Effects of Automated Speed Enforcement in Montgomery County, Maryland, on Vehicle Speeds, Public Opinion, and Crashes

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Abstract

Objectives: In May 2007, Montgomery County, Maryland, implemented the state's first automated speed enforcement program, with camera use limited to residential streets with speed limits of 35 mph or less and school zones. Changes were made to the program over time. In 2009, a state speed camera law increased the enforcement threshold and restricted school zone enforcement hours. In 2012, the county began using a corridor approach, in which cameras were periodically moved along the length of a roadway segment. The current study evaluated the long-term effects of the speed camera program on travel speeds, public attitudes, and crashes.

Methods: Changes in measured travel speeds at camera sites from 6 months before the speed camera program began (fall 2006) to 7½ years after (fall 2014) were compared with changes in speeds at control sites in the nearby Virginia counties of Fairfax and Arlington. A telephone survey of Montgomery County drivers was conducted in fall 2014 to examine attitudes and experiences related to automated speed enforcement. Using data on crashes during the years 2004-2013, logistic regression was conducted to examine the effects of the program on the likelihood that a crash involved an incapacitating or fatal injury and on the likelihood that a crash was speeding-related on camera-eligible roads and on potential spillover roads in Montgomery County, using crashes in Fairfax County as controls.

Results: About 7½ years after the program began, speed cameras were associated with a 10 percent reduction in mean speeds and a 59 percent reduction in the likelihood that a vehicle was traveling more than 10 mph above the speed limit at camera sites. When interviewed in fall 2014, 95 percent of drivers were aware of the camera program, 62 percent favored it, and most drivers had received a camera ticket or knew someone else who had. The overall effect of the camera program in its modified form, including both the law change and the corridors, was a 39 percent reduction in the likelihood that a crash resulted in an incapacitating or fatal injury. Speed cameras alone were associated with a 19 percent reduction in the likelihood that a crash resulted in an incapacitating or fatal injury, the law change was associated with a non-significant 8 percent increase, and the corridor approach provided an additional 30 percent reduction over and above the cameras.

Conclusions: This study adds to the evidence that speed cameras can reduce speeding, speeding-related crashes, and crashes involving serious injuries or fatalities.

Keywords: Speed cameras, Speeds, Public opinions, Crashes

1. Introduction

Speeding is common and viewed as acceptable behavior by many drivers, but it persists as a major factor in motor vehicle crashes, especially those resulting in serious injuries (Elvik, 2005). In the United States, speeding — defined as driving too fast for conditions, exceeding posted speed limits, or racing — has consistently been involved in about one-third of crash deaths. In 2013 alone, more than 9,600 people died in speeding-related crashes (Insurance Institute for Highway Safety (IIHS), 2014). Although speeding is often associated with travel on interstates and other high-speed roads, more than 80 percent of speeding-related fatalities occur on other types of roads. In 2013, 25 percent of all speeding-related fatalities occurred on streets with speed limits of 35 mph or less.

Publicized traditional police enforcement has been shown to reduce vehicle travel speeds and crashes (Stuster, 1995), although the effects can be localized and temporary unless increased enforcement is sustained (Barnes, 1984; Hauer et al., 1982). However, many enforcement agencies do not have sufficient resources to mount and sustain publicized speed enforcement programs. Between 1995 and 2013, the estimated number of vehicle miles traveled in the United States increased by 23 percent (Federal Highway Administration, 2014), but the number of law enforcement officers grew by only about 7 percent (Federal Bureau of Investigation, 1995, 2013). Traditional speed enforcement also can be difficult, if not hazardous, at some locations and times of the day and during periods of heavy traffic. In a survey of U.S. drivers, about 1 in 10 reported being stopped for speeding during the past year, even though 70 percent were identified as habitual or sometime speeders (National Highway Traffic Safety Administration, 2013).

Speed cameras are widely used around the world as a supplement to traditional police enforcement of speed limits. Speed cameras monitor traffic speeds and photograph vehicles traveling above specified speeds, usually at thresholds set well above the speed limit. Mobile cameras are accompanied by enforcement personnel and may be moved among various locations; fixed cameras monitor speeds at specific locations and are unaccompanied by officers.

Speed cameras can substantially reduce speeding violations and injury crashes (Decina et al., 2007; Pilkington and Kinra, 2005; Wilson et al., 2010). A systematic review of studies of speed camera effectiveness, mostly conducted in Europe or Australia, reported 14-65 percent reductions in the percentage of vehicles traveling above the speed limits or above designated speed thresholds relative to controls (Wilson et al., 2010). Crash reductions associated with speed camera enforcement ranged 8-49 percent, with 8-50 percent reductions in injury crashes and 11-44 percent reductions in crashes involving fatalities and serious injuries in the vicinity of camera sites. Over wider areas, 9-35 percent reductions for all crashes and 17-58 percent reductions in crashes involving fatalities and serious injuries were found.

In the United States, where the use of speed cameras has been more limited, only a few evaluations of their effects on speeds have been published. Studies of the use of speed cameras on residential streets in Montgomery County, Maryland, on a major highway in Scottsdale, Arizona, and on city streets in the District of Columbia found that the odds of drivers exceeding speed limits by more than 10 mph declined substantially after cameras were introduced (Retting & Farmer, 2003; Retting, Farmer, & McCartt, 2008; Retting, Kyrychenko, & McCartt, 2008). In Scottsdale and Montgomery County, speeds also were reduced by smaller amounts at locations not targeted by cameras, suggesting broader spillover effects.

There has been little strong research conducted in the United States on the effects of speed camera enforcement on crashes. A study in Scottsdale found that there were substantial reductions in injury crashes, property-damage-only crashes, and total crashes during non-peak periods associated with speed cameras (Shin, Washington, & Schalkwyk, 2009). Moreover, Retting, Kyrychenko, & McCartt (2008) found that the effects of the Scottsdale speed camera program on travel speeds spilled over to some of the sites used as controls, so the crash effects estimated by Shin et al. (2009) were probably underestimated.

The current study updates and extends the earlier evaluation of the Montgomery County speed camera program (Retting, Farmer, & McCartt, 2008). In May 2007, the county implemented the state's first automated speed enforcement program, with camera use limited by state statute to residential streets with speed limits of 35 mph or less and school zones. Following a 1-month warning period, camera citations began to be issued in June 2007. Over the years, the scope of the county's program has expanded considerably. The current study evaluates the longer term effects of the Montgomery County automated speed enforcement program on travel speeds and drivers' attitudes. In addition, the effects of the program on crashes are examined.

2. Methods

2.1. Program description

Montgomery County, Maryland, is a large, affluent suburb of the District of Columbia, with a geographic area of 491 square miles, a population of more than 1 million in 2014, and a median household income of $98,221 in 2013 (U.S. Census Bureau, 2013, 2014). Under the county's speed camera program, a photograph is taken of the rear license plate of vehicles exceeding the citation threshold; the driver is not photographed. Citations carry fines of $40, but no license penalty points are issued to the registered vehicle owner.

Montgomery County officials sought to develop a program that would optimize the safety benefits of camera enforcement and gain high levels of public support. A public information and education campaign ("Safe Speed") focused initially on building public awareness of the dangers of speeding and the role of speed cameras and then informed drivers that speed cameras were in use. In addition to publicity generated by the program at its inception, the program received considerable coverage by the area news media. However, there has been no active ongoing publicity campaign. Signs advising motorists of photo enforcement were posted on several major roadways entering Montgomery County, and "photo enforced" placards were installed below the speed limit signs and school zone signs on roads designated for camera enforcement.

Initially citations were issued for vehicles observed traveling at least 11 mph above the speed limit. To reflect changes in the state statute allowing speed camera programs, effective October 1, 2009, the threshold for camera citations was changed to 12 mph above the speed limit, and school zone camera operations were restricted to 6 a.m.-8 p.m. on weekdays. In May 2012, some cameras were used in a roadway corridor approach in which cameras were periodically moved throughout the length of a roadway segment. This approach aimed to encourage drivers to comply with the speed limit for the entire stretch of the monitored roadway rather than at specific locations only. A press conference was held when the county first implemented the approach, and the event was covered by the news media. "Speed Camera Corridor" signs were placed at the entrances to the corridors.

The speed camera program has gradually expanded since its inception. There were 18 mobile cameras when the program began; 60 fixed cameras, 10 portable cameras, and 6 mobile speed camera vans in 2009; 56 fixed cameras, 20 portable cameras, and 6 mobile speed camera vans in 2012; and 56 fixed cameras, 30 portable cameras, and 6 mobile speed camera vans in 2014. As of December 2014, there were 73 speed camera corridors and 61 speed camera sites located outside these corridors.

2.2. Vehicle speed measurements and analysis

The current study examined changes in travel speeds measured in November 2014, about 7½ years after the speed camera program was implemented, compared with speeds measured in September-October 2006, about 6 months before camera enforcement began.

One year in advance of the camera program, Montgomery County police identified 40 locations as potential camera sites, and 20 were randomly selected for evaluation. Nineteen of the 20 sites were on residential streets with speed limits of 25-35 mph. One site was located within a school zone on an arterial street where the speed limit was 30 mph for 1 hour at the beginning and the end of the school day and 40 mph at other times. To examine potential spillover effects, 10 sites were randomly selected from 20 Montgomery County locations that had similar characteristics (e.g., roadway characteristics, traffic volumes, residential land use) as most of the camera-enforced locations but were ineligible for cameras because they had a 40 mph speed limit.

As controls, speeds also were measured at sites on residential streets in Arlington County and Fairfax County, Virginia. These counties are similar to Montgomery County in terms of demographic characteristics, economic conditions, and traffic conditions and have not used speed cameras. Fairfax County borders Montgomery County, and Arlington County is proximate to Montgomery County. Ten control sites were randomly selected from 20 locations on residential streets that had roadway characteristics similar to those of the camera-eligible streets in Montgomery County. Speed limits at the Virginia sites ranged from 25 to 35 mph. One site was located in a school zone. The speed limit at this site was lowered from 35 to 25 mph at the beginning and the end of each school day. No control sites with a speed limit of 40 mph were selected.

An earlier study of the first 6 months of the Montgomery County program reported a 9 percent decline in mean speeds and a 70 percent decline in vehicles exceeding the speed limit by more than 10 mph at camera-enforced sites (Retting, Farmer, & McCartt, 2008).

In the current study, speed data from two of the 20 camera sites were excluded. This included the school zone site, which underwent a major roadway redesign, and another site that was undergoing extensive reconstruction when the speed data were collected in fall 2014. As of November 2014, cameras had been deployed near the observation site or on the same road for 16 of the 18 remaining sites at some point during the 7½ year camera program. Of the 10 original sites selected to examine potential spillover effects of camera enforcement, one was excluded from the current study due to a major roadway redesign. Of the 10 control sites located on residential streets in Arlington and Fairfax counties, one control site was excluded due to the addition of speed bumps.

Traffic speeds were recorded at all study sites using speed camera technology similar to the equipment used for the enforcement program. The study cameras were deployed on the roadside in a covert manner by photo enforcement vendors not affiliated with the Montgomery County speed camera program. The equipment electronically recorded the speeds of all passing vehicles. At each location, traffic speeds were measured during each study period from approximately 10 a.m. to 4 p.m. on a weekday. Measurements taken at the Virginia school zone location during times of reduced speed limits were excluded from analyses.

The analyses of vehicle speed data focused on changes in the mean speeds and the proportions of vehicles exceeding posted speed limits by more than 10 mph. Although the amount of time spent at each study site was approximately the same in the before and after periods, changes in traffic volume at some sites led to large differences in the before and after sample sizes. Thus, some sites accounted for a much larger portion of the sample in the after period compared with the baseline sample. To ensure consistent representation of each study site in the two time periods, overall statistics for each study group of sites were computed as a weighted mean of the statistics for each site, with weights defined as the proportion of vehicles observed at each site during the before period.

Linear regression models were estimated to evaluate the changes in mean vehicle speeds associated with the speed camera program, using the natural logarithm of speeds as the dependent variable and terms for site-to-site variability and expected variability over time. Logistic regression models also were used to estimate the effect of the program on the odds of vehicles exceeding posted speed limits by more than 10 mph. Because the odds ratios (ORs) derived from logistic regression models are not good approximations for relative risk ratios (RRs) when the incidence of the outcome of interest is not rare in the study population (i.e., greater than 10 percent), as is true for speeding, all odds ratios were transformed into relative risks as $RR=OR/[(1-P_0)+(P_0 \times OR)]$, where P_0 represents the proportion of vehicles exceeding speed limits by more than 10 mph in the before period for the control group (Zhang & Yu, 1998). For example, if the odds ratio is 0.38 when comparing the odds at the camera sites with the odds at the Virginia control sites, and 12.3 percent of vehicles exceeded the speed limit by more than 10 mph at the control sites in the before period, the relative risk is 0.41($0.38/[(1–0.123)+(0.123\times0.38)]$). In other words, a vehicle is 59 percent less likely to exceed the speed limit by more than 10 mph at the camera sites than at the Virginia control sites.

The effects of the speed camera program on mean vehicle speeds and the likelihood that a vehicle exceeded the speed limit by more than 10 mph at spillover sites in Montgomery County was not examined, due to the lack of appropriate control sites with the same speed limit in Virginia.

2.3. Telephone surveys

To assess public awareness of the speed camera program and attitudes toward camera enforcement, a telephone survey of drivers residing in Montgomery County was conducted in November 2014, approximately 7½ years following the implementation of the speed camera program. Random-digit-dialing methods were used to select the numbers to call. To reflect the fact that many people now use cellphones rather than landlines, 31 percent of the numbers randomly called were cellphone numbers. The cooperation rate, which was defined as the percentage of completed surveys out of the numbers called, was 9 percent. Of the 2,470 households reached, 36 percent initially declined participation, 25 percent did not qualify, 3 percent began but did not complete the interview, and 36 percent completed the interview. In all, 900 licensed drivers ages 18 and older completed the interviews. The responses were weighted to reflect the age (18-34, 35-64, and 65+) and gender distribution of the population ages 18 and older of the county in 2014. All of the results presented below are based on the weighted data set.

The statistical significance of demographic differences in the survey responses was evaluated using chi-square (χ^2) tests of homogeneity ($p<0.05$). Significant differences are noted.

2.4. Police-reported crashes

Police-reported crashes occurring during January 2004-December 2013 in Montgomery County and the control community of Fairfax County were examined. Electronic files of information on police-reported crashes were obtained from the Maryland State Police and the Virginia Department of Motor Vehicles. Several sites in Arlington County were control sites in the speed analysis, but Arlington County was not included as a control community for the crash analysis because there were red light camera programs in place during large parts of the study period: the first program was in effect during 1999-2005, and the second has been in place since 2010. Montgomery County had a red light camera program throughout the study period. Red light cameras were operated at 13 intersections in Fairfax County during the early part of the study period (January 2004-June 2005); crashes occurring at the camera intersections during the entire study period were excluded.

Police-reported crashes occurring on camera-eligible roads in Montgomery County, i.e., residential roads with 25-35 mph speed limits, were included in the speed camera study group. Crashes occurring on all roads with 25-35 speed limits, not only roads with speed cameras, were included. The corresponding control group consisted of crashes occurring on residential roads with 25-35 mph speed limits in Fairfax County. To explore any potential spillover effects of the cameras, crashes occurring on roads with a 40 mph speed limit in Montgomery County were examined, excluding crashes occurring in 40 mph school zones with speed cameras. The corresponding control group consisted of crashes occurring on roads with a 40 mph speed limit in Fairfax County.

January 2004-April 2007 represented the before study period. June 2007-December 2013 represented the after study period when the speed camera program was in place. Montgomery County issued only warning citations from speed cameras during May 2007, and so this month is excluded. October 2009 -December 2013 represented the after period following the speed camera law change, and June 2012-December 2013 represented the period when the corridor approach was in place.

Although Fairfax County is similar to Montgomery County in terms of location, demographics, and traffic conditions, it is possible that trends in traffic volume on the roads of interest may have differed for the two counties. As traffic volume data specific to the roads of interest were not available, it was decided to examine trends in the crashes relevant to speeding rather than trends in overall crashes. For example, higher speeds increase the likelihood that a collision will result in serious injuries. So it is reasonable to expect that lower speeds would be associated with a lower proportion of crashes that involve an incapacitating injury or fatality.

Logistic regression analysis was used to evaluate the effects of speed cameras, the 2009 law change, and the corridor approach on the likelihood that a police-reported crash was speeding-related and the likelihood that a police-reported crash involved an incapacitating injury or fatality. As in the analysis of vehicle speeds, the odds ratios derived from the logistic regression models were transformed into estimates of relative risk. Speeding-related crashes were defined as those involving at least one driver reported by the police to be exceeding the speed limit or driving too fast for conditions. Separate models examined the camera effects on camera-eligible roads and on potential spillover roads. In these models, the dependent variable was a binary crash indicator (crash being speeding-related or not, crash involving an incapacitating or fatal injury or not). The independent variables were the number of years since 2004, a quarter of year indicator, time of day indicator (9 p.m-6 a.m. vs. daytime), study period indicators (entire after period vs. before period, 2009 law change period vs. before period, corridor approach period vs. before period), study group indicator (Montgomery County vs. Fairfax County), road surface condition indicator (wet or snow/ice covered vs. dry), road alignment indicator (curved vs. straight). In addition, speed limit indicators (30 vs. 25 mph, 35 vs. 25 mph) were included in the models of crashes on camera-eligible roads, and a pedestrian involvement indicator was included in the models of crash severity. Crash data for the year 2008 were excluded from the analysis of the likelihood that a crash was speeding-related, due to anomalies in the identification of speeding-related crashes in the Fairfax County data for that year.

The logistic regression models also included three interaction variables for study group and study period indicators as the measures of the effects of the speed camera program, the additional effects of the 2009 law change over and above the camera effect, and the additional effects of the corridor approach over and above the camera effect and the 2009 law change effect. From the estimated parameters for these interaction terms, the change in the likelihood that a crash involved an incapacitating or fatal injury and the change in the likelihood that a crash was speeding-related beyond what would have been expected absent the speed cameras, the 2009 law change, or the corridor approach were calculated (Zhang & Yu, 1998). For example, if the parameter for the interaction term between study group and the entire camera period vs. the before period was -0.2302 in the model of crashes that involved incapacitating or fatal injuries on camera-eligible roads, the odds ratio was calculated as 0.79(exp(-0.2302)) when comparing the odds at camera-eligible roads with the odds that would have been expected if there were no speed cameras during the after period. With 6.8 percent of crashes involving fatal or incapacitating injuries at control sites, the relative risk was calculated as $(0.79/[(1–0.068)+(0.068\times0.79)])$, which yielded a 19.4 percent reduction in the likelihood that a crash involved an incapacitating or fatal injury compared with what would have been expected without speed cameras. In addition, if in the same model the parameter for the interaction term between study group and the 2009 law change period vs. the before period was 0.0828, and the parameter for the interaction term between study group and the corridor approach period vs. the before period was -0.3762, the odds ratio was calculated as 0.59(exp(-0.2302+0.0827-0.3762)) when comparing the odds on camera-eligible roads with the odds that would have been expected if there were none of these treatments during the after period. With 6.8 percent of crashes involving fatal or incapacitating injuries at control sites during the before period, the relative risk was calculated as (0.59/[(1–0.068)+(0.068×0.59)]), which yielded a 39.1 percent reduction in the likelihood that a crash involved an incapacitating or fatal injury compared with what would have been expected without any of the treatments.

3. Results

3.1. Vehicle speeds

Table 1 summarizes mean vehicle speeds and the proportion of vehicles exceeding speed limits by more than 10 mph for the three groups of study sites 6 months before and 7½ years after the implementation of the speed camera program. The mean speeds and the proportion of vehicles exceeding speed limits by more than 10 mph declined at all three sets of study sites from the before to the after period. The percentage declines in both mean speeds and the proportion of speeding vehicles at the Montgomery County camera sites were much larger than the declines at the Montgomery County potential spillover sites (i.e., sites on roads with 40 mph speed limit) or at the Virginia control sites.

Table 1
Vehicle speeds before and 7½ years after implementation of speed camera program

		Mean speeds (mph)			Percent of vehicles exceeding speed limit by more than 10 mph		
Location type	Number of sites	2006	2014*	Percent change	2006	2014*	Percent change
Maryland sites							
Camera sites	18	39.6	34.3	-13	29.1	10.5	-64
Spillover sites	9	43.0	40.6	-5	9.5	5.8	-39
Virginia control sites	9	36.5	35.0	-4	12.3	7.0	-43

*Computed as weighted means across sites, where the weights equal the proportion of vehicles observed at each site during the before period.

According to the estimated linear regression model, mean speeds would have declined by 4.6 percent over the 8 years without the speed camera program (Table A-1 in Appendix). At the Montgomery County camera sites, mean speeds declined by 10 percent relative to the control sites in Virginia; this is the estimated reduction in mean speeds attributable to the speed camera enforcement. This relative decline was significant.

At the Montgomery County camera sites, the likelihood that a vehicle exceeded the speed limit by more than 10 mph decreased by 59 percent relative to the Virginia control sites. This reduction was statistically significant (95% confidence interval of the relative risk = 0.38, 0.45).

3.2. Telephone surveys

A telephone survey of Montgomery County residents was conducted in November 2014, about 7½ years after the speed camera program was implemented. When asked if speeding is a problem on residential streets in the county, 56 percent of drivers said it is. Almost all drivers (95 percent) in the survey knew that speed cameras currently are in use on residential streets in the county.

When asked whether they favored the use of speed cameras on residential streets in the county, 62 percent of drivers favored it. Support for speed cameras was significantly higher among females than males; 69 percent of female drivers supported the speed cameras compared with 54 percent of male drivers (χ^2=23.1, df=1, p=0.0001). Support for speed cameras also differed significantly by driver age; the proportion of drivers favoring cameras was 54 percent among ages 18-34, 62 percent among ages 35-64, and 75 percent among drivers ages 65 and older (χ2=15.6, df=2, p=0.0004).

Drivers also were asked their opinions about the use of speed cameras in school zones in the county. The proportion of drivers who favored cameras in school zones was significantly higher than the proportion who favored cameras on residential streets (86 vs. 62 percent, χ2 = 130.5, p<0.0001).

Drivers aware of the camera program were asked a series of questions about their experiences with it (n=857). Seventy-six percent of drivers said that the camera enforcement had caused them to reduce their speeds when traveling on residential streets and in school zones. Fifty-nine percent of drivers had received at least one speed camera citation, and 75 percent knew someone else who received at least one camera citation. When asked if speed camera enforcement should be expanded, 38 percent of drivers supported expanding speed camera enforcement to arterial streets and 21 percent supported expanding the use of speed cameras to interstate highways.

Of the drivers who knew about the speed camera program, 14 percent were aware that in 2009 the speed threshold for issuing camera citations was raised from 11 to 12 mph over the posted limit. When asked whether the number of speed cameras in the county had increased, decreased, or stayed the same over the past several years, 76 percent said the number had increased.

3.3 Crash analyses

During the years 2004-2006 leading up to the start of the speed camera program in 2007, the yearly total crash counts were smaller on camera-eligible roads in Montgomery County than on the control roads in Fairfax County, and larger on potential spillover roads in Montgomery County than on the corresponding control roads in Fairfax County (Table 2). On both the camera-eligible roads in Montgomery County and the corresponding control roads in Fairfax County, the counts decreased by 33 percent from 2004 to 2013. On potential spillover roads in Montgomery County and the corresponding control roads in Fairfax County, the decrease from 2004 to 2013 was 30 percent in Montgomery County and 32 percent in Fairfax County.

Table 2
Total police-reported crash counts by year and study group

	Camera-eligible roads in Montgomery County	25-35 mph control roads in Fairfax County	Potential spillover roads in Montgomery County	40 mph control roads in Fairfax County
2004	7,174	9,723	2,693	1,328
2005	6,867	9,455	2,409	1,192
2006	6,789	9,450	2,394	1,194
2007	6,363	8,827	2,317	1,082
2008	5,899	8,162	2,363	1,109
2009	5,894	7,061	2,435	1,078
2010	5,751	6,333	2,239	952
2011	5,458	6,637	2,134	1,018
2012	5,026	7,083	2,131	1,097
2013	4,832	6,558	1,878	905

3.4. Likelihood that a crash involved an incapacitating or fatal injury

During the years prior to the start of the speed camera program in 2007, the proportion of police-reported crashes that involved an incapacitating or fatal injury was generally higher on camera-eligible roads in Montgomery County than on the control roads in Fairfax County (Figure 1). The same pattern was identified for crashes occurring on the potential spillover roads and the corresponding control roads. In both counties there was a general downward trend in the yearly proportion of crashes that involved an incapacitating or fatal injury. In Montgomery County, the proportion of crashes that involved an incapacitating or fatal injury on camera-eligible roads decreased from 7.6 to 3.9 percent from 2004 to 2013, a 49 percent decrease, compared with a 16 percent decrease on the control roads in Fairfax County (from 6.8 to 5.7 percent). The decrease was 39 percent on both the potential spillover roads in Montgomery County (from 9.6 to 5.9 percent) and the control roads in Fairfax County (from 8.5 to 5.2 percent).

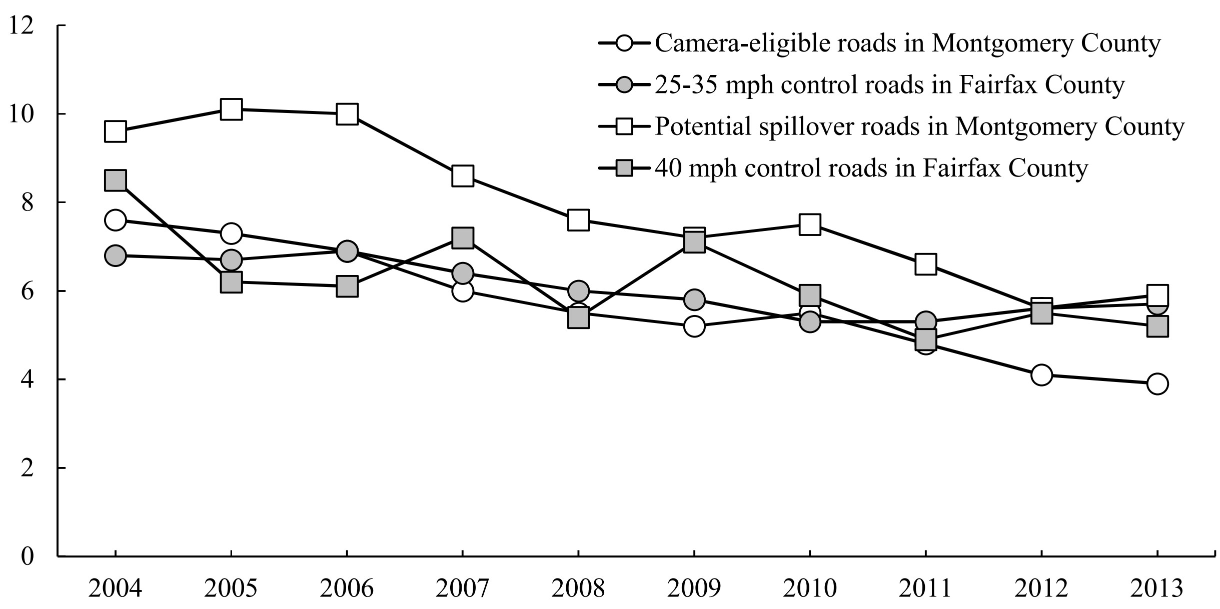

Fig. 1. Percentage of police-reported crashes that involved an incapacitating or fatal injury during 2004-2013 by study group.

Logistic regression models estimated the effects of speed cameras, the additional effects of the 2009 law change, the additional effect of the corridor approach, and the effects of other predictors on the likelihood that a crash involved an incapacitating or fatal injury. Separate models were developed for crashes on camera-eligible roads and on potential spillover roads (Tables A-2 and A-3 in Appendix). After adjusting for yearly and quarterly trends, time of day, speed limit, road surface condition, road alignment, pedestrian involvement, and study group (Montgomery County vs. Fairfax County), the estimated effects of the speed cameras, the 2009 law change, and the corridor approach are summarized in Table 3.

Table 3
Summary of results from logistic regression models of percentage change in the likelihood that crash involved incapacitating or fatal injury associated with use of speed cameras on camera-eligible roads and on potential spillover roads

	Camera-eligible roads		Potential spillover roads	
	Percent change in likelihood that crash involved incapacitating or fatal injury	p-value	Percent change in likelihood that crash involved incapacitating or fatal injury	p-value
Effects of speed cameras	-19.4	0.0002	-17.2	0.099
Effects of 2009 law change over and above effects of speed cameras	8.0	0.2547	6.0	0.6622
Effects of corridor approach over and above effects of speed cameras and 2009 law change	-29.9	<0.0001	-16.3	0.2763
Combined effects of speed cameras, 2009 law change, and corridor approach	-39.1	<0.0001	-26.6	0.0363

For crashes that occurred on camera-eligible roads, based on the interaction term between study group and the entire after period vs. the before period, the likelihood that a crash involved an incapacitating or fatal injury was an estimated 19.4 percent lower than would have been expected without the speed cameras, and this difference was statistically significant. The estimated additional effect of the 2009 law change over and above the effects of speed cameras was obtained by interpreting the interaction term between study group and the 2009 law change after period vs. the before period. The likelihood that a crash involved an incapacitating or fatal injury was an estimated 8.0 percent higher than would have been expected without the law change, but this difference was not statistically significant. The additional effect of the corridor approach over and above the effects of the speed cameras and the 2009 law change was estimated based on the interaction term between study group and the corridor approach after period vs. the before period. The likelihood that a crash involved an incapacitating or fatal injury was an estimated 29.9 percent lower than would have been expected without the corridor approach. This difference was significant. The combined effect of the speeds cameras, the 2009 law change, and the corridor approach was calculated based on the three interaction terms. The likelihood that a crash involved an incapacitating or fatal injury was an estimated 39.1 percent lower than would have been expected without any of the treatments, and this difference was statistically significant.

For crashes that occurred on potential spillover roads, the likelihood that a crash involved an incapacitating or fatal injury was an estimated 17.2 percent lower than would have been expected without the speed cameras. Over and above the effects of the speed cameras, the likelihood was 6.0 percent higher than would have been expected without the 2009 change to the law. Over and above the effects of the speed cameras and the 2009 law change, the likelihood was 16.3 percent lower than would have been expected without the corridor approach. None of these differences was statistically significant. With the combined effects of the speeds cameras, the 2009 law change, and the corridor approach, the likelihood was 26.6 percent lower than would have been expected without any of the treatments, and this difference was statistically significant.

3.5 Likelihood that a crash was speeding-related

During the years prior to the initiation of the speed camera program in 2007, the proportion of crashes that was speeding-related were higher on camera-eligible roads in Montgomery County than on the control roads in Fairfax County, and higher on the potential spillover roads in Montgomery County than on the control roads in Fairfax County (Figure 2). The proportions of crashes that were speeding-related in Fairfax County in 2008 were substantially higher than in other years. The reason for this anomaly could not be identified. As a result, the data from 2008 were excluded from the analyses of the effects of speed cameras on speeding-related crashes.

There was a general downward trend in the yearly proportion of crashes that were speeding-related on camera-eligible roads in Montgomery County and on the corresponding control roads in Fairfax County, and the proportions decreased more in Montgomery County than in Fairfax County. In Montgomery County, the proportion decreased from 21.3 to 15.6 percent from 2004 to 2013, a 27 percent decrease, compared with a 22 percent decrease in Fairfax County (from 15.8 to 12.3 percent). There was a general downward trend in the yearly proportion of crashes that were speeding-related on potential spillover roads in Montgomery County (from 23.5 to 17.8 percent from 2004 to 2013, a 24 percent decrease), whereas the proportion on the control roads in Fairfax County was relatively stable over time.

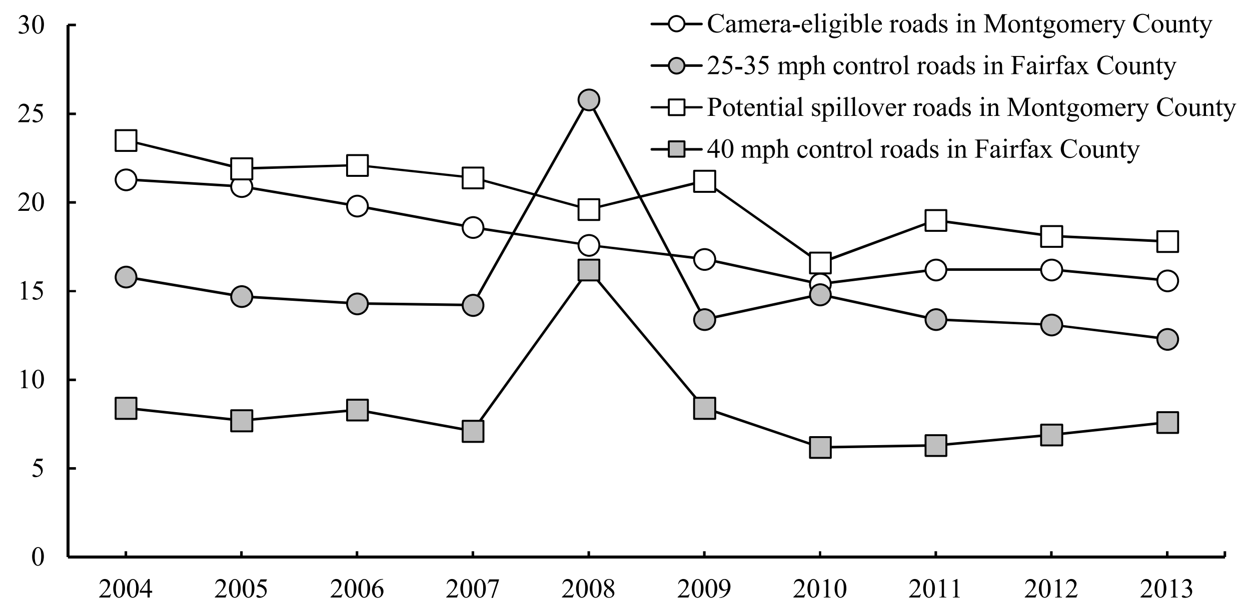

Fig. 2. Percentage of police-reported crashes that were speeding-related during 2004-2013 by study group

Logistic regression models estimated the effects of speed cameras, the additional effects of the 2009 law change, the additional effects of the corridor approach, and other predictors on the likelihood that a crash was speeding-related on camera-eligible roads and on potential spillover roads (Tables A-4 and A-5 in Appendix). After adjusting for yearly and quarterly trends, time of day, speed limits, road surface condition, road alignment, and study group (Montgomery County vs. Fairfax County), the estimated effects of the speed cameras, the 2009 law change, and the corridor approach are summarized in Table 4.

Table 4
Summary of results from logistic regression models of percentage changes in the likelihood that crash was speeding-related associated with use of speed cameras on camera-eligible roads and on potential spillover roads

	Camera-eligible roads		Potential spillover roads	
	Percent change in likelihood that crash was speeding-related	p-value	Percent change in likelihood that crash was speeding-related	p-value
Effects of speed cameras	-12.3	0.0026	-18.0	0.1024
Effects of 2009 law change over and above effects of speed cameras	-3.4	0.462	22.9	0.1182
Effects of corridor approach over and above effects of speed cameras and 2009 law change	8.0	0.1037	-22.8	0.0539
Combined effects of speed cameras, 2009 law change, and corridor approach	-8.4	0.0448	-22.0	0.0418

Note: Data from calendar year 2008 excluded.

For crashes that occurred on camera-eligible roads, based on the interaction term between study group and the entire after period vs. the before period, the likelihood of a crash being speeding-related was an estimated 12.3 percent lower than would have been expected without speed cameras, and this difference was statistically significant. The estimated effect of the 2009 law change in addition to the effect of speed cameras was a non-significant 3.4 percent decline from what would have been expected without the law change. The likelihood of a crash being speeding-related was an estimated 8 percent higher than would have been expected without the corridor approach, a difference that was not significant. With the combined effects of the speed cameras, the 2009 law change, and the corridor approach, the likelihood was 8.4 percent lower than would have been expected without any of the treatments, and this difference was statistically significant.

Similarly, for crashes that occurred on potential spillover roads, the likelihood of a crash being speeding-related was an estimated 18 percent lower than would have been expected without the speed cameras, an additional 22.9 percent higher than would have been expected without the 2009 law change, and an additional 22.8 percent lower than would have been expected without the corridor approach. None of these differences was significant, although the difference for the corridor approach neared significance.

With the combined effects of the speed cameras, the 2009 law change, and the corridor approach, the likelihood was 22 percent lower than would have been expected without any of the treatments, and this difference was statistically significant.

DISCUSSION

The current study estimated the long-term effects of the Montgomery County speed camera program on vehicle speeds, public opinions, and crashes. A prior evaluation found significant reductions in vehicle speeds at sites with cameras, and sites with warning signs but no cameras 6 months after camera enforcement began, relative to changes in speeds at control sites in northern Virginia (Retting, Farmer, & McCartt, 2008). The current results showed long-lasting significant reductions in speeds at the original sites with warning signs relative to speed changes at the control sites; cameras had been deployed at or near 16 of the 18 sites with warning signs.

Automated enforcement is controversial in many communities. Montgomery County sought to educate the public about the safety benefits of speed cameras when the program was launched, and 62 percent of drivers residing in the county said they favor automated speed enforcement on residential streets when interviewed in fall 2014, up slightly from 56 percent when interviewed about 6 months after camera ticketing began (Retting, Farmer, & McCartt, 2008). However, a sizeable minority of drivers, 38 percent, opposed the cameras on residential streets in the fall 2014 survey. In the 2014 survey, a large majority of drivers, 86 percent, favored speed cameras in school zones.

The proportion of Montgomery County drivers who thought speeding was a safety problem on residential streets was much lower in 2014 (56 percent) than in surveys conducted 6 months before (71 percent) and 6 months after (74 percent) the speed camera program was implemented (Retting, Farmer, & McCartt, 2008). This is consistent with an increase in the proportion of drivers who said they had reduced their travel speeds due to the speed cameras (76 percent in the fall 2014 survey vs. 59 percent in the 6-month after survey). Three-quarters of drivers in the fall 2014 survey reported knowing someone who received a speed camera citation, and 59 percent had received a citation themselves. As receiving a citation is likely to discourage speeding, at least for a while, all these findings are consistent with the reductions in observed travel speeds associated with the speed cameras.

Previous research from countries with extensive speed camera programs has found reductions in crashes and injuries associated with automated speed enforcement (Pilkington and Kinra, 2005; Wilson et al., 2010). The current study found that speed camera enforcement was associated with a significant 19 percent reduction in the likelihood that a crash involved an incapacitating or fatal injury and a significant 12 percent reduction in the likelihood that a crash was speeding-related on camera-eligible roads in the county.

The 2009 speed camera law change was not significantly associated with the likelihood that a crash involved an incapacitating or fatal injury or the likelihood that a crash was speeding-related. This is not surprising since most of the respondents in the fall 2014 telephone survey were not aware of the law change. In addition, the increase in the speed threshold for automated speed enforcement of 1 mph was likely not large enough to produce a substantial change in travel speeds. However, it appears that the county's corridor approach to speed camera enforcement has been effective in reducing the severity of crashes. The implementation of the corridor approach was associated with a 30 percent reduction in the likelihood that a crash involved an incapacitating or fatal injury on camera-eligible roads, over and above the reduction associated with speed camera enforcement. This is consistent with the goal of the corridor approach to encourage drivers to comply with the speed limit along an entire roadway segment. The corridor approach was associated with an increase in the likelihood of a crashes being speeding-related, but the increase was not significant. It should be noted that there was a relatively brief period for examining effects of the corridor approach on crashes (June 2012-December 2013). The estimated combined effect of speed cameras, the 2009 law change, and the corridor approach on camera-eligible roads was a significant 39 percent reduction in the likelihood that a crash involved an incapacitating or fatal injury and a significant 8 percent reduction in the likelihood that a crash was speeding-related.

With regard to the analysis of crashes on the potential spillover roads in Montgomery County, there were reductions in the likelihood that a crash involved an incapacitating or fatal injury and in the likelihood that a crash was speeding-related associated with the overall effect of speed cameras and with the corridor approach. The magnitude of these reductions ranged from 16 to 23 percent. Although none of the changes was significant, a 23 percent reduction in the likelihood of a crash being speeding-related associated with the corridor approach approached significance ($p=0.0539$). The estimated combined effect of speed cameras, the 2009 law change, and the corridor approach was a significant 27 percent reduction in the likelihood that a crash involved an incapacitating or fatal injury and a significant 22 percent reduction in the likelihood that a crash was speeding-related on potential spillover roads.

Increasing the perceived risk of detection is one of the most important objectives of speed enforcement strategies (Ostvik and Elvik, 1990). A countywide camera effect on crashes on camera-eligible residential roads would be expected because of the relatively large scale of the program as well as the high level of awareness of the enforcement that was documented in the fall 2014 survey of drivers. To raise the perceived risk of perception, it is important to promote a perception of widespread camera use through roadway signs and highly visible public information and education activities. Montgomery County had a well-developed public information and education campaign at the program's inception and installed signs warning drivers of the photo enforcement on specific roads and on major roads leading into the county. Informing drivers about the dangers of speeding and the role of automated enforcement and alerting drivers that cameras are in use help to build broad support for camera enforcement and are needed throughout the life of the enforcement program. It is possible that the effects of the speed camera enforcement would be even stronger if the county conducted periodic publicity campaigns about the program.

Several limitations of the study are worth noting. The potential spillover effects of the speed cameras on vehicle speeds were not examined due to the lack of appropriate control sites with the same speed limit. It was not possible to examine changes in crashes close to the specific locations with speed cameras relative to other locations on camera-eligible roads because of the lack of detailed information on the location of crashes relative to the camera locations. However, prior research (Wilson et al., 2010) found that the effects of speed cameras are not limited to camera sites only but rather extend to wider areas. In Virginia, the property damage threshold for reporting a crash increased from $1,000 to $1,500 in 2009; this may have reduced the total number of crashes that were reported. As a result, the effects on the likelihood that a crash involved a fatal or incapacitating injury and/or the likelihood that a crash was speeding-related may have been overestimated. However, it is believed the change in reporting crashes would have been very small as the current property damage threshold still reflects minor vehicle damage. Further, there was no large or anomalous drop between 2008 and 2009 in the total number of crashes reported in Fairfax County or in the proportion that involved a serious injury or fatality. In the analysis of speeding-related crashes, data from 2008 were excluded due to apparent anomalies in the coding of speeding-related crashes in the Fairfax County crash data. The Virginia Department of Vehicles changed the method for coding speeding-related crashes in 2009, and the anomalies may reflect this transition in coding methods. It is possible that Fairfax County was not an ideal control for the analysis of the camera effects crashes, since the yearly proportion of speeding-related crashes and the yearly proportion of crashes that involved a serious or fatal injury in Montgomery County were higher than in Fairfax County during the before period. However, the estimated logistic regression model controlled for such differences between the two counties, and the economic, demographic, and traffic characteristics of Fairfax County are similar to those of Montgomery County. As noted above, Fairfax County had a red light camera program during the early part of the study period. Although crashes that occurred at the camera intersections were excluded from the crash analysis for the entire study period, it is possible that the camera effects spilled over to some non-camera intersections within the county. It is believed that the red light camera program in Fairfax County would have had minimal effects on the results in the current study.

Despite the demonstrated safety benefits of speed camera enforcement and the support for cameras in many communities, cameras remain controversial in some communities. Although automated traffic enforcement is not a panacea, this study adds to the evidence that speed cameras can result in long-term substantial reductions in speeding, speeding-related crashes, and crashes involving serious injuries or fatalities. This evidence should be considered by communities considering ways to keep their roads safer.

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Appendix

Table A-1

Estimated effects of speed camera program on mean speeds based on linear regression model

Effect	F-value	p-value	Estimate	Percent change
Site	2476.08	<0.0001		
Time (2014 vs. 2006)	893.79	<0.0001	-0.0466	-4.6
Camera sites vs. control sites	3170.02	<0.0001	-0.1052	-10.0

Table A-2

Logistic regression results of effects of speed cameras on likelihood that crash involved incapacitating or fatal injury on camera-eligible roads

Parameter	Estimate	Standard error	p-value
Intercept	-3.0244	0.0406	<0.0001
Number of years (since 2004)	-0.0511	0.0145	0.0004
First quarter (Jan-Mar) vs. fourth quarter (Oct-Dec)	0.00889	0.0353	0.801
Second quarter (Apr-Jun) vs. fourth quarter (Oct-Dec)	0.061	0.0336	0.0695
Third quarter (Jul-Sep) vs. fourth quarter (Oct-Dec)	0.1435	0.0329	<0.0001
Entire after period (Jun 2007-Dec 2013) vs. before period (Jan 2004-Apr 2007)	0.0149	0.0574	0.7951
2009 law period (Oct 2009-Dec 2013) vs. before period (Jan 2004-Apr 2007)	-0.036	0.0607	0.5531
Corridor approach period (Jun 2012-Dec 2013) vs. before period (Jan 2004-Apr 2007)	0.1756	0.0636	0.0057
Montgomery County vs. Fairfax County	0.00403	0.0355	0.9098
Effects of speed cameras	-0.2302	0.061	0.0002
Effects of 2009 law change over and above speed cameras	0.0827	0.0726	0.2547
Effects of corridor approach over and above speed cameras and 2009 law change	-0.3762	0.0906	<0.0001
Wet or snow/ice covered road vs. dry road	-0.1599	0.0292	<0.0001
Curve road vs. straight road	0.5385	0.0302	<0.0001
Pedestrian involvement	2.2954	0.0406	<0.0001
Nighttime (9 p.m. to 6 a.m.) vs. daytime	0.201	0.0301	<0.0001
Speed limit 30 mph vs. 25 mph	0.2873	0.0387	<0.0001
Speed limit 35 mph vs. 25 mph	0.335	0.0285	<0.0001

Table A-3
Logistic regression results of effects of speed cameras on likelihood that crash involved incapacitating or fatal injury on potential spillover roads

Parameter	Estimate	Standard error	p-value
Intercept	-2.7255	0.078	<0.0001
Number of years (since 2004)	-0.0304	0.0264	0.2491
First quarter (Jan-Mar) vs. fourth quarter (Oct-Dec)	0.0694	0.0642	0.2797
Second quarter (Apr-Jun) vs. fourth quarter (Oct-Dec)	0.0977	0.0615	0.1118
Third quarter (Jul-Sep) vs. fourth quarter (Oct-Dec)	0.1106	0.0606	0.0681
Entire after period (Jun 2007-Dec 2013) vs. before period (Jan 2004-Apr 2007)	-0.0116	0.1302	0.9291
2009 law period (Oct 2009-Dec 2013) vs. before period (Jan 2004-Apr 2007)	-0.1595	0.1405	0.2562
Corridor approach period (Jun 2012-Dec 2013) vs. before period (Jan 2004-Apr 2007)	0.1012	0.1573	0.5199
Montgomery County vs. Fairfax County	0.3326	0.0735	<0.0001
Effects of speed cameras	-0.2017	0.1222	0.099
Effects of 2009 law change over and above speed cameras	0.0633	0.1448	0.6622
Effects of corridor approach over and above speed cameras and 2009 law change	-0.191	0.1754	0.2763
Wet or snow/ice covered road vs. dry road	-0.1793	0.0519	0.0006
Curve road vs. straight road	0.7319	0.0599	<0.0001
Pedestrian involvement	2.3743	0.09	<0.0001
Nighttime (9 p.m. to 6 a.m.) vs. daytime	0.0525	0.0567	0.3547

Table A-4
Logistic regression results of effects of speed cameras on likelihood that crash was speeding-related on camera-eligible roads

Parameter	Estimate	Standard error	p-value
Intercept	-2.1981	0.0288	<0.0001
Number of years (since 2004)	-0.0229	0.01	0.0228
First quarter (Jan-Mar) vs. fourth quarter (Oct-Dec)	0.00338	0.025	0.8923
Second quarter (Apr-Jun) vs. fourth quarter (Oct-Dec)	0.0158	0.0241	0.5135
Third quarter (Jul-Sep) vs. fourth quarter (Oct-Dec)	0.071	0.0239	0.0029
Entire after period (Jun 2007-Dec 2013) vs. before period (Jan 2004-Apr 2007)	-0.0205	0.0469	0.6615
2009 law period (Oct 2009-Dec 2013) vs. before period (Jan 2004-Apr 2007)	0.0303	0.0467	0.5165
Corridor approach period (Jun 2012-Dec 2013) vs. before period (Jan 2004-Apr 2007)	-0.0227	0.0444	0.6087
Montgomery County vs. Fairfax County	0.3467	0.0252	<0.0001
Effects of speed cameras	-0.1529	0.0508	0.0026
Effects of 2009 law change over and above speed cameras	-0.0409	0.0556	0.462
Effects of corridor approach over and above speed cameras and 2009 law change	0.0911	0.056	0.1037
Wet or snow/ice covered road vs. dry road	0.8903	0.018	<0.0001
Curve road vs. straight road	1.0215	0.02	<0.0001
Nighttime (9 p.m. to 6 a.m.) vs. daytime	0.864	0.0197	<0.0001
Speed limit 30 mph vs. 25 mph	-0.1881	0.0264	<0.0001
Speed limit 35 mph vs. 25 mph	-0.21	0.0194	<0.0001

Table A-5
Logistic regression results of effects of speed cameras on likelihood that crash was speeding-related on potential spillover roads

Parameter	Estimate	Standard error	p-value
Intercept	-3.0923	0.0739	<0.0001
Number of years (since 2004)	0.0229	0.0201	0.2544
First quarter (Jan-Mar) vs. fourth quarter (Oct-Dec)	0.0103	0.05	0.8366
Second quarter (Apr-Jun) vs. fourth quarter (Oct-Dec)	-0.0547	0.0487	0.2613
Third quarter (Jul-Sep) vs. fourth quarter (Oct-Dec)	0.0592	0.0475	0.2125
Entire after period (Jun 2007-Dec 2013) vs. before period (Jan 2004-Apr 2007)	0.0331	0.1344	0.8055
2009 law period (Oct 2009-Dec 2013) vs. before period (Jan 2004-Apr 2007)	-0.4123	0.1407	0.0034
Corridor approach period (Jun 2012-Dec 2013) vs. before period (Jan 2004-Apr 2007)	0.2399	0.1379	0.0819
Montgomery County vs. Fairfax County	1.1357	0.0694	<0.0001
Effects of speed cameras	-0.2146	0.1314	0.1024
Effects of 2009 law change over and above speed cameras	0.226	0.1447	0.1182
Effects of corridor approach over and above speed cameras and 2009 law change	-0.2789	0.1447	0.0539
Wet or snow/ice covered road vs. dry road	1.375	0.0347	<0.0001
Curve road vs. straight road	1.0176	0.0462	<0.0001
Nighttime (9 p.m. to 6 a.m.) vs. daytime	0.3638	0.0424	<0.0001