed data were collected from two different studies and for the national measurements it was not possible to control the placement of measuring spots. Furthermore, only hourly mean speed data were available from this dataset. Therefore, the proportion of speed violations cannot be estimated from these data. However, by using these data, a large national coverage of speed measurements is achieved and it seems reasonable to assume that the similar results on mean speed changes between the two studies carry over to speed violations as well. The general mean speed effect estimate based on combining the two data sets assumes that each study carries equal weight. A sensitivity analysis with different weights instead reflecting the number of measurements spots per speed limit and study was performed and showed only minor impacts on the results, changing the total estimate by 0.1 km/h.

Both the national speed measurements as well as the EB–study of crashes span over many years, making the results susceptible to other changes to the road network than the ones studied. The main changes to the rural road network in Sweden are a change of speed limits (Vadeby and Forsman, 2014) and that some roads have been rebuilt into 2 + 1 roads (Vadeby, 2016). This is positive for road safety but makes the evaluation more difficult and therefore extensive work based on information from the national road data base (NVDB) has been carried out in this study to ensure that the road sections included in the evaluation are unchanged in terms of both road type and speed limit.

The Empirical-Bayes methodology assumes that the normal crash outcome and over-dispersion parameters for the sections in question are known. The estimates used in this study are relatively uncertain, but the sensitivity analysis shows that possible misestimations do not significantly affect the results. This is most likely due to the large number of road sections and long time period studied, which should reduce regression-to-the-mean effects and, in turn, make the adjustments less impactful.

Finally, it is possible that using police reported injury data, which is less reliable than healthcare data, contributed to the inconclusive result regarding the effect on seriously injured. However, healthcare data suitable for Empirical Bayes before-after crash analysis was not available for this study. Nonetheless, Sweden does incorporate healthcare data in Strada and the number of hospitals with emergency care facilities reporting to Strada has gradually increased to reach nationwide coverage in 2016. This opens the possibility for future research to include more accurate injury data.

5. Conclusions

This study found that the Swedish strategy with spot speed cameras in a series led to an increased speed compliance and a comprehensive reduction in mean speeds and of the number of fatalities.

Overall, mean speeds were reduced by 3.5 km/h. The effects were strongest at the camera where mean speeds decreased by 7.9 km/h compared to 3.0 km/h between cameras. Furthermore, follow-up measurements for a subset of points showed that effects were maintained long-term.

The results also show that the speed cameras increased speed compliance – both at and between cameras. In total, speed compliance increased by 16 %-units, with a higher increase of 42 %-units close to the cameras compared to 13 %-units between cameras.

Regarding the speed cameras' effect on injury outcomes, the results show a 39 % decrease of the number of persons fatally injured and a 15 % decrease of the number of persons seriously injured. However, the effect for seriously injured was not statistically significant.

Finally, the combined effect of a reduced speed limit from 90 to 80 km/h and speed cameras was notably larger on both the mean speed and the injury outcomes, where the total mean speed was reduced by 7.1 km/h, and the fatalities and seriously injured were reduced by 62 % and 33 %, respectively.

CRediT authorship contribution statement

Anna Vadeby: Writing – review & editing, Writing – original draft, Visualization, Validation, Project administration, Methodology, Investigation, Funding acquisition, Formal analysis, Data curation, Conceptualization. **Christian Howard:** Writing – review & editing, Writing – original draft, Visualization, Validation, Methodology, Investigation, Formal analysis, Data curation, Conceptualization.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data availability

The authors do not have permission to share data.

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Annex 1.

Mean speed and speed compliance for cars and trucks with trailers

Table 13
Mean speed before and after speed cameras were installed for cars and trucks with trailers, at cameras and between cameras. All speed limits (50, 70, 80 and 90 km/h). 95 % confidence interval.

Category	No of sites	Before	After	Change (95 % CI)
Cars, at camera	44	75.8	67.6	−8.2 ± 2.4
Cars, between cameras	266	75.9	72.9	−3.1 ± 0.7
Cars, total effect	**310**	**75.9**	**72.3**	**−3.6 ± 0.6**
Trucks with trailer, at camera	44	74.0	68.4	−5.6 ± 1.6
Trucks with trailer between camera	266	72.5	71.2	−1.3 ± 0.7
Trucks with trailer, total effect	310	72.6	70.9	−1.7 ± 0.7

Table 14
Mean speed before and after speed cameras were installed for cars and trucks with trailers per speed limit (50, 70, 80 and 90 km/h) and for cars on roads with changed speed limit 90–80 km/h.

Category	No of sites	Before	After	Change (95 % CI)
Cars, 50 km/h	18	55.1	52.6	−2.6 ± 1.7
Trucks with trailer, 50 km/h	18	52.0	50.0	−2.0 ± 1.5
Cars, 70 km/h	60	74.0	70.4	−3.6 ± 1.4
Trucks with trailer, 70 km/h	60	71.0	69.4	−1.6 ± 1.5
Cars, 80 km/h	28	83.7	79.6	−4.1 ± 0.8
Trucks with trailer, 80 km/h	28	81.1	79.3	−1.8 ± 0.9
Cars, 90 km/h	204	91.2	88.0	−3.3 ± 0.3
Trucks with trailer, 90 km/h	204	82.3	81.4	−1.0 ± 0.3
Cars, 90–80 km/h	51	87.5	79.9	−7.6 ± 1.3

Table 15
Speed compliance **(%)** before and after speed cameras were installed for cars and trucks with trailers, at cameras and between cameras. Speed limits 70, 80 and 90 km/h. 95 % confidence interval.

Category	No of sites	Before (%)	After (%)	Change (95 % CI)
Cars, at camera	23	39.0	82.1	43.1 ± 3.1
Cars, between camera	73	39.4	52.9	13.4 ± 2.2
Cars, total effect	**96**	**39.4**	**55.8**	**16.4 ± 2.0**
Trucks with trailer, at camera	23	31.4	60.3	28.9 ± 3.3
Trucks with trailer between camera	73	37.2	45.5	8.3 ± 2.1
Trucks with trailer, total effect	**96**	**36.6**	**47.0**	**10.4 ± 1.9**

Table 16
Speed compliance (%) before and after speed cameras were installed for cars and trucks with trailers per speed limit (70, 80 and 90 km/h).

Category	No of sites	Before (%)	After (%)	Change (95 % CI)
Cars, 70 km/h	12	34.5	46.2	11.7 ± 3.7
Trucks with trailer, 70 km/h	12	34.9	42.9	8.0 ± 3.3
Cars, 80 km/h	28	41.1	61.1	20.1 ± 2.6
Trucks with trailer, 80 km/h	28	39.0	52.3	13.3 ± 2.8
Cars, 90 km/h	56	48.7	62.4	13.7 ± 1,7
Trucks with trailer, 90 km/h	56	29.7	32.8	3.1 ± 1.8

References

Carnis, L., Blais, E., 2013. An assessment of the safety effects of the french speed camera program. Accid. Anal. Prev. 51, 301–309. https://doi.org/10.1016/j.aap.2012.11.022.

Casella, G., Berger, R.L., 1990. Statistical inference. Duxbury Press, Belmont, California.

Elvik, R., 2013. A re-parameterisation of the power model of the relationship between the speed of traffic and the number of accidents and accident victims. Accid. Anal. Prev. 50, 854–860. https://doi.org/10.1016/j.aap.2012.07.012.

Elvik, R., Vadeby, A., Hels, T., van Schagen, I., 2019. Updated estimates of the relationship between speed and road safety at the aggregate and individual levels. Accid. Anal. Prev. 123, 114–122. https://doi.org/10.1016/j.aap.2018.11.014.

Elvik, R., 2014. Speed and road safety - new models (in Norwegian). TØI report 1296/2014.

Gains, A., Nordstrom, M., Heydecker, B.G., Shrewsbury, J., 2005. The national safety camera programme: four-year evaluation report. PA Consulting Group and University College London.

Hauer, E., Harwood, D., Council, F., Griffith, M., 2002. Estimating safety by the Empirical Bayes method. A tutorial. Transp. Res. Rec. 1784 paper 02-2181.

Høye, A., 2014. Speed cameras, section control, and kangaroo jumps – a meta-analysis. Accid. Anal. Prev. 73, 200–208. https://doi.org/10.1016/j.aap.2014.09.001.

Li, H., Graham, D.J., 2016. Heterogeneous treatment effects of speed cameras on road safety. Accid. Anal. Prev. 97, 153–161. https://doi.org/10.1016/j.aap.2016.09.007.

Li, H., Graham, D.J., Majumdar, A., 2013. The impacts of speed cameras on road accidents: an application of propensity score matching methods. Accid. Anal. Prev. 60, 148–157. https://doi.org/10.1016/j.aap.2013.08.003.

Li, H., Zhu, M., Graham, D.J., Zhang, Y., 2020. Are multiple speed cameras more effective than a single one? Causal analysis of the safety impacts of multiple speed cameras. Accid. Anal. Prev. 139 https://doi.org/10.1016/j.aap.2020.105488.

Montella, A., Imbriani, L.L., Marzano, V., Mauriello, F., 2015. Effects on speed and safety of point-to-point speed enforcement systems: evaluation on the urban motorway A56 tangenziale di napoli. Accid. Anal. Prev. 75, 164–178. https://doi.org/10.1016/j.aap.2014.11.022.

Greijer, Å., Nyfjäll, M., 2020. Speed survey 2020, report on results (in Swedish). Trafikverket publikation 2020:267. Borlänge.

OECD/ITF, 2018. Road Safety - Annual Report 2018.

Shin, K., Washington, S.P., van Schalkwyk, I., 2009. Evaluation of the Scottsdale loop 101 automated speed enforcement demonstration program. Accid. Anal. Prev. 41 (3), 393–403. https://doi.org/10.1016/j.aap.2008.12.011.

Soole, D.W., Watson, B.C., Fleiter, J.J., 2013. Effects of average speed enforcement on speed compliance and crashes: a review of the literature. Accid. Anal. Prev. 54, 46–56. https://doi.org/10.1016/j.aap.2013.01.018.

Stuart, A., Ord, K., 1994. Kendall's Advanced Theory of Statistics, Distribution Theory Volume 1. Wiley, 6th edition.

Swedish Road Administration, 2009. The effects of automated road safety cameras on speed and traffic safety. Publication 2009:162, Borlänge.

Swedish Transport Administration (Trafikverket), 2020. Saving Lives Beyond 2020 The Next Steps Recommendations of the Academic Expert Group for the Third Ministerial Conference on Global Road Safety 2020.

Vadeby, A., 2016. Traffic safety effects of narrow 2+1 roads with median barrier in Sweden. Proceedings of the 17th International Conference on Road Safety on Five Continents, Rio De Janeiro.

Vadeby, A., 2023. How many lives could be saved if everyone complied with the speed limit? a case study from Sweden. Transp. Res. Procordia 72, 3024–3030. https://doi.org/10.1016/j.trpro.2023.11.850.
Vadeby, A., Björketun, U., 2015. New speed limits in Sweden - long term traffic safety effects (in Swedish). VTI report 860 - 2015. VTI. Linköping.
Vadeby, A., Howard, C., 2022. Speed Cameras in Sweden. Effects on Speed and Traffic Safety (in Swedish). VTI report 1107. VTI. Linköping.
Vadeby, A., Forsman, Å., 2014. Evaluation of new speed limits in Sweden: a sample survey. Traffic Inj. Prev. 15 (8), 778–785. https://doi.org/10.1080/15389588.2014.885650.
Vadeby, A., Forsman, Å., 2017. Changes in speed distribution: applying aggregated safety effect models to individual vehicle speeds. Accid. Anal. Prev. 103, 20–28. https://doi.org/10.1016/j.aap.2017.03.012.