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Abstract

This paper briefly examines the effectiveness of photo radar, or the use of automatic camera-equipped traffic monitoring devices, in reducing road fatalities and collisions. Photo radar has become a controversial subject among the driving public, largely due to its tendency to produce substantially increased revenues for the implementing governments. From the road safety literature, there appears to be a causal link between driving at excessive speeds and traffic accidents (and fatalities). Photo radar is designed to reduce speeding by increasing the likelihood of catching those drivers over some predetermined speed threshold, but can be limited in certain circumstances by the inability to identify the driver. A simplified driver-choice model is provided to demonstrate the effects of photo radar on speeding when the driver can be identified (and demerit points applied) and when the vehicle owner is applied a monetary fine alone. Raw data from Victoria, Australia, suggest that photo radar has significantly reduced both fatalities and collisions after its introduction in 1990, and controlling for other factors, including proxies for weather conditions and drunken driving, we find that photo radar can indeed be an effective road safety device.

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In response to declining police budgets and rising traffic fatalities and accidents, governments have become increasingly concerned with new methods of promoting road safety, including the use of camera-equipped radar devices, commonly known as photo radar. Photo radar first appeared in Europe more than twenty years ago (in Switzerland and Germany), but has since spread across the globe to over forty-five countries. The issue is of particular importance in Canada, where photo radar has been in place for years in Calgary and Edmonton, has new programs arising in Lethbridge, Winnipeg and British Columbia, and was briefly experimented with in Ontario in late 1994 and early 1995. Although photo radar systems are often costly to implement, it has proven to be a substantial money-maker, a fact that has drawn criticism from those who believe that road safety is less of a concern to governments than the revenues generated. Previous analyses of the effectiveness of photo radar have pointed to trends and other informal methods. In this paper, we develop a general model of the driver's decision to speed or comply with speed limits in order to analyze the effect of driver heterogeneity in income on speeding, and evaluate the incentives of photo radar relative to traditional enforcement incentives. Data from Victoria, Australia, where photo radar has been employed since 1990, are used to test whether the presence of photo radar can generate significant reductions in both traffic collisions and fatalities.

The commonly held view is that increases in speed cause more accidents (i.e. speed kills). Solomon (1964), Cirillo (1968), Lave (1985) and others have noted that the relationship between average speed and traffic accidents or fatalities is weak, although the variance of speed (or speed differential from the limit or mean) is influential.[1] In all of the regressions performed by Lave, the coefficient on average speed is found to be statistically insignificant, suggesting that, "once the effect of variance is held constant, there is no discernible effect of speed on the fatality rate." However, speed variance is positively and significantly related to fatalities, implying that both the fastest and slowest drivers cause accidents. Follow-up studies by Levy and Asch (1989), Snyder (1989), Fowles and Loeb (1989), Bowie and Waltz (1993), Jorgensen and Polak (1993), and Kloeden et al. (1997) using different data

[1] For Lave, speed variance is measured by the 85th percentile of average speed less the average speed, or approximately one standard deviation.

sets, confirm that speed variance has a noticeable effect on fatalities, although (contrary to Lave) each of these studies also finds a significant relationship between average speed and fatalities. McKnight, Klein and Tippetts (1990), Garber and Graham (1990), Streff and Schultz (1991), and Lave and Elias (1994) have shown significant increases in injuries and/or fatalities when speed limits were increased. Photo radar, if effective in reducing the numbers of speeders and the extent to which each individual exceeds the limit, would impact on both the average speed and speed variance, by shifting downward only the distribution of speeders above the limit. In the following section, a simple model od driver-choice is presented in which the incentives of photo radar can be examined. Previous theoretical studies of this manner, such as Graves, Lee and Sexton (1989, 1993) and Rodriguez (1990), are primarily concerned with the optimality of speed limits and punishments. This paper analyzes the effectiveness of speed enforcement which requires a model of private, and not social, choice. Empirical results are outlined in section 2, and concluding remarks and recommendations are provided in section 3.

1 Incentives, Punishment and Speed Enforcement

Any law meant to deter criminal activity must provide incentives to conform to the law, or equally, proper disincentives to break it. In regard to speed enforcement, this is typically achieved through fines or license suspensions, or some combination of the two, and to be effective, the expected punishment must be no smaller than the benefit a driver derives from speeding.[2] The value of the reduced travel time is presumably the benefit to drivers. As the value of a driver's time, normally measured by or proportionate to that person's wage, varies across drivers, the fine must also vary across drivers for effective deterrence. However, it is generally considered unjust to set fines according to income, and as a result, fines are typically fixed across individuals (although the punishment may be an increasing function of

[2] This, of course, assumes risk-neutral or risk-averse drivers. We assume that the probability of getting into an accident is independent of the probabilty of being caught speeding. While the probability of getting into an accident is increasing in speed, the functional form is the same under both photo radar and conventional speed enforcement, and thus is ignored in the theoretical model. Through this assumption, the question of valuing the cost of an accident or fatality is circumvented, and benefits become certain and not expected.

the extent of the violation). Even without income discrimination, speeding can be deterred for all individuals through very high fines. Again, social and political pressures may set constraints on fines below the level necessary to discourage the highest income drivers from speeding, and thus, fines alone would be insufficient to prevent speeding. This bias towards high income drivers can be offset through the identification and reporting of drivers to insurance companies, as well as through the frequently utilized "demerit point" system. In addition to higher insurance premiums, driver offenses can be assigned demerit points, again increasingly with the extent of the speeding, which provide a different, and potentially more powerful, type of punishment: the eventual loss of the driver's license if the points accumulated exceed some predetermined threshold, which would then result in significantly increased travel times. While a fine may have more of an effect on individuals who have low incomes than on those with high incomes, demerit points have the advantage of being implicitly progressive. Just as the benefit from speeding is higher for high-income persons, the benefit of holding a driver's license may also be greater, as the inconvenience derived from public transportation may be higher. By assigning demerit points, the government can circumvent the problem of not being able to raise fines high enough to deter high-income drivers.

Speeding is thus a risky action for a driver. If caught, he or she incurs a fine, increasing in the speed deviation from the limit, S, as well as higher insurance rates, the extent of which, for simplicity, depends on the demerit points accumulated, $D(\alpha S)$, also increasing in S, where $0 \leq \alpha \leq 1$ is a scaling parameter that signifies the extent to which demerit points are imposed. Under the assumption of utility of expected value maximizing behaviour (or equivalently, risk neutrality), the driver's objective is

$$\max_{<X,L>} U(X, L), \tag{1}$$

where X represents the consumption level of a composite commodity, and L that of leisure time, subject to the expected income constraint

$$wH = PX + \bar{I} + \pi F(S) + \pi I(D(\alpha S)), \tag{2}$$

where w is the wage rate, H is the time spent working, P is the price of X, $F(S)$ is the fine, π is the probability of being caught,[3] and $\overline{I}$ and $I(D(\alpha S))$ are the fixed and variable components of the insurance cost, respectively, and the time constraint

$$T = L + H + \bar{R} - R(S), \tag{3}$$

where T is the total time endowment, $\overline{R}$ is the time spent if he or she drives at the speed limit, and $R(S)$ represents the reduction in driving time as an increasing function of S. Upon substitution of L from (3) into (1), with H given by (2), the driver's utility maximizing choices of X and S must then satisfy

$$\frac{U_1(X,L)}{P} = \frac{U_2(X,L)}{w}, \tag{4}$$

and

$$\frac{w}{P}R'(S) = \pi[F'(S) + \alpha I'(D(\alpha S))D'(\alpha S)], \tag{5}$$

respectively.[4] Equation (4) is the standard result that, in equilibrium, the marginal utility of leisure relative to its marginal cost, w, has to be equal to the marginal utility of the consumption of X relative to its marginal cost, P;in another way, leisure is consumed up to the point where the (expected) utility received from an additional unit of leisure relative to the income sacrificed (the wage) from that additional unit is equal to the (expected) utility received from an additional unit of the composite commodity relative to the cost of that unit (the price). Equation (5) states that the marginal benefit of speeding equals the marginal cost. Thus, a driver increases his or her speed until the additional benefit from speeding, which is the real income potentially earned from the reduced driving time (the real wage multiplied by the time gained), is just equal to the expected loss from the fine and added insurance cost (expected premium increase).

[3] For a fixed enforcement budget, the probability of being caught speeding can be considered constant and independent of the extent of the violation. Furthermore, it is assumed that a driver caught driving above the limit is inevitably convicted.

[4] The interior solution described by equations (5) and (6) represents a maximum, as the Hessian is negative semi-definite. The assumptions made are: $U_1 > 0$, $U_2 > 0$, $U_{11} \leq 0$, $U_{22} \leq 0$, $U_{12} = U_{21} > 0$, $R' > 0$, $R'' < 0$, $F' > 0$, $F'' > 0$, $D' > 0$, $D'' > 0$, $I' > 0$, and $I'' > 0$. Strict concavity or convexity is assumed for simplicity only.

One can note that an increase in the income of an individual serves to increase the extent to which he or she speeds, by raising the marginal benefit of speeding:

$$\frac{dS}{dw} = \frac{R'(S)}{\pi P F''(S) + \alpha^2 \pi P \{I''(D(\alpha S))[D'(\alpha S)]^2 + I'(D(\alpha S))D''(\alpha S)\} - wR''(S)} > 0. \quad (6)$$

As mentioned above, a fine that is a function of the wage would allow the marginal cost of speeding to increase along with the marginal benefit. However, when the fine does not vary with the wage of the individual, the added income from the reduced travel time from speeding is greater, the higher the wage. This makes the fine less effective in reducing speeds, and should result in higher income individuals driving faster than lower income individuals. Cellular telephones and other recent technologies allow some work to be performed on the road, which could reduce the income impacts on speeding.

Under a traffic camera system, analysis of the other deterrence method, demerit points, becomes more complicated, as the owner of the vehicle, and not the driver, receives the ticket. Conventional speed traps can unequivocally identify the driver of the vehicle at the time of the infraction, while photo radar cannot.[5] In some cases, this inability to discern the driver has caused governments to eliminate the demerit points applied to photo radar offenses.[6] In the above model, the absence of demerit points reduces the expected marginal cost associated with speeding, the additional expected insurance cost, which results in a higher speed for all drivers, independently of their income. But even without demerit points, photo radar can be more effective than conventional enforcement through higher productivity, as shown by the far greater numbers of tickets given by photo radar than otherwise possible, which significantly increases the probability of being caught. In fact, in the above model, photo radar is effective (that is, resulting in lower speeds) in this situation

[5]The cameras could be equipped with a polarizing filter to eliminate windshield glare and identify the driver. However, this is sometimes considered an invasion of privacy and is generally avoided.

[6]For example, Ontario did not apply demerit points to infractions caught by photo radar during its 1995-96 employment of the system, although points were appied to speed offenses caught through conventional means during the same period. However, this problem has been circumvented in other areas by applying the demerit points to the owner of the vehicle unless he or she legally swears another person was driving the vehicle at the time of the offence, in which case the identified driver becomes liable (as is the case in Victoria, Australia).

if

$$d\pi > -\pi \left\{ \frac{\alpha S I''(D(\alpha S))[D'(\alpha S)]^2 + \alpha S I'(D(\alpha S))D''(\alpha S)}{F'(S) + \alpha I'(D(\alpha S))D'(\alpha S)} \right\} d\alpha, \tag{7}$$

that is, if the increase in the probability of being caught speeding is greater than the expected change in the marginal insurance cost of speeding as a percentage of the total marginal cost of speeding brought about by the decrease in the extent to which demerit points can be imposed. With α equal to unity under conventional enforcement, and to zero under photo radar, (7) reduces to

$$\frac{\pi^R - \pi^C}{\pi^C} > \frac{S I''(D(S))[D'(S)]^2 + S I'(D(S))D''(S)}{F'(S) + I'(D(S))D'(S)}, \tag{8}$$

where π^C is the probability of being caught by conventional speed enforcement methods, π^R is the probability of being caught by photo radar, so that the left-hand-side of (8) represents the percentage change in the probability of being caught induced by the switch to photo radar.

Overall, it would then seem that a photo radar system should be effective in reducing traffic speeds if demerit points are applied to these offences, and possibly effective if demerit points cannot be imposed. The previously mentioned studies suggest that a policy which reduces speeds and/or speed variance should also reduce the numbers of traffic accidents and fatalities. The following section empirically tests the hypothesis that photo radar is effective when demerit points are utilized, as in Victoria, Australia.

2 Data, Methodology and Regression Results

The results of this section are based on aggregated monthly data from the state of Victoria, Australia, for the period from January, 1986 to December, 1995. Traffic fatalities, accidents and camera hours were obtained from the Traffic Camera Office of the Victoria Police, the numbers of licensed drivers from VicRoads, alcohol related collisions from the Monash University Accident Research Centre, and the precipitation figures from the Australian Bureau of Meteorology. Three observations, during the trial period of photo radar in Victoria in the months of April, May and June, 1990, are screened out due to insufficient data regarding camera hours.[7] Separate regressions were fitted to the data for the dependent variables, fatalities per million licensed drivers (FATAL/MLD) and collisions per million licensed drivers (COLL/MLD).[8,9] Accidents and fatalities in the region are provided in Figures 1 and 2.

Photo radar was instituted in Victoria in July of 1990, following record numbers of collisions in 1988 (53,894, up from 46,711 in 1986) and fatalities in 1990 (777, up from 669 in 1986). In the years from the introduction to the end of 1995, Victoria has experienced a dramatic decrease in both traffic fatalities and collisions, with minimums of 418 in 1995 and 41,307 in 1994, respectively. At the monthly level, fatalities fell from 82 in September of 1989 to just 17 in September of 1994, and accidents fell from 4874 in May of 1988 to 2999 in January of 1994. The logical question to ask is whether these declines are a result of the presence of photo radar, or if they are simply coincidence. To answer such a question, it is obviously necessary to hold the effects of other observable influences constant.[10] From a perusal of the breakdown of contributing factors of collisions, driver error is clearly the greatest cause of traffic accidents, as can be expected. However, some observable factors play a prominent role, particularly driving while under the influence of alcohol and weather/road conditions. Thus, both collisions involving alcohol per million licensed drivers, ALC/MLD, as a proxy for drunken drivers, and average precipitation, PRECIP,[11] are included as independent variables in the regressions of a priori grounds. To test the influence of photo radar, hours of camera operation, HOURS, and the square of camera hours, HRSSQ (to account for the expected diminishing returns to additional camera hours), are also included. TIME is included to eliminate any time trend in the data

[7] Standard missing variable interpolation techniques, including the cubic spline, linear and step methods, were tried with little impact on the results and conclusions. Given the nature of the trial period, it is not unreasonable to assume that none of these methods would accurately reflect the camera hours during the missing three months, and therefore the results omitting these observations are presented.

[8] The determinants of collisions and fatalities may differ because of changes in automobile safety standards and devices (such as anti-lock brakes and airbags).

[9] Income, a variable possibly influencing speeding and accidents at the individual level but relatively constant and thus inappropriate at the aggregate level, is not included in the regressions.

[10] As data on conventional enforcement efforts are not available, it is reasonably assumed that these efforts remained constant with the introduction of photo radar.

[11] Average precipitation was calculated from the precipitation measures of a cross-section of fifteen weather stations across Victoria.

that is independent of the presence of photo radar or other included variables.[12] Summary statistics for the dependent and independent variables are provided in Table 1.

The two equations estimated are

$$\frac{FATAL}{MLD} = \beta_0 + \beta_1 \frac{ALC}{MLD} + \beta_2 HOURS + \beta_3 HRSSQ + \beta_4 PRECIP + \beta_5 TIME \quad (9)$$

and

$$\frac{COLL}{MLD} = \gamma_0 + \gamma_1 \frac{ALC}{MLD} + \gamma_2 HOURS + \gamma_3 HRSSQ + \gamma_4 PRECIP + \gamma_5 TIME. \quad (10)$$

If photo radar is effective in reducing fatalities and collisions (but at a diminishing rate), β_2 and γ_2 are expected to have a significantly negative sign (and β_3 and γ_3 a significantly positive sign). If photo radar is ineffective, these signs will be zero. To reiterate, more drunken drivers (approximated by alcohol related collisions) and less ideal driving conditions (more precipitation) each cause greater numbers of traffic accidents, so that the signs of β_1 and γ_1, and β_4 and γ_4, respectively, are expected to be positive. There is no expectation associated with the signs of the time trend coefficients β_5 and γ_5.

VARIABLE	**PRE-RADAR MEAN (VARIANCE)**	**POST-RADAR MEAN (VARIANCE)**	**ENTIRE SAMPLE MEAN (VARIANCE)**
FATAL/MLD	23.01(16.27)	12.69(8.37)	17.19(38.15)
COLL/MLD	1633.4(48911)	1234.0(7520)	1408.1(64858)
ALC/MLD	49.68(228.37)	29.87(39.09)	38.50(217.72)
HOURS	NA	$3384.9(0.13 * 10^7)$	NA
PRECIP	61.29(851.65)	67.16(1205.1)	64.6(1050.9)

Table 1. Summary statistics. NA - not applicable.

The results of the estimation of (9) and (10) are shown in Table 2.[13] In each regression, the coefficients on alcohol related collisions, camera hours, and the square of camera hours

[12] Although wealth is included in the above theoretical analysis, it is omitted in the empirical tests because of the use of aggregated data.

[13] Testing suggests no autocorrelation of the error terms, as would be expected in such an examination, and analysis of the standardized residuals and Cook's distances from each regression suggests no excessive influence of any particular observation. Further, no structural change at the implementation of photo radar (by Chow test) and an acceptable coefficient of variation (CV) for each regression suggest reasonably reliable predictions.

have the expected sign and are statistically significant at the 5 percent level, implying that increases in drunken driving increase the numbers of both collisions and fatalities, and more camera hours reduce these numbers but at a diminishing rate (that is, photo radar is effective in reducing both collisions and fatalities). The coefficient on precipitation is statistically significant in the collisions regression, but is insignificant in the fatalities regression. Thus, additional precipitation increases the number of collisions, but not fatalities. This may suggest that drivers drive more carefully in rain or snow, but slick roads cause more "minor" accidents. From these results, it would not be inappropriate to conclude that photo radar is an effective alternative to conventional speed enforcement procedures. By eliminating the effects of other observable influences on traffic fatalities and collisions, the premise that the reductions in these measures are purely coincidental can be rejected.

	FATAL/MLD	**COLL/MLD**
ALC/MLD	0.1203(3.43)**	7.6546(5.10)**
HOURS	−0.0030(−2.22)*	−0.1241(−2.15)*
HRSSQ	0.0000005(2.24)*	0.00003(2.94)**
PRECIP	−0.0067(−0.71)	1.2030(2.99)**
TIME	−0.06446(−2.42)*	−3.1940(−2.74)**
CONSTANT	19.007(11.92)**	1258.3(18.43)**
Adjusted R^2	0.7251	0.7036

Table 2. Regressions results, t-statistics in parentheses.

* denotes significance at the 5% level, ** at the 1% level.

3 Concluding Remarks

Despite widespread use of traffic speed cameras, or photo radar, around the world, such a system is often criticized for being a "cash-cow" rather than a road safety device. An analysis of the incentives provided by such a system suggests that photo radar may have a positive or negative effect on road safety, depending on the presence or absence of demerit points in respect to offences caught by photo radar cameras, assuming that there exists a direct, significant relationship between speeds (or speed variance) and collisions and fatalities. This follows from the fact that, after the initial start-up costs, one photo radar van can give out tickets at a much faster and more cost-effective rate than one police cruiser, stopping more speeders while generating far more revenues at the same time (not unimportant in the face of declining budgets). A negative impact may arise without demerit points as a higher probability of being caught and a fine alone may not be as effective at deterring drivers as a lower probability, fine and demerit points. Through empirical testing, photo radar is shown to reduce traffic fatalities, injuries and collisions in the situation where demerit points are applied to speeding offences. Future empirical analysis can examine the effectiveness of photo radar in a jurisdiction which employs photo radar without the imposition of demerit points.

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