Effects of Turning On and Off Red Light Cameras on Fatal Crashes in Large U.S. Cities

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Abstract

Introduction: Although numerous studies have demonstrated that automated enforcement reduces red light running, a growing number of communities have deactivated their red light camera programs in recent years. This study updates estimates of the effects of turning on cameras and offers a first look at the effects of turning them off.

Method: Among the 117 large U.S. cities with more than 200,000 residents in 2014, trends in citywide per capita rates of fatal red light running crashes and of all fatal crashes at intersections were compared between 57 cities that initiated camera programs during 1992-2014 and 33 cities without cameras during this period to examine the effects of activating camera programs. Trends also were compared between 19 cities that turned off cameras and 31 regionally matched cities with continuous camera programs to evaluate the effects of terminating camera programs. Because several cities turned cameras off during 2005-08, the estimated effects might have been confounded by the U.S. economic downturn immediately afterward. The primary analyses were limited to the 14 cities that turned off cameras during 2010-14 and compared trends in the 14 cities with those in 29 regionally matched cities with continuous camera programs. Poisson regression was used to examine the relationship of activating and deactivating camera programs with fatal crash rates.

Results: After controlling for temporal trends in annual fatal crash rates, population density, and unemployment rates, rates of fatal red light running crashes and of all fatal crashes at signalized intersections in cities with cameras programs were 21 and 14 percent lower, respectively, after cameras were turned on than what would have been expected without cameras. Rates of fatal red light running crashes and of all fatal crashes at signalized intersections in 14 cities that terminated cameras programs during 2010-14 were 30 and 16 percent higher, respectively, after cameras were turned off than would have been expected had cameras remained. Increases in rates of fatal red light running crashes (18%) and of all fatal crashes at signalized intersections (8%) in all 19 cities that turned cameras off were not significant.

Conclusions: The current study adds to the body of existing research indicating that red light cameras can reduce the most serious crashes at signalized intersections, and it is the first to demonstrate that terminating camera programs increases fatal crashes.

Practical applications: Communities interested in improving intersection safety should consider this evidence. Legislators and communities thinking about terminating camera programs should consider the impact to safety if programs end.

Keywords: Turning on red light cameras; Turning off red light cameras; Fatal crash rates; Signalized intersections; Large cities.

1. Introduction

In 2014, more than 2.5 million police-reported motor vehicle crashes in the United States occurred at intersections or were intersection-related, accounting for 43 percent of all police-reported crashes (Insurance Institute for Highway Safety, 2016a). These crashes resulted in about 55,000 serious nonfatal injuries and 7,697 deaths. More than a third of these deaths occurred at signalized intersections.

Running a red light is a common traffic violation, although drivers view red light running as dangerous. A 2015 national survey of drivers found that while 59 percent thought that running red lights was a very serious threat to personal safety, 39 percent reported driving through a traffic light that had just turned red in the past month (AAA Foundation for Traffic Safety, 2016). A study observing 19 intersections in four states found that there was an average of 3.2 red light running violations per intersection per hour (Hill & Lindy, 2003).

Red light running violations can have tragic consequences. In 2014, 709 people were killed and an estimated 126,000 were injured in police-reported red light running crashes, and more than half of those killed were pedestrians, bicyclists, or occupants of vehicles struck by red light runners (Insurance Institute for Highway Safety, 2016a).

Traditional police enforcement of red light running can help mitigate the problem, but other demands on police resources can limit its effectiveness. Red light cameras are a countermeasure that increases the public's perception that there is a high likelihood of being apprehended for running a red light. The installation of red light cameras has led to significant reductions in red light running violation rates at intersections with cameras, and at nearby signalized intersections without cameras (McCartt & Hu, 2014; Retting, Williams, Farmer, & Feldman, 1999a; Retting, Williams, Farmer, & Feldman, 1999b). Red light cameras also have been shown to reduce injury crashes (Aeron-Thomas & Hess, 2005; Retting & Kyrychenko, 2002). For example, Retting and Kyrychenko (2002) found that after the installation of red light cameras in Oxnard, California, injury crashes declined by 29 percent and right angle crashes involving injuries dropped by 68 percent at signalized intersections.

Hu, McCartt, and Teoh (2011) performed the first study that investigated the effects of red light cameras on fatal crashes in large U.S. cities. Among the 99 cities with more than 200,000 residents in 2008, 14 cities were identified with red light camera enforcement programs for all of 2004-08 but not at any time during 1992-96, and 48 cities were identified without camera programs during either period. Analyses compared the citywide per capita rate of fatal red light running crashes and the citywide per capita rate of all fatal crashes at signalized intersections during the two study periods, and rate changes were compared for cities with and without camera programs. After controlling for population density and land area, the rates of fatal red light running crashes and all fatal crashes at signalized intersections were 24 percent and 17 percent lower, respectively, in cities with cameras during 2004-08 than what would have been expected without cameras.

Surveys of residents of cities with red light camera programs have found that a large majority of residents in most cities favor the programs (Cicchino, Wells, & McCartt, 2014; McCartt & Eichelberger, 2012). Yet, despite public support and the clear benefits of red light cameras, the programs have been controversial. Although the number of U.S. municipalities using red light camera enforcement increased rapidly before peaking in 2012 at 533 communities, by 2015 this number declined to 467 communities. Although new camera programs continued to be added, 158 communities ended their red light camera programs between 2010 and 2015. Communities have ended programs for a variety of reasons including changes in state law disallowing red light cameras, public referendums where voters rejected cameras, decisions by local government, court rulings, and lapsed contracts with vendors. Numerous studies have examined the safety effects of red light camera enforcement, but few if any strong studies have examined the effects of terminating camera programs on crashes.

The goals of the current study were twofold. The first was to update Hu et al.'s (2011) estimates of the effects of installing red light cameras on per capita rates of fatal red light running crashes and per capita rates of all fatal crashes at signalized intersections in large cities. The current study accounted for the effects of the economy, used a more rigorous design that accounts for trends in crash rates over time within cities, and examined a larger number of cities with red light cameras than Hu et al. (2011). Trends in per capita fatal crash rates over time were compared for cities with and without camera programs for each crash measure. The second goal was to assess the effects of deactivating red light camera programs on per capita rates of fatal red light running crashes and per capita rates of all fatal crashes at signalized intersections. For each fatal crash measure, temporal trends in crash rates were compared for cities that turned off cameras and cities with continuous camera programs.

2. Method

The first U.S. community with a camera program for traffic enforcement was New York City, which tested one red light camera in 1992 and turned on more cameras in the following year. The number of communities using red light cameras has increased dramatically since then (Insurance Institute for Highway Safety, 2016b). Fatal crash data at the time of the current study were available only through 2014, so analyses covered the period 1992-2014.

Large U.S. cities were defined as those with more than 200,000 residents; there were 117 such cities in 2014 (U.S. Census Bureau, 2014). Information on red light camera programs in these 117 cities was obtained from news reports and calls to city police departments or public works departments. For cities with camera enforcement, program start and end dates were obtained. Other historical information was sought but was not available for all cities, including the number of cameras and number of signalized intersections over time.

Among the 117 cities in this study, 57 cities turned on red light cameras at some point during 1992-2014, and the cameras remained on in 2014; 38 cities had no camera programs during the entire time period; 20 cities turned cameras on and later turned them off, including 3 cities (Los Angeles, CA; San Diego, CA; Houston, TX) that turned cameras off twice; and 2 cities (Virginia Beach, VA, and Arlington, VA) that turned cameras off and later turned them on.

Data on fatal crashes at intersections with signal lights in each city were extracted for 1992-2014 from the Fatality Analysis Reporting System (FARS), which contains detailed information on all fatal motor vehicle crashes occurring on U.S. public roads (National Highway Traffic Safety Administration, 1992-2014). Fatal red light running crashes were defined as the subset of these crashes that involved a driver traveling straight who was assigned the driver level contributing factor of "failure to obey traffic control devices." This definition was developed jointly by the Insurance Institute for Highway Safety and Federal Highway Administration so that consistent estimates of red light running crash losses would be produced (Retting, 2006). Annual counts of fatal red light running crashes and all fatal crashes at signalized intersections were obtained for each of the 117 cities in each year during 1992-2014.

Annual population estimates for 1992-2014 were obtained for each city from the U.S. Census Bureau (1999, 2010a, 2014). For each city in each year, the annual per capita rates of fatal red light running crashes and rates of all fatal crashes at signalized intersections were calculated as the annual fatal crash counts divided by annual population estimates (crashes per million population). Census information on cities' land areas is available only from the decennial reports (U.S. Census Bureau, 1990, 2000, 2010b). Therefore, the 1990 land area data were used for years 1992-99, the 2000 data for years 2000-09, and the 2010 data for years 2010-14. Six of the 117 cities in the study (Gilbert, AZ; Chula Vista, CA; Louisville, KY; Fayetteville, NC; Winston-Salem, NC; Laredo, TX) had substantial changes in land areas (more than 50% increase) during the study period. These six cities, of which five had no camera programs and the remaining one (Fayetteville, NC) had turned cameras off, were excluded from analyses.

The annual population density was calculated as the population divided by the land area. Hu et al. (2011) found that an increase in population density was associated with decreases in fatal crash rates, although not always significantly. A possible explanation is that denser populations generally lead to lower travel speeds and thus fewer fatal crashes (Cerrelli, 1997).

Annual unemployment rates during 1992-2014 were obtained for each city from the U.S. Bureau of Labor Statistics (1992-2014). Annual unemployment rate was included to account for potential effects of the economy on fatal crash rates. It is well-established that fatal crash rates and economic factors are associated with one another (Partyka, 1991).

2.1. Analyses of effects of turning on red light cameras

Years 1992-2014 represented the study period. The 57 cities that turned cameras on and kept them on comprised the camera group. The 33 non-camera cities without substantial changes in land areas comprised the control group. The 22 cities where cameras had been turned off during the study period were excluded from these analyses. Table 1 lists cities in the camera and control groups and the program start year in each camera city.

Using the city-specific data, Poisson regression models were used to rigorously examine the relationship of camera enforcement and other variables with fatal crashes. The Poisson models accounted for the autoregressive (first order) covariance structure due to repeated measures, because each independent unit of analysis (city) had 23 consecutive annual observations (years 1992-2014). Separate models were developed for the fatal red light running crashes and all fatal crashes at signalized intersections, with the annual crash counts as the dependent variable and annual population per million as the exposure variable. Independent variables in the models were number of years since 1992, individual city indicators, annual population density (in thousands of people per square mile), annual unemployment rate, and a camera indicator.

For each of the 57 camera cities, the camera indicator had a value of 0 for the years prior to the program start year and 1 for the years with active camera programs. For the 33 control cities, the camera indicator had a value of 0 for all years. After accounting for the effects of population density, unemployment rates, and other uncontrolled differences among cities, the camera indicator tested whether temporal trends in fatal crash rates in camera cities changed from before to after cameras were turned on, relative to the trends in control cities. The estimated change in annual crash rate trends in camera cities from before to after cameras were turned on, relative to the trends in control cities, was taken as the primary measure of effectiveness. It was interpreted as the change in annual fatal crash rates for cities with camera programs during the years cameras were active beyond what would have been expected absent the programs. For example, if the estimated parameter for the camera indicator was -0.2396 in the model of fatal red light running crashes, the average annual crash rate after cameras were turned on was

21.3 percent lower ([exp(-0.2396)-1]×100) than would have been expected without cameras. Variables with p-values less than 0.05 were taken as statistically significant.

Table 1. Cities included in camera and control groups for analyses of effects of turning on cameras

City	Program start year*	City	Program start year*	City	Program start year*
Cities in camera group					
New York, NY	1993	Modesto, CA	2005	New Orleans, LA	2008
Mesa, AZ	1997	Philadelphia, PA	2005	Tacoma, WA	2008
Oxnard, CA	1997	Atlanta, GA	2006	Tucson, AZ	2008
San Francisco, CA	1997	Cleveland, OH	2006	Orlando, FL	2009
Scottsdale, AZ	1997	Columbus, OH	2006	Spokane, WA	2009
Sacramento, CA	1999	Plano, TX	2006	Aurora, IL	2010
Washington, DC	2000	Seattle, WA	2006	Memphis, TN	2010
Chandler, AZ	2001	Arlington, TX	2007	Newark, NJ	2010
Fremont, CA	2001	Corpus Christi, TX	2007	Chesapeake, VA	2011
Toledo, OH	2001	Dallas, TX	2007	Des Moines, IA	2011
Phoenix, AZ	2002	El Paso, TX	2007	Jersey, NJ	2011
Portland, OR	2002	Irving, TX	2007	Miami, FL	2011
Bakersfield, CA	2003	Riverside, CA	2007	Rochester, NY	2011
Santa Ana, CA	2003	St. Louis, MO	2007	Yonkers, NY	2011
Chicago, IL	2004	Austin, TX	2008	Jacksonville, FL	2012
Garland, TX	2004	Baton Rouge, LA	2008	St. Petersburg, FL	2012
Raleigh, NC	2004	Denver, CO	2008	Tampa, FL	2012
Stockton, CA	2004	Fort Worth, TX	2008	Richmond, VA	2013
Aurora, CO	2005	Montgomery, AL	2008	Norfolk, VA	2014
Cities in control group					
Anaheim, CA	—	Fort Wayne, IN	—	North Las Vegas, NV	—
Anchorage, AK	—	Henderson, NV	—	Oklahoma City, OK	—
Birmingham, AL	—	Huntington Beach, CA	—	Omaha, NE	—
Boise City, ID	—	Indianapolis, IN	—	Pittsburgh, PA	—
Boston, MA	—	Irvine, CA	—	Reno, NV	—
Buffalo, NY	—	Las Vegas, NV	—	San Antonio, TX	—
Cincinnati, OH	—	Lexington-Fayette, KY	—	San Jose, CA	—
Columbus, GA	—	Lincoln, NE	—	St. Paul, MN	—
Detroit, MI	—	Madison, WI	—	Tulsa, OK	—
Durham, NC	—	Milwaukee, WI	—	Honolulu, HI	—
Fontana, CA	—	Nashville, TN	—	Wichita, KS	—

**Note:* If a program started prior to or on July 1 in a year, this year was coded as the start year. If cameras were turned on after July 1 in a year, the following year was coded as the start year.

2.2. Analyses of effects of turning off red light cameras

Unlike the camera cities in the analyses of turning cameras on that were scattered across the country, 13 of the 19 cities that turned cameras off without substantial changes in land areas during the study period were clustered in California, Arizona, Colorado, New Mexico, and Texas. The remaining six cities were located in North Carolina, Maryland, Minnesota, Missouri, and Florida. Among the 19 camera-off cities, the earliest year when cameras were turned on was 1998. To make control cities comparable with the camera-off cities, among the 57 cities with continuous camera programs, only those that regionally matched the camera-off cities and that turned on cameras in or after 1998 were included in analyses. Thirty-one cities with continuous camera programs were included in the control group. The 33 cities with no camera programs during the entire time period and the two cities that turned cameras off and then turned them back on were excluded from the analyses.

Of the 19 study cities that turned cameras off, five cities turned off cameras during 2005-08 and 14 cities turned off cameras within the latest 5 years for which fatal crash data were available (2010-14). Separate analyses were performed to evaluate the effects of ending camera programs by including the 14 cities that turned off cameras during 2010-14 as the camera-off city group and by including all the 19 cities as the camera-off city group.

The analyses that included 14 cities that ended camera programs during 2010-14 were the primary camera-off analyses in the study. Because the analyses with 19 camera-off cities included several that turned off cameras during 2005-08, the estimated effects of ending camera enforcement might have been confounded by the U.S. economic downturn immediately afterward and other changes that might have occurred during the relatively long periods after cameras were turned off. For the analyses including 14 camera-off cities, the control cities were limited to those 29 that regionally matched the camera-off cities.

Table 2 lists cities in the camera-off and control groups and the years when cameras were turned on and off, if applicable, in each city. No city with continuous camera programs activated the cameras in 1998. The programs in Houston, TX, and Long Beach, CA, were turned off in late 2010 (November and December) and the program end year for both cities was coded as 2011. Three of the camera-off cities turned cameras off twice. For Los Angeles and San Diego, CA, only the effects of the second camera-off event were evaluated by using observations in years since the second camera programs began. For Houston, TX, the second program lasted for less than 2 months (July 9-August 24, 2011). The effects of the first camera-off event were evaluated, and year 2011 was treated as a camera-off year. For each of the cities included in the analyses, the study period started from the year when the cameras were turned on (as shown in Table 2) and ended in 2014. Observations in years before cameras were turned on were not included in the analyses.

Similar to the analyses of the effects of turning on cameras as described earlier, for both the analyses with 14 camera-off cities and 19 camera-off cities, Poisson regression models were used to examine the relationship of turning off camera enforcement and other variables with fatal crash rates. Analyses accounted for the autoregressive (first order) covariance structure due to repeated measures in each city. Independent variables in the model were number of years since cameras were turned on, individual city indicators, annual population density (in thousands of people per square mile), annual unemployment rate, and a camera-off indicator. For each of the camera-off cities, the camera-off indicator had a value of 0 for the years with an active camera program and 1 for the years after the camera program was terminated. For the control cities, the camera-off indicator had a value of 0 for all years.

The camera-off indicator tested whether temporal trends in fatal crash rates in camera-off cities changed from before to after cameras were turned off, relative to trends in cities with continuous camera programs, after accounting for the effects of population density and unemployment rates and other uncontrolled differences among cities. The estimated change in annual crash rate trends in camera-off cities from before to after cameras were turned off, relative to the trends in control cities, was taken as the primary measure of effectiveness. It was interpreted as the change in annual fatal crash rates for cities that turned off camera programs during the years cameras were off beyond what would have been expected had the programs not been terminated. For example, if the estimated parameter for the camera-off indicator was 0.2631 in the model of fatal red light running crashes, the average annual crash rate after cameras were turned off was 30.1 percent higher ($[\exp(0.2631)-1]\times100$) than would have been expected if cameras had not been turned off. Variables with p-values less than 0.05 were taken as statistically significant.

Table 2. Cities included in camera-off and control groups for analyses of effects of turning off cameras

City	Program start year[1]	Program end year[2]	City	Program start year[1]	Program end year[2]
Cities that turned off red light camera programs					
Charlotte, NC[3]	1998	2006	Moreno Valley, CA	2007	2013
Baltimore, MD	1999	2013	Glendale, AZ	2008	2011
Fresno, CA[3]	2002	2006	Lubbock, TX[3]	2007	2008
Long Beach, CA	2002	2011	Glendale, CA	2008	2012
Greensboro, NC[3]	2003	2005	Kansas City, MO	2009	2014
San Diego, CA	2003	2013	Oakland, CA	2009	2014
Albuquerque, NM	2005	2012	Hialeah, FL	2010	2012
Minneapolis, MN[3]	2005	2006	San Bernardino, CA	2010	2013
Los Angeles, CA	2006	2012	Colorado Springs, CO	2011	2012
Houston, TX	2007	2011			
Cities in control group					
Sacramento, CA	1999	—	Dallas, TX	2007	—
Washington, DC	2000	—	El Paso, TX	2007	—
Chandler, AZ	2001	—	Irving, TX	2007	—
Fremont, CA	2001	—	Riverside, CA	2007	—
Phoenix, AZ	2002	—	St. Louis, MO	2007	—
Portland, OR	2002	—	Austin, TX	2008	—
Bakersfield, CA	2003	—	Denver, CO	2008	—
Santa Ana, CA	2003	—	Fort Worth, TX	2008	—
Garland, TX	2004	—	Tucson, AZ	2008	—
Raleigh, NC[3]	2004	—	Orlando, FL	2009	—
Stockton, CA	2004	—	Des Moines, IA[3]	2011	—
Aurora, CO	2005	—	Miami, FL	2011	—
Modesto, CA	2005	—	Jacksonville, FL	2012	—
Plano, TX	2006	—	St. Petersburg, FL	2012	—
Arlington, TX	2007	—	Tampa, FL	2012	—
Corpus Christi, TX	2007	—			

[1] If a program started prior to or on July 1 in a year, this year was coded as the start year. If cameras were turned on after July 1 in a year, the following year was coded as the start year.
[2] If cameras were turned off on or after July 1 in a year, the camera-off period started from the following year; if cameras were turned off prior to July 1 in a year, the camera-off period started from this year.
[3] These cities were included only in the analyses with 19 camera-off cities, and were not included in the analyses with 14 cities that turned off cameras during 2010-14.

3. Results

3.1. Effects of turning cameras on

Figure 1 shows the average annual per capita rates of all fatal crashes at signalized intersections (crashes per million population) across cities during 1992-2014 for the camera group and the control group. During the first several years of the study period, when most of the cities in the camera group had not turned on camera programs yet, rates of fatal crashes were relatively high in the camera group, and then the trends went downward for the rest of the study period. In the control group, the rates of fatal crashes remained relatively stable during the study period. The trends in the average annual rates of fatal red light running crashes were similar to the trends in rates of all fatal crashes at signalized intersections for each city group.

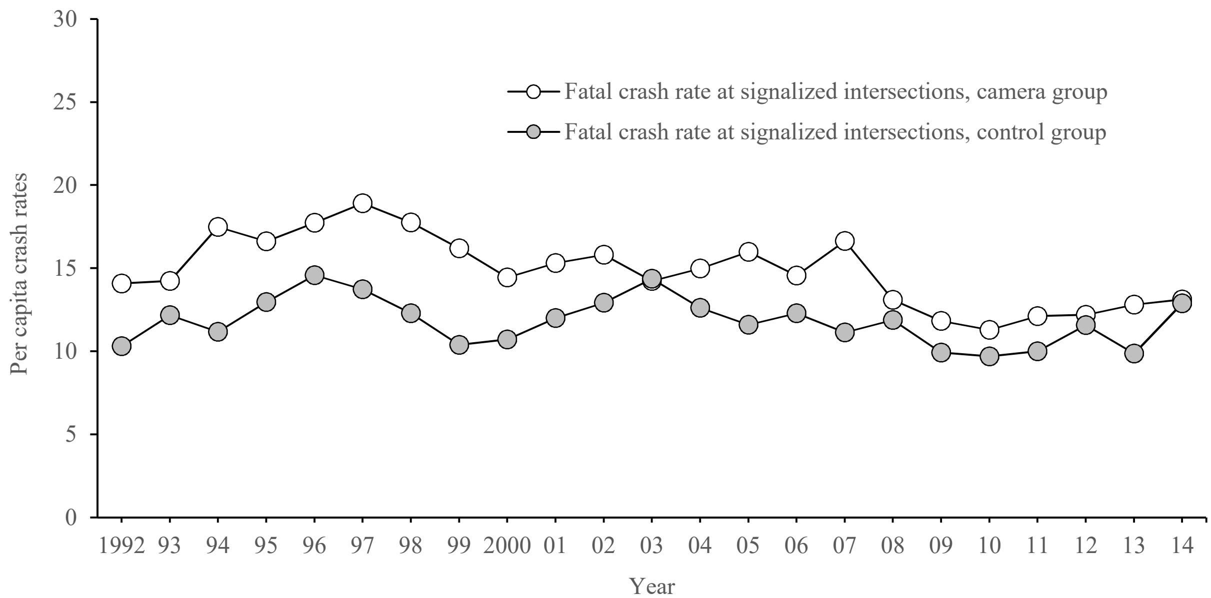

Figure 1. Average annual per capita rates of all fatal crashes at signalized intersections (crashes per million population) for camera and control groups for analyses of effects of turning on cameras, 1992-2014

Table 3 lists results of the Poisson regression model that estimated the effects of red light camera enforcement and other predictors on the per capita rate of fatal red light running crashes. The estimates for the city indicators are not included in Table 3 or in subsequent tables. After accounting for the effects of other predictors, the rate of fatal red light running crashes significantly decreased by 1.9 percent per year since 1992 in cities with no cameras. An increase in population density (in thousands of people per square mile) and one-point increase in the unemployment rate reduced the rate of fatal red light running crashes by an estimated 11.4 and 3.3 percent, respectively. Both changes were significant. The estimated effect of camera enforcement on the rate of fatal red light running crashes was obtained by interpreting camera-on indicator directly. Based on this parameter, the annual rate of fatal red light running crashes in cities with cameras programs after cameras were turned on was 21.3 percent lower than what would have been expected without cameras. This difference was significant.

Table 3. Poisson model of effects of red light camera enforcement on annual per capita rate of fatal red light running crashes

Parameter	Estimate	Percent change in crash rates*	Standard Error	Z	P value
Intercept	1.8613		0.5871	3.17	0.0015
Number of years since 1992	-0.0196	-1.9	0.0033	-5.97	<0.0001
Population density (in thousands of people per square mile)	-0.1208	-11.4	0.0342	-3.53	00.0004
Unemployment rate	-0.0337	-3.3	0.0081	-4.16	<0.0001
Camera on indicator (effect of cameras on fatal crash rates)	-0.2396	-21.3	0.0539	-4.45	<0.0001

**Note:* Percent change in crash rates associated with one-unit increase in the corresponding independent variable.

Table 4 lists results of the Poisson regression model that estimated the effects of red light camera enforcement and other predictors on the per capita rate of all fatal crashes at signalized intersections. Based on the camera-on indicator, the annual rate of all fatal crashes at signalized intersections in cities with cameras programs after cameras were turned on was significantly 14.2 percent lower than what would have been expected without cameras.

Table 4. Poisson model of effects of red light camera enforcement on annual per capita rates of all fatal crashes at signalized intersections

Parameter	Estimate	Percent change in crash rates*	Standard Error	Z	P value
Intercept	3.2356		0.2604	12.43	<0.0001
Number of years since 1992	-0.0041	-0.4	0.0021	-1.95	0.051
Population density (in thousands of people per square mile)	-0.0979	-9.3	0.015	-6.54	<0.0001
Unemployment rate	-0.0228	-2.3	0.0049	-4.63	<0.0001
Camera on indicator (effect of cameras on fatal crash rates)	-0.153	-14.2	0.0328	-4.66	<0.0001

**Note:* Percent change in crash rates associated with one-unit increase in the corresponding independent variable.

3.2. Effects of turning cameras off

Tables 5 and 6 list results of the Poisson regression models that estimated the effects of ending red light camera enforcement and other predictors on the per capita rate of fatal red light running crashes and on the per capita rate of all fatal crashes at signalized intersections, respectively, by using the 14 cities that ended camera program during 2010-14. The estimated effects of turning off camera enforcement on the fatal crash rates were obtained by interpreting the camera off indicator directly. Based on this parameter, the annual rate of fatal red light running crashes in the 14 camera-off cities after cameras were turned off was 30.1 percent higher than what would have been expected had cameras not been turned off. The annual rate of all fatal crashes at signalized intersections in camera-off cities after cameras were turned off was 16.1 percent higher than what would have been expected with cameras on. Both increases were significant.

Table 5. Poisson model of effects of turning off red light camera enforcement on annual per capita rate of fatal red light running crashes, using 14 cities that turned off cameras during 2010-14

Parameter	Estimate	Percent change in crash rates*	Standard Error	Z	P value
Intercept	7.4598		2.2816	3.27	0.0011
Number of years since cameras were turned on	-0.0298	-2.9	0.0133	-2.24	0.0248
Population density (in thousands of people per square mile)	-0.5979	-45.0	0.2404	-2.49	0.0129
Unemployment rate	-0.0165	-1.6	0.0166	-0.99	0.3203
Camera off indicator (effect of turning off cameras on fatal crash rates)	0.2631	30.1	0.1213	2.17	0.0301

Note: Percent change in crash rates associated with one-unit increase in the corresponding independent variable.

Table 6. Poisson model of effects of turning off red light camera enforcement on annual per capita rates of all fatal crashes at signalized intersections, using 14 cities that turned off cameras during 2010-14

Parameter	Estimate	Percent change in crash rates*	Standard Error	Z	P value
Intercept	6.1968		1.2157	5.1	<0.0001
Number of years since cameras were turned on	-0.0028	-0.3	0.0079	-0.36	0.7221
Population density (in thousands of people per square mile)	-0.3313	-28.2	0.1275	-2.6	0.0094
Unemployment rate	-0.0182	-1.8	0.0097	-1.87	0.0609
Camera off indicator (effect of turning off cameras on fatal crash rates)	0.1493	16.1	0.0705	2.12	0.0344

Note: Percent change in crash rates associated with one-unit increase in the corresponding independent variable.

Tables 7 and 8 list results of the Poisson regression models that estimated the effects of ending red light camera enforcement and other predictors on the per capita rate of fatal red light running crashes and the rate of all fatal crashes at signalized intersections, respectively, by using all the 19 camera-off cities. Based on the camera off indicator, the annual rates of fatal red light running crashes and all fatal crashes at signalized intersections in the 19 camera-off cities after cameras were turned off were 17.9 and 8.4 percent higher, respectively, than would have been expected had cameras been on. Neither increase was significant.

Table 7. Poisson model of effects of turning off red light camera enforcement on annual per capita rate of fatal red light running crashes, using all 19 camera-off cities

Parameter	Estimate	Percent change in crash rates*	Standard Error	Z	P value
Intercept	6.0341		2.0902	2.89	0.0039
Number of years since cameras were turned on	-0.0342	-3.4	0.0125	-2.74	0.0061
Population density (in thousands of people per square mile)	-0.4372	-35.4	0.2193	-1.99	0.0462
Unemployment rate	-0.0274	-2.7	0.0157	-1.75	0.0809
Camera off indicator (effect of turning off cameras on fatal crash rates)	0.1647	17.9	0.1131	1.46	0.1454

**Note:* Percent change in crash rates associated with one-unit increase in the corresponding independent variable.

Table 8. Poisson model of effects of turning off red light camera enforcement on annual per capita rates of all fatal crashes at signalized intersections, using all 19 camera-off cities

Parameter	Estimate	Percent change in crash rates*	Standard Error	Z	P value
Intercept	5.2662		1.166	4.52	<0.0001
Number of years since cameras were turned on	-0.0067	-0.7	0.0077	-0.88	0.3804
Population density (in thousands of people per square mile)	-0.2278	-20.4	0.1217	-1.87	0.0613
Unemployment rate	-0.0233	-2.3	0.0096	-2.44	0.0146
Camera off indicator (effect of turning off cameras on fatal crash rates)	0.0807	8.4	0.0685	1.18	0.2392

**Note:* Percent change in crash rates associated with one-unit increase in the corresponding independent variable.

4. Discussion

Red light running is a frequent traffic violation with dangerous safety consequences. Prior research found that red light cameras were associated with reductions in red light running, not only at camera-equipped intersections but also at other signalized intersections without cameras (Retting et al., 1999a, 1999b), as well as citywide crash reductions at signalized intersections (Retting and Kyrychenko, 2002).

The current study updated Hu et al. (2011) by using a more rigorous methodology that accounted for trends in fatal crash rates over time within cities and unemployment rates, and by including four times as many cities with red light camera programs as in the original study. Consistent with prior research, the current study confirmed that establishing red light camera programs reduces fatal red light running crash rates and fatal crash rates at signalized intersections. The introduction of red light cameras in large cities cut citywide fatal red light running crash rates by 21 percent and fatal crash rates at signalized intersections by 14 percent, when compared with rates that would have been expected without red light camera enforcement. These estimates are similar in size to the estimated 24 percent decline in fatal red light running crash rates and a 17 percent reduction in fatal crash rates at signalized intersections found in the earlier study. The larger effect of camera enforcement on the rate of fatal red light running crashes would be expected because these are the crashes targeted by cameras. However, if the camera enforcement affected only red light running, then the overall effect at signalized intersections would be only about 6 percent (a 21 percent reduction in the 30 percent of signalized intersection fatal crashes that are coded as red light running). The significant reduction in the rate of all types of fatal crashes at signalized intersections is much larger, 14 percent. Although it is possible that the difference is partly due to undercounting of red light running crashes, the data suggest that cameras have a generalized effect on driver behavior at intersections that extends beyond running red lights.

Just as activating red light cameras has positive safety benefits, the current study found that deactivating them has safety disbenefits. This study is the first to our knowledge to evaluate the effects of terminating camera enforcement on fatal crashes. When red light camera programs were terminated during 2010-14 in the 14 cities, fatal red light running crash rates increased 30 percent and fatal crash rates at signalized intersections increased 16 percent from what would have been expected if automated enforcement had continued. Laws are effective at changing behavior when drivers believe they will be detected and apprehended for violating them. Prior research has established that high visibility enforcement of laws governing issues such as seat belt nonuse and alcohol-impaired driving decreases unsafe behavior and crashes, but the prevalence of unsafe behavior and crashes rise when the heightened and publicized enforcement ends (e.g., Jonah & Smith, 1985; Tison & Williams, 2010; Williams & Wells, 2004; Wells et al., 1992; Williams et al., 1987). The current study demonstrates that this phenomenon extends to automated enforcement of red light running. Drivers likely no longer perceive that there is a high probability of receiving a ticket for running red lights when automated enforcement programs end, and thus become less attentive to the driving environment and more willing to violate the law, leading to increases in fatalities.

It is possible that police coding of crashes involving red light running at signalized intersections can be prone to bias, particularly in cities that have recently ended a high-profile automated enforcement program. It is possible, for example, that law enforcement officers may be unwittingly more likely to categorize a crash at a signalized intersection as a red light running crash if the circumstances were unclear. The bias in coding of red light running crashes could potentially inflate estimates of the effects of turning off red light cameras. It is confirming that effects of establishing and terminating red light camera programs were also found on fatal crashes at signalized intersections, where classification bias is not an issue.

The analyses of the effects of terminating camera programs that included all 19 cities that turned off cameras at any time also found increases in both fatal crash rates relative to what would have been expected had cameras remained on. However, the increases were smaller than what was found in the analyses of the 14 cities that turned off cameras during 2010-14 and were not significant. It is possible that the findings in the additional cities that ended camera programs during 2005-08 were confounded by the economic recession that occurred immediately after these cities turned off their cameras, beyond what could be captured by controlling for unemployment rates. It could also be the case that the increases in fatalities that were seen in cities that shut off cameras recently do not persist at such high levels over time.

Several limitations of the study are worth noting. The definition of red light running crashes excluded some crashes such as those involving a driver making an illegal turn on red. Other factors not included in the study, such as the number of cameras and number of signalized intersections, may have influenced fatal crash rates for the camera cities but could not be examined due to limitations in the data. Attempts were made to obtain historical information on the numbers of red light cameras and signalized intersections in the cities included in the study, but the information could not be obtained for many of the cities. For the analyses of the effects of turning off cameras, most of the study cities that turned off cameras clustered in California, Arizona, Colorado, New Mexico, and Texas. The control cities were regionally matched to these cities that turned off cameras. The effect of turning off cameras in other regions may differ quantitatively, but it is noteworthy that the estimated effect of turning off cameras is statistically consistent with the estimate of the effect of turning on cameras, which is based on more cities in more regions.

The current study adds to the body of existing research indicating that red light cameras can reduce the most serious crashes. This evidence should be considered by communities interested in reducing injuries and fatalities at intersections. Despite the widespread support (Cicchino et al., 2014; McCartt & Eichelberger, 2012) and the safety benefits of red light camera enforcement, cameras remain controversial in some communities. During the past several years, more camera programs were discontinued than were initiated. The current study found that turning off cameras was associated with increases in citywide fatal crash rates at signalized intersections. Legislators and communities considering terminating camera programs should consider the impact to public safety if the programs end.

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