Toward a Macroscopic Model of Road Fatalities in Queensland *

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Abstract

This paper is a progress report on some explorations with modelling, at a macroscopic level, the determination of road fatalities in Queensland. The emerging results suggest that there has been a gradual, long-run downward trend underlying the number of road fatalities per registered vehicle. Further, the rate of seat belt usage appears to have had a major impact on the incidence of road fatalities. As for the other safety policy measures – such as the random road watch program, the deployment of speed cameras and the lowering of the maximum blood alcohol level to 0.05% – the results obtained to date suggest a significant impact from them as a combined package. However, reliable estimates of the individual effects must await further research. Eventual findings will add to the body of evidence that supports decision-making by policy-makers and advisers.

1. Introduction

Traffic accidents on Queensland roads result in hundreds of fatalities and thousands of serious injuries every year. The economic costs of these accidents are in the range of billions of dollars. In order to limit and reduce the incidence of road crashes, authorities in Queensland as well as other Australian states have implemented a range of intervention measures. How effective have these measures been? To answer this important question properly requires a thorough understanding of the main determinants of serious road accidents. Such understanding will contribute to the body of knowledge that informs and supports decision- and policy-making in this area.

There is a well-established tradition of employing macroscopic regression models to analyse road accidents in countries overseas and elsewhere in Australia. In a highly influential survey, for example, Hakim et al [2] review a large number of previous studies undertaken in various countries, with a view to identifying the main characteristics underlying the estimated models. They find that the variables which are most often used as predictors of the number of fatalities or injuries are: vehicle miles travelled, vehicle population, income level, percentage of young drivers, and the presence of intervention policies.

In Australia, a series of studies undertaken at Monash University Accident Research Unit (MUARC), including Newstead et al [5] and Newstead et al [6], apply multiple regression techniques to estimate the roles of economic activity, alcohol sales, and safety policy measures in contributing to the reduction in road trauma in Victoria during the early-1990s. Although the MUARC results are challenged by White et al [8], they are by and large confirmed by a re-examination conducted by Tay [7]. For Queensland, recent studies by Leggett [3] and Leggett and Chapman [4] also highlight the role of economic activity, vehicle population, and policy countermeasures. For convenience, in what follows we shall refer to the paper by Leggett and Chapman [4] as LC.

In this paper, we report progress made in recent explorations with similar macroscopic models of the determinants of road fatalities in Queensland. The main difference between these explorations and LC is that the current research pays greater attention to methodological issues and is more explicit in recognising estimation problems such as non-stationarity, multi-collinearity and the possible omission of variables. The main aim of the paper, and of related on-going research, is to gain a better understanding of the factors involved in determining the number of serious road accidents and fatalities in the state.

The remainder of the paper is organised as follows. Section 2 describes the data sources and, where relevant, how variables are constructed. Section 3 presents a (mostly graphical) review of the trends and patterns that can be seen readily among the data series. Section 4 presents econometric results arising from explorations with OLS regressions. Section 5 summarises the main findings, notes some important reservations about such findings and suggests directions for future research.

2. Data Sources and Construction

RFP: Road fatalities per 100,000 residents
  Source: Queensland Transport
VEP: Vehicles on register per 100 residents
  Source: Queensland Transport
GSP: Real Gross State Product per capita

Source: Office of Economic & Statistical Research (Queensland Treasury) and Australian Bureau of Statistics (ABS)

The following data are available from the ABS:

a) Gross state product (GSP) in chain-volume terms, 2003-04 prices, for QLD, from 1986

b) GSP in constant-price terms, 1989-90 prices, for QLD, from 1975

c) GSP in chain-volume terms, 2003-04 prices, for Australia, from 1960

The (b) and (c) series are spliced onto (a), using overlapping observations in 1986 and 1975, respectively, to produce an estimate of real GSP for QLD from 1960, expressed in millions of dollars, 2003-04 prices.

The GSP data are divided by population data to produce GSP per capita, expressed as thousands of dollars per person, in 2003-04 prices.

BAC: Maximum permissible blood alcohol concentration for drivers

This upper limit was originally set at 0.10% in 1968, lowered to 0.08% in April 1974 and to 0.05% in November 1982. Correspondingly, there are three pure dummy (0, 1) variables associated with this factor.

* BAC10 is set at 1 for 1968 and subsequent years, 0 for previous years.
* BAC08 is set at 1 for 1975 and subsequent years, 0 for previous years.
* BAC05 is set at 1 for 1983 and subsequent years, 0 for previous years.

Note that BAC08 is meant to capture the effects of lowering the legal limit beyond 0.10% (that is, effects that are over and beyond those captured by BAC10) and, similarly, BAC05 represents possible impact that would be additional to BAC08.

ENG: Engineering enhancements

Source: Queensland Transport

The rate of seat belt usage (wearing) is considered negligible for 1968 and previous years -- thus, ENG = 0 for these years. Following legislation requiring seat belts, usage began to increase noticeably from 1969. Royal Automobile Club of Queensland (RACQ) survey data are available for 1983, 1985, 1987, 1991 and 1997. The reported rates are 76%, 81%, 89%, 93% and 93%, respectively. On the basis of these observations, LC constructed a linear series for the years 1969-1991: in each of these years, an increase of 0.1 over the previous year is assumed. The value of 2.30 (reached in 1991) corresponds to the seat belt usage rate of 93%, the highest level seen in surveys. It is assumed that this rate was then sustained (but not increased) in subsequent years.

Air bags were introduced in July 1995 (Australian Design Rule 69). Based on US research (Cummings et al. [1]) LC concluded that airbags can be expected to have smaller effects than seat belts and some scaling is therefore necessary. This resulted in an increase of 0.02 in ENG in 1996, and an increase of 0.01 in each of the years 1997 to 2004, inclusive.

An alternative way to measure the impact of these car engineering enhancements is to construct two separate variables. This approach results in BLT and BAG, described below.

BLT: Seat Belt Wearing Rate

This is set equal to the seat belt wearing rates recorded in the RACQ surveys -- e.g., 76 for 1983, and 81 for 1985. Data for the non-survey years are obtained through simple interpolation. Year 1968 is set to be the last year for which a zero wearing rate is recorded. The maximum value of 93 is assigned to 1991 and subsequent years.

BAG: Air Bag Installation Rate

Upon advice from Queensland Transport, it is assumed that the percentage of passenger cars with air bags installed increased by 7 points per year initially, and by 5 points per year subsequently. This implies that, for example, in 2002, seven years after their introduction, air bags were installed in approximately one-half of the passenger car fleet.

RBT: Random Breath Tests Conducted

Source: Queensland Transport. These are the numbers of random breath tests conducted in each of the reported periods.

RRW: Random Road Watch police enforcement program

Source: Queensland Transport.

The RRW program started in November 1991, with the participation of one out of the eight regions of Queensland. Thus, RRW is set at 0 for all years before 1992, and 0.1 for 1992. This is increased to 0.5, representing five out of the eight regions, for 1993; and to 0.7 (seven regions) for 1994. For 1996 and subsequent years, this is increased to 1.4, to reflect a doubling of coverage in each of the participating region -- initially the program covered road sections accounting for about 50% of fatal crashes in each region, but coverage was then extended to all roads in each region.

An alternative way to capture the impact of the introduction of the RRW program is to use a pure dummy (0, 1) variable, as described below

DRRW: Dummy variable for RRW program

This is set equal to 1 for 1996 and subsequent years, and zero for all years before 1996.

SCM: Speed camera deployment

Source: Queensland Transport.

Speed cameras were introduced in 1997. Accordingly, SCM is set at 0 for all years before 1998, and 1 for 1998 to 2000, inclusive. For 2001 and subsequent years this is increased to 2 to reflect an expansion in deployment.

An alternative way to capture the impact of the deployment of speed cameras is to use a pure dummy (0, 1) variable, as described below

DSCM: Dummy variable for speed camera deployment

This is set equal to 1 for 2001 and subsequent years, and zero for all years before 2001.

3. Trends and Patterns

Figure 1 shows the number of road fatalities per 100,000 residents (RFP). The series displayed a distinct upward trend until around 1973, when a new, downward trend became evident.

Figure 1

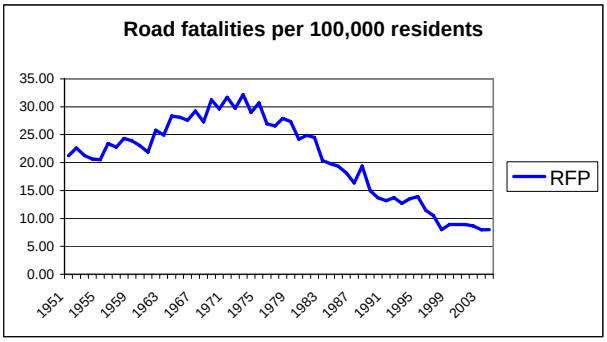
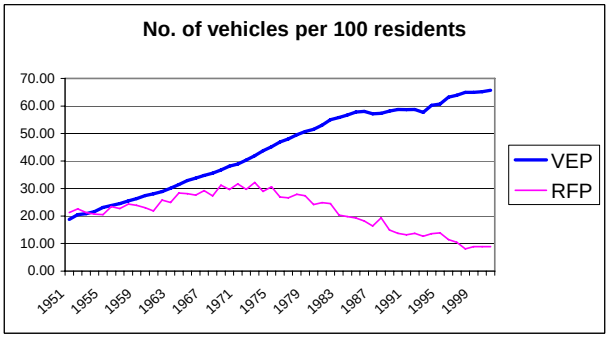


Figure 2 shows the number of passenger motor vehicles on register per 100 residents (VEP). The series displayed a rising trend throughout the study period, but with a flattening of the slope during the second half of the 1980s and first half of the 1990s. As RFP began to turn downward after 1973, it and VEP tended to diverge from each other after this date.

Figure 2



The changing nature of the relationship between RFP and VEP is shown in another way in Figure 3: The logic behind the first segment of the curve is intuitive and strong: as the number of cars increased, it can be expected that the number of car accidents (including fatal ones) would also rise -- the simple correlation coefficient between RFP and VEP in the 1951-1973 sub-period is 0.94; see also Table 2. By contrast, the second segment of the curve is highly counter-intuitive (the correlation coefficient for the 1973-2004 sub-period is -0.96). Rather than interpreting this as indicating that more cars on the road imply fewer fatalities, it is much more plausible to assume that the relevant observations reflect the impact of other determinants, such as engineering enhancements and safety measures.

Figure 3

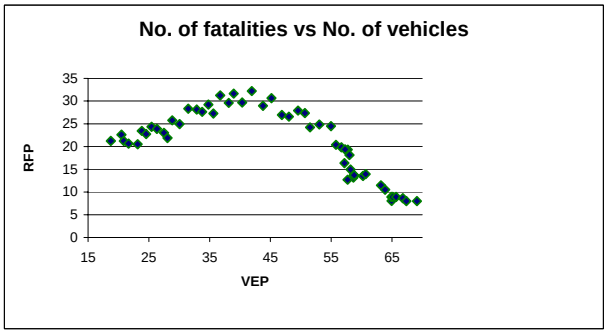


Table 1
Correlation coefficients, 1960-2004

	RFP	VEP	GSP	BAC10	BAC08	BAC05	ENG	RRW	SCM	RFP/VEP	BLT	BAG
VEP	-0.83	1.00										
GSP	-0.86	0.93	1.00									
BAC10	-0.33	0.73	0.62	1.00								
BAC08	-0.66	0.88	0.72	0.66	1.00							
BAC05	-0.90	0.85	0.79	0.45	0.69	1.00						
ENG	-0.90	0.97	0.90	0.64	0.87	0.91	1.00					
RRW	-0.79	0.67	0.84	0.27	0.41	0.59	0.65	1.00				
SCM	-0.62	0.53	0.75	0.19	0.29	0.42	0.47	0.78	1.00			
RFP/VEP	0.91	-0.98	-0.91	-0.63	-0.87	-0.90	-0.99	-0.68	-0.51	1.00		
BLT	-0.85	0.97	0.86	0.66	0.91	0.89	0.99	0.57	0.40	-0.98	1.00	
BAG	-0.65	0.56	0.78	0.20	0.31	0.45	0.50	0.84	0.98	-0.55	0.43	1.00
RBT	-0.85	0.72	0.90	0.31	0.47	0.67	0.73	0.88	0.88	-0.75	0.64	0.90

Table 2
Correlation coefficients, selected periods

Variable pair	Period	Coefficient
RFP and VEP	1951-1973	0.94
RFP and VEP	1973-2001	-0.96
RFP and GSP	1960-1973	0.90
RFP and GSP	1973-2004	-0.90
RFP and ENG	1969-1990	-0.96
RFP and ENG	1990-2004	-0.84
RFP and RRW	1992-2004	-0.86
RFP and BLT	1970-2004	-0.91
RFP and BLT	1970-1991	-0.93
RFP and BAG	1996-2004	-0.78
RFP and RBT	1987-2004	-0.85

Figure 4 shows real output (GSP) per capita. The relationship between RFP and GSP is similar to the RFP-VEP relationship; see also Figure 5. Intuitively, it is expected that as income (output) level increased, so did car ownership and car usage. (In this regard, the number of vehicle-kilometres travelled would have been, in principle, a more suitable explanatory variable for RFP than, on their own, either VEP or GSP. However, data for vehicle-kilometres travelled are available for only selected years.)

Given the downward trend in RFP after 1973, it is relevant to consider the roles that policy intervention measures may have played in bringing about the trend reversal. Figure 6 shows movements over time in the values of some of the intervention measures thought to have been most influential. As can be expected, all are negatively correlated with RFP. Not surprisingly, therefore, they also tend to be correlated with each other (see also Table 1).

Figure 4

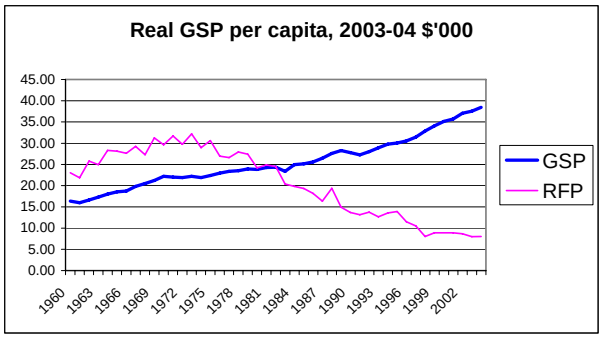


Figure 5

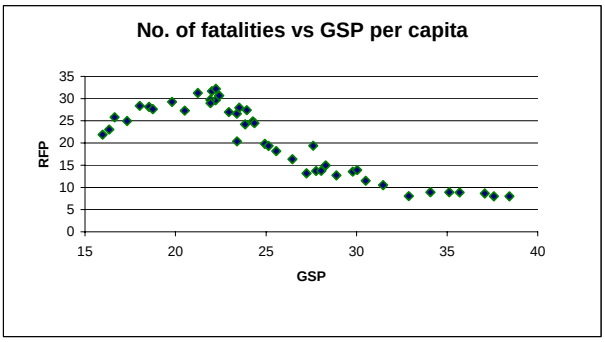
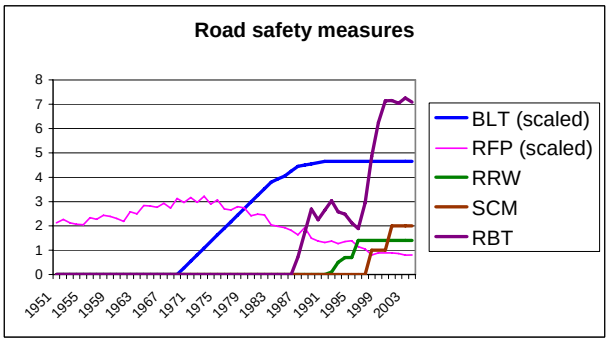


Figure 6



Of the safety measures considered, ENG (which essentially reflects movements in BLT) shows perhaps the clearest association with RFP. This point is illustrated in Figures 7, where the collection of dots rising vertically above the point where BLT = 0 correspond to the years before seat belt wearing became widespread. The data show that, between 1969 and 1991, as BLT rose steadily, RFP tended to fall, thus exhibiting a clear, negative relationship between the two, as illustrated in Figure 7. Of course, that is not the end of the story: after 1991, while BLT was static, RFP continued to fall -- reflecting a possible association between RFP and other safety measures. Figure 8 contrasts movements in RFP with movements in some of these measures, including RRW, RBT, and SCM during the period 1990-2004. The collinearity among the policy measures during this period is evident, and is confirmed by inspection of the relevant correlation coefficients in Table 1.

Figure 7

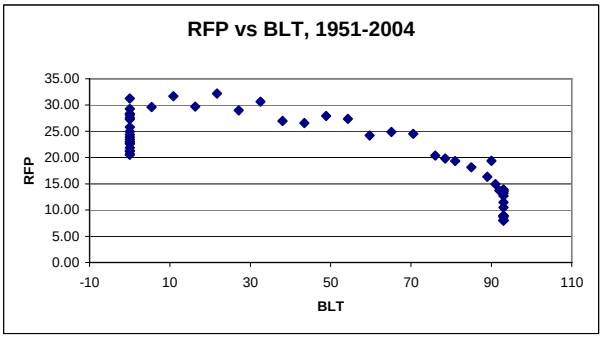


Figure 8

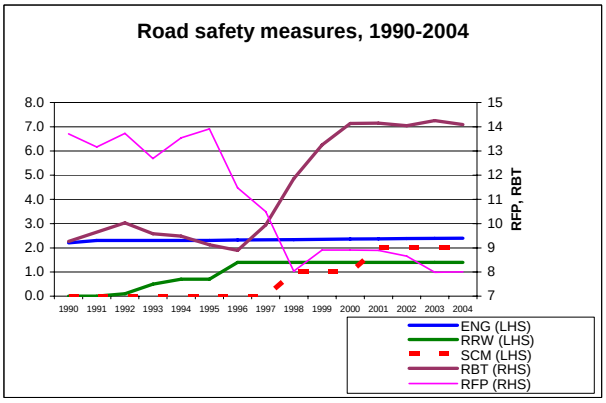


Figure 9 shows the RFP/VEP ratio -- i.e., the number of road fatalities per year per 1,000 vehicles. This ratio displayed a tendency to trend downward throughout the study period. This trend probably reflected a range of factors, such as safety-enhancing improvements in road construction and design, continuous improvements in car design, and improvements in the medical treatment of emergency cases. From the figure, it can be seen that during the 1973-1991 sub-period, the downward trend was noticeably more pronounced than in the pre-1973 sub-period. A plausible working hypothesis is that ENG (or more precisely, BLT) was the main factor underlying this steepening of the slope.

As for the post-1991 sub-period, that is, after the rate of seat belt usage had reached its historical maximum, the data show that the RFP/VEP ratio during much of this time declined at a rate which, in proportionate terms, was sharper than in the pre-1973 sub-period. To illustrate this point more effectively, Figure 10 presents the same data and trends, but in natural logs form. In this representation, a straight, upward line would indicate the path of a variable that grows smoothly and exponentially at a constant rate. Conversely, a straight downward line represents the path of a variable that declines exponentially at a constant rate. Formally:

$$Y_t = Y_0.e^{rt}$$

where Y_t is the value of variable Y at time t, and r is the rate of growth or decline of Y per unit of time. In this case, $Y_t = RFP_t/VEP_t$.

Figure 9

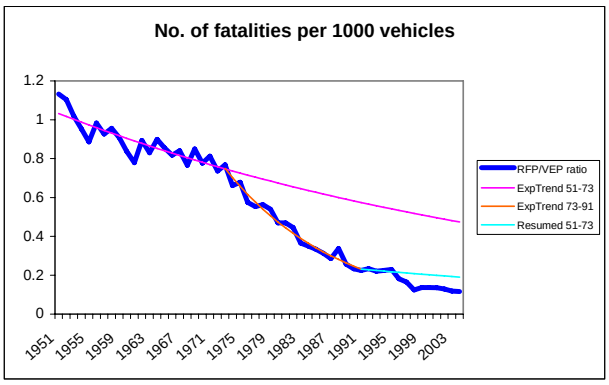


Figure 10

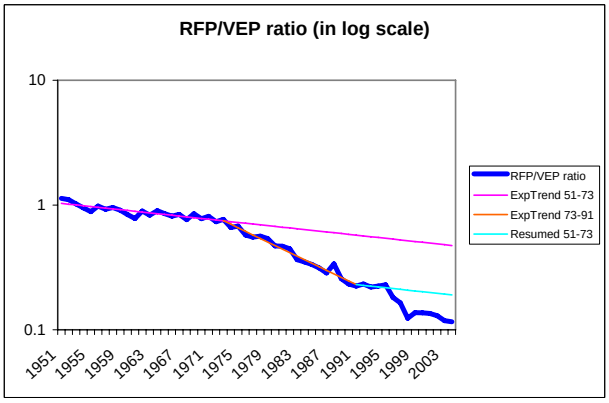


Figure 10 illustrates a trend of the above form, fitted to the actual data for the pre-1973 sub-period, and extended as a straight line beyond 1973. Parallel to this line is a lower, straight line, indicating the path that the RFP/VEP ratio would have taken if it had resumed the more gradual, pre-1973 trend after 1991.

As Figure 10 shows, the actual movements in this ratio followed a rather complex pattern during the post-1991 sub-period. From 1991 to 1995, the data appear to have fitted the (grafted) pre-1971 trend quite well, indicating a rate of decline that was similar to that observed before 1971.

From 1995, however, the actual path diverged sharply downward from the counterfactual trend line, indicating that RFP/VEH began to decline at rates which were generally faster in proportionate terms than during the pre-1973 sub-period. Indeed, during much of the post-1995 time, the annual proportionate rate of decline was sharper than even during the 1973-1991 sub-period, when increasing compliance with seat belt usage requirements had exerted a clearly discernable impact. It is plausible to associate these steep declines after 1995 with the introduction of a series of distinct policy countermeasures, as documented in LC [4] and official sources.

Compared with RFP, the RFP/VEP ratio has the advantage of being less scale-dependent. Although RFP has been, to some extent, de-scaled by the division of road fatalities by population, some elements of scale remain, in that over time vehicle ownership per capita tended to rise and the effects of this are embodied in the RFP data. By contrast, the RFP/VEP ratio is free of these effects. As will be seen below, a key difference between the present paper and LC is the relative emphasis placed by the current study on modelling the RFP/VEP ratio as an indirect approach to understanding and predicting RFP, as opposed to studying and modelling RFP directly (LC adopted the latter approach).

4. Explorations with OLS Regressions

In this section, explorations with OLS regressions are described. The explorations take, as a starting point, regressions selected by LC [4], and proceed to further investigate the properties of such regressions, especially the standard errors associated with parameter estimates and the behaviours of the residuals. Additional explorations are undertaken to model the ratio RFP/VEP, compared with LC's models of RFP.

In line with LC, two key "models" are estimated. Both are of the following form:

$$\text{RFP} = f(\textit{Scale}, \textit{Policies}), \qquad (1)$$

where *Scale* is VEP in Model 1 and GSP in Model 2, and *Policies* is the vector of policy measures (including ENG, RRW, SCM, BAC10, BAC08, etc.). A third model is also estimated:

$$\text{RFV} = \text{RFP/VEP} = f(\text{TRND}, \textit{Policies}) \qquad (2)$$

where RFV is the ratio of RFP/VEP, and TRND is a time trend term.

4.1 Unit Root Tests

Prior to undertaking OLS regressions, unit-root (non-stationarity) tests are carried out on all key variables, including RFP, VEP, GSP, and RFV. We employ the standard Augmented Dickey-Fuller (ADF) test, as implemented in the software EViews (version 5.1). As can be expected from an inspection of the relevant graphs, all four variables display clear secular trends and are found to be non-stationary -- in other words, none of them is integrated of order zero, or I(0). However, first differencing results in stationarity for all four: they are thus I(1).

Although these key variables are not I(0), OLS regressions involving them may still yield meaningful (non-spurious) results, as they are all I(1). Following the Engle-Granger approach, if the residuals from the resultant OLS regression are found to be stationary, the I(1) variables involved may be considered co-integrated, and the OLS regression may be considered a representation of the long-run relationships between them.

4.2 Model 1 Regressions

Tables 3 and 4 present a summary of explorations involving Model 1. (These regressions are carried out

with the use of EViews, versions 4 and 5.1.)

Table 3
Regressions for Model 1
(Dependent variable: RFP)

Variables	1.1	1.2	1.3	1.4	1.5
Constant	11.21	11.83	8.68	8.51	3.45
	(6.06) ***	(6.65) ***	(5.66) ***	(5.64) ***	(1.05)
VEP	0.48	0.46	0.59	0.59	0.94
	(7.10) ***	(7.04) ***	(11.49) ***	(11.66) ***	(4.55) ***
VEP^2					-0.006
					(1.75) *
ENG	-9.62	-10.44	-10.75		
	(7.56) ***	(9.85) ***	(9.45) ***		
BLT				-0.22	-0.18
				(9.39) ***	(5.21) ***
RRW	-3.64	-3.29	-3.72	-4.82	-3.50
	(4.59) ***	(4.47) ***	(4.79) ***	(5.73) ***	(3.15) ***
SCM	-2.14	-2.11	-2.38		
	(3.64) **	(3.58) ***	(3.79) ***		
RBT				-1.02	-0.81
				(4.91) ***	(3.38) ***
BAC10	2.72	2.98			
	(2.64) **	(2.95) ***			
BAC08	-1.40				
	(1.16)				
BAC05	-4.69	-4.02	-4.88	-5.07	-4.81
	(3.72) ***	(3.57) ***	(4.17) ***	(4.81) ***	(4.61) ***
Statistics/Tests					
Start year	1951	1951	1951	1951	1951
End year	2004	2004	2004	2004	2004
No of obs	54	54	54	54	54
Adj R-squared	0.96	0.96	0.96	0.96	0.96
SER/Mean (%)	6.91	6.94	7.45	7.07	6.93
Durbin-Watson	2.04	1.93	1.47	1.62	1.64
Breusch-Godfrey *F-stat*	0.30	0.38	2.90 *	0.50	0.96
White's F-stat	1.04	1.04	0.73	0.53	0.72
Jarque-Bera	1.00	0.96	1.91	1.55	1.13
Ramsey RESET	0.63	1.34	4.42 **	7.94 ***	6.64 **
Augmented DF#	-7.45 ***	-6.99 ***	-5.60 ***	-6.07 ***	-6.28 ***

Notes
Figures in brackets are (absolute) t-statistics
* Significant at 10%
** Significant at 5%
*** Significant at 1%
# Rejection of H_0 in ADF indicates that the residuals are stationary

To start with, Equation 1.1 includes VEP as the scale explanatory variable, and ENG, RRW, SCM, BAC10, BAC08 and BAC05 as policy intervention variables. This is very similar to an equation presented by LC [4]. Adjusted R-squared is high (0.96), due mainly to the association of variables with clear trends. Nevertheless, the standard error of the regression (SER) is relatively high, representing 6.91% of the mean value of the dependent variable (RFP). Neither the Durbin-Watson statistic nor the Breusch-Godfrey F-statistic indicates any serious problems with serial correlation (the latter test allows for the possibility of serial correlation of order 2). White's F-statistic also does not reject the null hypothesis of no heteroscedasticity, nor does the Jarque-Bera test reject the null hypothesis of normally distributed residuals. Ramsey's RESET test does not indicate any significant problems with misspecification. Further, the ADF test rejects the null hypothesis of a unit root, thus suggesting that the residuals are stationary. Most of the slope coefficients are highly significant and are of the expected sign. There are two exceptions: BAC08 is not significant, and BAC10 is significant but of the "wrong" sign. These problems are indicative of multicollinearity.

To reduce multicollinearity, BAC08 is dropped in Equation 1.2 and additionally BAC10 is dropped in Equation 1.3. As a result, the SER/Mean ratio rises, and there are indications of serial correlation (Breusch-Godfrey) and misspecification (RESET) in Equation 1.3. Taken together, the results suggest that multicollinearity makes it difficult to obtain accurate estimates of the marginal (separate) impact of individual policy measures under present circumstances. Statistically, BAC10 may be important as an explanatory variable, but in Equation (1.2) it appears to stand in for some factors other than its own, expected role.

In a further departure from LC's implementation of Model 1, ENG is replaced by its constituent series, BLT and BAG, and RBT is included as an explanatory variable. Equation 1.4 is representative of the resultant explorations (insignificant variables have been dropped). It meets most of the usual criteria for goodness of fit, except the RESET test. In view of the downward trend in the RFP/VEP ratio (see Figure 9), this result suggests that the linear specification (which would imply a constant, rather than falling, RFP/VEP ratio) is unsuitable as an approximation of the true situation.

One way to handle this issue is to introduce nonlinearity via the inclusion of the VEP-squared variable, VEP^2, in Equation 1.5. As expected, this new variable has a negative sign, indicating that as VEP increases, its impact on RFP tends to fall. Despite the introduction of this non-linearity, the RESET test indicates that some significant misspecification remains. A plausible explanation for this is that some variables that have been excluded (e.g., to reduce multicollinearity) may be in fact influential and should have been kept in the model.

Table 4
Regressions for Model A1
(Dependent variable: lnRFP)

Variables	A1.1	A1.2	A1.3	A1.4
Constant	1.31	0.80	0.49	1.05
	(4.26) ***	(3.36) ***	(1.05)	(4.52) ***
lnVEP	0.57	0.73	0.62	0.65
	(6.08) ***	(10.21) ***	(5.22) ***	(9.42) ***
ENG	-0.41	-0.37		
	(6.88) ***	(8.02) ***		
lnENG			-0.12	
			(3.46) ***	
BLT				-0.006
				(6.74) ***
RRW	-0.25	-0.27		-0.26
	(6.28) ***	(7.22) ***		(6.42) ***
lnRRW			-0.17	
			(6.84) ***	
SCM	-0.14	-0.15	-0.18	
	(5.03) ***	(4.97) ***	(4.57) ***	
RBT				-0.07
				(6.96) ***
BAC10	0.12			
	(2.42) **			
BAC08	0.05			
	(0.86)			
BAC05	-0.17	-0.23	-0.50	-0.24
	(2.68) **	(4.05) ***	(9.03) ***	(4.73) ***
Statistics/Tests				
Start year	1951	1951	1951	1951
End year	2004	2004	2004	2004
No of obs	54	54	54	54
Adj R-squared	0.97	0.97	0.94	0.97
SER/Mean (%)	2.43	2.53	3.56	2.40
Durbin-Watson	1.62	1.35	0.97	1.56
Breusch-Godfrey *F-stat*	0.81	2.33	8.50 ***	1.28
White's F-stat	0.96	0.76	3.06 ***	1.23
Jarque-Bera	0.61	0.22	0.75	1.18
Ramsey RESET	2.34	0.75	0.26	6.47 **
Augmented DF#	-5.87 ***	-5.40 ***	-5.11 ***	-5.96 ***

Notes
Figures in brackets are (absolute) t-statistics
* Significant at 10%
** Significant at 5%
*** Significant at 1%
# Rejection of H_0 in ADF indicates that the residuals are stationary

Another way to handle nonlinearity is to adopt the double-log form, preferred by previous researchers, e.g., Tay [7]. An added advantage of this form is that the relevant coefficients can conveniently be interpreted as elasticities. Table 4 report explorations using this form of Model 1, which might be described as Model A1.

Equation A1.1 is the analogue of Equation 1.1, and their properties are quite similar in many respects. The coefficient on lnVEP, however, involves the assumption of a constant elasticity, which is rather more defensible than the constant-slope assumption embodied in Equation 1.1. In addition, the SER/Mean ratio is reduced to 2.43%. Further explorations, as in Equations A1.2 and A1.3, indicate continuing problems with multicollinearity and its effects. Equation A1.4 features more intuitive measures of policy interventions and a lower SER/Mean ratio, but fails the RESET test.

4.3 Model 2 Regressions

Tables 5 and 6 are similar to Tables 3 and 4, but refer to explorations relating to Model 2, where the scale variable is GSP per capita rather than the number of vehicles registered. The results for Model 2 display similar patterns to those observed above for Model 1. Once again, multicollinearity is an underlying problem, as it affects key policy variables, which if omitted would result in indications of serial correlation and/or misspecification, but which would be associated with "wrong" or insignificant coefficients if retained in the model. To avoid repetition, the discussion of these results is kept purposely brief. For further detail, please refer to Tables 5 and 6.

Table 5
Regressions for Model 2
(Dependent variable: RFP)

Variables	2.1	2.2
Constant	11.67	3.70
	(2.06) ***	(0.79)
GSP	0.82	1.31
	(2.56) **	(5.26) ***
ENG	-9.32	-8.10
	(5.04) ***	(5.76) ***
RRW	-4.65	-6.77
	(4.01) ***	(6.51) ***
SCM	-3.49	-4.88
	(3.07) ***	(4.74) ***
BAC10	3.46	
	(2.62) **	
BAC08	1.99	
	(1.45)	
BAC05	-3.71	-5.79
	(2.52) **	(4.24) ***
Statistics/Tests		
Start year	1960	1960
End year	2004	2004
No of obs	45	45
Adj R-squared	0.96	0.95
SER/Mean (%)	8.12	8.96
Durbin-Watson	1.71	1.39
Breusch-Godfrey *F-stat*	0.62	3.03 *
White's F-stat	1.60	1.05
Jarque-Bera	2.12	0.57
Ramsey RESET	2.51	1.19
Augmented DF#	-5.90 ***	-4.93 ***

Notes
Figures in brackets are (absolute) t-statistics
* Significant at 10%
** Significant at 5%
*** Significant at 1%
# Rejection of H_0 indicates the residuals are stationary

Table 6
Regressions for Model A2
(Dependent variable: lnRFP)

Variables	A2.1	A2.2
Constant	0.80	-0.06
	(0.81)	(0.93)
lnGSP	0.86	1.16
	(2.47) **	(4.89) ***
ENG	-0.46	-0.35
	(5.33) ***	(5.45) ***
RRW	-0.30	-0.37
	(5.79) ***	(8.15) ***
SCM	-0.20	-0.22
	(4.51) ***	(5.43) ***
BAC10	0.10	
	(1.43)	
BAC08	0.15	
	(2.25) **	
BAC05	-0.15	-0.25
	(2.00) *	(-3.72) ***
Statistics/Tests		
Start year	1960	1960
End year	2004	2004
No of obs	45	45
Adj R-squared	0.97	0.96
SER/Mean (%)	2.81	3.02
Durbin-Watson	1.40	1.16
Breusch-Godfrey *F-stat*	1.72	4.08 **
White's F-stat	1.66	3.66 ***
Jarque-Bera	1.01	0.69
Ramsey RESET	7.72 ***	1.33
Augmented DF#	4.87 ***	4.23 ***

Notes
Figures in brackets are (absolute) t-statistics
* Significant at 10%
** Significant at 5%
*** Significant at 1%
# Rejection of H_0 indicates the residuals are stationary

4.4 Model 3 Regressions

In a key departure from LC's analysis, the current study conducts exploratory OLS regressions of Model 3 and its logged-dependent-variable analogue, Model A3 (see Tables 7 and 8). These models represent a different approach to the nonlinearity of the RFP-VEP relationship: the downward trend in the ratio is now represented directly by means of a trend term. For example, in Equation 3.2, the TRND term has a slope coefficient of -0.0131 (before scaling) indicating that each year the RFP/VEP ratio tends to fall by 1.31 percentage points in the absence of special intervention measures, such as BLT, RRW, or RBT.

This estimate is close to the estimated slope of a simple, linear trend regression based on the 1951-1973 sub-period (illustrated in Figure 9). It may be interpreted as an estimate of the long-term, continuous effect of steady, minor improvements in automobile and road design and construction (excluding major breakthroughs such as the introduction of mandatory seat belts) and any net improvements in the public's standard practice with respect to road safety (reflecting, e.g., both greater awareness of safety issues and greater complacency and over-reliance on built-in safety features of car and road design). The equations presented in Table 7 can be interpreted in a similar manner to those in Tables 3 and 5.

Table 7
Regressions for Model 3
(Dependent variable: RFV = RFP/VEP)
(For readability, intercept and slope coeffs have been multiplied by 100)

Variables	3.1	3.2	3.3	3.4
Constant	104.20 (53.97) ***	103.00 (53.48) ***	102.50 (58.15) ***	101.99 (72.31) ***
TRND	-1.54 (7.50) ***	-1.31 (7.50) ***	-1.24 (8.36) ***	-1.17 (10.31) ***
ENG	-4.12 (1.02)	-10.97 (1.02)		
BLT			-0.27 (4.48) ***	-0.33 (7.65) ***
RRW	2.41 (1.01)	3.03 (1.01)	0.15 (0.06)	
SCM	1.74 (1.00)	1.09 (1.00)		
RBT			0.34 (0.56)	
BAC10	4.58 (1.63)			
BAC08	-8.42 (2.51) **			
BAC05	-6.42 (1.75) *	-3.92 (1.75) *	-4.31 (1.49)	
Statistics/Tests				
Start year	1951	1951	1951	1951
End year	2004	2004	2004	2004
No of obs	54	54	54	54
Adj R-squared	0.98	0.98	0.98	0.98
SER/Mean (%)	7.51	8.03	7.52	7.47
Durbin-Watson	1.79	1.29	1.41	1.37
Breusch-Godfrey *F-stat*	0.60	3.40 **	1.75	1.99
White's F-stat	1.38	1.44	1.89	4.50 ***
Jarque-Bera	1.29	0.87	5.64 **	5.40 *
Ramsey RESET	4.59 **	4.58 **	1.37	0.02
Augmented DF#	-7.19 ***	-4.06 ***	-4.71 ***	4.72 ***

Notes
Figures in brackets are (absolute) t-statistics
* Significant at 10%
** Significant at 5%
*** Significant at 1%
# Rejection of H_0 indicates the residuals are stationary

Table 8
Regressions for Model A3
(Dependent variable: lnRFV)
(For readability, intercept and slope coeffs have been multiplied by 100)

Variables	A3.1	A3.2
Constant	4.54 (1.27)	7.03 (2.02) **
TRND	-1.33 (4.72) ***	-1.53 (5.61) ***
BLT	-0.58 (5.07) ***	-0.53 (4.62) ***
RRW	-28.47 (6.97) ***	
DRRW		-31.69 (5.03) ***
SCM	-12.34 (3.81) ***	
DSCM		-23.14 (3.54) ***
BAC05	-27.26 (5.13) ***	-30.76 (5.85) ***
Statistics/Tests		
Start year	1951	1951
End year	2004	2004
No of obs	54	54
Adj R-squared	0.99	0.99
SER/Mean (%)	9.91	10.00
Durbin-Watson	1.24	1.12
Breusch-Godfrey *F-stat*	3.56 **	6.07 ***
White's F-stat	1.76	2.56 **
Jarque-Bera	0.88	0.46
Ramsey RESET	10.95 ***	***
Augmented DF#	-4.95 ***	-4.51 ***

Notes
Figures in brackets are (absolute) t-statistics
* Significant at 10%
** Significant at 5%
*** Significant at 1%
# Rejection of H_0 indicates the residuals are stationary

An inherent weakness in the formulation of Model 1 is that it specifies the above long-term trend as a linear trend. This implies that the RFP/VEP ratio falls by a fixed absolute amount each year, and that in principle the ratio will fall to zero if the trend persists for a finite number of years. A more satisfactory assumption is to postulate an exponential trend, which implies that each annual fall tends to be smaller in absolute terms than previous ones, but of the same size in proportionate terms. In this case, the ratio will only approach zero as the time horizon become infinite. This formulation is embodied in Model A3, and Table 8 summarises the explorations undertaken to date using this model.

The parameter estimates obtained for both Models A3.1 and A3.2 suggest that countermeasures such as BLT (mandatory wearing of seat belts), RRW (introduction of the random road watch program), SCM (introduction of speed cameras) and BAC05 (lowering of maximum legal blood alcohol reading to 0.05%) may have had significant and negative impacts on the number of fatalities per vehicle registered, over and above the long-term, continuous decline brought about by "normal" annual improvements in safety. (The main difference between these two estimated models is that Model A3.2 makes use of pure (0, 1) dummy variables to capture the impact of the RRW and SCM initiatives.) Continuing problems with multicollinearity and possible model misspecification, however, mean that these individual estimates cannot be regarded as reliable, until they have been verified by further research, preferably with the use of additional data and/or analytical techniques.

5. Summary of Findings and Directions of Further Research

None of the estimated equations presented in Section 4 can be considered definitive. On balance, the "preferred" equation is probably Equation A3.1, but it does suffer from a number of defects, including failure to pass the Breusch-Godfrey test for serial correlation and, perhaps for related reasons, the Ramsey test for misspecification (see Table 8). Nevertheless, the explorations reported above have served to enhance understanding of the relationship between the number of road fatalities in Queensland and factors determining this number. In particular:

- The key variables of interest, such as RFP, VEP, GSP, and RFP/VEP are found to be non-stationary, but are integrated of order 1, and some may be co-integrated with one another. In the latter case, a long-term relationship between the co-integrated variables may be estimated with OLS.
- While a great deal of further work is required before firm conclusions can be safely reached, it is likely that such work will confirm that there is a strong and positive (but non-linear) relationship between RFP (the number of road fatalities scaled by population) and VEP (the number of vehicles on registration scaled by population). It may be preferable to investigate RFP indirectly via models of the ratio RFP/VEP, rather than directly.
- It appears that there has been a long-term, continuing

downward trend in the ratio RFP/VEP (see Figures 9 and 10). This declining trend may be explainable in terms of continuous, minor improvements in the design and construction of automobiles and roads as well as the public's attitude and practice with regard to safety. On theoretical grounds, the trend should probably be seen as exponential rather than linear.

- It appears that there has been a strong and negative relationship between RFP (or RFP/VEP) and BLT (the rate of actual usage of seat belts). The sign of this relationship is likely to prove robust in any further studies, although the numerical estimates may be subject to substantial changes.
- There is even greater uncertainty surrounding the estimation of the individual impacts of other policy measures, such as RRW, SCM, BAC and RBT, due mainly to collinearity among the relevant data series. By contrast, it seems reasonable to conclude that, taken together as a whole package, the policy measures adopted after seat belt usage had reached saturation (e.g., after 1995) did make a significant impact on the RFP/VEP ratio, reducing it below the annual levels which would have prevailed had the only sources of further improvements been the small, continuous progress already captured in the above-mentioned long-run trend (see Figures 9 and 10).
- A problem which must be addressed in future research is how to handle collinearity among the large number of policy measures which were operative during overlapping periods. The inclusion of all variables representing such measures would reduce the regression's degree of freedom and result in unreliable numerical estimates of individual parameters (as evidenced in coefficients that are of the wrong sign or are insignificant). Yet omitting some of these variables may lead to biased estimates of the remaining parameters.

Because of the uncertainty and problems identified above, the regressions reported in this paper should be interpreted with care. In particular, precise numerical estimates should not be treated as reliable until they have been validated by further research. The eventual findings will add to the body of knowledge supporting the formulation of policies in this important area.

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