The Relationship between Socio-economic Factors and Road Safety in Western Australia

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Abstract
The major objective of this project was to identify key measures of economic activity and establish the relationship between these factors and road trauma in Western Australia using advanced statistical time series techniques. Explanatory structural time series modelling of the relationship between selected socio-economic factors and the level of road trauma in Western Australia has identified unemployment rate as having a significant association with each of the overall levels of road trauma investigated, namely fatal crashes; fatal plus hospitalisation crashes; fatal crashes during high alcohol hours; and fatal plus hospitalisation crashes during high alcohol hours. Over the analysis period of March 1995 to December 2009 inclusive, reductions in the unemployment rate in Western Australia relative to March 1995 levels have been associated with an additional 311 fatal crashes (average 21 per year); 1,793 fatal plus hospitalised crashes (average 120 per year); 158 fatal crashes during high alcohol hours (average 11 per year); and 1,098 fatal plus hospitalised crashes during high alcohol hours (average 73 per year).

Unemployment rate offers a measure of economic activity useful for the road safety context. Road safety target setting in strategies must be mindful that changes in economic circumstances can affect the likelihood of reaching set targets. In addition, evaluation of road safety countermeasures or strategy performance must include methodology that explicitly measures or controls for the effects of economic factors on road trauma outcomes. This is necessary in order to measure the specific effects of road safety programs on road trauma outcomes.

Keywords
Road Trauma, Statistical Modelling, Economic Factors, Unemployment

Contents

EXECUTIVE SUMMARY

Introduction

In recent years, Western Australia has experienced an exceptionally strong economy, at times outperforming other Australian states by a significant margin. At the same time, Western Australia experienced the smallest fall in road deaths of all states and territories. It has long been recognised that economic factors affect transport and hence road safety. The association between movements in the economy and road crashes has been investigated in other jurisdictions previously and various relationships have been established. However, this has not been done for Western Australia. A key question is whether changes in road safety outcomes in Western Australia are associated with changes in economic activity, and if so, how have socio-economic factors influenced road safety performance in the past and what are their likely effects in the future.

The major objective of this project was to identify key measures of economic activity and establish the relationship between these and other relevant socio-economic factors and road trauma in Western Australia using advanced statistical time series techniques. Identification of the association between selected factors and road trauma through estimation of explanatory time series models allows examination of the influence of the factors on road safety outcomes.

Analysis Data

Outcome Variables: Road Trauma Outcomes

Quarterly road crash data was obtained from Main Roads Western Australia for the analysis period of March 1995 to December 2009 inclusive. Overall models were run for the following road trauma outcomes which are target measures of the Western Australian Road Safety Strategy 2008-2020 "Towards Zero" (Road Safety Council 2009): fatal crashes; and fatal plus hospitalised crashes. The same models were also run for road trauma that occurred during time periods when illegal drink driving is more likely to occur ("high alcohol hours").

Explanatory Variables

This project aimed to assess the relationship between key socio-economic factors and the observed level of road trauma. A critical aspect of defining the analysis was identification of the most appropriate explanatory factors to be included in the models. Previous research gave a guide to the types of socio-economic measures that the incidence of crashes may depend upon. These included: productivity measures; employment measures; vehicle fleet characteristics; population factors; distance travelled; and alcohol consumption. In addition to these factors, measures of major road safety program activity were included in the models in the form of the number of random breath tests conducted and the number of speed camera infringements issued.

Socio-Economic Factor Selection

Productivity and Employment

Productivity and employment measures covered factors that are driven by the underlying economic process in Western Australia. They included gross state product (total, per capita); state final demand; retail turnover; unemployment rate; and employed persons (total, per capita). Each of these variables were found to be highly correlated with all the others other (correlation > 0.9) meaning they all provide a similar measure of the economy in WA. Highly correlated variables cannot be included together in an analysis model because it creates problems for model estimation and interpretation of parameters associated with correlated factors. To avoid these problems, it was decided to select only one factor in unemployment rate for inclusion in the models to represent the underlying economic process that likely drives both it and the other correlated variables associated with it equally. Although any one of the factors could have been reasonably included in the models, the selection of unemployment rate was consistent with previous research that excluded income and productivity measures in lieu of unemployment to represent underlying economic conditions. The choice of variable to use in the model is somewhat arbitrary but because they are all so highly correlated the choice made little difference to the efficacy and interpretation of the final model.

Vehicle fleet characteristics, Population factors and Distance travelled

The next socio-economic measure categories were vehicle fleet characteristics, population factors and distance travelled with variables. They included number of registered vehicles (total, trucks, motorcycles); population of Western Australia; sales of petroleum products (automotive fuel sales); and vehicle kilometres travelled (total, trucks, motorcycles). These measures were also all highly correlated with each other and would again introduce an undesirable level of collinearity if they were included as explanatory variables thus causing concern in interpretation. In addition to being highly correlated, each of these variables is a measure of travel exposure with a high degree of inherent inertia and consequently little monthly variation. As experienced in previous research, including any of these factors as independent (predictor) variables in the models risked swamping the effects of the other explanatory variables making the interpretation of the model spurious. It was therefore decided that it would be more appropriate to use these variables to create a rate based outcome measure in the model allowing the other explanatory variables to be estimated after controlling for exposure. Hence in addition to models based on quarterly crash frequency, models were estimated for quarterly rates of road trauma by population and vehicle kilometres travelled for each of the overall models. The availability of vehicle kilometres travelled estimates for trucks and motorcycles meant that actual travel exposure in the form of vehicle kilometres travelled (total, trucks, motorcycles) was able to be used in preference to the less specific measure in number of registered vehicles.

Alcohol consumption

The final category of variable considered was alcohol consumption reflecting the known association between alcohol use and road crash risk. The closest measure of alcohol consumption available for inclusion in the models was sales of alcohol as measured by liquor retailing turnover for Western Australia deflated by the alcohol and tobacco consumer price index for Perth.

Results

Modelling of the relationship between socio-economic factors and the level of road trauma in Western Australia identified economic activity (as represented by the chosen measure of unemployment rate) as having a significant association with each of the road trauma outcome measures investigated (fatal crashes; fatal plus hospitalisation crashes; fatal crashes during high alcohol hours; and fatal plus hospitalisation crashes during high alcohol hours). Similar relationships were identified regardless of whether absolute crash numbers or crash rates per unit travel were used, hence only the former are summarised here

Fatal crashes: It was found that a 1% increase in the unemployment rate[1] was associated with a statistically significant 0.41% decrease in fatal crashes effective 2 quarters after the unemployment rate increase (the effect lags by 2 quarters).

Fatal plus hospitalised crashes: A 1% increase in the unemployment rate was found to be associated with a 0.22% decrease in fatal plus hospitalised crashes, statistically significant at the 10% level.

Fatal crashes during high alcohol hours: It was found that a 1% increase in the unemployment rate was associated with a 0.44% decrease in fatal crashes during high alcohol hours, statistically significant at the 5% level.

Fatal plus hospitalised crashes during high alcohol hours: A 1% increase in the unemployment rate was found to be associated with a 0.30% decrease in fatal plus hospitalised crashes during high alcohol hours effective 1 quarter after the unemployment rate increase (the effect lags by 1 quarter). This result was statistically significant at the 5% level.

Interpreting the results of the modelling showed that over the analysis period of March 1995 to December 2009 inclusive, reductions in the unemployment rate in Western Australia relative to March 1995 levels have been associated with an additional:

- 311 fatal crashes (average 21 per year);
- 1,793 fatal plus hospitalised crashes (average 120 per year);
- 158 fatal crashes during high alcohol hours (average 11 per year); and
- 1,098 fatal plus hospitalised crashes during high alcohol hours (average 73 per year).

Conclusions

This project established the relationship between key socio-economic factors and road trauma in Western Australia. Changes in economic activity in Western Australia over the period 2000-2009 were associated with higher levels of road trauma than would have been observed had economic conditions remained constant at year 2000 levels. Analysis results have identified the need to consider future possible economic circumstances in setting road safety targets and to consider past changes in economic circumstances in assessing progress towards meeting targets set.

[1] This refers to a 1% increase in the unemployment rate (e.g. from 10.0% to 10.1%), not a 1 percentage point increase (which would be from 10% to 11%).

1.0 Introduction

In recent years, Western Australia has experienced an exceptionally strong economy, at times outperforming other Australian states by a significant margin. Over the period June 2000 to June 2012, gross state product increased by 73% compared with Australia's largest state, New South Wales, where Gross State Product increased by 28%, and nationally where Gross Domestic Product increased by 43%. Over the same period, the Western Australian population increased by 30% compared to a national increase of 19%. Meanwhile, from 2003 to 2012 Western Australia experienced the smallest relative fall in road deaths of all states and territories with a 1.9% p.a. average trend reduction per 100,000 population and a 1.3% p.a. average trend reduction per 100 million vehicle kilometres travelled compared with national per annum average trend reductions of 4.2% and 3.8% respectively.

It has long been recognised that economic factors affect transport and hence road safety. The association between movements in the economy and road crashes has been investigated in other jurisdictions previously and various relationships have been established. However, this has not been done for Western Australia. A key question is whether changes in road safety outcomes in Western Australia are associated with changes in economic activity, and if so, how have socio-economic factors influenced road safety performance in the past and what are their likely effects in the future.

The major objective of this project was to identify key measures of economic activity and establish the relationship between these and other key socio-economic factors and road trauma in Western Australia using advanced statistical time series techniques. Identification of the association between selected factors and road trauma through estimation of explanatory time series models allows examination of the influence of the factors on road safety outcomes.

2.0 Analysis Data

2.1 OUTCOME VARIABLES: ROAD TRAUMA OUTCOMES

Quarterly road crash data was obtained from Main Roads Western Australia for the analysis period of March 1995 to December 2009 inclusive. Overall models were run for the following road trauma outcomes which are target measures of the Western Australian Road Safety Strategy 2008-2020 “Towards Zero” (Road Safety Council 2009):

- Fatal crashes; and
- Fatal plus hospitalised crashes.

These models were also run for road trauma that occurred during time periods when illegal drink driving is more likely to occur, i.e. during “high alcohol hours”:

- Fatal crashes – High alcohol hours (HAH); and
- Fatal plus hospitalised crashes – High alcohol hours (HAH).

Harrison (1990) found that during high alcohol hours, 38% of drivers killed or admitted to hospital in Victoria had illegal blood alcohol concentration (BAC), whereas only 4% of such drivers had illegal BACs at other times. These high alcohol hours have been applied to Western Australia assuming a similar pattern.

The high alcohol hours defined by Harrison (1990) are:

- 4 p.m. Sunday to 6 a.m. Monday;
- 6 p.m. to 6 a.m. Monday to Thursday nights;
- 4 p.m. Friday to 8 a.m. Saturday;
- 2 p.m. Saturday to 10 a.m. Sunday.

Low alcohol hours are the residual times of the week.

Models were also estimated for the following vehicle and road user sub-groups:

- Number of crashes where a truck was involved;
- Number of crashes where a motorcycle was involved;
- Number of crashes where a bicycle was involved; and
- Number of crashes where a pedestrian was involved.

Only the total number of crashes was used for each sub-group in order to maximise the amount of data available to run the models.

Quarterly time series of each of the road trauma outcomes outlined above are shown in Appendix A.

2.2 EXPLANATORY VARIABLES: SOCIO-ECONOMIC FACTORS

This project aimed to assess the relationship between key socio-economic factors and the observed level of road trauma. A critical aspect of defining the analysis was identification of the most appropriate explanatory factors to be included in the models. A paper by Scuffham and Langley (2002), who also used structural time series models to construct explanatory models of traffic crashes in New Zealand, gave a guide to the types of socio-economic measures that the incidence of crashes may depend upon. These included:

- Productivity measures;
- Employment measures;
- Vehicle fleet characteristics;
- Population factors;
- Distance travelled; and
- Alcohol consumption.

For each category, the following variables were available in a consistent and suitably long time series and were considered relevant for Western Australia based on previous research. IT was also important for validity that each of these variables was available from a reputable and validated source, generally being the Australian Bureau of Statistics or other official Government sources.

Productivity measures	Source
Gross state product; Western Australia	Australian Bureau of Statistics
Gross state product per capita; Western Australia	Australian Bureau of Statistics
State final demand; Western Australia	Australian Bureau of Statistics
Retail turnover; Western Australia	Australian Bureau of Statistics

Employment measures	Source
Unemployment rate; Western Australia	Australian Bureau of Statistics
Employed persons – total; Western Australia	Australian Bureau of Statistics
Employed persons – total per capita; Western Australia	Australian Bureau of Statistics

Vehicle fleet characteristics	Source
Number of registered vehicles; Western Australia	Australian Bureau of Statistics
Number of registered trucks; Western Australia	Australian Bureau of Statistics
Number of registered motorcycles; Western Australia	Australian Bureau of Statistics

Population factors	Source
Population; Western Australia	Australian Bureau of Statistics

Distance travelled	Source
Sales of petroleum products (automotive fuel sales); Western Australia	Department of Resources, Energy and Tourism
Vehicle kilometres travelled; Western Australia	Bureau of Infrastructure, Transport and Regional Economics
Vehicle kilometres travelled – trucks; Western Australia	Bureau of Infrastructure, Transport and Regional Economics
Vehicle kilometres travelled – motorcycles; Western Australia	Bureau of Infrastructure, Transport and Regional Economics

Alcohol consumption	Source
Turnover – Liquor retailing; Western Australia	Australian Bureau of Statistics
deflated by Consumer price index – Alcohol and tobacco; Perth	Australian Bureau of Statistics

2.3 EXPLANATORY VARIABLES: ADJUSTING FACTORS

Explanatory models were estimated in order to assess the influence of socio-economic factors on road trauma outcomes. Similar to the approach used by Scuffham and Langley (2002) the models were adjusted for the influence of other major factors that may have had an effect on road trauma outcomes. In examining road fatality rates across Australia, the Bureau of Infrastructure, Transport and Regional Economics (2010) identified three main safety measures that are considered to have made progressive improvements in road safety in the forty year period since the late 1960s, namely seat belts, random breath testing and speed cameras. It was noted that prior to the late 1980s progressive increases in seat belt wearing contributed significantly to the reduction in fatality rates whereas thereafter random breath testing and speed camera measures became more dominant factors, with seat belt wearing becoming almost universal. As such, the factors quarterly number of random breath tests (RBT) and quarterly number of speed camera infringements (INF) in Western Australia (Figures 2.1 and 2.2 respectively) were included as adjusting factors in the explanatory models for the current study which has an analysis period of March 1995 to December 2009 inclusive.

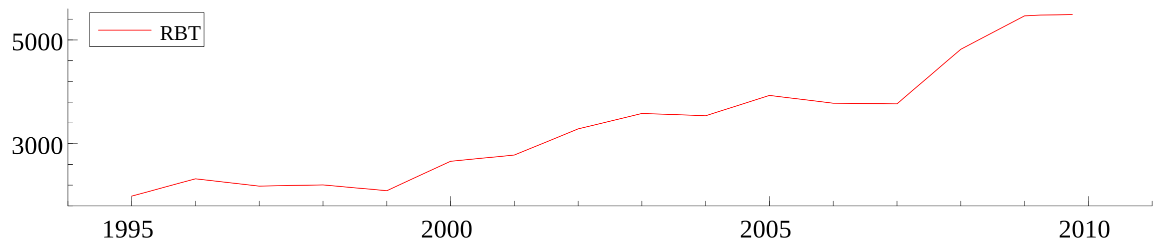

Figure 2.1: Random breath tests in Western Australia

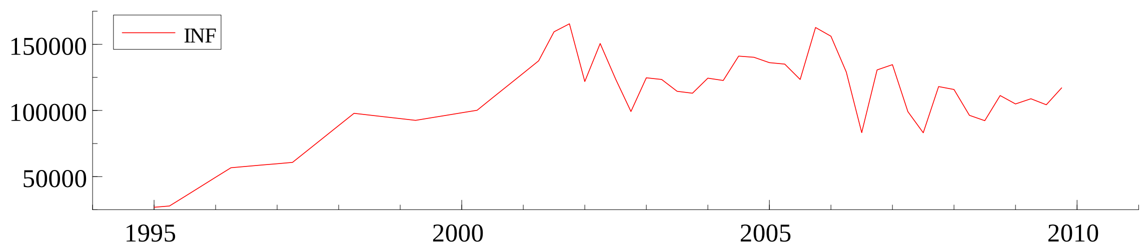

Figure 2.2: Speed camera infringements in Western Australia

This is not to say that other critical factors such as road improvements and vehicle safety improvements have not had an effect. Such effects are gradual so cannot be modelled using the methods utilised here. Improvement due to these factors is captured in the long term trend and only factors with quarterly variation can be included.

It should be noted that inclusion of measures of road safety activity in the model will not give the capacity to formally evaluate the effectiveness of these programs on reducing road trauma. Over the period of analysis the programs considered were already in place so there is no opportunity to assess road trauma levels in the absence of these programs. Instead, the objective of their inclusion is to represent the influence of broad changes in the level of enforcement over the period of analysis to remove this as a confounding effect in interpreting the influence of economic factors on road trauma outcomes.

3.0 Method

This section begins by outlining theory on structural time series models. It then describes how explanatory models were constructed to estimate the influence of socio-economic factors on road trauma in Western Australia.

3.1 STRUCTURAL TIME SERIES MODELS

The analysis was based on the structural time series models developed by Harvey (1989) which are formulated directly in terms of trend μ_t, seasonal s_t and irregular ε_t (noise) components. These models are like the classical decomposition model defined by:

$$y_t = \mu_t + s_t + \varepsilon_t$$

in which the components are of direct interest themselves. However, unlike the classical decomposition model, in which the trend and seasonal components are deterministic (fixed), structural time series models allow for random (stochastic) variation in these components.

A simple example of a structural time series model is the local level model. Trend consists of two components, namely the level, which is the actual value of the trend, and the slope. The local level model consists of a random walk component to capture the underlying level μ_t, plus the irregular component ε_t as follows:

$$\begin{aligned} y_t &= \mu_t + \varepsilon_t, \quad \varepsilon_t \sim NID(0, \sigma_\varepsilon^2) \\ \mu_t &= \mu_{t-1} + \eta_t, \quad \eta_t \sim NID(0, \sigma_\eta^2) \end{aligned}$$

where η_t is the disturbance driving the level. Both ε_t and η_t are serially and mutually independent and normally distributed with zero mean and variances σ_ε^2 and σ_η^2 respectively.

The addition of stochastic variation results in a model which is very flexible, and can be achieved within the framework of a state-space representation. Once a structural time series model is placed in state-space form, the general procedure for state-space models based on the Kalman filter can be utilised for model estimation and forecasting. The analysis models were fit using the STAMP software package (Koopman et al. 2007).

3.1.1 Logarithmic Transformation of the Data

Prior to estimating the structural time series models, a logarithmic transformation was applied to all crash data series. It was thought more appropriate to fit models to the logarithm of the data as this ensured that fitted values from the model were non-negative, a property required of predicted crashes. The explanatory (independent) variables were also log transformed to allow interpretation of the parameter estimates as elasticities. In general, elasticity is defined as the percentage change in the outcome variable divided by the percentage change in the independent variable. The use of log-log models ensures that the property of constant elasticity is satisfied and is a commonly used form in econometric modelling.

3.2 MODEL CONSTRUCTION

Explanatory structural time series models were constructed using quarterly data for the analysis period of March 1995 to December 2009 inclusive. Following the appropriate selection of explanatory variables, initial structural time series models were formulated to include level, slope and seasonal components allowing for stochastic variation. Where a component was estimated to be deterministic, a *t*-test was performed to determine whether its coefficient was non-significantly different from zero, i.e. could be removed from the model. The model was then re-run and the final model was tested against a range of diagnostics to ensure key model assumptions were met.

3.2.1 Minimisation of Collinearity

In order to build structural time series models that were numerically stable and could easily be interpreted, *collinearity* was first tested between potential explanatory variables. Collinearity refers to the linear correlation between two explanatory variables, the word collinearity in the context of a time series of data referring to the fact that to variables move together in the same way over time. An explanatory variable that is highly correlated with another is potentially measuring the influence of the same phenomenon on the outcome variable and could therefore be considered redundant. A further possibility is that the variables are correlated purely by chance but this is less likely. A technical problem with variables that are collinear in a regression model is that they can in the extreme prevent the model from being estimated and in the least mean interpretation of the relationship between each factor and the outcome can be spurious due to the factors essentially competing with each other to represent the same relationship in the model. There is some debate about the level of correlation between variables that will present a serious collinearity problem in the model. Some argue that correlations of over 0.9 represent problematic collinearity whereas others point out that correlation above about 0.6 presents a problem for parameter interpretation

The presence of collinearity was investigated through analysis of the Pearson correlations between the variables. In order to minimise collinearity, only one variable from a highly correlated group of variables was included in the models, with the other correlated variables not included. An explanatory variable remaining in the model could then be considered to represent the underlying process or phenomenon that drives itself as well as the removed correlated variable/s associated with it equally.

4.0 Results

This section presents results of time series modelling examining the association between key factors and the road trauma outcomes outlined in Section 2.1. Firstly, the socio-economic factor selection process is described within the context of minimising collinearity between potential explanatory variables. Then, the modelling results are shown along with diagnostic tests and assessment of goodness-of-fit.

4.1 SOCIO-ECONOMIC FACTOR SELECTION

The first step in the model estimation process was the appropriate selection and use of the socio-economic factors outlined in Section 2.2. These included variables under the categories of gross domestic product; unemployment; vehicle fleet characteristics; population factors; distance travelled; and alcohol consumption.

4.1.1 Productivity and Employment

The first two categories of gross domestic product and unemployment covered factors that are representative of underlying economic conditions in Western Australia. They included gross state product (total, per capita); state final demand; retail turnover; unemployment rate; and employed persons (total, per capita). As mentioned under Section 3.2.1, the presence of collinearity was investigated through analysis of the Pearson correlations between the variables (Appendix B). From Table B.1 it can be seen that the variables are all highly correlated with each other with absolute correlation values ranging from 0.88 to 0.99, all in the range suggesting serious collinearity problems. As such, each variable may be considered to be measuring the same underlying economic process in Western Australia with all but one variable redundant.

The selection of a single variable from a group of correlated variables to represent an underlying phenomenon is consistent with other earlier approaches, such as that taken by Newstead et al. (2004) in their evaluation of the Road Safety Initiatives Package (RSIP) implemented in Queensland during 2003-2004. In particular, Newstead et al. (2004) considered that variables with a correlation coefficient higher than 0.5 had sufficiently high collinearity to cause concern in interpreting analysis results. As described under Section 3.2.1, in order to minimise the collinearity problem, it was decided to select unemployment rate (UER) for inclusion in the models to represent underlying economic conditions in WA. Any of the correlated variables could reasonably have been selected for inclusion in the models and would have led to the same conclusions about association. The selection of unemployment rate to represent economic conditions was consistent with other work (Cameron et al. 1993; Newstead et al. 1995, 2004; Thoresen et al. 1992) that excluded other income and productivity measures in lieu of unemployment to represent underlying economic conditions. It is of note that absolute measures such as number employed were highly correlated with rate based measures such as unemployment rate so the choice of rate based measures against absolute measures for the model would have made little difference.

Figure 4.1 shows the unemployment rate for Western Australia (Australian Bureau of Statistics, 2013d) taken at quarterly intervals for the analysis period of March 1995 to December 2009 inclusive. During this period UER reached a maximum of 7.72% at August 1996 and a minimum of 2.71% at September 2008. The analysis period encompasses the historical (post-February 1978) low of 2.71% at September 2008. The historical high for UER was 11.08% at September 1992 which is before the analysis period but has been considered in looking at the range of possible road safety outcomes related to UER.

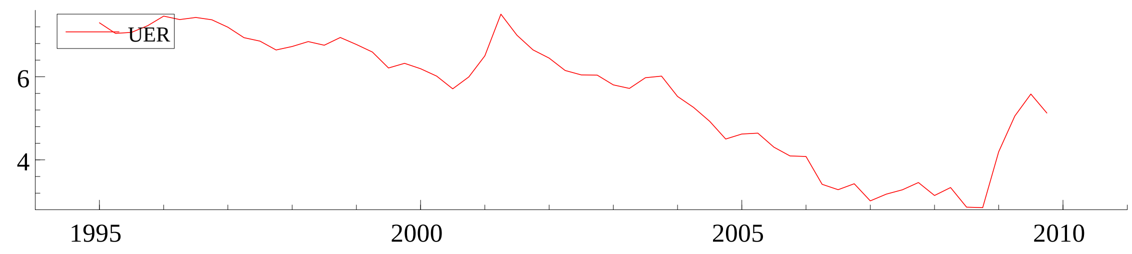

Figure 4.1: Unemployment rate in Western Australia

Another consideration in including unemployment rate to represent underlying economic conditions involved recognising that economic factors can have delayed effects. In particular, Scuffham and Langley (2002) found that unemployment rate had a delayed effect of 9-12 months suggesting that a change in economic circumstances takes some time to affect crash outcomes. As such, for each road trauma outcome variable, in addition to examining unemployment rate alone, it was also investigated with individual lags of one to four quarters in order to build models that produced the strongest possible association between each road trauma outcome and the rate of unemployment. It was found that unemployment rate had the strongest association with fatal crashes when it was lagged by 2 quarters (UER_2) and on fatal plus hospitalised crashes during high alcohol hours when it was lagged by 1 quarter (UER_1). For the other road trauma outcomes, unemployment rate had the strongest association when it was not lagged.

4.1.2 Vehicle fleet characteristics, Population factors and Distance travelled

The next categories listed under Section 2.2 were vehicle fleet characteristics, population factors and distance travelled with variables that included number of registered vehicles (total, trucks, motorcycles); population of Western Australia; sales of petroleum products (automotive fuel sales); and vehicle kilometres travelled (total, trucks, motorcycles). These measures were all highly correlated with each other and would introduce an undesirable level of collinearity if they were included as explanatory variables thus causing concern in interpretation.

It is noted that each of these variables, in addition to being highly correlated, are indicative measures of crash exposure. In particular, Scuffham and Langley (2002) found that including these factors as independent variables swamps the effects of the other explanatory variables in the model. It was therefore decided that apart from automotive fuel sales, from which estimates of vehicle kilometres travelled are derived, it would be more appropriate to use these variables to create quarterly rate models allowing the other explanatory variables to be estimated after controlling for exposure. Hence in addition to models based on quarterly crash frequency, models were estimated for quarterly rates of road trauma by population and vehicle kilometres travelled for each of the overall models. Quarterly rate models were also estimated for the truck and motorcycle vehicle sub-groups using the variables vehicle kilometres travelled – trucks and vehicle kilometres travelled – motorcycles respectively. The availability of vehicle kilometres travelled estimates for trucks and motorcycles meant that travel exposure in the form of vehicle kilometres travelled (total, trucks, motorcycles) was able to be used in preference to the number of registered vehicles (total, trucks, motorcycles), as estimates of vehicle kilometres travelled were considered to represent actual travel more closely than the number of registered vehicles.

The two measures of exposure utilised for the overall models, namely population of Western Australia (POP) and vehicle kilometres travelled in Western Australia (VKT) are shown in Figures 4.2 and 4.3 respectively. The estimated resident population of Western Australia was obtained from the Australian Bureau of Statistics (2013a). It increased from an estimated 1,725,786 at March 1995 to 2,269,749 at December 2009 (or by 32%). Estimates of vehicle kilometres travelled were obtained from the Bureau of Infrastructure, Transport and Regional Economics (2011). They increased from an estimated 4,825 million kilometres for the March 1995 quarter to 6,230 million for the December 2009 quarter (or by 29%). For the truck and motorcycle vehicle sub-groups, vehicle kilometres travelled – trucks (rigid plus articulated) (VKt) and vehicle kilometres travelled – motorcycles (VKm) were also obtained from the Bureau of Infrastructure, Transport and Regional Economics (2011) and are shown in Appendix C.

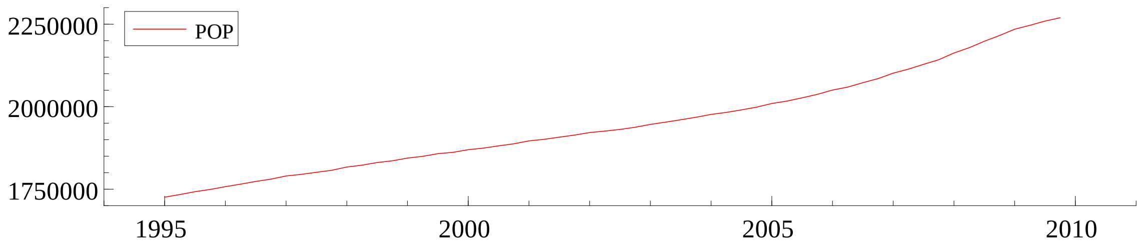

Figure 4.2: Population of Western Australia

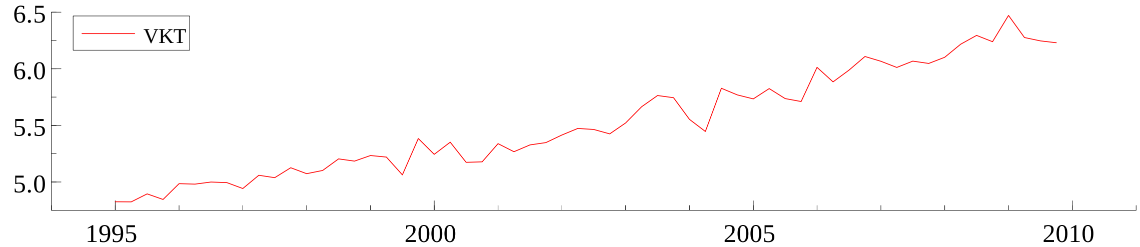

Figure 4.3: Vehicle kilometres travelled in Western Australia (billion km)

4.1.3 Alcohol consumption

The final category listed under Section 2.2 was alcohol consumption. The closest measure of alcohol consumption available for inclusion in the models was sales of alcohol as measured by liquor retailing turnover for Western Australia (Australian Bureau of Statistics, 2013c) deflated by the alcohol and tobacco consumer price index for Perth (Australian Bureau of Statistics, 2013b). No CPI index component for alcohol alone was available hence the combined index was used, Figure 4.4 shows quarterly alcohol sales deflated by the consumer price index (ALS) that was included in the models for the analysis period of March 1995 to December 2009 inclusive.

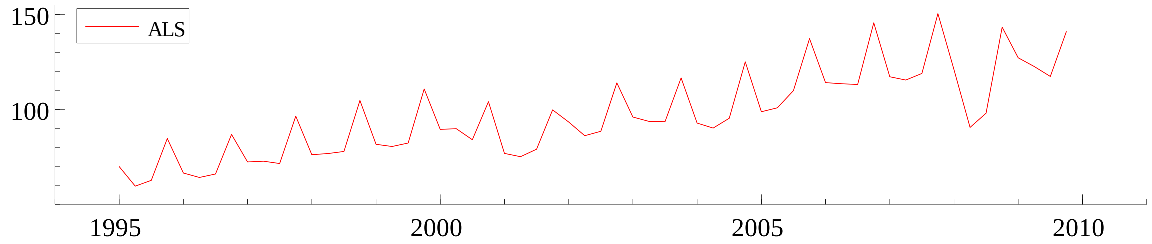

Figure 4.4: Alcohol sales (deflated) in Western Australia

4.2 ESTIMATED MODELS

Figures 4.5 and 4.6 show the fitted log-log models for fatal crashes and fatal plus hospitalised crashes respectively. For each figure, the first chart shows the underlying trend in the data whilst the second chart shows the estimated seasonal component of the data. The irregular component has not been shown. Parameter estimates with levels of significance for the fitted models of fatal crashes and fatal plus hospitalised crashes are presented in Tables 4.1 and 4.2 respectively. The tables also show parameter estimates for rates of road trauma by population (POP) and vehicles kilometres (VKT) travelled. As stated in Section 3.1.1, because the outcome and explanatory variables were log transformed the parameter estimates may be interpreted as elasticities. Each statistically significant parameter estimate (highlighted in orange at the 5% level and light orange at the 10% level) indicates the change in the outcome variable associated with a unit change in the factor. So for fatal crashes, a 1% increase[2] in unemployment rate (UER_2) is associated with a 0.41% decrease in crashes effective 2 quarters after the unemployment rate increase (the effect lags by 2 quarters).

The models of fatal plus hospitalised crashes and rates of fatal plus hospitalised crashes were fitted with an intervention term to account for the significant discontinuity apparent in hospitalised crash data around 2001. Chapman and Rosman (2008, 2010) noted that there was a change to the Western Australia Police crash report form in 2001 that may have affected how hospitalisation was recorded in Police crash data. However, they concluded that no satisfactory explanation for the apparent discontinuity around this period could be found. The intervention term is in the form of a level break fit at the first quarter of 2002 (Q1 2002) as part of the model estimation process which can detect outliers and structural breaks in a fitted time series model through the use of auxiliary residuals (Harvey & Koopman, 1992). Inclusion of an intervention term accounts for the discontinuity in hospitalised data through effective adjustment of the other parameter estimates.

[2] This refers to a 1% increase in the unemployment rate (e.g. from 10.0% to 10.1%), not a 1 percentage point increase (which would be from 10% to 11%).

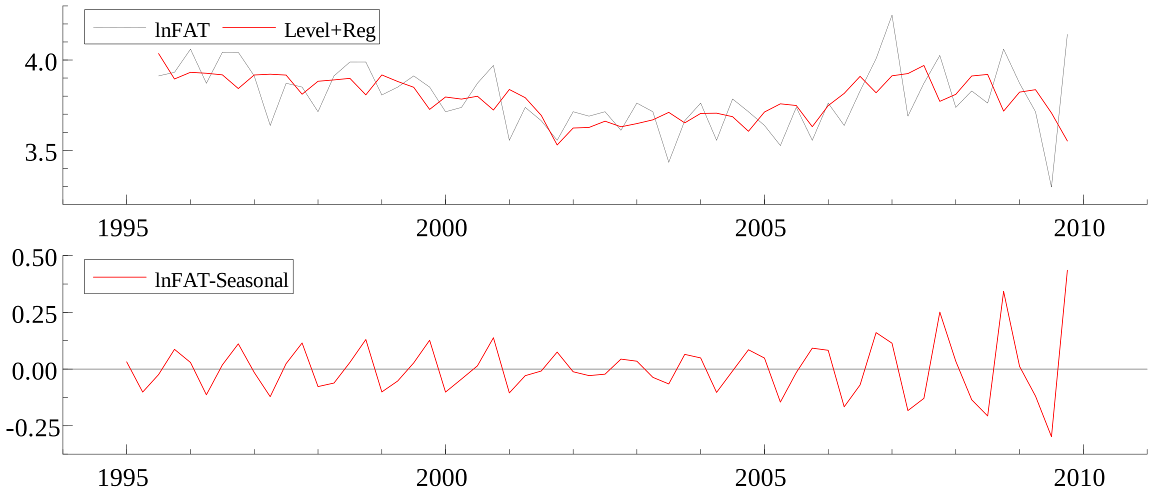

Figure 4.5: Fitted model – Fatal crashes

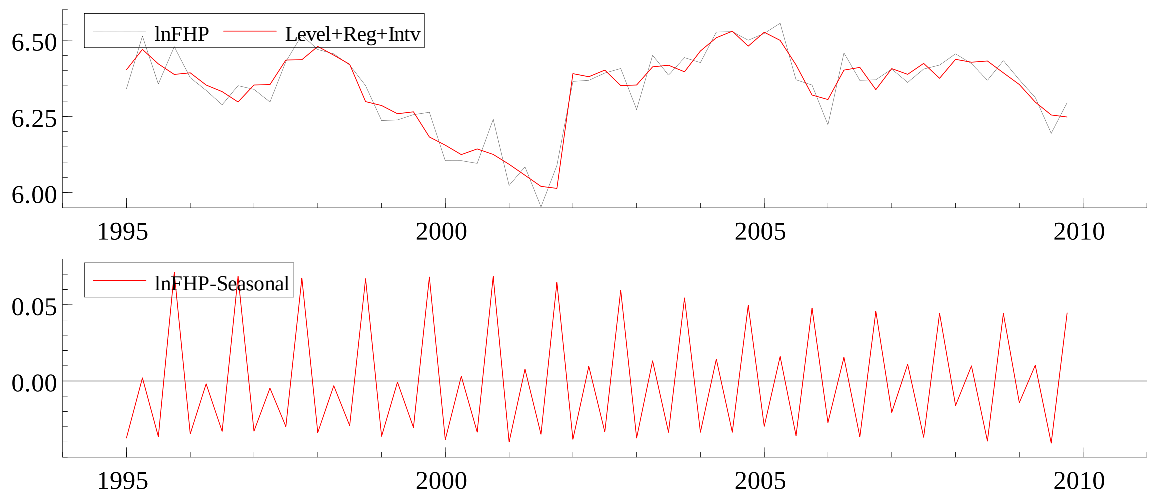

Figure 4.6: Fitted model – Fatal plus hospitalised crashes

Table 4.1: Parameter estimates – Fatal crashes

	Fatal crashes		***per POP***		***per VKT (billion km)***	
	Coefficient	*p-value*	Coefficient	*p-value*	Coefficient	*p-value*
UER_2	-0.41	*0.0132*	-0.44	*0.0011*	-0.43	*0.0015*
ALS	-0.35	*0.2284*	-0.25	*0.2591*	-0.29	*0.2007*
RBT	-0.62	*0.0255*	-0.52	*<0.00005*	-0.51	*<0.00005*
INF	-0.19	*0.0325*	-0.15	*0.0334*	-0.15	*0.0290*

UER_2 – Unemployment rate lagged by 2 quarters, ALS – Alcohol sales (deflated), RBT – Random breath tests, INF – Speed camera infringements, POP – Population, VKT – Vehicle kilometres travelled

Table 4.2: Parameter estimates – Fatal plus hospitalised crashes

	Fatal plus hospitalised crashes		***per POP***		***per VKT (billion km)***	
	Coefficient	*p-value*	Coefficient	*p-value*	Coefficient	*p-value*
Q1 2002	0.35	*0.0001*	0.35	*0.0001*	0.33	*0.0004*
UER	-0.22	*0.0537*	-0.22	*0.0596*	-0.21	*0.0781*
ALS	-0.14	*0.4427*	-0.15	*0.4143*	-0.16	*0.3981*
RBT	-0.059	*0.8156*	-0.15	*0.5573*	-0.16	*0.5548*
INF	-0.043	*0.5469*	-0.049	*0.5013*	-0.056	*0.4512*

UER – Unemployment rate, ALS – Alcohol sales (deflated), RBT – Random breath tests, INF – Speed camera infringements, POP – Population, VKT – Vehicle kilometres travelled

Figures 4.7 and 4.8 show the fitted log-log models for fatal crashes and fatal plus hospitalised crashes respectively that occurred during high alcohol hours (HAH). Parameter estimates with levels of significance for the fitted models of fatal crashes (HAH) and fatal plus hospitalised crashes (HAH) are presented in Tables 4.3 and 4.4 respectively. The tables also show parameter estimates for rates of road trauma by population (POP) and vehicles kilometres (VKT) travelled.

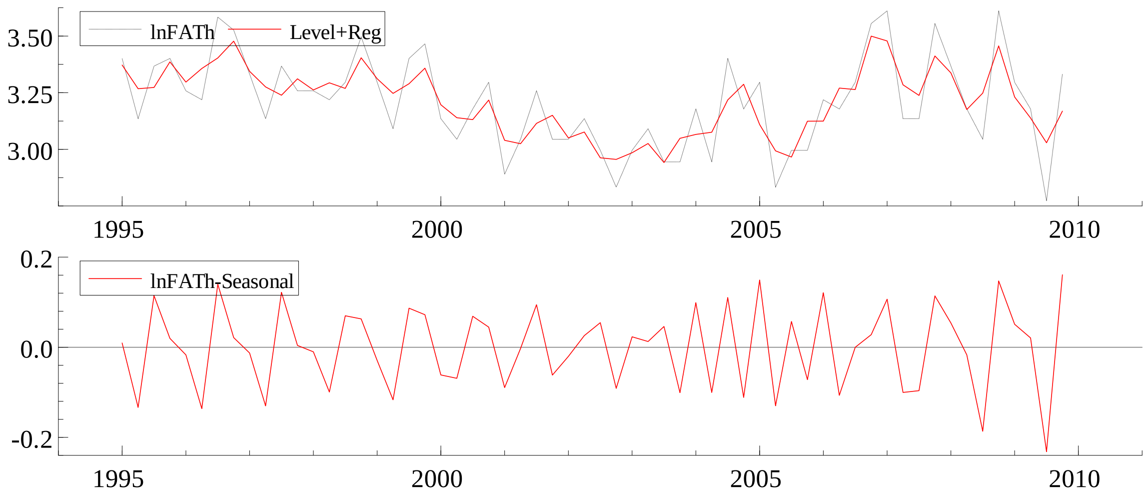

Figure 4.7: Fitted model – Fatal crashes (HAH)

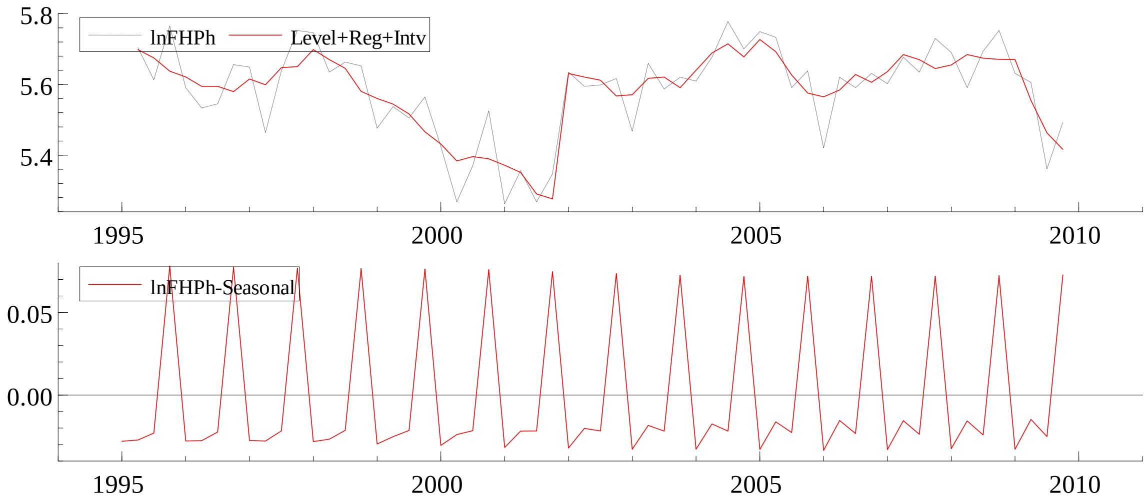

Figure 4.8: Fitted model – Fatal plus hospitalised crashes (HAH)

Table 4.3: Parameter estimates – Fatal crashes (HAH)

	Fatal crashes (HAH)		***per POP***		***per VKT (billion km)***	
	Coefficient	*p-value*	Coefficient	*p-value*	Coefficient	*p-value*
UER	-0.44	*0.0272*	-0.45	*0.0251*	-0.44	*0.0228*
ALS	0.37	*0.2512*	0.36	*0.2543*	0.32	*0.3015*
RBT	-0.46	*0.3692*	-0.46	*0.3614*	-0.47	*0.3225*
INF	0.27	*0.0696*	0.26	*0.0733*	0.25	*0.0894*

UER – Unemployment rate, ALS – Alcohol sales (deflated), RBT – Random breath tests, INF – Speed camera infringements, POP – Population, VKT – Vehicle kilometres travelled

Table 4.4: Parameter estimates – Fatal plus hospitalised crashes (HAH)

	Fatal plus hospitalised crashes (HAH)		***per POP***		***per VKT (billion km)***	
	Coefficient	*p-value*	Coefficient	*p-value*	Coefficient	*p-value*
Q1 2002	0.34	*0.0004*	0.35	*0.0002*	0.33	*0.0011*
UER_1	-0.30	*0.0188*	-0.32	*0.0092*	-0.24	*0.0642*
ALS	-0.10	*0.6298*	-0.017	*0.9350*	-0.16	*0.4716*
RBT	-0.22	*0.3729*	0.054	*0.8606*	-0.32	*0.2197*
INF	-0.0077	*0.9253*	0.037	*0.6614*	-0.031	*0.7227*

UER_1 – Unemployment rate lagged by 1 quarter, ALS – Alcohol sales (deflated), RBT – Random breath tests, INF – Speed camera infringements, POP – Population, VKT – Vehicle kilometres travelled

Results for the vehicle and road user sub-group models are presented in Appendix D. Estimated log-log models for the total number of crashes where a truck, motorcycle, bicycle or pedestrian was involved are shown in Figures D.1 to D.4 respectively. Parameter estimates with levels of significance for each of the fitted models are presented in Tables D.1 to D.4 respectively.

4.2.1 Diagnostic Tests and Goodness-of-Fit

All significance tests in the models were based on three assumptions concerning the residuals of the analysis. These residuals should satisfy the following three properties, listed in decreasing order of importance (Commandeur & Koopman 2007):

1. Independence;

2. Homoscedasticity; and

3. Normality.

As part of the modelling process, a range of diagnostics, presented in Appendix E, were checked in order to ensure that these assumptions were met.

With regards to goodness-of-fit the basic measure is the *prediction error variance* and its square root, given as the *std. error*. Also provided where appropriate over the traditional measure of goodness-of-fit (R^2) was the more relevant coefficient of determination for seasonal data with a trend, R_s^2. R_s^2 measures fit against a random walk plus drift and fixed seasonal components.

The diagnostic tests show that for each of the overall models, all model assumptions were met. All model assumptions were also met for each of the vehicle and road user sub-group models with model diagnostics and goodness-of-fit summaries also presented in Appendix E.

5.0 Discussion

Modelling of the relationship between socio-economic factors and the level of road trauma in Western Australia has identified unemployment rate, the chosen measure of economic activity, as having a significant association with each of the overall levels of road trauma investigated, i.e. with fatal crashes; fatal plus hospitalisation crashes; fatal crashes during high alcohol hours; and fatal plus hospitalisation crashes during high alcohol hours. Alcohol sales (deflated) was not found to be statistically significantly associated with any of the overall road trauma outcomes, although a more specific measure of alcohol consumption may be required to fully investigate any potential association between alcohol use and overall road trauma, especially during high alcohol hours.

Significant associations were found between the included non-socio-economic factors representing major road safety program activity, namely number of random breath tests and number of speed camera infringements, and the overall road trauma outcomes of fatal crashes and fatal crashes during high alcohol hours. As described in Section 2.3, these factors were included as “adjusting factors” in the explanatory models to account as far as possible for changes to road trauma outcomes attributable to changes in broad road safety countermeasures so that the net effect of socio-economic factors on road trauma could be examined. An interpretation of the effect of these countermeasures on road trauma could be made using the constructed models: for example Table 4.1 shows that increases in the number of random breath tests are highly statistically significantly associated with reductions in fatal crashes per population and fatal crashes per vehicle kilometres travelled. However, the explanatory models were not designed to formally evaluate the effectiveness of road safety programs on road trauma. In order to draw inferences on the effectiveness of specific programs, separate dedicated and properly designed evaluation studies would be required that would take into account all the complexities inherent in such programs. This would ideally include the analysis of data from the time before these programs were in place so as to be able to measure the road trauma effects of introducing such programs and not merely the marginal effects of changes in their level of activity which is the most that can be gleaned from the models presented here given the time period of data available.

It should also be stressed that the estimated explanatory time series models were constructed to identify any significant associations between the included socio-economic factors and the road trauma outcomes of interest. Further separate investigations would be required to determine whether cause and effect relationships exist and what the specific mechanism of effect is. This would require a much larger research program than that undertaken here. This might include hypothesising causal mechanisms and testing these using specifically designed studies. For example, one hypothesis that has been presented is that crash risk reduces in times of poor economic circumstances due to people engaging in less discretionary travel in high risk times as well as through better compliance with regulation due to decreased capacity to easily meet fines for traffic infringements accumulated for high risk behaviours such as speeding. This is an untested hypothesis and would require the collection of detailed exposure, attitudinal and economic information via surveys at a personal level to link exposure and risk taking behaviour to personal economic circumstances and outlooks.

Unemployment rate was selected for inclusion in the models to represent economic activity in WA. As noted the other economic measures considered, including gross state product; state final demand; retail turnover; and employed persons, were all highly correlated with unemployment rate and each other. Any of these could have reasonably been chosen for inclusion in the models in place of unemployment rate. The decision to use unemployment rate was based on its use in previous studies and the desire to be able to make direct comparisons with these studies. This study found unemployment rate to be inversely associated to crashes. This is consistent with the various other studies referenced including by Scuffham and Langley (2002), Wagenaar 1984; Hakim et al. 1991; Gantzer et al. 1995; Newstead et al. 1995 and with more recent work undertaken by the Monash University Accident Research Centre that examined the relationship between socio-economic factors and the level of road trauma in New South Wales and Victoria (D'Elia & Newstead 2007, 2012). As noted, it has been hypothesised that the inverse relationship reflects increased unemployment leading to both a reduced ability to pay for discretionary travel and a reduced demand for employment related travel (Scuffham & Langley, 2002). As suggested, further detailed research would need to be undertaken to fully understand the complex relationship between unemployment rate, or economic activity more generally, and travel patterns.

A particular strength of the analytical approach used in this study was the use of structural time series models as the analysis tool. Structural time series models have an inherent flexibility in their formulation to allow accurate and valid time series models to be readily fitted to the data. They include components that are readily interpretable in the context of the outcome being studied. They also allow the inclusion of covariates in the modelling structure to determine the association between these factors and the outcome being modelled. Finally, they allow accurate forecasts to be readily estimated, with the accuracy of the forecast indicated by prediction intervals.

An alternative approach to the analysis design used in this study would be to conduct a cross section analysis of the relationship between economic circumstances and road trauma levels between jurisdictions, for example different Australia states. In theory this is possible, but in practice would be difficult to achieve since road trauma levels are driven by a large number of factors beyond just economic circumstances. These include the available road infrastructure, the vehicle fleet, the enforcement regime and the types of travel exposure of the population. A large number of jurisdictions would need to be compared to adequately control for the effects of all these factors in order to establish the residual effects of the economy in contributing to jurisdictional differences. Furthermore, it is also possible that the fundamental causal relationship between economic activity and road trauma outcomes, should one exist, differs between jurisdictions depending on the nature of activity which drives the economy and the level and type of base wealth of the population. For these reasons the intra-jurisdictional longitudinal study design used here was favoured over the inter-jurisdictional cross sectional study design.

Table 4.1 shows that a 1% increase in the unemployment rate[3] was associated with a 0.41% decrease in fatal crashes effective 2 quarters after the unemployment rate increase (the effect lags by 2 quarters). For the rate models, Table 4.1 shows that a 1% increase in the unemployment rate was associated with a 0.44% decrease in fatal crashes per population and a 0.43% decrease in fatal crashes per vehicle kilometres travelled effective 2 quarters after the unemployment rate increase. All these results were statistically significant at the 5% level. Figure 5.1 shows the number of fatal crashes that occurred over the analysis period and the expected number of crashes had the unemployment rate remained fixed at the March 1995 level. This translates into an additional 311 fatal crashes having occurred over the analysis period or an additional 21 crashes per year on average.

[3] This refers to a 1% increase in the unemployment rate (e.g. from 10.0% to 10.1%), not a 1 percentage point increase (which would be from 10% to 11%).

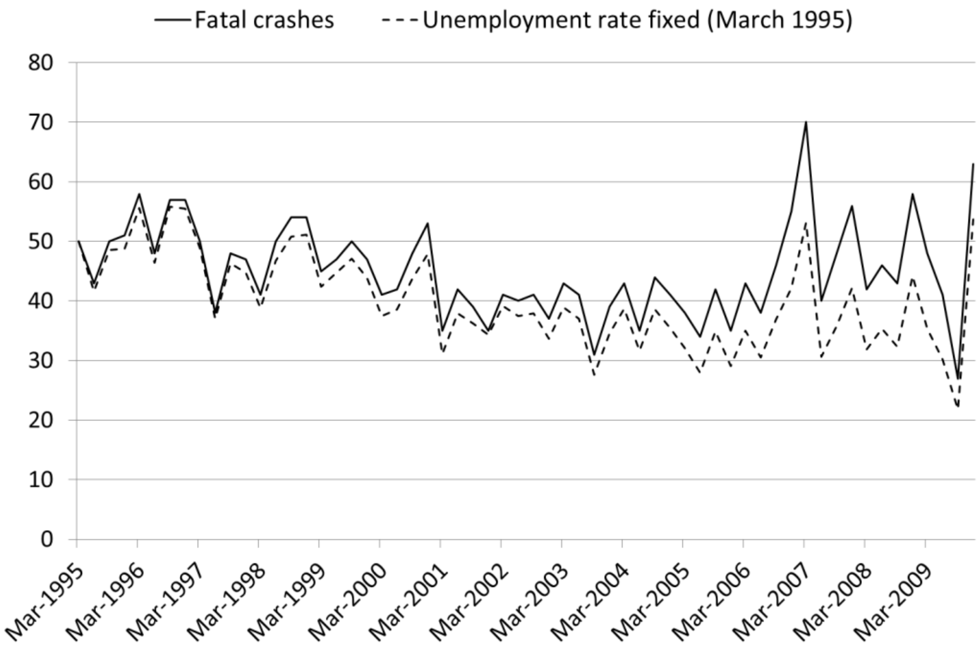

Figure 5.1: Fatal crashes

Table 4.2 shows that a 1% increase in the unemployment rate was associated with a 0.22% decrease in fatal plus hospitalised crashes. For the rate models, Table 4.2 shows that a 1% increase in the unemployment rate was associated with a 0.22% decrease in fatal plus hospitalised crashes per population and a 0.21% decrease in fatal plus hospitalised crashes per vehicle kilometres travelled. All these results were statistically significant at the 10% level. Figure 5.2 shows the number of fatal plus hospitalised crashes that occurred over the analysis period and the expected number of crashes had the unemployment rate remained fixed at the March 1995 level. This translates into an additional 1,793 fatal plus hospitalised crashes having occurred over the analysis period or an additional 120 crashes per year on average.

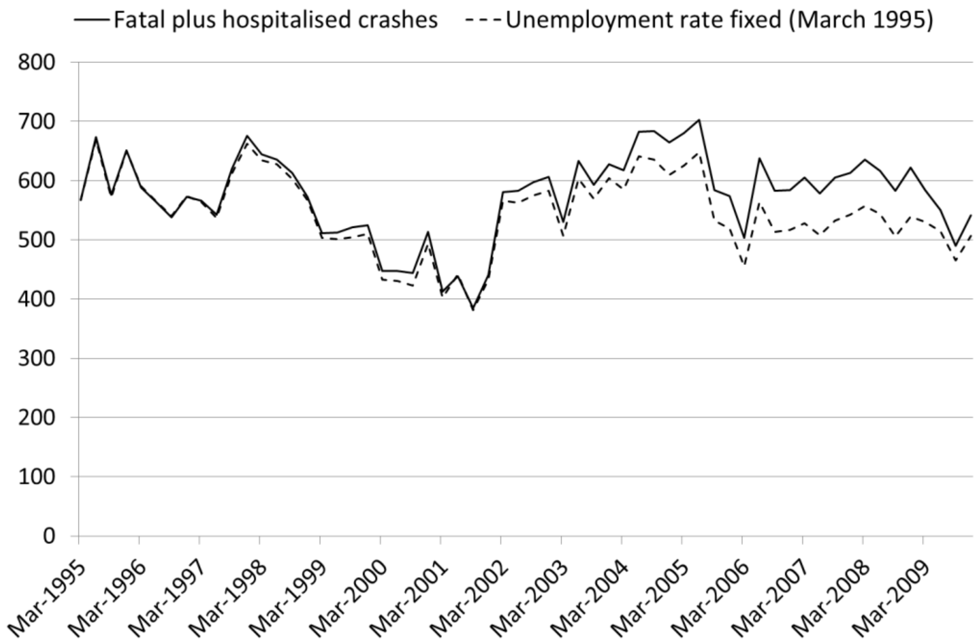

Figure 5.2: Fatal plus hospitalised crashes

Table 4.3 shows that a 1% increase in the unemployment rate was associated with a 0.44% decrease in fatal crashes during high alcohol hours. Table 4.3 shows that a 1% increase in the unemployment rate was associated with a 0.45% decrease in fatal crashes per population and a 0.44% decrease in fatal crashes per vehicle kilometres travelled during high alcohol hours. All these results were statistically significant at the 5% level. Figure 5.3 shows the number of fatal crashes during high alcohol hours that occurred over the analysis period and the expected number of crashes had the unemployment rate remained fixed at the March 1995 level. This translates into an additional 158 fatal crashes having occurred during high alcohol hours over the analysis period or an additional 11 crashes per year on average.

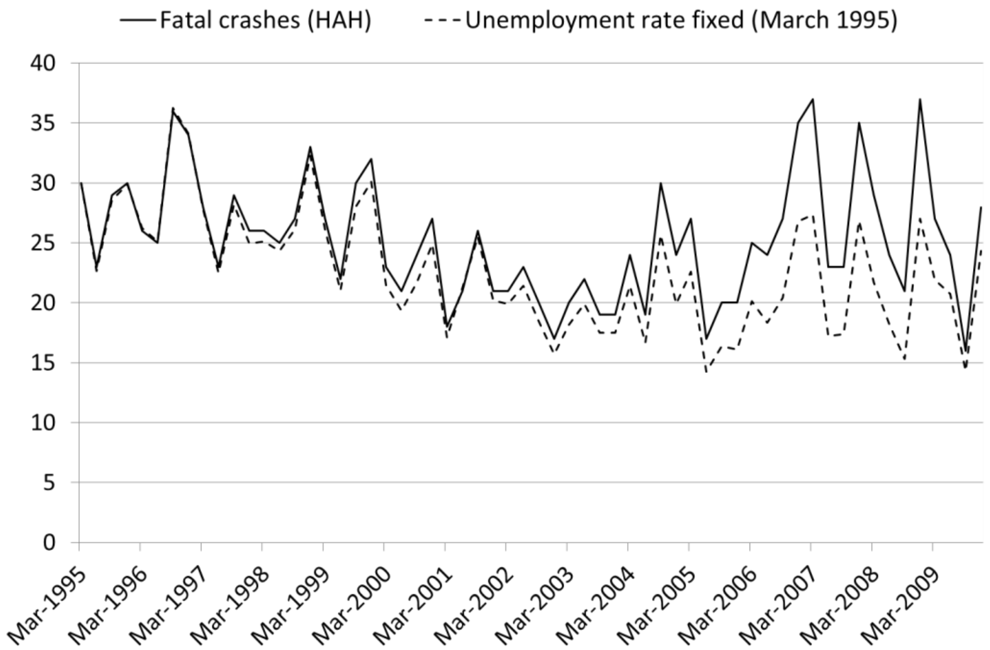

Figure 5.3: Fatal crashes – High alcohol hours (HAH)

Table 4.4 shows that a 1% increase in the unemployment rate was associated with a 0.30% decrease in fatal plus hospitalised crashes during high alcohol hours effective 1 quarter after the unemployment rate increase (the effect lags by 1 quarter). Table 4.4 shows that a 1% increase in the unemployment rate was associated with a 0.32% decrease in fatal plus hospitalised crashes per population and a 0.24% decrease in fatal plus hospitalised crashes per vehicle kilometres travelled during high alcohol hours effective 1 quarter after the unemployment rate increase. These results were statistically significant at the 5% level for the crash frequency model and crashes per population rate model and at the 10% level for the crashes per vehicle kilometres travelled rate model. Figure 5.4 shows the number of fatal plus hospitalised crashes during high alcohol hours that occurred over the analysis period and the expected number of crashes had the unemployment rate remained fixed at the March 1995 level. This translates into an additional 1,098 fatal plus hospitalised crashes having occurred during high alcohol hours over the analysis period or an additional 73 crashes per year on average.

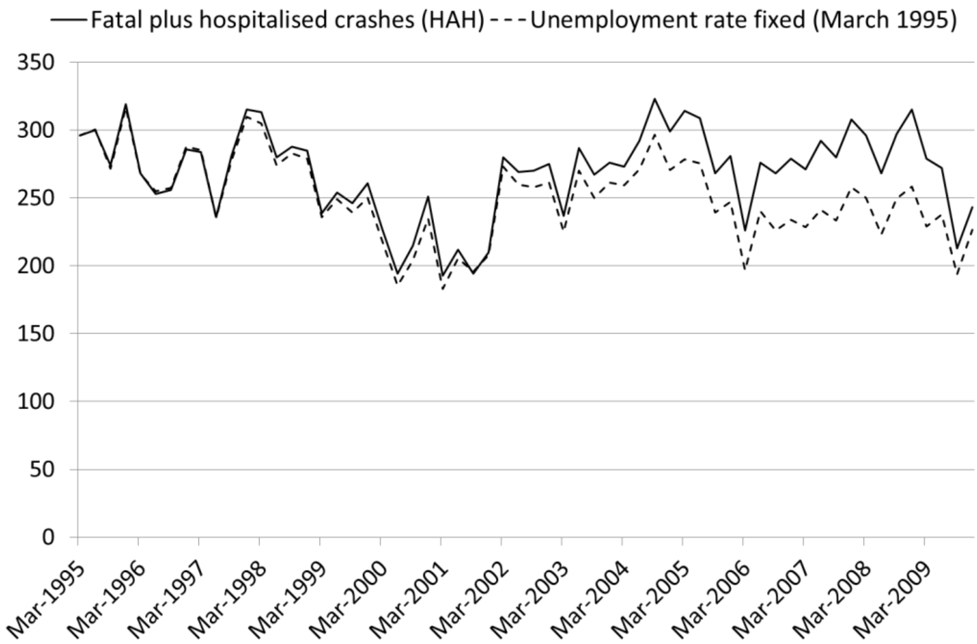

Figure 5.4: Fatal plus hospitalised crashes – High alcohol hours (HAH)

In summary, over the analysis period of March 1995 to December 2009 inclusive, reductions in the unemployment rate in Western Australia relative to March 1995 levels have been associated with an additional:

- 311 fatal crashes (average 21 per year);
- 1,793 fatal plus hospitalised crashes (average 120 per year);
- 158 fatal crashes during high alcohol hours (average 11 per year); and
- 1,098 fatal plus hospitalised crashes during high alcohol hours (average 73 per year).

The analysis conducted in this study provides a clear indication that socio-economic factors can influence the levels of road trauma observed in Western Australia. Unemployment rate offers a measure of economic activity that is useful for the road safety context. Changes in unemployment rate, representing changes in economic activity, have the potential to significantly help or hinder achieving the road trauma targets specified in the Western Australian Road Safety Strategy 2008-2020 “Towards Zero” (Road Safety Council 2009). Understanding the influence of factors external to strategy activities is critical in order to understand whether strategy targets have been met with the assistance of such factors and hence may not be sustainable in the longer term, or whether targets are not likely to be met due to the factors hence dictating the need to put extra resources into the strategy in order to meet the targets.

The next phase of this research aims to produce forecasts of road trauma into the near future including a consideration of potential changes to socio-economic factors and their effect on the forecasts. Identification of the association between selected factors and road trauma through estimation of explanatory time series models as presented in this report will allow examination of the influence of potential future movement of the factors on future road safety outcomes to be examined as part of the next phase of work. This includes use of the rate models to forecast road trauma outcomes under different future scenarios of population growth and vehicle travel exposure.

6.0 Conclusion and Recommendations

This project established the relationship between key socio-economic factors and road trauma in Western Australia. Changes in economic activity in Western Australia over the past 10 years were associated with higher levels of road trauma than would have been observed had economic conditions remained constant. Analysis results have identified the need to consider future possible economic circumstances in setting road safety targets and to consider past changes in economic circumstances in assessing progress towards meeting targets set.

It is recommended that:

- As future economic circumstances are difficult to predict, strategy target setting should include a range of targets based on various scenarios of future economic circumstances. Alternatively, if fixed targets are set, additional resources or programs should be considered in order to meet targets in times of improving economic circumstances;
- When economic circumstances are improving, an option could be to aim to exceed targets in order to accommodate the effects of increasing road trauma when the worsening economic trend reverses;
- Evaluation of road safety countermeasures or strategy performance should include methodology that explicitly measures or controls for the effects of economic factors on road trauma outcomes. This is necessary in order to measure the specific effects of road safety programs on road trauma outcomes.
- If there is a desire to establish a causal relationship between economic circumstances and road trauma outcomes beyond the associations demonstrated in this study, detailed survey based research relating economic circumstances and outlooks to travel, exposure and risk taking behaviour and ultimately crash risk at the individual level is recommended.

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Appendix A – Outcome Variables: Road Trauma Outcomes

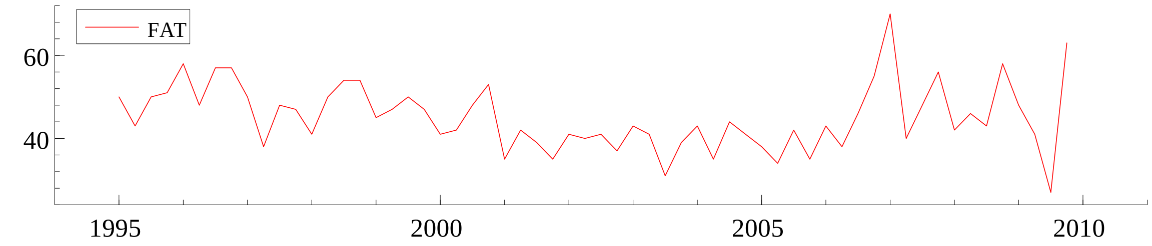

Figure A.1: Fatal crashes

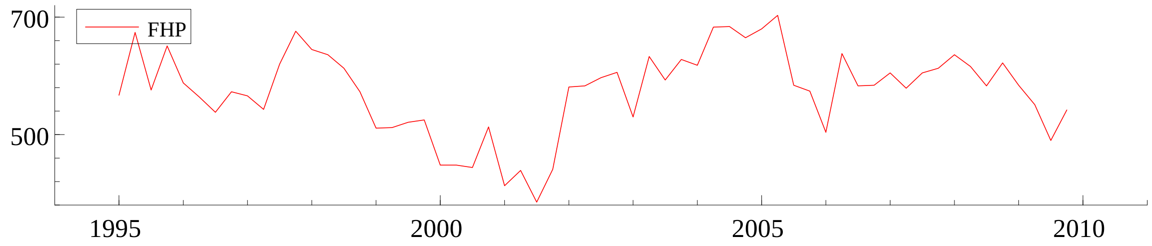

Figure A.2: Fatal plus hospitalised crashes

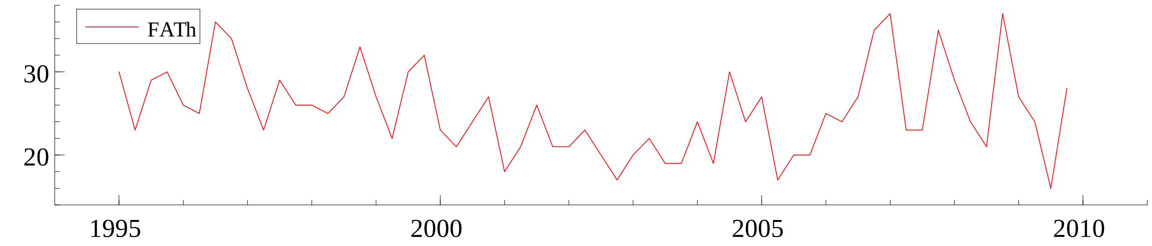

Figure A.3: Fatal crashes – High alcohol hours (HAH)

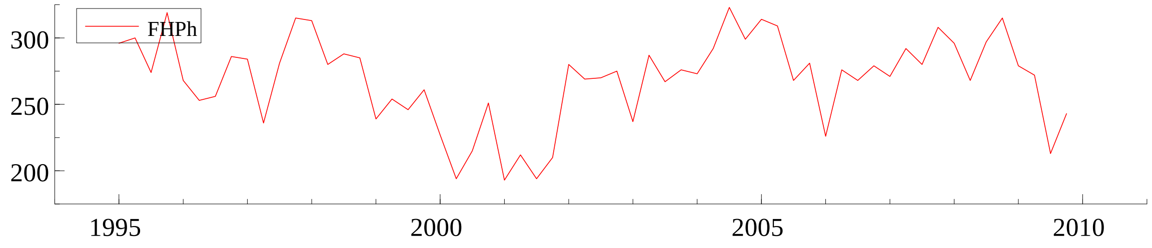

Figure A.4: Fatal plus hospitalised crashes – High alcohol hours (HAH)

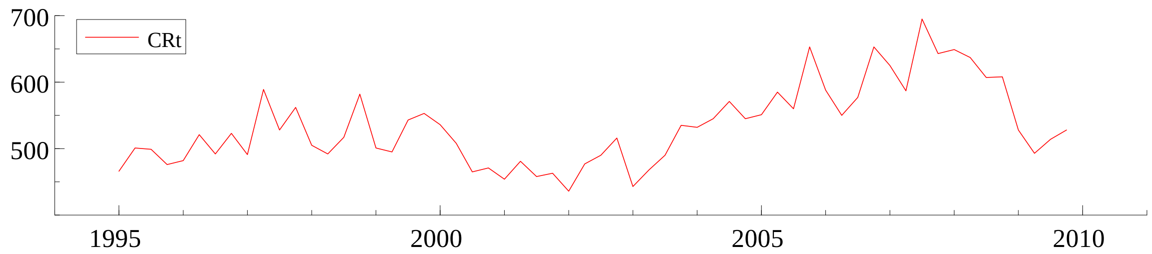

Figure A.5: Number of crashes where a truck was involved

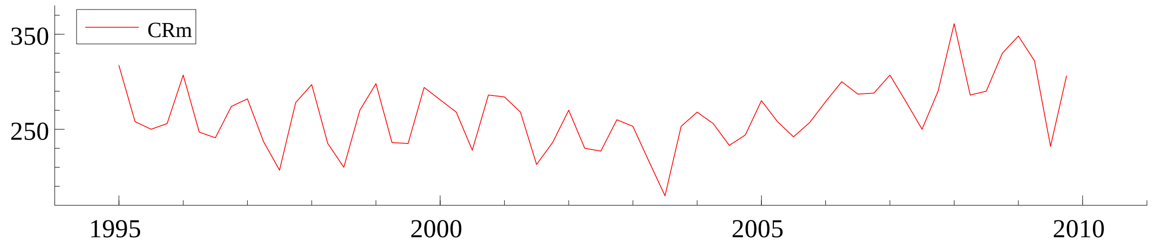

Figure A.6: Number of crashes where a motorcycle was involved

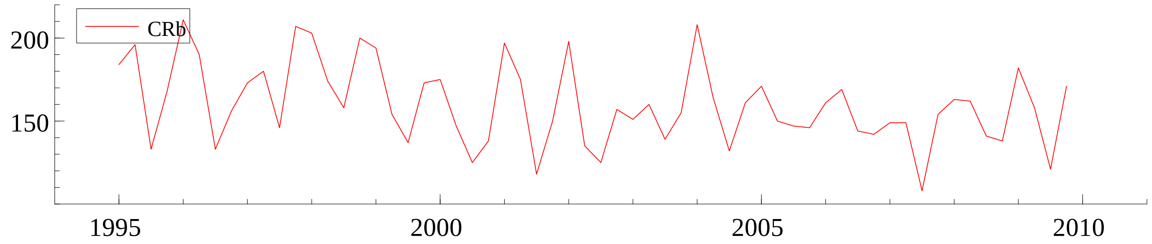

Figure A.7: Number of crashes where a bicycle was involved

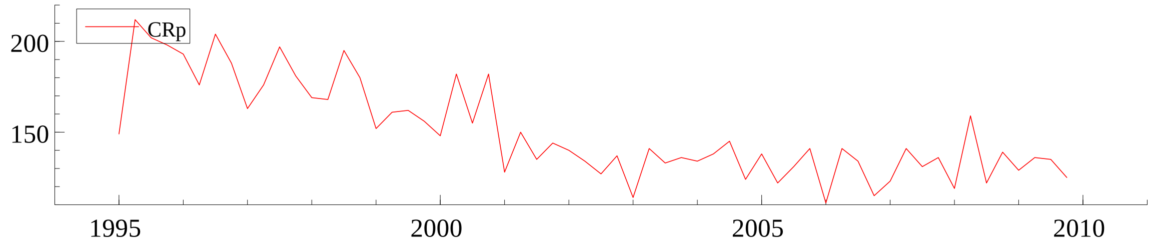

Figure A.8: Number of crashes where a pedestrian was involved

Appendix B – Correlation Coefficients: Productivity and Employment Measures

Table B.1: Pearson correlations – Productivity and employment measures

	GSP	GSPc	SFD	RT	UER	EMP	EMPc
GSP	1	0.99	0.98	0.99	-0.88	0.99	0.94
GSPc	0.99	1	0.96	0.99	-0.90	0.98	0.94
SFD	0.98	0.96	1	0.98	-0.88	0.99	0.96
RT	0.99	0.99	0.98	1	-0.92	0.99	0.96
UER	-0.88	-0.90	-0.88	-0.92	1	-0.90	-0.95
EMP	0.99	0.98	0.99	0.99	-0.90	1	0.97
EMPc	0.94	0.94	0.96	0.96	-0.95	0.97	1

KEY

Productivity measures; Western Australia
GSP – Gross state product
GSPc – Gross state product per capita
SFD – State final demand
RT – Retail turnover

Employment measures; Western Australia
UER – Unemployment rate
EMP – Employed persons – total
EMPc – Employed persons – total per capita

Appendix C – Vehicle Kilometres Travelled by Vehicle Type, Western Australia

Vehicle kilometres travelled (rigid plus articulated trucks) increased from a combined estimated 292 million kilometres for the March 1995 quarter to 433 million kilometres for the December 2009 quarter (or by 48%).

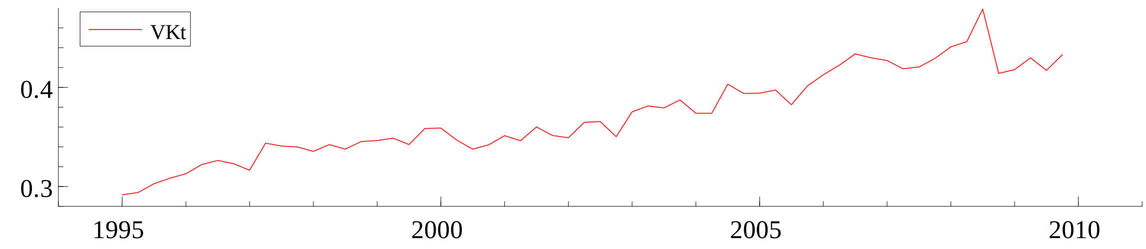

Figure C.1: Vehicle kilometres travelled – Trucks (Rigid plus Articulated) (billion km)

Vehicle kilometres travelled (motorcycles) increased from an estimated 33 million kilometres for the March 1995 quarter to 64 million kilometres for the December 2009 quarter (or by 94%).

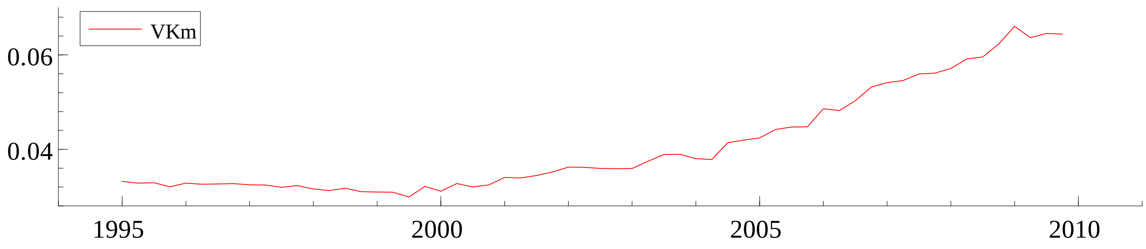

Figure C.2: Vehicle kilometres travelled – Motorcycles (billion km)

Appendix D – Results for Vehicle and Road User Sub-groups

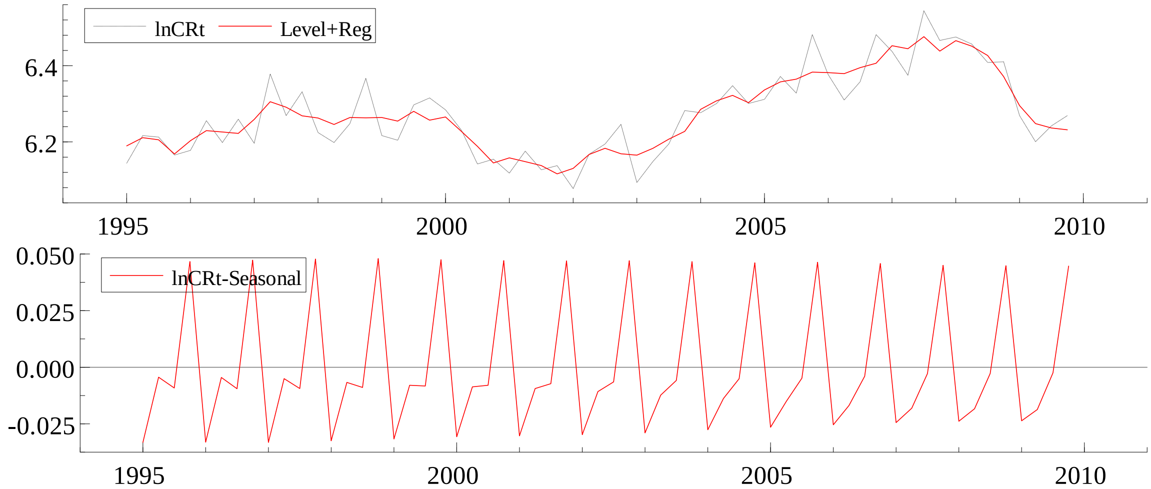

Figure D.1: Fitted model – Truck involved crashes

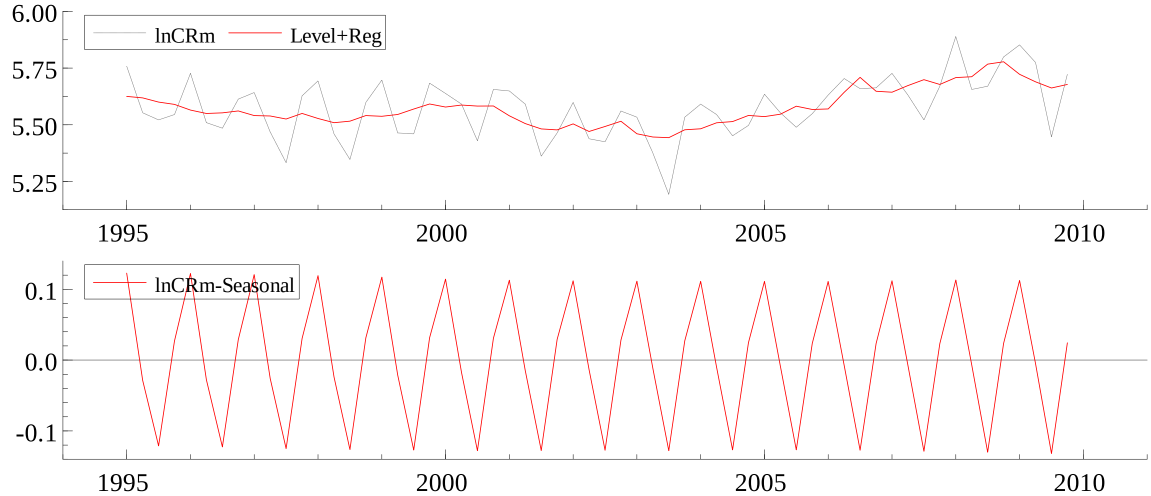

Figure D.2: Fitted model – Motorcycle involved crashes

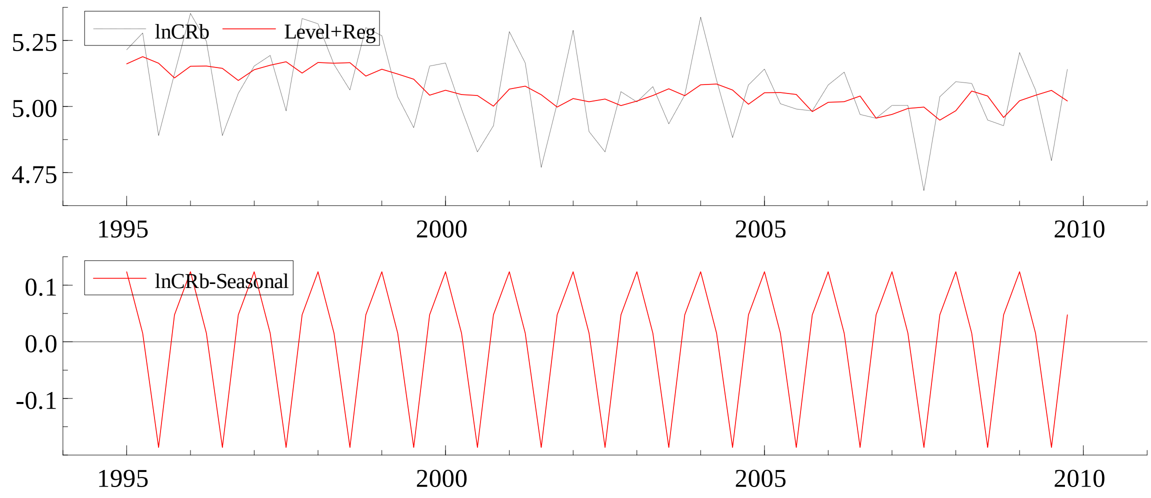

Figure D.3: Fitted model – Bicycle involved crashes

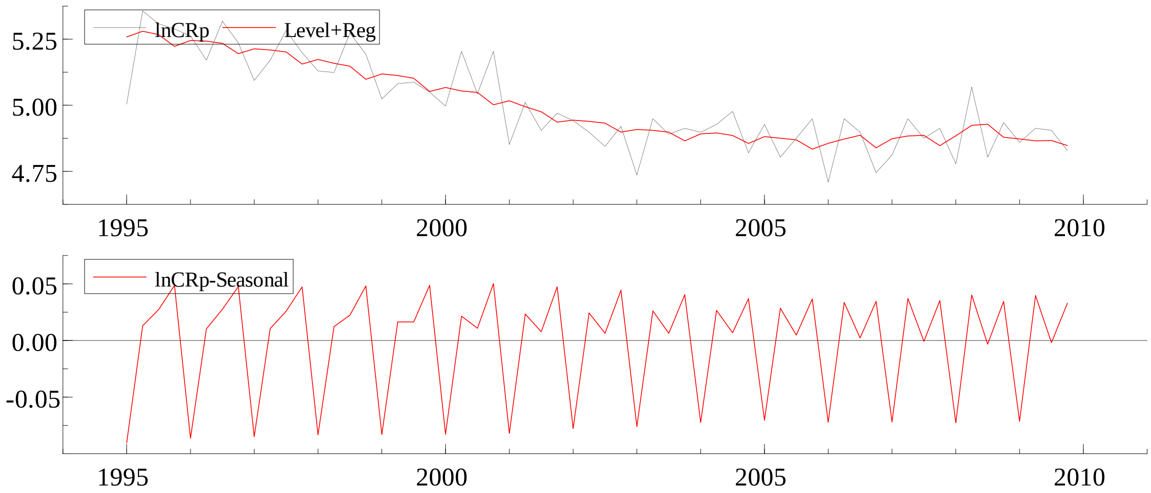

Figure D.4: Fitted model – Pedestrian involved crashes

Table D.1: Parameter estimates – Truck involved crashes

	Total crashes		***per VKt (billion km)***	
	Coefficient	*p-value*	Coefficient	*p-value*
UER	-0.15	*0.0924*	-0.12	*0.0912*
ALS	-0.066	*0.6369*	0.16	*0.0113*
RBT	-0.088	*0.6334*	-0.27	*0.0251*
INF	-0.00030	*0.9957*	-0.060	*0.2027*

Table D.2: Parameter estimates – Motorcycle involved crashes

	Total crashes		***per VKm (billion km)***	
	Coefficient	*p-value*	Coefficient	*p-value*
UER	-0.17	*0.0462*	-0.16	*0.1377*
ALS	0.058	*0.6941*	-0.0085	*0.9622*
RBT	0.079	*0.6048*	-0.034	*0.8931*
INF	-0.13	*0.0329*	-0.12	*0.1272*

Table D.3: Parameter estimates – Bicycle involved crashes

	Total crashes	
	Coefficient	*p-value*
UER	0.089	*0.4063*
ALS	-0.17	*0.3720*
RBT	-0.037	*0.8274*
INF	-0.063	*0.3729*

Table D.4: Parameter estimates – Pedestrian involved crashes

	Total crashes	
	Coefficient	*p-value*
UER	-0.066	*0.4865*
ALS	-0.12	*0.5023*
RBT	0.039	*0.8521*
INF	-0.028	*0.7187*

Appendix E – Model Diagnostics and Goodness-of-fit

All significance tests in the models were based on three assumptions concerning the residuals of the analysis. These residuals should satisfy the following three properties, listed in decreasing order of importance (Commandeur & Koopman 2007):

1. Independence;
2. Homoscedasticity; and
3. Normality.

As part of the modelling process, a range of diagnostics, presented in Table E.1, were checked in order to ensure that these assumptions were met. Independence of the residuals was checked using the Box-Ljung statistic Q(P, d) based on the first P residual autocorrelations and tested against a χ^2-distribution with d degrees of freedom. For Q(9, 6) and Q(8, 6) the critical value is $\chi^2_{(6;\ 0.05)} = 12.53$. Also shown are the values of the autocorrelations at lags 1 and q, r(1) and r(P) respectively, which should not exceed the 95% confidence limits of $\pm 2/\sqrt{n} = \pm 2/\sqrt{60} = \pm 0.258$. The second assumption of homoscedasticity (equal variance) of the residuals was checked using the statistic H(h) which tests whether the variance of the residuals in the first third part of the series is equal to the variance of the last third part and is tested against an F-distribution with (h, h) degrees of freedom. All of the analyses presented here have values of H(17) (or 1/H(17) if $H < 1$) or H(16) (or 1/H(16) if $H < 1$) lower than the critical values of $F_{(17,\ 17;\ 0.025)} = 2.67$ or $F_{(16,\ 16;\ 0.025)} = 2.76$ respectively. The last assumption of normality of the residuals was checked using the Bowman-Shenton test statistic N which incorporates measures of skewness and kurtosis. This was tested against a χ^2-distribution with two degrees of freedom, i.e. against a critical value of $\chi^2_{(2;\ 0.05)} = 5.99$.

In addition, Table E.1 shows the Durban-Watson (DW) statistic which detects the presence of autocorrelation. A value of 2 indicates a lack of autocorrelation of the residuals. With regards to goodness-of-fit the basic measure is the *prediction error variance* and its square root is given in Table E.1 as the *std. error*. Also provided where appropriate over the traditional measure of goodness-of-fit (R^2) was the more relevant coefficient of determination for seasonal data with a trend, R_s^2. R_s^2 measures fit against a random walk plus drift and fixed seasonal components.

The diagnostic tests show that for each of the overall models, all model assumptions were met. All model assumptions were also met for each of the vehicle and road user sub-group models with model diagnostics and goodness-of-fit summaries presented in Table E.2.

Table E.1: Model diagnostics and goodness-of-fit – Overall models

	Fatal crashes		**Fatal plus hospitalised crashes**	
	Overall	HAH	Overall	HAH
P	9	9	8	8
d	6	6	6	6
h	16	17	17	16
Q(P, d)	6.08	7.39	5.12	9.60
r(1)	-0.130	-0.0810	0.000763	-0.0535
r(P)	0.131	-0.0735	-0.0812	0.0175
H(h)	2.57	1.57	0.861	0.995
N	0.246	1.35	0.856	2.43
DW	2.17	2.11	1.94	2.03
std. error	0.136	0.158	0.0737	0.0846
R_s^2	0.630	0.536	0.408	0.455
	per POP			
P	8	9	8	9
d	6	6	6	6
h	16	17	17	16
Q(P, d)	5.39	7.51	5.49	11.4
r(1)	-0.128	-0.0788	-0.0182	-0.0835
r(P)	0.0285	-0.0731	-0.0756	-0.153
H(h)	2.65	1.55	0.914	0.920
N	0.0324	1.32	0.636	1.41
DW	2.17	2.10	1.94	2.15
std. error	0.135	0.157	0.0748	0.0826
R_s^2	0.629	0.540	0.392	0.492
	per VKT (billion km)			
P	8	9	8	8
d	6	6	6	6
h	16	17	17	16
Q(P, d)	3.34	7.78	6.33	9.94
r(1)	-0.117	-0.0771	-0.0233	-0.0590
r(P)	0.0433	-0.106	-0.0518	0.00527
H(h)	2.26	1.34	0.877	1.05
N	0.135	1.42	2.30	3.50
DW	2.13	2.10	1.96	2.02
std. error	0.136	0.156	0.0753	0.0905
R_s^2	0.624	0.549	0.446	0.440

Table E.2: Model diagnostics and goodness-of-fit – Vehicle and road user sub-groups

	Total Crashes			
	Truck	Motorcycle	Bicycle	Pedestrian
P	8	8	8	9
d	6	6	6	6
h	17	17	17	17
Q(P, d)	7.87	2.62	9.25	8.75
r(1)	0.0384	0.0266	-0.0448	-0.226
r(P)	-0.236	-0.0670	0.0207	-0.0937
H(h)	0.980	1.49	0.602	1.07
N	0.206	1.66	0.992	1.88
DW	1.92	1.92	2.04	2.42
std. error	0.0625	0.0720	0.0954	0.0869
R_s^2	0.228	0.431	0.482	0.514
	per VKt (billion km)			
P	8	9		
d	7	6		
h	18	17		
Q(P, d)	7.77	7.11		
r(1)	0.0940	0.00807		
r(P)	-0.215	-0.164		
H(h)	2.43	1.74		
N	0.291	0.722		
DW	1.78	1.95		
std. error	0.0626	0.0807		
R^2 / R_s^2	0.611 (R^2)	0.365 (R_s^2)		