

Determinants of Road Traffic Safety: New Evidence from Australia using a State-Space Analysis

Son H. Nghiem^a and Luke B. Connelly^b

^aCorresponding author, Senior Research Fellow, Institute of Health and Biomedical Innovation, Queensland University of Technology. Phone: 61-432-066059 Email: son.nghiem@qut.edu.au.

^bProfessor, CONROD, Australian Centre for Economic Research on Health (ACERH), The University of Queensland. Email: l.connelly@uq.edu.au

Abstract

This paper examines determinants of road and traffic crash fatalities in Queensland in the 1973-2007 period using a state-space time-series model. In particular, we investigate the effects of policies that aimed to reduce drink-driving and economic environment to traffic fatalities. The results show that random breath testing reduced fatalities by 10 per cent and that the zero BAC for young drivers reduced fatalities by 15 per cent. Reductions in economic activity also lead to reductions in road fatalities, estimating that a one per cent increase in the unemployment rate leads to a reduction of traffic fatalities of 0.22 per cent.

Key words: Road traffic crashes, safety, alcohol, young drivers, state space, Queensland

Introduction

It is well known that drink-driving has long played a substantial role in road traffic crashes, injuries and deaths, especially among young drivers (Renwick et al., 1982; Mayhew et al., 1986; Zador et al., 2000; Voas et al., 2006; Ramstedt, 2008). Over the past four decades, governments in Australia have implemented legislative change and enforcement measures that are designed to reduce the road toll and improve traffic safety. In relation to drink-driving in particular, the legal limit of blood alcohol concentration (BAC) for drivers was reduced from 0.08 (i.e., 80 milligrams of alcohol per 100 millilitres of blood) to 0.05 in 1983, which resulted in significant reduction of road accidents involving drink-driving (Smith, 1986, 1988). Many other policies that target driving under the influence of alcohol have been implemented since the introduction of a lower BAC limit. In particular, the random breath test (RBT) program was introduced in 1988 and was expanded in 1997 to deter drink-drinking. In 1991, a “zero tolerance” policy was introduced for drivers under the age of 25, who are required to have a BAC of zero when driving a motor vehicle. . The literature on this topic has shown that effects of policies on alcohol-impaired driving may vary by jurisdiction, especially as different jurisdictions implemented such measures at different times and different ways. Estimates of the effects of such policies by jurisdiction are thus worthwhile (Mann et al., 2001; Goss et al., 2008), but to the best of our knowledge, the effects of these measures have not been estimated for Queensland. Our contribution is to examine the effects of the policies that governments have used over the past few decades to reduce the influence of alcohol on traffic fatalities in Queensland. We do so using annual data for the period 1973-2007 period and applying a state-space time series model to control for effects of unobserved components in road traffic fatalities. Our estimates suggest that these policies – the implementation of which is typically resource-intensive – did indeed have a profound effect

on road traffic fatalities in this jurisdiction. While we do not attempt to conduct a cost-benefit analysis (CBA) here, we suggest that as a next step in this program of research.

Literature review

The association between alcohol and road traffic fatalities has been investigated wide. At the time of writing, a search on the term “alcohol and traffic accidents” produces 283 results (or approximately 118,000 results when the quotation marks were dropped) in Google Scholar. Therefore, in this section we focus on summarizing results from meta-analyses and review only those studies that are the most relevant to our objectives in this paper. Jones and Joscelyn (1978) was the first study to review the association between alcohol and traffic safety. One of their findings was that young male drivers are at high risk of driving under the influence of alcohol. Mayhew et al. (1986) focused on reviewing three groups of studies: the extent of drink-driving by youth, alcohol use among young drivers who were involved in road crashes, and the relative risk of crashing by young drink drivers. They found that young drivers under the influence of alcohol were more likely to be involved in road crashes than their sober peers. They proposed two hypotheses in connection to this observation: first, that young drivers were “inexperienced” with drink-driving; and second, that after drinking young drivers systematically engaged in more risky behaviour. A meta-analysis by Erke et al. (2009) to determine the effect of driving under influence (DUI) checkpoints in reducing crash numbers across Australia, New Zealand, USA, Canada and the Netherlands indicated the Australian random breath test (RBT) to be the most effective in reducing crashes. Overall, they found the DUI checkpoints to be effective in reducing the alcohol related crash numbers by a minimum of approximately 17 per cent.

Mann et al. (2001) reviewed the effects of lower BAC on traffic accidents and consequences. They revealed that most studies showed beneficial effects of lowering BAC limits on traffic safety measures but these effects varied in magnitude and duration of effect (i.e., with some having temporary and others having lasting effects). In addition, they found that the beneficial effects shown by most studies are due to general deterrence, i.e., they are not restricted only to lowering the BAC limit.

We agree with others who have written on this topic that it is difficult, if not impossible, to differentiate effects of different road safety policies that were introduced during the same period of time. Nevertheless, reviews by Shults et al. (2001) and Goss et al. (2008) have found that two-thirds of the studies of this kind find significant reductions in fatal crashes due to increased enforcement. The review by Zwering and Jones (1999) also suggest that a zero tolerance towards drunk driving by young drivers is also a very effective way to reduce alcohol-related fatalities, and several more recent studies also corroborate this argument (Voas et al., 2003; Liang and Huang, 2008; Chang et al., 2012).

The traffic safety literature also shows that young male drivers are the most likely to be involved in accidents and to drive under influence of alcohol (Renwick et al., 1982; Lloyd, 1992; Ramstedt, 2008), and hence, policy interventions to lower risk of this group may be expected to be the most beneficial. The main factors that lead to the relatively higher risks to young drivers include the development process from adolescence to emerging adults and differences in risk perception. Arnett (2002), for instance, has argued that young males have higher levels of testosterone and these are also linked to risky driving behaviours. They argue that young males are hence more aggressive and tend to engage in (what they believe to be) shows of bravery and toughness, especially in the presence of young females. Thus, young male drivers appear often take more risk on the road in the presence of passengers (Preusser et al., 1998), especially young female passengers (Simons-Morton et al., 2005). Other explanations of the higher rate of involvement of younger people in serious crashes include

an optimistic bias, whereby young drivers overestimate their driving skills and hence take more risk than do other age groups (Tränkle et al., 1990). The results from previous studies (Voas et al., 2003; Carpenter, 2004; Chang et al., 2012) broadly support this view.

In Australia, most previous studies also suggest that lower BAC limits have improved traffic safety. For example, Homel (1994) and Smith (1988) found that the reduction of BAC limits from 0.08 to 0.05 was associated with a significant reduction in traffic fatalities in both New South Wales and Queensland. More recently Howard et al. (2014) reviewed the implications of Australian alcohol policy on public health and found evidence that RBT, lowered BAC limits and low BAC for young drivers were highly effective counter measures. Evidence from Begg et al. (2007) suggests nearly 336 fatalities among young Australians each year and that 31 per cent of these are alcohol-related. Gruenewald et al. (1999) and Chikritzhs and Stockwell (2006) found that increased alcohol consumption and later trading hours of hotels in Perth, Western Australia, were also associated with more crashes by drinking-impaired drivers. Yakovlev and Inden (2010) have also recently found that alcohol consumption (along with air temperature and precipitation) was one of the strongest determinants of traffic fatalities in the U.S. from 1982 – 2006, in the 48 contiguous states.

The role of the business cycle is not always controlled in quantitative studies, but there is reason to believe that doing so may be important. Leigh and Waldon (1991), for instance, hypothesized three possible effects of unemployment on fatalities. First, as aggregate unemployment increases, driving and fatalities should decrease. Second, the effect of unemployment on drinking per se is ambiguous: some unemployed may drink more due to stress, but lower incomes may lead to less drinking, making the net effect uncertain. Third, unemployment may increase aggregate levels of stress and unhappiness, perhaps leading to poorer concentration, perhaps leading to more crashes and fatalities. Using US data by state the authors found evidence in support of two of these hypotheses: holding vehicle miles constant, unemployment increased road crash fatalities (the stress hypothesis), but because unemployed people drove less, there were fewer fatalities overall. Ruhm (1995) has also examined the effects of macroeconomic conditions on alcohol consumption and found them to be pro-cyclical.

Finally, in relation to the methods that have been used in this literature on the relationship between alcohol and traffic safety, we found state-space time series models to be under-represented, even though models from the same family (e.g., structural time series) are fairly common (Bergel-Hayat, 2012; Commandeur et al., 2012). The main difference between structural time series models and the autoregressive integrated moving average (ARIMA), which is also widely applied in traffic safety studies, is the treatment of unobserved components such as trends, slope, cycles and seasonality. Structural time-series models aim to estimate the variance/covariance of these components, while in ARIMA modelling the objective is to remove these components using methods such as first-differencing. Here, we apply a state-space method from the structural time series family to examine the effect of policy interventions that address drink driving in the State of Queensland, Australia.

Methodology

We estimate the determinants of traffic safety based on the latent risk model by Bijleveld et al. (2008), which states that losses can be decomposed into exposure to risks and outcomes of risk. In this study, we use the amount of petrol consumed as our indicator of exposure risk, the outcomes of this risk are indicated by the number of crashes, and the losses due to crashes are indicated by the number of traffic fatalities. Since the indicator variables we use may contain measurement errors, unobserved level, slope, seasonal effects and other exogenous

factors (i.e., regression effects), we apply a state-space model¹ introduced by Harvey and Durbin (1986) to estimate unobserved components (e.g., level and slopes) and determinants (e.g., weather and socio-economic conditions) of traffic fatalities as follows:

$$\begin{cases} \log F_t = \mu_t^1 + \eta \log A_t + \gamma^1 \log X_t^1 + \varepsilon_t^1 \\ \mu_t^1 = \mu_{t-1}^1 + \beta_{t-1}^1 + \tau_t^1 \\ \beta_t^1 = \beta_{t-1}^1 + \xi_t^1 \end{cases} \quad (1)$$

$$\begin{cases} \log A_t = \mu_t^2 + \varphi \log E_t + \gamma^2 \log X_t^2 + \varepsilon_t^2 \\ \mu_t^2 = \mu_{t-1}^2 + \beta_{t-1}^2 + \tau_t^2 \\ \beta_t^2 = \beta_{t-1}^2 + \xi_t^2 \end{cases} \quad (2)$$

$$\begin{cases} \log E_t = \mu_t^3 + \gamma^3 \log X_t^3 + \varepsilon_t^3 \\ \mu_t^3 = \mu_{t-1}^3 + \beta_{t-1}^3 + \tau_t^3 \\ \beta_t^3 = \beta_{t-1}^3 + \xi_t^3 \end{cases} \quad (3)$$

where:

- F_t is the number of road traffic fatalities: an indicator of risk losses;
- A_t is the number of traffic accidents: an indicator of risk outcomes;
- E_t is the amount of petrol consumed: an indicator of risk exposure;
- Superscripts 1, 2 and 3 represent components of equations 1, 2 and 3, respectively;
- μ_t and β_t are the unobserved level and slope, respectively;
- X_t^1 , X_t^2 and X_t^3 is the set of exogenous covariates such as economic activities and traffic safety interventions, which may differ among equations 1, 2 and 3; and
- ε_t^1 , ε_t^2 and ε_t^3 are random noises, which are assumed not to be mutually correlated, with variances $\delta_{\varepsilon^1}^2$, $\delta_{\varepsilon^2}^2$ and $\delta_{\varepsilon^3}^2$, respectively.

In each of Equations 1, 2 and 3 above, the first sub-equation is referred to as an “observed” equation whilst the last two sub-equations are called “state” equations. Both the level and slope components of these equations are assumed to follow normal distributions with zero means and non-zero variances. Observations from the three equations above also suggest that the estimation of Equation 1 alone may produce biased results because the assumption that regressors are independent are violated (i.e., $\log A_t$ correlates with $\log X_t^2$, which include some components of $\log X_t^1$). Estimating Equations 1, 2 and 3 simultaneously provides the additional benefit that we are able to estimate the variances and covariance between unobserved factors (i.e., the levels and slopes).

Parameters of exogenous variables and policy interventions in a state-space model can be interpreted in a way that is similar to that of standard log-log ordinary least-squares regression. For example, the parameters of continuous variables (e.g., GSP per capita, rainfall) can be interpreted as elasticities while the parameters of policy interventions represent the aggregate impacts of the interventions on traffic fatalities.

Compared to the standard regression approach, though, the main difference of the state-space model is that the level (i.e., constant or intercept) components are permitted to change over

¹ This is also referred to in the literature as “unobserved component” or “multivariate structural time series” model. For more detailed discussions of this method, see for example Durbin and Koopman (2001).

time at different rates. Thus, in the special case that the variance of the level and slope of the above system are equal to zero, a standard OLS approach can be applied.

Data

Sources of data

The data that are used in this study were collected from several sources including the Australian Bureau of Statistics, the Australian Bureau of Meteorology, Queensland Statistics, and Queensland Transport. Despite our considerable attempts, we simply could not however obtain information on the number of accidents and injuries for 1990 and 1991. The missing data for these years have been imputed by interpolating data from the closest two years. The data on vehicle kilometres travelled (VKT) also have a number of missing observations. In general, VKT data are missing at every 3 to 5 years. On the basis of this source of measurement error, we decided not to use this variable even though it is widely used in the literature as a measure of exposure to accidents. Other variables that we would like to have included, such as unemployment and petrol consumption, were not available from 1966 and 1973, respectively. Before that period, these variables were only available one every four to five years. Therefore, we decided to conduct the analysis from 1973, from which time all of the variables of interest to us are available.

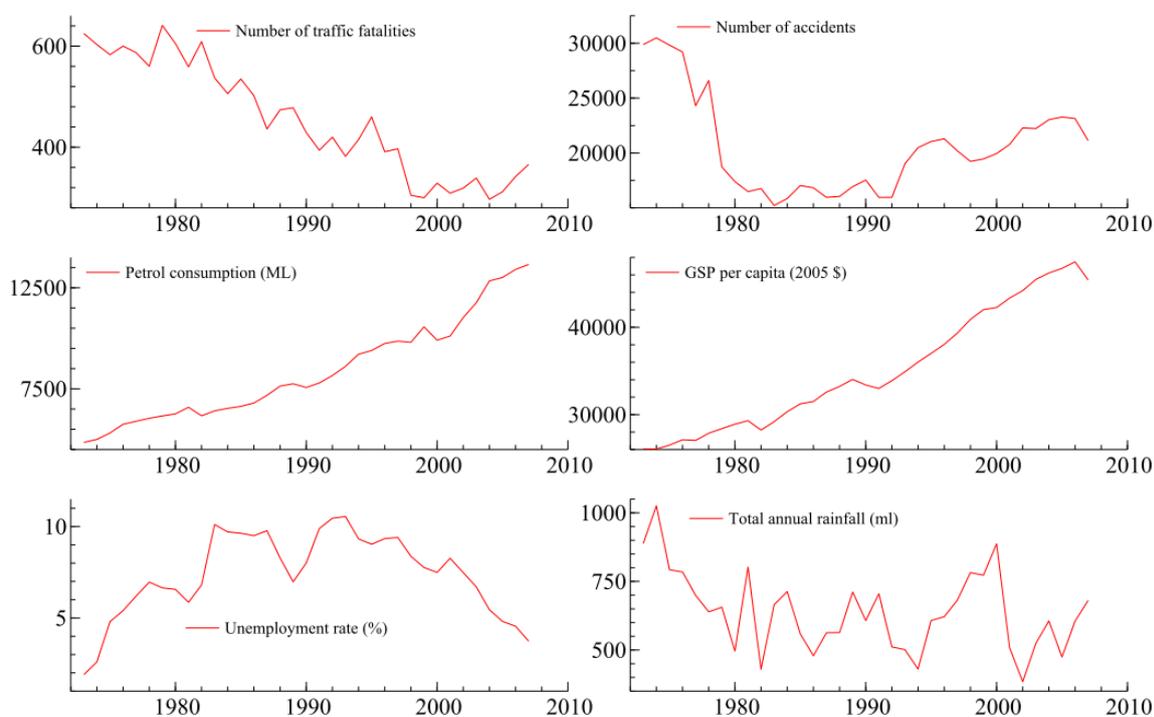


Figure 1. Main variables

Figure 1 shows that during the study period traffic fatalities in Queensland declined continuously, with the exception of several outlier years (e.g., 1980, 1995 and 2007). However, the number of accidents fell sharply in the late 1980s and remained very low until the early 1990s after which time it has generally increased to the end of the series. Another notable observation is that our indicator of economic development—which is measured by the real Gross State Product (GSP) per capita—is almost monotonically increasing, as is the level of petrol consumption (which is our proxy for traffic exposure). The unemployment rate shows a slight increase in the study period whilst the annual rainfall declined slightly. Overall, observations from the actual data seem not to reveal any clear relationship except that higher economic development is strongly associated with exposure.

Variable selection

Since it is not possible to examine the effects of the many legislative changes that were introduced during the study period using the available data (especially when these measures overlap), we focus on two periods when major policies that aimed to address the drink-driving were introduced. The specific interventions of interest are as follows:

- The introduction of random breath testing on 1 December 1988;
- The imposition of a zero blood alcohol concentration (BAC) limit on learner drivers and young drivers in the first three years of having a driver licence (up to 25 years old) on 1 January 1991;
- The random breath test program's expansion in 1997; and
- The “Safe4life” road safety strategy that was introduced in Queensland in 2004, which gave priority to addressing driving under influence of drugs and alcohol, which was the leading cause of traffic fatalities in the state.

We expect these alcohol-targeted interventions to produce greater effects on traffic fatalities, even if their effects on accidents and traffic exposure are less obvious. The rationale for being uncertain about the effects of these policies on accidents *per se*, is due to risk compensation theory (Wilde, 1988, 1998), which suggests that when the likelihood of accidents reduces, people may decide to drive in a way that is actually more risky.

Apart from policy interventions, environmental factors such as weather condition and economic activities can affect traffic safety. The best proxy for weather conditions that is available to us is the total rainfall. Rain deteriorates driving conditions, and hence, the likelihood of traffic accidents and fatalities should increase as a result. Yet, heavy rainfall may also make people less likely to drive, and to take greater precautions when driving, so the net effect of this driving conditions proxy is an empirical matter.

We expect economic activities have positive association with traffic fatalities. An increase in economic activities increases the demand for transport and travel, which may also lead to more traffic crashes and casualties. In this study, we choose gross state product (GSP) per capita at 2005 prices, and unemployment rates as measures of economic development and activities. We expect unemployment rates to be negatively associated with traffic injuries and for GSP per capita to follow an inverse U-shaped relationship in relation to traffic fatalities. Previous studies such as Kopits and Cropper (2005), Bishai et al. (2006) and Iwata (2010) suggested that the relationship between income and traffic fatalities becomes negative when income per capita reaches \$6000 to \$18000. On that basis, one may hypothesise that the relationship between GSP per capita and traffic fatalities in Queensland will be negative as income per capita in Queensland for the study period was between \$30,000 and \$50,000 (see Figure 1).

Results and discussion

The results show that residuals of three regressions satisfy the assumptions of homoscedasticity, normality and serial independence at the five percent level. In particular, we apply the Ljung and Box (1978) Q test, the $H(m)$ test (Jarque and Bera, 1980), and the Bowman and Shenton (1975) N -test test the assumptions of serial independent, homoscedasticity and normality, respectively. Graphically, these residuals lie within the intervals ($\pm 2/\sqrt{n} = \pm 0.34$) and do not deviate much from that of the normal distribution (see Figure 2).

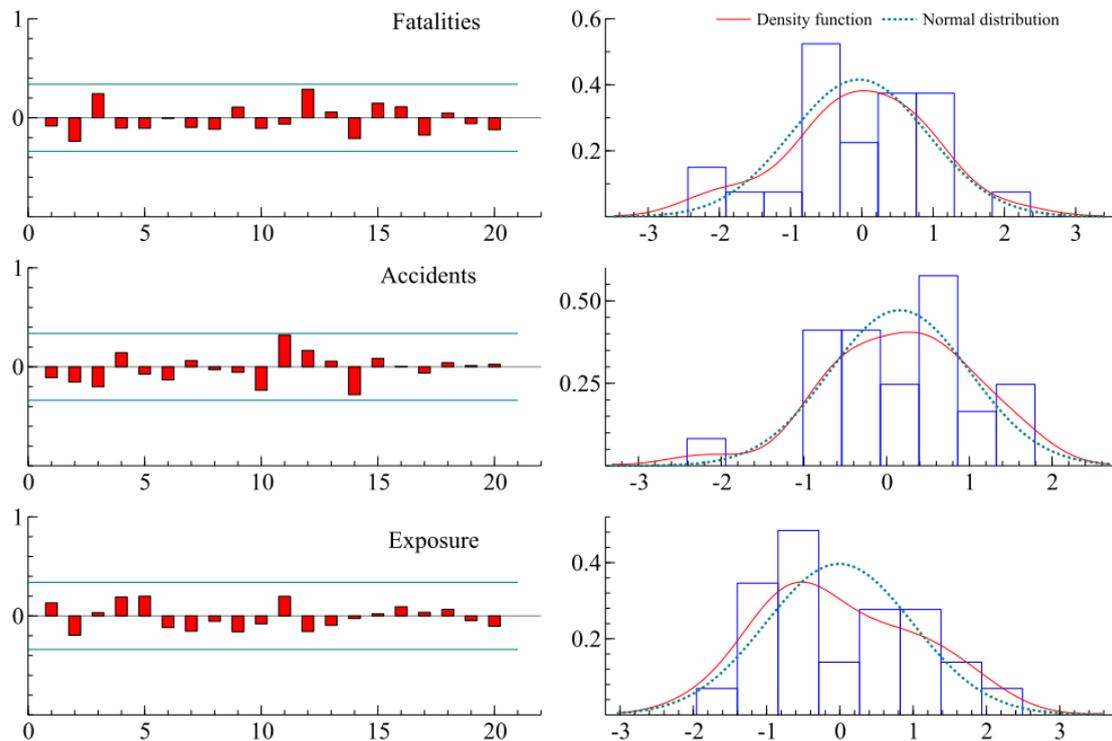


Figure 2. Autocorrelation functions and histograms of standardised residuals

The decomposition of unobserved components in Figure 3 shows that the regression line fits the data very closely (first row). The unobserved level component shows a gradual increasing trend of traffic fatalities in the study period (second row). Since the observed traffic fatalities decreased continuously over the same period, the impacts of policy interventions (and other exogenous factors) must increase substantially over time to not only compensate for the unobserved increasing trend but also result in declining traffic fatalities over time. The unobserved slope component confirms an overall unobserved increasing trend in traffic fatalities (i.e., positive slope) during the study period, with the exception of 1983 where slope was zero (third row). In addition, the slope estimates suggest that the rate of the unobserved increasing trend flattened in two periods: 1973-1983 and 1990-1995.

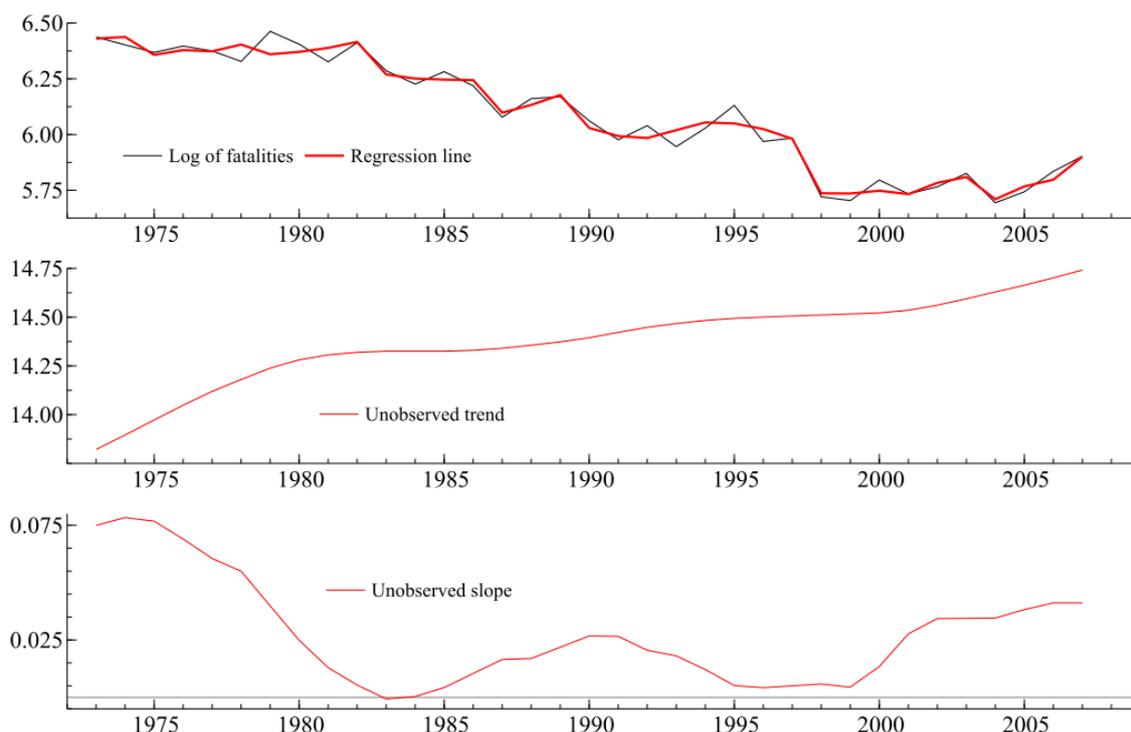


Figure 3. Unobserved components of traffic fatalities

The multivariate results in Table 1 (Multivariate 1) show that the unemployment rate and all policy interventions are statistically significant determinants of traffic fatalities in Queensland. In particular, the introduction of the random breath test program in 1988, the imposition of zero BAC for young drivers in 1991, the expansion of the random breath test program in 1998, and the “Safe4life” strategy in 2004 all led to reductions of traffic fatalities: by 12.1, 13.5, 22.8 and 15.3 per cent, respectively.² The results also suggest that a one per cent decrease in unemployment rate is associated with a 0.22 per cent reduction in traffic fatalities, on average. Notably, though, the frequency of accidents, GSP per capita and rainfall have no significant effects on traffic fatalities.

Table 1. Determinants of road traffic fatalities

Parameters	Multivariate 1	Multivariate 2	Univariate
Log of accidents	-0.083	***0.268	-0.065
Log of GSP per capita	-0.504	*-0.978	-0.644
Log of unemployment rate	***-0.221	***-0.225	** -0.162
Log of rainfall	-0.038	-0.011	-0.035
Random breath test program started (1=1988 onwards)	** -0.13	*-0.101	** -0.126
Zero BAC for young drivers (1=1991 onwards)	** -0.146	***-0.169	*-0.131
Random breath test expansion (1=1998 onwards)	***-0.259	***-0.223	***-0.296
“Safer4life” strategy (1=2004 onwards)	***-0.166	***-0.173	** -0.143

² As the regressions are in the log-log form, these numbers are calculated as $(e^\beta - 1) \times 100$, where β is the parameters of the dummy variables for policy interventions.

Level variance (σ_{ξ}^2)	0.0003	.000002	0.001
Slope variance (σ_{τ}^2)	0.0002	0.0002	.00004
Irregular variance (σ_{ϵ}^2)	0.0017	0.002	0.002
Normality: test statistics (p-value)	1.47 (0.47)	1.41 (0.50)	0.03 (0.98)
Homoscedasticity: test statistics (p-value)	0.58 (0.77)	0.22 (0.98)	0.47 (0.84)
Akaike Information Criterion (AIC)	-5.47	-5.27	-5.14
R²	0.80	0.76	0.72

Note: Significant level: ***=1%; **=5% and *=10%. Covariance on unobserved components and parameters of other equations in multivariate models are not reported for brevity.

The results also show a high correlation coefficient between the slope and level components of both the exposure and accidents series and the fatality series (see Table 2). This suggests that the level and slope of these series are affected by the same unobserved mechanism. To test this hypothesis, we re-estimated the model by imposing restrictions that the three equations follow a common trend and slope. The new results (Multivariate 2) show that the parameters of accidents become positive and statistically significant as expected. In particular, one per cent increase in accidents results in 0.27 per cent increase in traffic fatalities. Moreover, the parameter of GSP per capita is statistically significant at the ten percent level, suggesting that a one percent increase in GSP per capita is associated with 0.98 per cent reduction in traffic fatalities. The sign and magnitude of other parameters are similar the previous estimates. For example, the effects of random breath test, zero BAC and expansion of random breath test contribute to the reduction of traffic fatalities by 10, 17 and 22 per cent, respectively. The “Safe4life” strategy contributed to another 17 per cent reduction in traffic fatalities since its introduction in 2004. However, the introduction of the common trend and slope produce a slightly less desirable according to model selection criteria resulting in a lower R² and higher test statistic on the Akaike Information Criterion (AIC).

Table 2. Covariance\correlation matrices of unobserved components

	Fatalities	Accidents	Exposure
<i>Level</i>			
Fatalities	0.0003	0.6595	0.9519
Accidents	<i>0.0005</i>	0.0021	0.3975
Exposure	<i>0.0003</i>	<i>0.0003</i>	0.0003
<i>Slope</i>			
Fatalities	0.0002	-0.6963	0.9968
Accidents	<i>-0.0002</i>	0.0005	-0.7515
Exposure	<i>0.0001</i>	<i>-0.0002</i>	0.0001

Note: Diagonal components are variances; lower-diagonal components are covariance (in italic); upper diagonal components are correlation coefficients (in bold)

For sensitivity analysis, we also present results of a univariate estimate (i.e., estimating Equation 1, only). These results suggest that the effect of the zero BAC policy is only statistically significant at the ten percent level, while the statistical significance of the unemployment rate and other policy interventions falls to the five percent level, with the exception of the random breath test expansion program (see Table 1, Univariate). In addition, both the R² and AIC confirm that the multivariate model is a superior choice to the univariate specification.

We acknowledge that, apart from controlling for drink driving, many other road safety initiatives were also implemented during the study period. Some of these we cannot take into

account such as the compulsory seat belt wearing in vehicles started from 1973 as it covers the whole study period (i.e., so have no reference period to compare the effects of this initiative). Nevertheless, this issue has been investigated by Bhattacharyya and Layton (1979), who found that the seat belt law was associated with 46 per cent reduction in traffic fatalities in Queensland. Other interventions were introduced at the same periods that captured by the dummy variables in the analyses. For example, a policy to reduce impaired driving was introduced on the same period as the random breath test programs in 1988; the red light camera and random road watch programs were introduced on the same period as the zero BAC programs in 1991; and the Integrated Planning Act that aim for improve road design as implemented on the same period as the expansion of the random breath test program.

Conclusions

This paper has examined the effects of traffic safety interventions in Queensland in the 1973-2007 period, especially those target the drink driving behaviour using a state-space time series model that can control for unobserved components such as trend and slope. We found that the random breath test program, zero BAC policy for young drivers and random breath test expansion resulted in sizeable reductions in traffic fatalities, estimating their effects to be reductions of 10, 17 and 22 per cent, respectively. The “Safe4life” strategy in 2004 contributed to a substantial and statistically significant reduction in traffic fatalities of 17 percent. Among other exogenous factors, unemployment rates are the sole significant determinant of traffic fatality rates and the parameter estimates suggest a one percent increase in unemployment rate is associated with a 0.22 per cent reduction in traffic fatalities. These results suggest that policies that have targeted drink-driving as a way to combat road traffic casualties have proved very effective in this jurisdiction. In future work, it would be useful to subject these policies to a formal cost-benefit analysis, to determine if the resulting benefits outweighed the costs of implementing these policies. One of the difficulties of doing so is that detailed information on expenditures for such programs are likely to be difficult to obtain and, in particular, difficult to disaggregate by initiative. Nevertheless, work of the kind presented here could be used as the basis for such a study of the net welfare effects of these very effective policies.

References

- Arnett, J. (2002): ‘Developmental sources of crash risk in young drivers’, *Injury Prevention*, 8: ii17–ii23.
- Begg, S., Vos, T., Barker, B., Stevenson, C., Stanley, L. and Lopez, A. (2007): ‘Burden of disease and injury in Australia, 2003’, Working Paper, Australian Institute of Health and Welfare AIHW.
- Bergel-Hayat, R. (2012): ‘Time-series models of aggregate road risk and their applications to European countries’, *Transport Reviews: A Transnational Transdisciplinary Journal*, 32: 653–670.
- Bhattacharyya, M. and Layton, A. P. (1979): ‘Effectiveness of seat belt legislation on the Queensland road toll—An Australian case study in intervention analysis’, *Journal of the American Statistical Association*, 74: 596–603.

- Bijleveld, F., Commandeur, J., Gould, P. and Koopman, S. J. (2008): 'Model-based measurement of latent risk in time series with applications', *Journal of the Royal Statistical Society: Series A (Statistics in Society)*, 171: 265–277.
- Bishai, D., Quresh, A., James, P. and Ghaffar, A. (2006): 'National road casualties and economic development', *Health Economics*, 15: 65–81.
- Bowman, K. and Shenton, L. (1975): Omnibus test contours for departures from normality based on b_1 and b_2 ', *Biometrika*, 62: 243–250.
- Carpenter, C. (2004): 'How do zero tolerance drunk driving laws work?', *Journal of Health Economics*, 23: 61–83.
- Chang, K., Wu, C.-C. and Ying, Y.-H. (2012): 'The effectiveness of alcohol control policies on alcohol-related traffic fatalities in the united states', *Accident Analysis & Prevention*, 45: 406–415.
- Chikritzhs, T. and Stockwell, T. (2006): 'The impact of later trading hours for hotels on levels of impaired driver road crashes and driver breath alcohol levels', *Addiction*, 101: 1254–1264.
- Commandeur, J. J. F., Bijleveld, F. D., Bergel-Hayat, R., Antoniou, C., Yannis, G. and Papadimitriou, E. (2012): 'On statistical inference in time series analysis of the evolution of road safety', *Accident Analysis & Prevention*, 60: 424–434.
- Durbin, J. and Koopman, S. (2001): *Time series analysis by state space methods*, Oxford University Press.
- Erke, A., Goldenbeld, C. and Vaa, T. (2009): 'The effects of drink-driving check-points on crashes—A meta-analysis'. *Accident Analysis & Prevention*, 41: 914–923.
- Goss, C. W., Van Bramer, L. D., Gliner, J. A., Porter, T. R., Roberts, I. G. and Diguisseppi, C. (2008): 'Increased police patrols for preventing alcohol-impaired driving', *Cochrane Database System Review* : CD005242.
- Gruenewald, P. J., Stockwell, T., Beel, A. and Dyskin, E. V. (1999): 'Beverage sales and drinking and driving: the role of on premise drinking places', *Journal of Studies on Alcohol and Drugs*, 60: 47–53.
- Harvey, A. C. and Durbin, J. (1986): 'The effects of seat belt legislation on British road casualties: A case study in structural time series modelling', *Journal of the Royal Statistical Society. Series A (General)*, 149: 187–227.
- Homel, R. (1994): 'Drink-driving law enforcement and the legal blood alcohol limit in New South Wales', *Accident Analysis & Prevention*, 26: 147–155.
- Howard, S. J., Gordon, R. and Jones, S. C. (2014): 'Australian alcohol policy 2001-2013 and implications for public health', *BMC public health*, 14: 848.
- Iwata, K. (2010): 'The relationship between traffic accidents and economic growth in China', *Economics Bulletin*, 30: 3306–3314.
- Jarque, C. M. and Bera, A. K. (1980): 'Efficient tests for normality, homoscedasticity and serial independence of regression residuals', *Economics Letters*, 6: 255–259.
- Jones, R. K. and Joscelyn, K. B. (1978): 'Alcohol and highway safety 1978: A review of the state of knowledge', Report, US Department of Transportation, Washington DC.

- Kopits, E. and Cropper, M. (2005): 'Traffic fatalities and economic growth', *Accident Analysis & Prevention*, 37: 169–178.
- Leigh, J. P. and Waldon, H. M. (1991): 'Unemployment and highway fatalities', *Journal of health politics, policy and law*, 16: 135–156.
- Liang, L. and Huang, J. (2008): 'Go out or stay in? The effects of zero tolerance laws on alcohol use and drinking and driving patterns among college students', *Health Economics*, 17: 1261–1275.
- Ljung, G. and Box, G. (1978): 'On a measure of lack of t in time series models', *Biometrika*, 65: 297–304.
- Lloyd, C. J. (1992): 'Alcohol and fatal road accidents: estimates of risk in Australia 1983', *Accident Analysis & Prevention*, 24:339–348.
- Mann, R. E., Macdonald, S., Stoduto, G., Bondy, S., Jonah, B. and Shaikh, A. (2001): 'The effects of introducing or lowering legal per se blood alcohol limits for driving: an international review', *Accident Analysis & Prevention*, 33: 569–583.
- Mayhew, D., Donelson, A., Beirness, D. and Simpson, H. (1986), 'Youth, alcohol and relative risk of crash involvement', *Accident Analysis & Prevention*, 18: 273–287.
- Preusser, D. F., Ferguson, S. A. and Williams, A. F. (1998): 'The effect of teenage passengers on the fatal crash risk of teenage drivers', *Accident Analysis & Prevention*, 30: 217–222.
- Ramstedt, M. (2008): 'Alcohol and fatal accidents in the united states—A time series analysis for 1950-2002', *Accident Analysis & Prevention*, 40: 1273–1281.
- Renwick, M. Y., Olsen, G. G. and Tyrrell, M. S. (1982): 'Road fatalities in rural New South Wales: weighing the causes', *Medical Journal of Australia*, 1:291–294.
- Ruhm, C. (1995): 'Economic conditions and alcohol problems', *Journal of Health Economics*, 14: 583–603.
- Shults, R. A., Elder, R. W., Sleet, D. A., Nichols, J. L., Alao, M. O., Carande-Kulis, V. G., Zaza, S., Sosin, D. M., Thompson, R. S. et al. (2001): 'Reviews of evidence regarding interventions to reduce alcohol-impaired driving', *American Journal of Preventive Medicine*, 21: 66–88.
- Simons-Morton, B., Lerner, N. and Singer, J. (2005): 'The observed effects of teenage passengers on the risky driving behavior of teenage drivers', *Accident Analysis & Prevention*, 37: 973–982.
- Smith, D. I. (1986): 'Effect of low proscribed blood alcohol levels (BACs) on traffic accidents among newly-licenced drivers', *Medical Science and the Law*, 26: 144–148.
- Smith, D. I. (1988): 'Effect on traffic safety of introducing a 0.05% blood alcohol level in Queensland, Australia', *Medicine, Science and the Law*, 28(2): 165–170.
- Tränkle, U., Gelau, C. and Metker, T. (1990): 'Risk perception and age-specific accidents of young drivers', *Accident Analysis & Prevention*, 22: 119–125.
- Voas, R. B., Romano, E., Tippetts, A. S. and Furr-Holden, C. D. M. (2006): 'Drinking status and fatal crashes: which drinkers contribute most to the problem?', *Journal of Studies on Alcohol and Drugs*, 67: 722–729.

- Voas, R. B., Tippetts, A. S. and Fell, J. C. (2003): 'Assessing the effectiveness of minimum legal drinking age and zero tolerance laws in the United States', *Accident Analysis & Prevention*, 35: 579–587.
- Wilde, G. (1988): 'Risk homeostasis theory and traffic accidents: propositions, deductions and discussion of dissension in recent reactions', *Ergonomics*, 31: 441–468.
- Wilde, G. (1998): 'Risk homeostasis theory: an overview', *Injury Prevention*, 4:89–91.
- Yakovlev, P. A. and Inden, M. (2010): 'Mind the weather: A panel data analysis of time-invariant factors and traffic fatalities', *Economics Bulletin*, 30: 2685–2696.
- Zador, P. L., Krawchuk, S. A. and Voas, R. B. (2000): 'Alcohol-related relative risk of driver fatalities and driver involvement in fatal crashes in relation to driver age and gender: an update using 1996 data', *Journal of Studies on Alcohol and Drugs*, 61: 387–395.
- Zwerling, C. and Jones, M. P. (1999): 'Evaluation of the effectiveness of low blood alcohol concentration laws for younger drivers', *American Journal of Preventive Medicine*, 16: 76–80.