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EVALUATION OF THE BICYCLE HELMET WEARING LAW IN VICTORIA DURING ITS FIRST FOUR YEARS

by

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Abstract

This research project evaluated the effect of the mandatory bicycle helmet wearing legislation which was introduced in Victoria in 1990, using data from the Hospital Admissions database which includes data for all bicyclists admitted to a public hospital after a crash. The project built on earlier work conducted by the Monash University Accident Research Centre, and in particular on Newstead, Cameron, Gantzer, & Finch (1994).

Newstead et al. analysed bicyclist injury data for the first three years of mandatory helmet wearing and reported conflicting results which suggested the effects of the helmet wearing legislation may have declined in the third year. Preliminary analyses of the hospital admissions data in the current project suggested the apparent increase in bicyclist admissions to hospital in the third and fourth years after the legislation was most likely the result of changes in the funding arrangements for publicly funded hospitals. The bicyclist data in the hospital admissions database were corrected to remove this effect.

Multivariate time series analyses of the corrected number of bicyclist admissions to hospital in Victoria indicated admissions in the first four years of the helmet legislation were 40% below the number expected on the basis of pre-legislation trends. The inclusion of other road-safety related factors in the modelling process suggested the reduction in bicyclist admissions was largely due to the helmet legislation. Analysis of the severity of head injuries for crash-involved bicyclists similarly indicated the severity of head injuries has declined after the introduction of the helmet wearing legislation.

It was concluded that the mandatory helmet wearing legislation has had a significant, positive effect on the number and severity of injuries amongst bicyclists, and that this effect has persisted for the four years since the introduction of the legislation.

Key Words
(IRRD except where marked *)
bicycle, crash helmet, cyclist, injury, evaluation (assessment), statistics, traffic regulations, safety, time series analysis*.

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Introduction

Legislation requiring the use of a helmet while riding a bicycle was introduced in Victoria in July 1990. The purpose of the legislation was the reduction of both number and severity of head injuries through increased use of bicycle helmets by all age groups.

Surveys of bicycle helmet use have shown that post-legislation wearing rates were significantly greater than pre-legislation rates in all age groups (Finch, Heiman & Neiger, 1993), although Finch et al. (1993) reported that the introduction of the legislation was accompanied by reduced bicycle use in the first year for all age groups, especially teenagers. Bicycle use by teenagers and younger children remained lower than pre-legislation levels in the second year while bicycle use by adults increased.

The reported increase in helmet wearing rates (and the apparent reduction in exposure to crashes through reduced bicycle use) leads to the expectation that the number of bicyclists presenting with crash-related head injuries has declined since 1990, as has the severity of bicyclist head injuries.

In the first two years of the legislation, the number and proportion of head injuries amongst hospitalised bicyclists declined (Cameron, Vulcan, Finch & Newstead, 1994). An evaluation of the first three years of helmet legislation, however, reported conflicting data (Newstead, Cameron, Gantzer & Finch, 1994) indicating an increase in the number and proportion of hospitalised cyclists sustaining head injuries in crashes involving a motor vehicle during the third year.

The aim of this report was to present a thorough analysis of the effects of the first four years of helmet legislation.

Data Problems

Newstead et al. (1994) noted some differences between the two data sources used in their study - the Hospital Admissions data based on Health Department records of admissions to public hospitals, and the claims data from the Transport Accident Commission which is responsible for "no-fault" injury compensation in the case of crashes involving motor vehicles. In addition there was also an apparent increase in head injuries in the third year of the legislation.

The numbers and proportions of head injured victims of crashes in each database from 1987/88 to 1993/94 were examined, and it was concluded that a substantial part of the apparent increase in head injuries amongst crash-involved bicyclists related to a change in admissions policy in the Victorian hospital system (Casemix Funding), resulting from the use of incentives for hospitals based on their throughput and the number of injuries treated.

Data Analysis Technique

Multivariate time-series techniques were used to model the changes in the number of head-injured bicyclists. The changing level of injury severity was taken into account.

Data from the Hospital Admissions database were used in the analyses, but were corrected for the possible effects of Casemix Funding. It was noted that the relative rate of head injury for all hospital admissions had increased markedly since the 1992/93 financial year (from 87/88 to 92/93 the numbers were more or less constant) and this overall increase was used as a correction factor in the time series analysis of the bicyclist head injury data.

Number of Head-Injured Bicyclists

Time series models of the number of bicyclists admitted to hospital with head injuries indicated that the helmet wearing legislation has had a substantial impact. It was estimated from these models that the first four years of this legislation has seen a (statistically reliable) 39.5% reduction in the number of head-injured admissions across Victoria.

The inclusion of other possible contributory factors in the modelling process suggests that the change is largely due to the introduction of the mandatory helmet wearing legislation, although it is possible that a part of the change relates to the reduced exposure to crash risk of bicyclists since the legislation's introduction.

Injury Severity

Investigation of the levels of head injury severity of bicyclists admitted to hospital similarly indicated that the legislation has had an impact. The proportion of admitted bicyclists with the highest (critical) head injury severity remained unchanged in the post-legislation period, but there were clear reductions in the proportion of admitted bicyclists with head injuries in the serious and severe categories. The proportion of bicyclists in with head injuries in these severity categories declined by 40% (all admitted bicyclists) and 46% (admitted bicyclists where a motor-vehicle was involved in the crash).

Conclusions

The detailed analysis of the data relating to bicyclist head injuries presented in this report indicates that the mandatory helmet wearing legislation has had a significant, positive impact on both the number of head-injured bicyclists and on the severity of injuries for bicyclists admitted to hospital. These changes have continued through the first four years post-legislation and are apparent in spite of recent anomalies in the Hospital Admissions data.

1. Introduction

In July 1990, a mandatory bicycle helmet wearing law was introduced in Victoria. This law was preceded by ten years of promotion, involving education, mass media publicity, support by professional associations, and community groups, consultation with bicycle groups, and financial incentives.

The law requires all persons cycling (and their passengers) on the road, a shared or segregated footpath, a separate bicycle path, or in a public place to wear a securely fitted and approved bicycle helmet. The maximum penalty for non-compliance, if taken to court, is $ 100. However, usually a Bicycle Offence Penalty Notice of $ 20 is issued.

Victoria was the first jurisdiction (state or country) to introduce a mandatory bicycle helmet wearing law. The aim of the law was to increase helmet wearing practices, and thus significantly decrease both the number and severity of bicyclist head injuries.

1.1 Background to the project

The effects of the Victorian mandatory bicycle helmet wearing law (BHL) on helmet wearing rates and the risk of head injury have been assessed in previous Monash University Accident Research Centre (MUARC) projects. The law has achieved its goal of increasing bicycle helmet wearing rates for all age groups of bicyclists (Finch et al, 1993, TTM Consulting, 1994). A direct result of the increased helmet wearing rates was expected to be a significant reduction in the number and severity of head injuries to bicyclists involved in crashes and this was found for the first two years after the law was introduced. The third post-law year provided conflicting evidence of the effectiveness of the law with an upturn in the proportion of hospitalised cyclists sustaining head injuries (Cameron et al, 1994a).

There are various factors affecting injury numbers and rates. The variations in post-law numbers and rates of head injuries can be explained in a number of ways:

- changes in the number of bicyclists involved in crashes resulting in serious injury (killed or admitted to hospital);
    - includes exposure reduction;
    - includes population increase;
- changes in the risk of head injury for bicyclists who were seriously injured;
- changes in exogenous factors affecting road safety in the post-law period;
- changes to hospital admissions & coding policies.

Cameron et al (1994a) suggested that a reduction in the total number of severely injured bicyclists in the post-law period may have been due to a reduction in bicycle use, along with other factors affecting the risk of accident involvement. Finch et al (1993) reported that observational studies in 1991 and 1992 showed overall bicycle usage up 9% and 12% respectively compared to Nov.'87/Jan.'88, but a substantial reduction in teenage cyclist usage compared with a survey in May 1990, immediately prior to the BHL. Various surveys in other states of Australia have suggested a possible reduction in the number of cyclists on the roads in post-law periods (Walker, 1992; Mead, 1993; Ratcliffe, 1993).

Cameron et al (1994a) reported that percentages of seriously injured bicyclists who suffered a head injury during the post-law period were considerably lower than the pre-law levels. With reference to the upturn in third-year head injury rates, Newstead et al (1994) reported the third post-law year level to be no different from the downward trend predicted by the model using pre-law wearing rate trends.

The introduction of the BHL was immediately preceded by the introduction of two other major road safety initiatives directed at drink/driving (Random Breath Testing, RBT) and speeding (Speed Camera Program, SCP). This has led to an overall drop in total road deaths and serious injuries in the following years (Cameron et al, 1994b). In the case of pedestrians both the number of Transport Accident Commission (TAC) claims for injury compensation and also the proportion of head injuries dropped markedly after these two initiatives.

The relationship between speed of impact and injury severity in the case of bicyclists is on the one hand intuitively obvious, on the other hand hard to specify without suitable data. Janssen and Wismans (1985) estimated that in vehicle-cyclist accidents, a drop in impact speed from 40 to 30 km/hr would reduce head impact acceleration by 50%. Weiss (1992) showed in the case of motorcyclists that motorcycle speed was significantly correlated with injury severity, while the effectiveness of helmets decreased at higher motorcycle speeds.

1.1.1 Bicycle Injury Data Investigation

After the 3rd year bicycle helmet evaluation resulted in conflicting conclusions about the effectiveness of mandatory helmet wearing, particularly in that year, it was decided that a thorough investigation of the two main data sources, TAC claims, and Hospital Admissions data was necessary. A separate study has been conducted and a report written examining the TAC and Hospital Admissions data with Casemix in mind. The following is basically a summary of that report and how the results are to be applied to this study.

The two data sources investigated in the Bicycle Injury Data Investigation are described below:

1. **TAC claims.** Transport Accident Commission (TAC) claims for "no fault" injury compensation.

2. **Hospital Admissions data.** The Victorian Inpatient Minimum Database (VIMD) includes Health Department records of acute presentations to Victorian public hospitals resulting in admission.

In July 1993, "Casemix Funding" was introduced in all Victorian public hospitals. Under this system, hospitals would be funded in general terms according to the number and severity of different injuries which were treated. Also incentives were made available to public hospitals for increased throughput of admitted patients. There is a view that these changes increased both the number of injuries formally recorded and the number of cases where a patient suffering from a suspected head injury was "admitted" for observation rather than retained for several hours in the Emergency Department. It is also considered that the trend in this direction began during 1992/93, the year leading up to the introduction of Casemix. During the same period, the community level of private health insurance was decreasing, probably resulting in a drift to public hospital treatment. The various changes in injury patterns, possibly as a result of Casemix, were to be addressed in this study.

Firstly trends in head injuries were investigated (the Healy definition of head injury was used in this study; see Appendix 6.1). Hospital Admissions data were examined for overall trends (for all hospital admissions, not only road users), as well as those for bicyclists and pedestrians. Both absolute (number) and relative (percentage) measures of head injured were examined. An exploratory analysis of adjustment of head injured numbers was also considered. Similarly for TAC data the numbers and percentages of head injured were analysed. Finally the Hospital Admissions data and TAC data were compared by selecting the Hospital Admissions motor vehicle involved and the TAC hospital admitted respectively (Carr and Cameron, 1995).

All ICD-9CM codes were examined in the VIMD data, and the ICD-9 codes in the TAC data. A breakdown of cases by admission duration was seen as an avenue to identify a possible problem area, with admission durations of ≤ 1 day expected to be different than longer durations of admission.

The following represents a summary of some of the findings for all reported injuries (not just bicyclists):

- The Hospital Admissions data showed substantial increases in recorded injuries associated with the introduction of Casemix.
  - All injury diagnoses (not cases of injury) increased 65% from 1991/92 to 1993/94.
  - Head injuries increased 29% from 1991/92 to 1993/94.
  - Non-head injuries increased 68% from 1991/92 to 1993/94.
  - Overall proportion of head injuries in fact decreased in spite of Casemix.
  - Short durations (≤ 1 day) have double the proportion of head injuries compared to longer durations of stay (15.5% compared to 7.7%).
  - The patient analysis showed similar results to the injury based analysis.
- TAC data did not show such dramatic Casemix related increases.
  - Strong decrease in numbers of injuries (1987/88 to 1991/92) followed by a mild increase.
  - Numbers of head injury decrease markedly from 1987/88 to 1991/92, followed by a slight increase.
  - Twice as many long duration head injuries (proportionally) compared to short durations of stay.
  - While admissions of long duration showed little variation in the proportion of head injuries from 1987/88 to 1993/94 (range 9.5%-11.5%), short durations showed a strong decrease (from 7.4% to 2.8%) from 1987/88 to 1991/92, followed by a rise to 4.8% in the 1993/94 head injury proportion.

When the data from 1993/94 were compared to 1991/92, the Hospital Admissions data showed an overall increase of 29% in diagnoses of head injuries, whereas in the years 1987/88 to 1991/92 the numbers of head injuries were relatively constant. The TAC data showed a substantial decrease of 64% between 1987/88 to 1991/92, but this was followed by a 38% increase to 1993/94.

In this analysis the rate of head injured patients admitted to hospital in the Hospital Admissions data (relative to the July 1987 value (409)) was used as a possible correction factor for the suspected general increase in head injuries since the introduction of Casemix.

1.2 Background to the analysis

Newstead et al (1994) expected two dimensions to be improved as a result of the introduction of BHL:

1. Number of head injuries
2. Severity of head injuries

The statistical analysis of the impact of the BHL can address both of these dimensions.

1.2.1 Time series models

In the road safety field time series models have often been used to evaluate the effects of an *intervention* such as a countermeasure. The effects on numbers of either serious injuries or fatalities of speed limits, compulsory seat belts, and drinking/driving legislation have been investigated with the use of these models. Invariably the Box and Tiao intervention model has been used to model these autocorrelated time series (Abraham, 1987; Lassarre & Tan, 1982; Haque, 1990; Stewart, 1985; Bhattacharyya & Layton, 1979; Ray, 1989). Harvey & Durbin (1986) used structural modelling intervention techniques instead in the evaluation of seat belt legislation. The intervention class of models allows the joint estimation of the effects of various countermeasures and covariates, as well as any seasonal or short-memory effects. The countermeasures can be modelled with simple *dummy* variables, leading to estimates of *percentage change* in the variable of interest (i.e. numbers of seriously injured). Instead of using *dummy* variables, more suitable *surrogate* variables can be modelled to represent the various countermeasures.

1.2.2 Surrogate variables

Cameron et al (1994b) showed the monthly numbers of speeding tickets (Traffic Infringement Notices) as a good measure of the implementation of the Speed Camera Program, while for Random Breath Testing, the number of tests is a suitable measure of this countermeasure's implementation. These two measures quantify the countermeasures' implementation, but do not necessarily reflect the impact on road safety. To more closely ascertain the impact of these more or less coincidental countermeasures, one can analyse data from two groups of road users that have much common ground with bicyclists: pedestrians and motorcyclists. The head injuries of these two groups in this time span reflect the overall effect of these two other countermeasures on head injuries per se, and enable a more specific analysis of the direct effect of helmet wearing on bicyclist head injuries, when these occur on road. In particular pedestrians are more likely to be the suitable comparison group.

With the number of head injuries always being related to exposure, and with evidence that the bicyclist helmet wearing law has lead to less bicyclist road use, previous MUARC projects have used bicyclists without a head injury as a correcting factor for the effects of varying exposure, leading to the analysis of proportions of head injury. In this analysis numbers of persons without a head injury will also be incorporated into the model, in an analogous fashion.

1.2.3 Analysis of injury severity

The analysis of severity of injury is somewhat more complex, with various problems arising in the definition of the evaluation. The original definition of *head injury* used in previous related MUARC projects dates back to Healy (1986), and all previous evaluations of bicycle helmet wearing effects on head injury have been based on it. In the Hospital Admissions data, the injuries are coded using the ICD-9CM coding scheme. These ICD-9CM codes can be converted to AIS (Abbreviated Injury Scale) severity scores using a procedure developed in the U.S.A. (MacKenzie et al, 1986). The AIS scores range from 0 (no injury) to 6 (maximum). This conversion leads to severity scores for various body regions in two alternative classifications, using either 6 or 9 body regions. In the first instance, the categories Head and Neck are grouped together in one body region, while in the 9 body region version, Head and Neck injuries are separate categories. The conversion from ICD-9CM to AIS calculates the maximum AIS for each body region. This conversion has it's limitations and is only approximate; however the analysis of injury severity is interested in relative changes over time and for this purpose the conversion is most adequate.

To analyse the effects the BHL has on severity of injury, an ordered probit model can be used—Weiss (1992) used this model on injury scores to evaluate motorcycle helmet use. This model is very similar to a logistic regression for ordinal data—these models incorporate the effects of various covariates similarly to *intervention* models, except for the ability to model dynamic interventions as is the case in intervention time series models (Box & Tiao, 1975). The disadvantage with this approach is that any improvements are across-the-board (i.e across all AIS levels).

Alternatively simple pre-post comparisons can be used which also enable changes in individual AIS levels to be seen, while other levels may remain more or less unchanged.

2. Analysis of numbers of head injured bicyclists

The first part of the statistical evaluation of the effects of the mandatory bicycle helmet wearing law will investigate the *numbers* of head injured bicyclists in Victoria between 1987/88 and 1993/94. The data source is the Hospital Admissions data which was preferred to the TAC claims data on this occasion, due to the availability of additional information on injury severity obtained by conversion of ICD-9CM codes. Between 1987/88 and 1993/94 there were some 8272 injured bicyclists admitted to a public hospital in Victoria. The following is a brief breakdown of some of the characteristics of this data:

Table 2.1: Characteristics of injured bicyclists admitted to public hospitals in Victoria during 1987/88 to 1993/94

Characteristic	N	Percentage
Head injured *	2509	30.3%
Non-head injured	5763	69.7%
Motor vehicle involved	1892	22.9%
Single bike	6322	76.4%
Other	58	0.7%
Location of residence of cyclist		
Melbourne #	4963	60.0%
Rest of Victoria	3309	40.0%

* Healy (1986) head injury definition (see Appendix 6.1).
# Melbourne Statistical Division

2.1 Relative rate of head injury

As was mentioned in section 1.1.1, the relative rate of head injury in the Hospital Admissions data (1987/88-1993/94) was included as an explanatory variable in the analysis. Table 2.2 shows how the number of patients recorded as admitted to a public hospital with a head injury has increased quite markedly in the last two years (in particular in 1993/94), after several years of almost constant levels from 1987/88 to 1991/92.

Assuming that this increase has also effected the numbers of head injured bicyclists, it is necessary to correct for this apparently Casemix related increase, to be able to make inferences about the time profile of head injured bicyclists. Two methods can be considered to correct for this recent marked increase in head injuries for patients admitted to hospital. One possibility is to standardize the head injured bicyclist data by a correction factor (i.e. the reciprocal of the head injury rate, relative to a reference level such as 1987/88) before the sophisticated models are employed. This method (used in the Bicycle Injury Data Investigation) will be described below, using yearly totals. Another possibility is to include the series of rates of head injury as an explanatory variable in the modelling process (this will be done in the multivariate time series models using monthly totals, described in section 2.3).

As numbers of head injured bicyclists and head injured pedestrians are under examination in this study, they are excluded from the overall total which leads to the Corrected Total. The yearly totals of head injured bicyclists and head injured pedestrians have been adjusted in the table for the apparent change in head injury coding practices. An example of the adjustment is (bicyclists, 93/94): $342 * (100/119.76) = 286$. The following table shows the respective numbers and their adjustments:

Table 2.2: Numbers of head injured in the Hospital Admissions data from 1987/88 to 1993/94

	87/88	88/89	89/90	90/91	91/92	92/93	93/94
All head injured	6196	6180	5904	5897	5866	6057	7075
Corrected Total *	5289	5349	5144	5319	5314	5434	6334
Percentage of 87/88	100.00	101.13	97.26	100.57	100.47	102.74	119.76
Bicyclist head injured	490	429	426	267	268	287	342
Adjusted	490	424	438	265	267	279	286
Pedestrian head injured	417	402	334	311	284	336	399
Adjusted	417	397	343	309	283	327	333

* "Corrected by subtracting the number of head injured bicyclists and pedestrians"

In this study we analysed all data on a monthly basis—analogous to the "Percentage of 87/88" row in the table above, monthly totals of head injured (Healy, 1986) patients admitted to hospital from the Hospital Admissions data (1987/88 to 1993/94) were calculated. For the purposes of correcting the number of head injured bicyclists for the apparent Casemix related increase in the years 1992/93 and 1993/94, the series of monthly totals of head injured patients admitted to hospital were standardized using the first month (July 1987) as a reference.

Figure 2.1 shows the data used for the rates of head injury, relative to July 1987; the curve has been smoothed using several passes through a Hanning filter (Hipel & McLeod, 1994); this filter smooths a time series according to the formula:

$$y_t = 0.25y_{t-1} + 0.50y_t + 0.25y_{t+1}$$

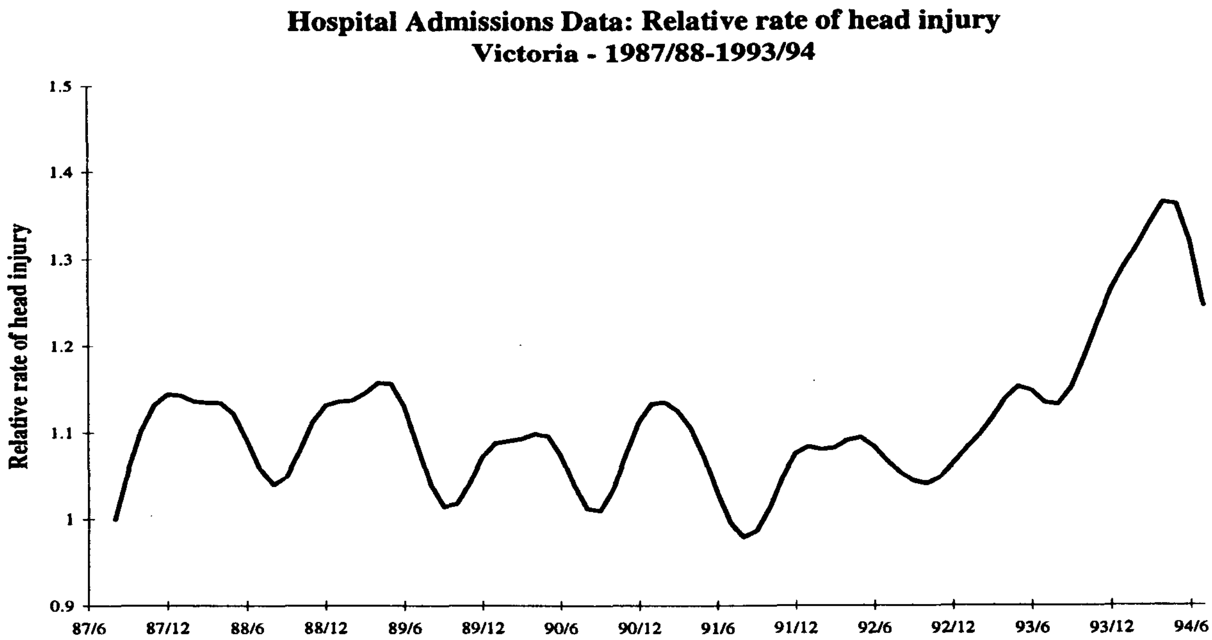

Figure 2.1: Monthly relative rates of head injury for all patients admitted to hospital in Victoria from 1987/88 to 1993/94.

2.2 Preliminary analysis considerations

Numbers of head injured bicyclists can either be modelled per se, or as a proportion of all bicyclist injuries. In previous MUARC projects the proportion of bicyclist hospital admissions who had head injuries has been modelled. When the actual numbers of head injuries are modelled, more sophisticated time series models can be used—the possibilities of using either stochastic or deterministic seasonal effects, and/or stochastic or deterministic trends. Furthermore effects such as trading day (differences between weekday and weekend), and also *length of month* (differences in monthly counts attributable to differences in the number of days in a month) can be considered for inclusion in the modelling process.

Before any modelling is undertaken, it can be quite informative to display time series data graphically and scrutinize the various characteristics (i.e. features, patterns, trends, and levels of variation). As in previous MUARC projects on the effects of the bicycle helmet wearing law, the time series of number of head injured bicyclists admitted to hospital is considered with respect to changes in the number of injured bicyclists admitted to hospital without a head injury. Figure 2.2 shows the numbers of both head injured bicyclists admitted to hospital in Victoria between 1987/88 and 1993/94, as well as the numbers of injured bicyclists admitted to hospital without a head injury.

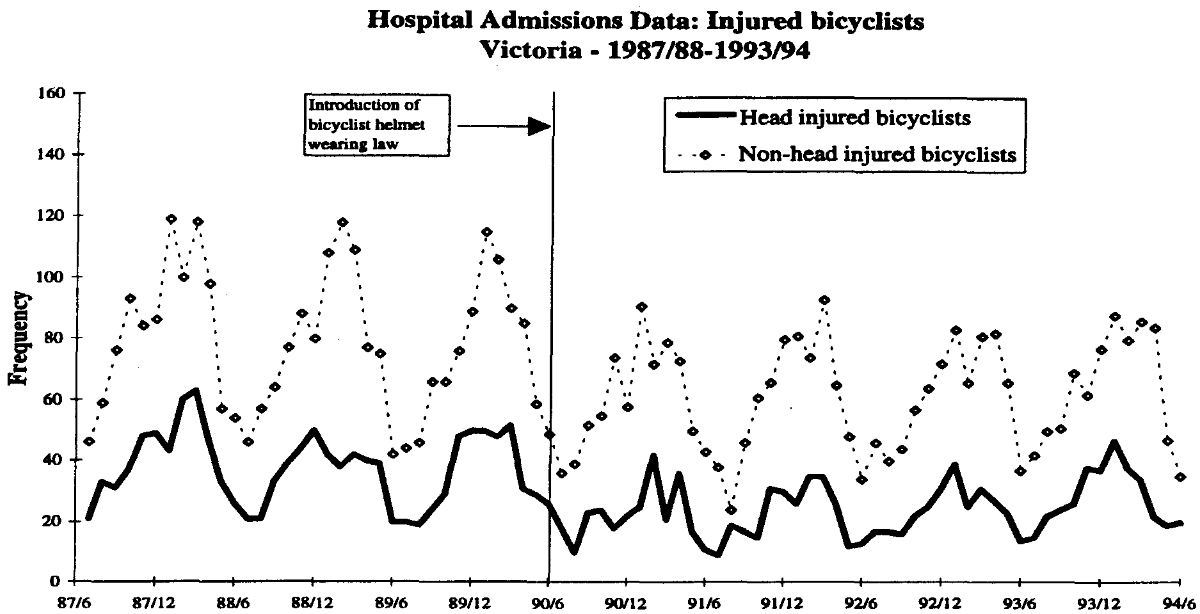

Figure 2.2: Monthly numbers of head and non-head injured bicyclists admitted to hospital in Victoria from 1987/88 to 1993/94.

Figure 2.2 shows a very distinct seasonal pattern in both head and non-head injuries; also apparent is the asymmetrical nature of the data, with the *peaks* tending to be more pronounced than the *troughs*. For a time series of counts of independent events (like crashes), which follow a Poisson distribution, a transformation such as the *square root* or *log* transformation leads to a time series whose variance is independent of the level of the series—there are definite advantages in taking the *log* transformation, as it is quite simple to transform model parameters back into the original scale. The *log* transformation will be used to model numbers of head injured in the multivariate time series models.

2.3 Descriptive comparisons of law effect

In the evaluation of the effects the introduction of the mandatory helmet wearing law had on numbers of head injured bicyclists, it is possible to simply compare the overall pre- and post-law levels in numbers of head injured bicyclists. Table 2.3 shows the percentage differences between pre- and post-law means of monthly numbers of head injured bicyclists, and pre- and post-law medians of monthly numbers of head injured bicyclists respectively.

Table 2.3: Simple estimates of percentage reductions in numbers of head injured bicyclists admitted to hospital (means and medians: 1987/88-1989/90 compared with 1990/91-1993/94

Jurisdiction	% Differences in Means	% Differences in Medians
Victoria: All crashes	35.1%	40.3%
Melbourne: All crashes	28.3%	33.3%
Victoria: Motor vehicle involved	38.0%	41.7%

These sorts of comparisons are very crude, and sometimes called *naive*, because they neither take any other factors into account, nor do they address the fact that the data are most likely serially (auto-) correlated to some degree. Box (1976) showed that even relatively low levels of serial correlation have drastic effects on significance or otherwise of parametric and non-parametric tests of differences, such as the T-test.

However when the percentage reductions in pre- and post-law medians (Table 2.3) are compared with the estimated percentage reductions from the multivariate time series models in the next section (Table 2.4), one can see that these figures are a robust approximation of the effects of the helmet wearing law on head injuries. The percentage differences in means in Table 2.3 seem to be a conservative estimate of possible benefits of the helmet wearing law.

2.4 Multivariate time series model

In the modelling of monthly *numbers* of head injured bicyclists admitted to hospital the various predictors shown in Appendix 6.3 were entertained for inclusion in the explanatory model. These included numbers of non-head injured bicyclists admitted to hospital, Random Breath Tests, numbers of Speed Camera TINs, numbers of head injured pedestrians, and relative rates of head injury for patients admitted to hospital.

When considering the effects of the helmet wearing law, there are two possible modelling alternatives. One method incorporates the interpolated helmet wearing rates, which has the advantage of representing the increases in helmet wearing practices pre-law. The other possibility is to represent the pre- and post-law periods by a simple dummy variable—this approach not only accounts for the increase in helmet wearing rates, but also any other indirect effects that may be attributable to changes due to the introduction of the law (awareness, attitudes, and/or exposure). By using helmet wearing rates, one cannot account for any changes in exposure, as the helmet wearing rates only account for those actually using bicycles. The second approach will be preferred as it also incorporates possible reductions in exposure.

As was mentioned earlier in this chapter, the multivariate model has a variety of choices regarding types of seasonality, trend, as well as effects such as trading day, and length of month. This is an iterative process with various scenarios being modelled, with each model being assessed for it's goodness-of-fit, as well as whether the assumptions of normally distributed and non-correlated residuals are fulfilled.

The software package used for this multivariate time series analysis was the X-12-ARIMA package from the U.S. Bureau of the Census. This package includes a wide range of features useful in time series modelling, and in particular has special capabilities for both monthly and quarterly data. In the iterative modelling process the following model components were tried for inclusion in the model:

- deterministic and stochastic trends
- both deterministic seasonality (seasonal dummies and sums of cosines/sines) as well as stochastic seasonality (stochastic difference equations)
- calendar effects (length of month effects; trading day effects)

Also comprehensive diagnostics are a part of the package such as outlier checks, autocorrelation analysis (Ljung-Box tests), and information criteria for selection of models, as well as a histogram to check the assumption of normality of the residuals.

Three models were fitted to numbers of head injured bicyclists in the Hospital Admissions data:

1. Victoria: All crashes
2. Melbourne: All crashes
3. Victoria: motor vehicle involved crashes

The edited details of the models are in Appendix 6.4. Both the models for all head injured bicyclists in Victoria, and in Melbourne included the term for the rate of head injury in the Hospital Admissions data. The step dummy variable representing the introduction of the mandatory bicycle helmet wearing law was highly significant in all three models. Details of the estimated percentage reductions in numbers of head injured bicyclists admitted to hospital (estimated from the multivariate time series models) are given in Table 2.4. Otherwise none of the other predictors considered had any statistically significant effect on the numbers of head injured bicyclists.

Figure 2.3 shows the results of the model fitted to all head injured bicyclists admitted to hospital in Victoria. The fitted model is an excellent approximation to the variation in the time series of head injured bicyclists.

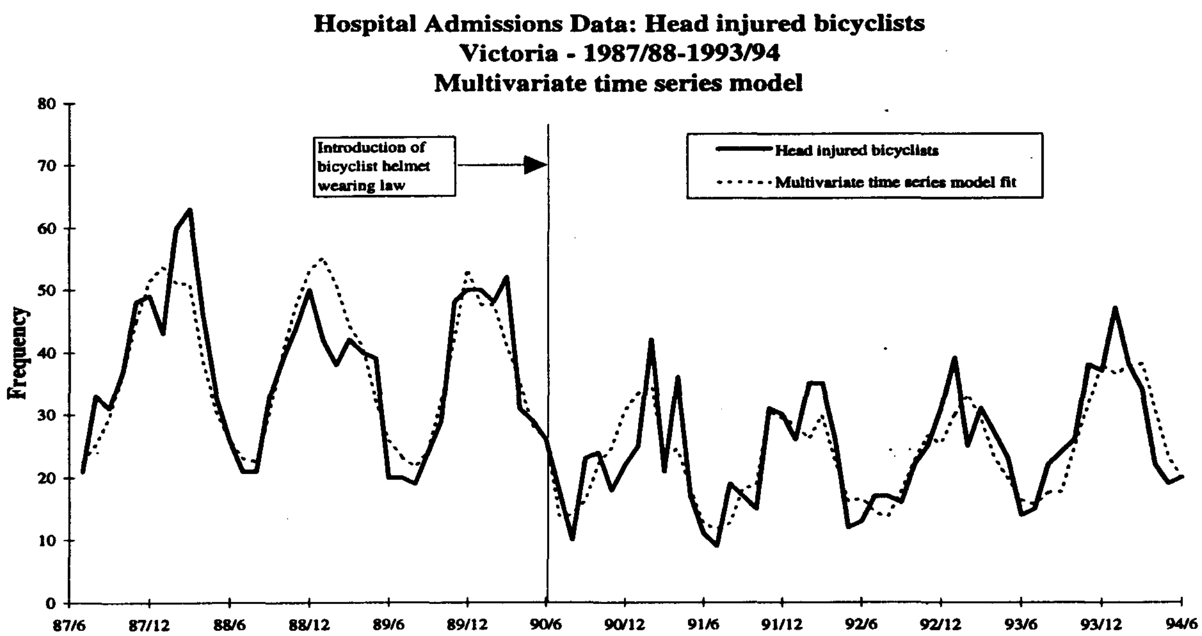

Figure 2.3: Monthly numbers of head injured bicyclists admitted to hospital in Victoria from 1987/88 to 1993/94, with fitted model

The graph shows a distinct seasonal pattern, with a fairly obvious decrease in the level of the series after the introduction of the bicycle helmet wearing law—this is commonly called a *level shift*. Also the increase in the last two years of data seems to have been adequately accommodated by the inclusion of the relative rate of head injury in the Hospital Admissions data in the model. There is no obvious downward trend (which should not be confused with a level shift) and the fitted model accounts for some 80.7% of the variation in the observed frequencies of head injured bicyclists (see Appendix 6.4.1 for details of the model).

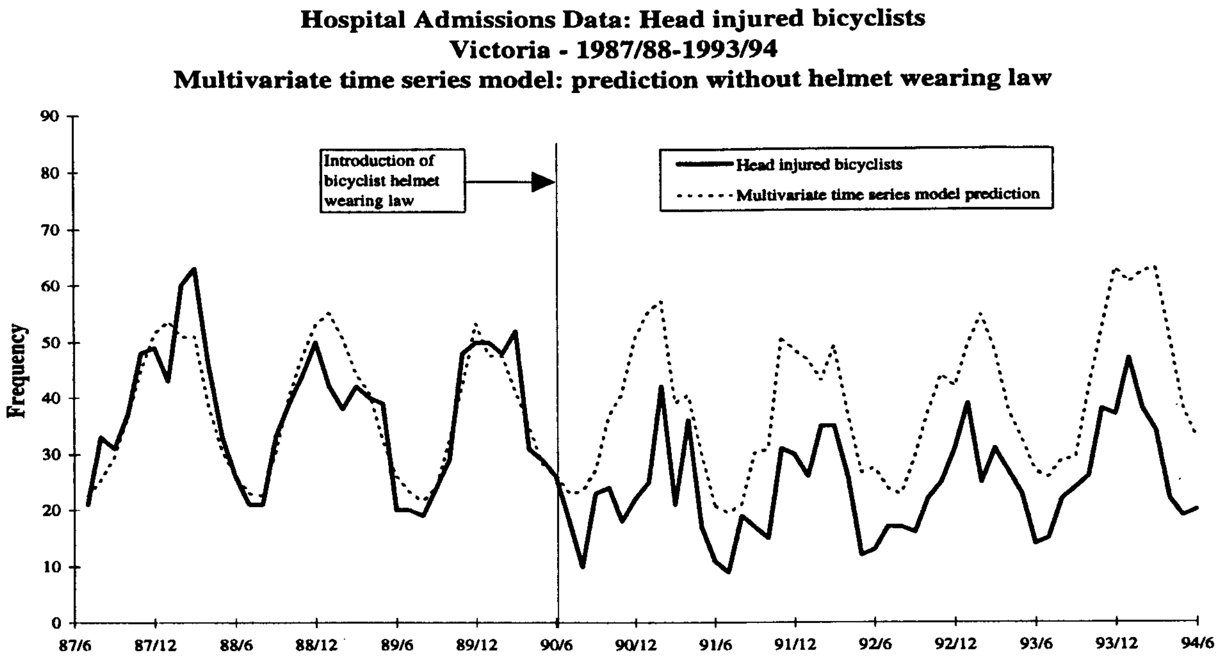

Figure 2.4: Monthly numbers of head injured bicyclists admitted to hospital in Victoria from 1987/88 to 1993/94, with model prediction of head injured numbers without the introduction of the helmet wearing law

Figure 2.4 shows the multivariate time series model prediction of head injured numbers, without the introduction of the helmet wearing law. The post-law numbers show that the data are homogenous in that the expectation without the helmet wearing law is almost always well above the actual numbers of head injured.

After having modelled the overall Victorian figures, it is of interest to determine whether the subsets of bicyclist crashes in Melbourne, and bicyclists crashes with motor vehicle involvement, also show similar patterns to the Victorian data. Figure 2.5 shows the raw data, and fitted model for numbers of head injured bicyclists in Melbourne admitted to hospital between 1987/88 and 1993/94.

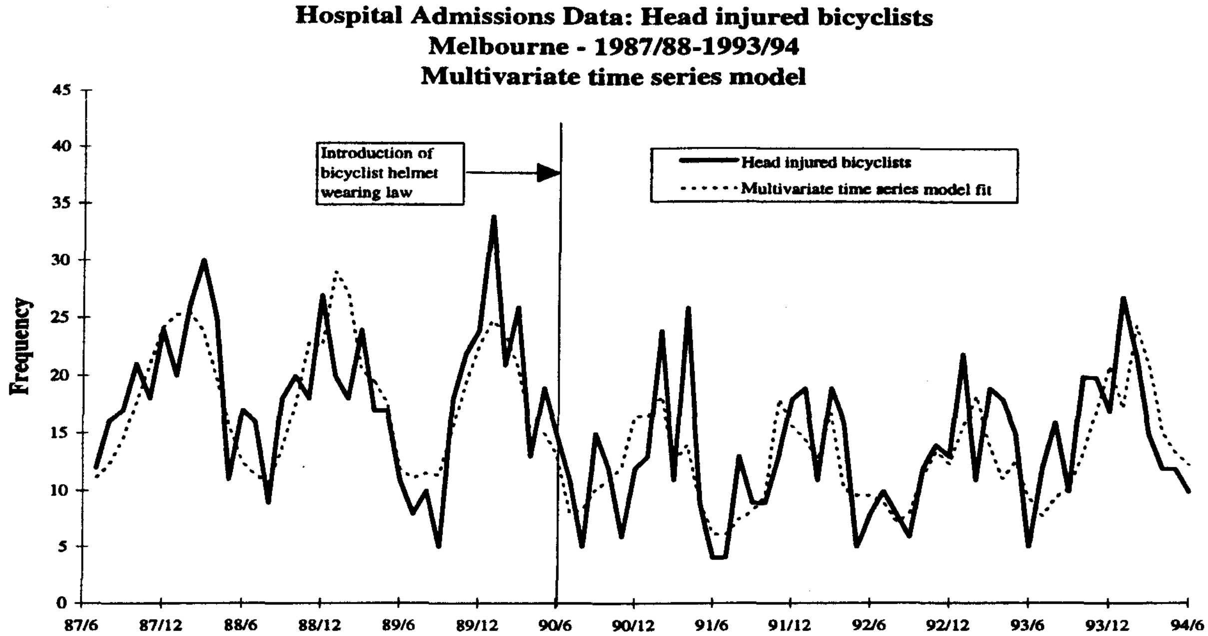

Figure 2.5: Monthly numbers of head injured bicyclists in Melbourne admitted to hospital from 1987/88 to 1993/94, with fitted model

The graph shows also seasonal variation, with a fairly obvious decrease in the level of the series (level shift) after the introduction of the bicycle helmet wearing law; there is also a distinct increase in the last year of the data—this is accounted for by the inclusion of the relative rate of head injury in the model. Apart from the level shift, there seems to be a slight downward trend in the data, but this was not significant; the fitted model accounts for some 55.1% of the variation in the observed frequencies of head injured bicyclists (see Appendix 6.4.2 for details of the model).

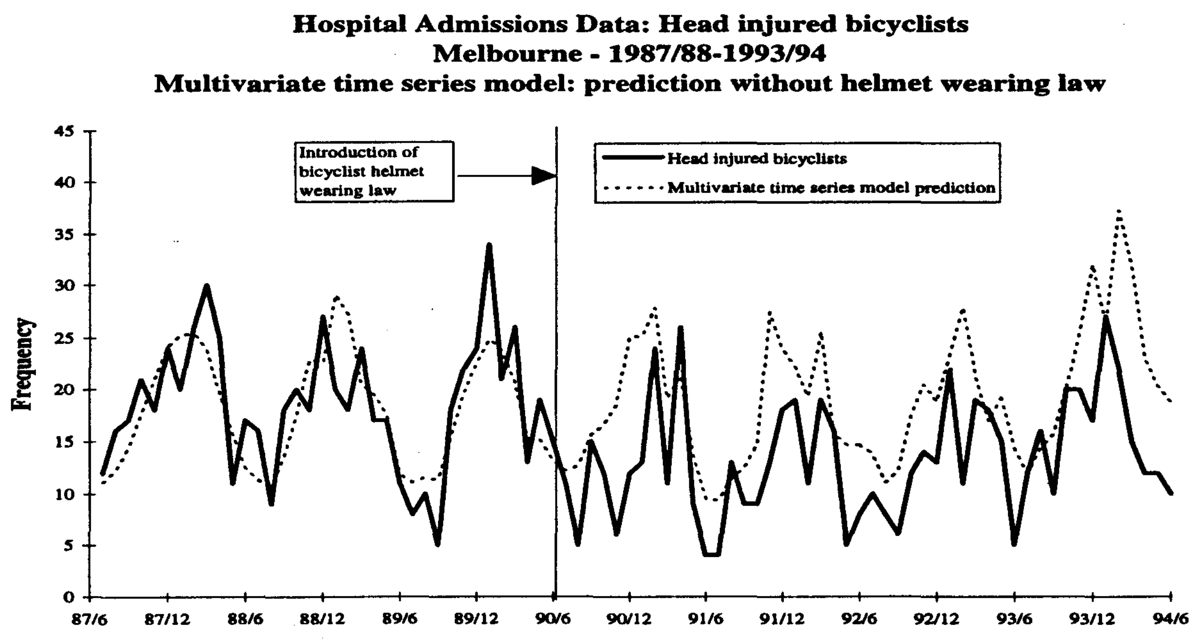

Figure 2.6: Monthly numbers of head injured bicyclists in Melbourne admitted to hospital from 1987/88 to 1993/94, with model prediction of head injured numbers without the introduction of the helmet wearing law

Figure 2.6 shows the mutivariate time series model prediction of head injured numbers in Melbourne, without the introduction of the helmet wearing law. In contrast to the previous model, there seems to be much more irregular variation, with some post-law values at levels expected if the helmet wearing law had not been introduced.

The third model addresses the subset of head injured bicyclists in motor vehicle involved crashes in Victoria. Figure 2.7 shows the numbers of head injured bicyclists in motor vehicle crashes in Victoria.

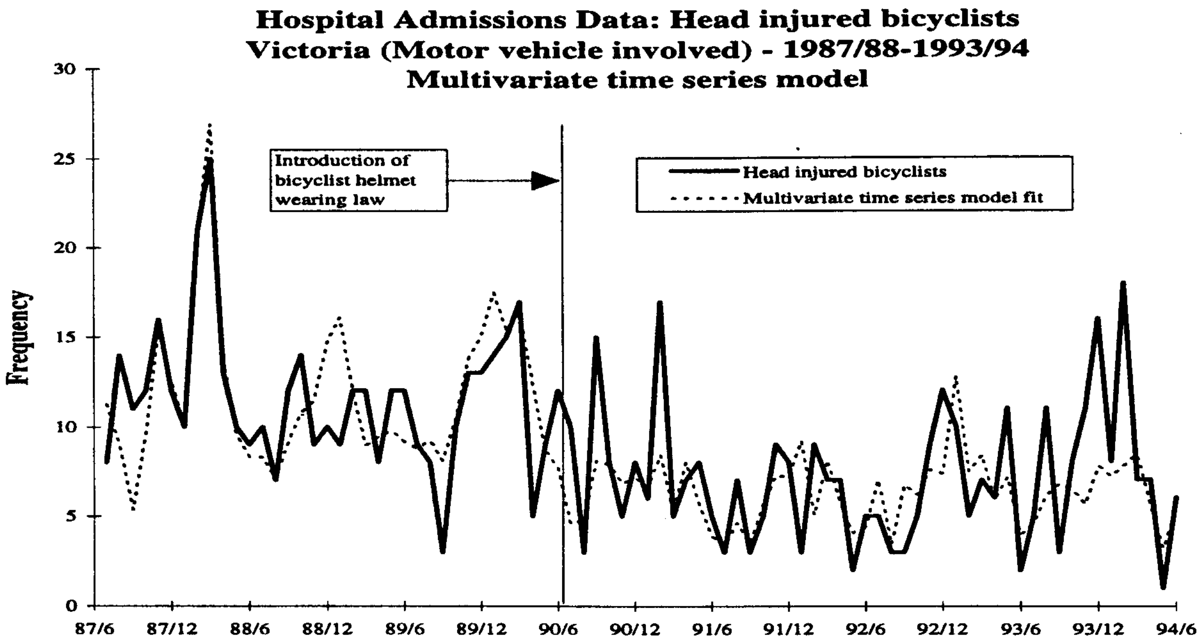

Figure 2.7: Monthly numbers of head injured bicyclists admitted to hospital in Victoria (motor vehicle involved) from 1987/88 to 1993/94, with fitted model

The graph does not display an obvious seasonal variation, but does display a lower level of the series after the introduction of the bicycle helmet wearing law. There is no obvious downward trend, but there seems to be a relatively large amount of random fluctuation—this is not surprising in view of the relatively small numbers of head injured bicyclist with motor vehicle involvement. The model accounts for 48.0% of the variation in the observed frequencies of head injured bicyclists (see Appendix 6.4.3 for details of the model).

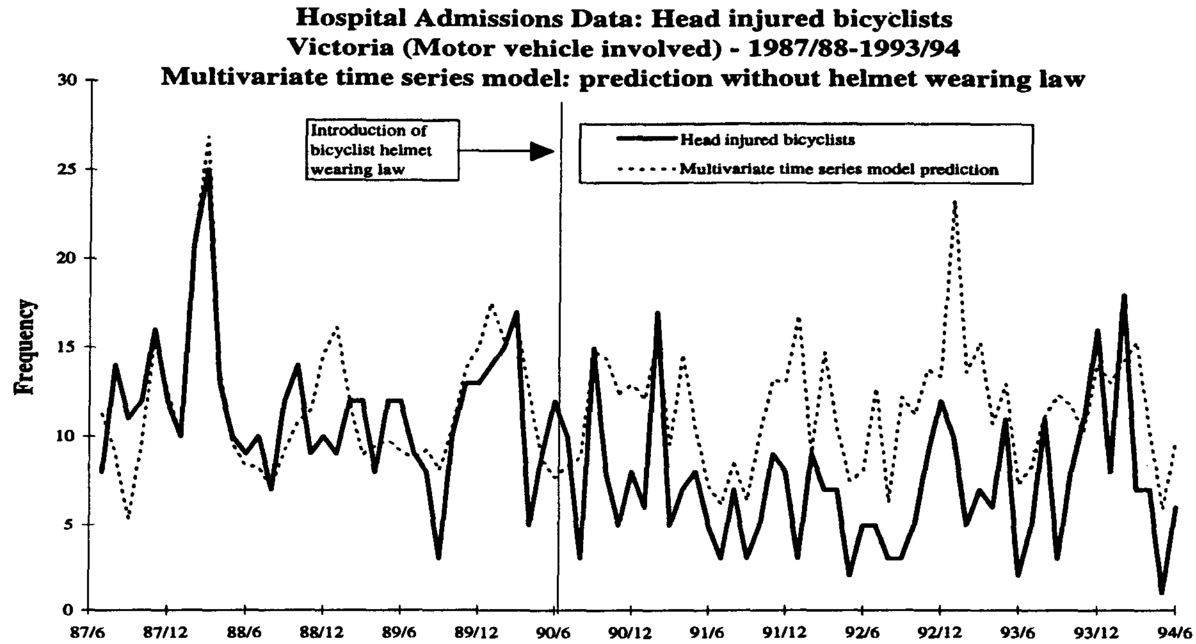

Figure 2.8: Monthly numbers of head injured bicyclists admitted to hospital in Victoria (motor vehicle involved) from 1987/88 to 1993/94, with model prediction of head injured numbers without the introduction of the helmet wearing law

The post-law numbers of head injured bicyclists show irregular patterns relative to predictions of head injuries had the helmet wearing law not been introduced. In the last year (1993/1994), the two peaks December and February are not captured by the model.

The following table gives a summary of the estimated percentage reductions in numbers of head injured bicyclists seemingly attributable to the introduction of the helmet wearing law.

Table 2.4: Estimated percentage reductions in numbers of head injured bicyclists admitted to hospital from the multivariate time series models

Jurisdiction	Estimated percentage reduction	Significance levels (p-value)
Victoria: All crashes	39.5%	0.0001
Melbourne: All crashes	34.3%	0.0001
Victoria: Motor vehicle involved	45.3%	0.0001

As several other countermeasures were introduced in the same period as the mandatory bicycle helmet wearing law one must be cautious in making conclusions about causality of this effect. Speed camera TINs and numbers of RBTs were included in the models, but were found to have no apparent relationship with the monthly numbers of head injured bicyclists (these factors had been found by Cameron et al. (1994b) to be linked with total numbers of serious casualty crashes in each month). Use of the numbers of pedestrian head injuries as a surrogate measure of other general improvements in road safety for the relatively unprotected road users (i.e pedestrians, and bicyclists) did not lead to inclusion in any of the models. There may be other measures of road safety improvements which merit further investigation, that have not been considered here.

The use of the *relative rate of head injury* in the modelling process was undoubtedly necessary; whether the chosen method of including the variable as an explanatory variable was preferable to *adjusting* the time series of numbers of head injured bicyclists is debatable. The problem with the estimated models is that any deterioration (increase) in numbers of head injured bicyclists in 1993/94, may be *masked* by the effect of the Casemix related increase. On the other hand *adjusting* data prior to analysis might make perhaps unduly strong assumptions which may not hold under closer scrutiny; furthermore *adjusting* data can readily be criticized as being possibly related to the conclusions of the respective models.

The methodology used was most successful, and in particular the model for overall numbers of head injured bicyclists in Victoria provides an excellent approximation to the actual variation observed. In the other two models fitted, the smaller numbers of head injured bicyclists made modelling more difficult, with the random component being 45% and 52% respectively.

3. Analysis of injury severity

The second dimension which can benefit from the wearing of a bicycle helmet is the severity of injury. The previous section analysed the reductions in head injuries brought about by the introduction of the helmet wearing law. Assuming that a certain number of head injuries will occur, a helmet may in fact reduce the severity of some of those injuries. This section will endeavour to discover any appreciable reductions in the proportions of the different levels of injury severity.

As was mentioned in the introduction, the procedure developed by MacKenzie et al (1986) allows the conversion from ICD-9CM codes into AIS levels—this is on the basis of most likely AIS level for each specific injury coding. The Hospital Admissions data uses the 5-digit ICD-9CM codes and this conversion was carried out. The data from 1987/88 to 1993/94 comprised of some 8462 hospitalised injured bicyclists. Of these injured bicyclists, some 8229 injured bicyclists had at least one injury with a body region defined (in the MacKenzie et al (1986) classification) resulting in a total 12556 injuries; 29.2% occurred with motor vehicle involvement, while 70.6% of the injuries were in single bicycle accidents.

The head injury definition used in the analysis of severity is the "head" body region defined by the MacKenzie et al (1986) conversion from ICD-9CM to AIS levels (see Appendix 6.2). This is not identical to the Healy (1986) definition of head injury (see Appendix 6.1) used in the analysis of numbers of head injured bicyclists, which was aimed at evaluation of bicyclist helmet wearing. There is however a very high correspondence between the two definitions, and the minor differences should not strongly effect the conclusions of this analysis.

3.1 Injury severity of all bicyclist injuries

Before the changes in head injury severity patterns are investigated, it is necessary to investigate the patterns in severity of all bicyclist injuries to ascertain any changes that may have occurred between 1987/88 and 1993/94.

Figure 3.1 shows the time profile of maximum AIS levels for all injured bicyclists admitted to hospital in Victoria from 1987/88 to 1993/94.

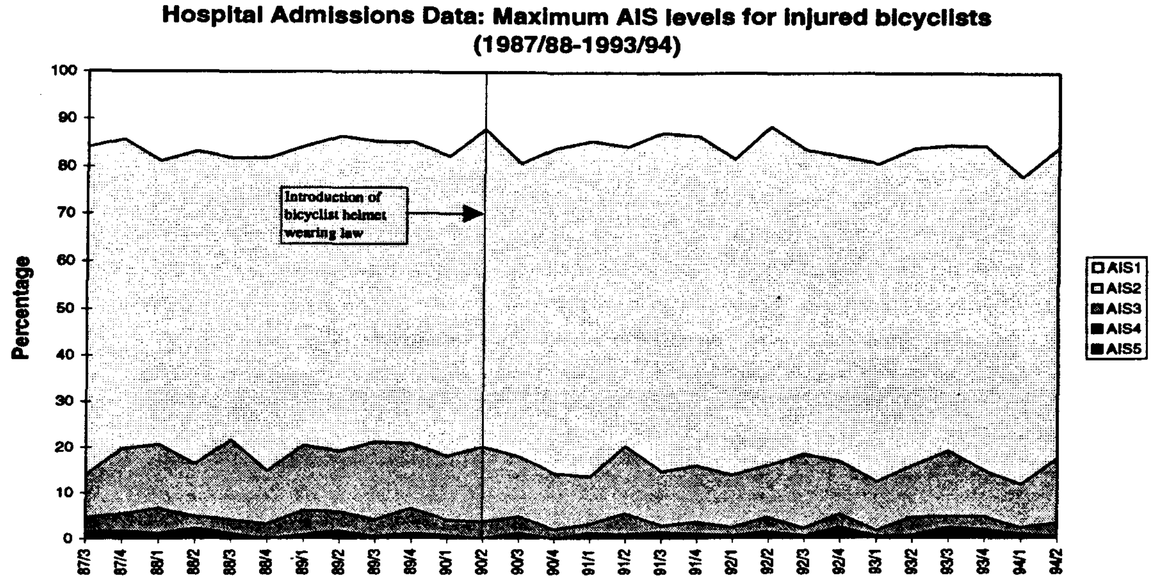

Figure 3.1: Maximum AIS levels for injured bicyclists admitted to hospital in Victoria from 1987/88 to 1993/94.

The critical AIS level (5) seems approximately unaltered by the introduction of the law, but the serious AIS levels (3: serious, and 4: severe) seem to have decreased since the introduction of the law. Table 3.1 gives the overall numbers and percentages pre- and post-law.

Table 3.1: Maximum AIS levels for pre- and post-law phases for injured bicyclists admitted to hospital in Victoria from 1987/88 to 1993/94.

Maximum AIS level (MAIS)	Pre-law (7/1987-6/1990)		Post-law (7/1990-6/1994)		
	N	(%)	N	(%)	Total
1	653	(16.1)	673	(16.4)	1326
2	2634	(64.9)	2791	(68.2)	5425
3	562	(13.9)	485	(11.9)	1047
4	163	(4.0)	99	(2.4)	262
5	44	(1.1)	46	(1.1)	90
Total	4056		4094		8150

As we can see from this table the post-law AIS levels of severity 3 (serious) and 4 (severe) are down from 17.9% to 14.3%, a reduction of 20.1%.

Figure 3.2 shows the time profile of maximum AIS levels for all motor vehicle involved injured bicyclists admitted to hospital in Victoria from 1987/88 to 1993/94.

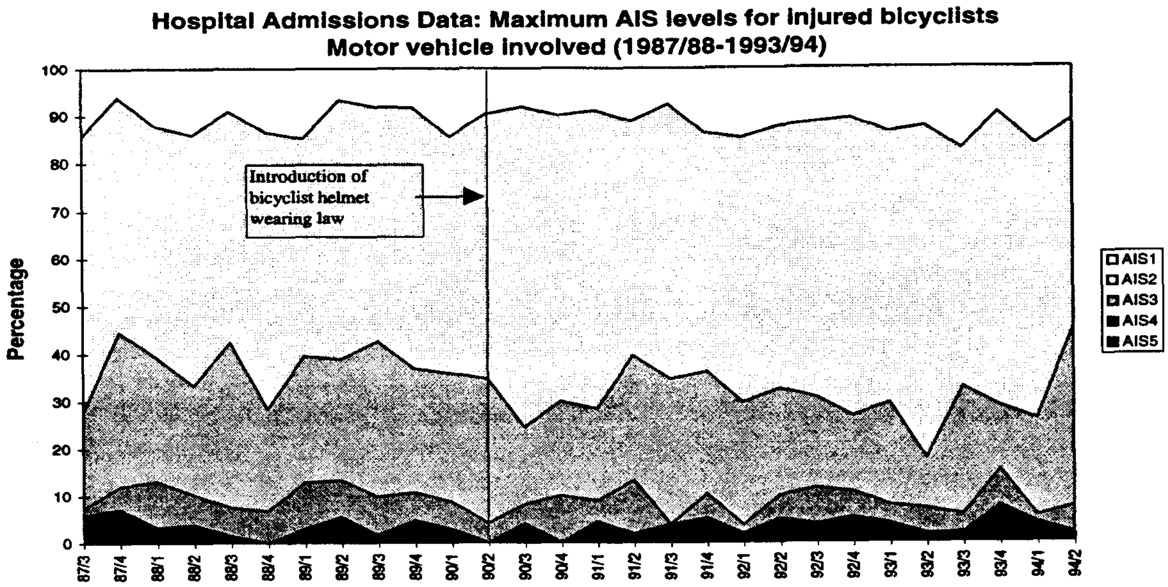

Figure 3.2: Maximum AIS levels for motor vehicle involved injured bicyclists admitted to hospital in Victoria from 1987/88 to 1993/94.

Again the critical AIS level (5) seems approximately unaltered by the introduction of the law, but the serious AIS levels 3 (serious) and 4 (severe) seem to have decreased since the introduction of the law. Table 3.2 gives the overall numbers and percentages pre- and post-law.

Table 3.2: Maximum AIS levels for pre- and post-law phases for motor vehicle involved injured bicyclists admitted to hospital in Victoria from 1987/88 to 1993/94.

Maximum AIS level (MAIS)	Pre-law (7/1987-6/1990)		Post-law (7/1990-6/1994)		
	N	(%)	N	(%)	Total
1	112	(11.2)	99	(12.1)	211
2	518	(51.7)	468	(57.4)	986
3	272	(27.1)	178	(21.8)	450
4	67	(6.7)	42	(5.2)	109
5	34	(3.4)	29	(3.6)	63
Total	1003		816		1819

As we can see from this table the post-law serious AIS levels (3: serious, and 4: severe) are down from 33.8% to 27.0%, a reduction of 20.1%.

3.2 Injury severity of bicyclist head injuries

In this section the maximum Head AIS levels of head injured bicyclists will be investigated. The head injury definition is the "head" body region defined in the MacKenzie et al (1986) conversion from ICD-9CM codes to AIS levels (see Appendix 6.2). Figure 3.3 shows the time profile of maximum AIS levels for all head injured bicyclists in Victoria in the Hospital Admissions data from 1987/88 to 1993/94.

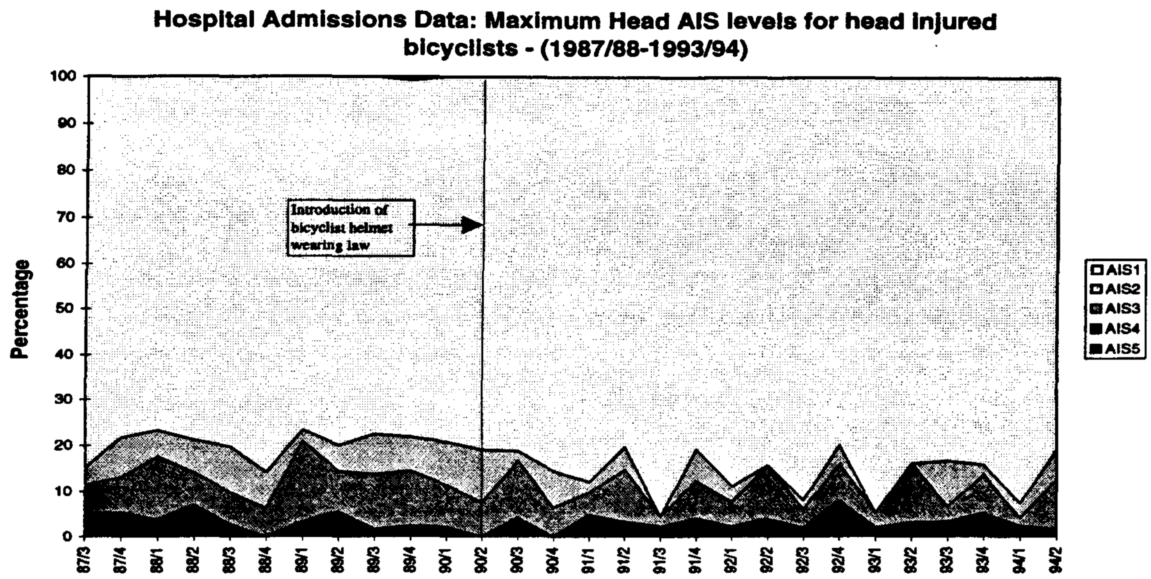

Figure 3.3: Maximum AIS levels for head injured bicyclists admitted to hospital in Victoria from 1987/88 to 1993/94.

The critical Head AIS level (5) seems approximately unaltered by the introduction of the law, but the serious Head AIS levels (3: serious, and 4: severe) seem to have decreased since the introduction of the law. Table 3.3 gives exact information about overall numbers and percentages pre- and post-law.

Table 3.3: Maximum Head AIS levels for pre- and post-law phases for head injured bicyclists admitted to hospital in Victoria from 1987/88 to 1993/94.

Maximum Head AIS level (MAIS)	Pre-law (7/1987-6/1990)		Post-law (7/1990-6/1994)		
	N	(%)	N	(%)	Total
1	1	(0.1)	0	(0.0)	1
2	1013	(79.5)	976	(86.4)	1989
3	91	(7.1)	39	(3.5)	130
4	127	(10.0)	77	(6.8)	204
5	42	(3.3)	38	(3.4)	80
Total	1274		1130		2404

As we can see from this table the post-law serious Head AIS levels of severity 3 (serious) and 4 (severe) are down from 17.1% to 10.3%, a reduction of 39.8%.

When we investigate the subset of motor vehicle involved cases from all head injured bicyclists admitted to hospital in Victoria, the time profile of severity levels is shown in Figure 3.4.

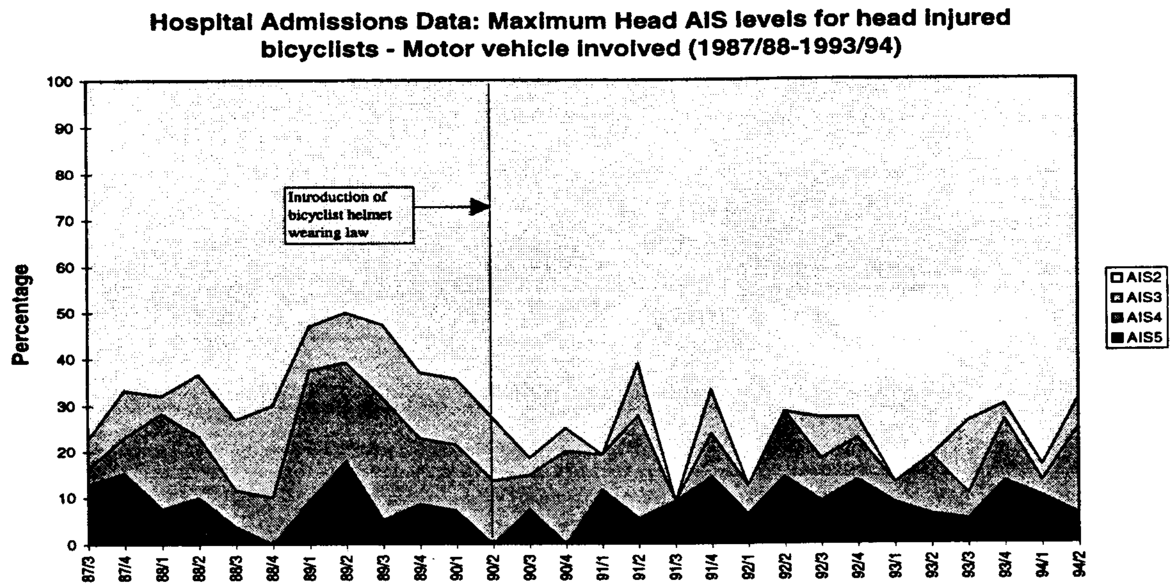

Figure 3.4: Maximum Head AIS levels for motor vehicle involved head injured bicyclists admitted to hospital in Victoria from 1987/88 to 1993/94.

The critical Head AIS level (5) seems approximately unaltered by the introduction of the law, but the serious Head AIS levels (3: serious, and 4: severe) seem to have decreased since the introduction of the law. Table 3.4 gives exact information about overall numbers and percentages pre- and post-law.

Table 3.4: Maximum AIS levels for pre- and post-law phases for motor vehicle involved head injured bicyclists admitted to hospital in Victoria from 1987/88 to 1993/94.

Maximum AIS level (MAIS)	Pre-law (7/1987-6/1990)		Post-law (7/1990-6/1994)		
	N	(%)	N	(%)	Total
1	0	(0.0)	0	(0.0)	0
2	251	(64.9)	245	(76.6)	496
3	45	(11.6)	14	(4.4)	59
4	58	(15.0)	32	(10.0)	90
5	33	(8.5)	29	(9.1)	62
Total	387		320		707

As we can see from this table the post-law AIS levels of severity (3: serious, and 4: severe) are down from 26.6% to 14.4%, a reduction of 45.9%.

4. Conclusions

This evaluation has shown that substantial reductions have been achieved in both number and severity of head injuries to bicyclists admitted to hospital since the introduction of the mandatory helmet wearing law in mid-1990. As there have been numerous other improvements in road safety in Victoria in this time frame, as well as increased availability of bicyclist paths etc., it is paramount that a cautious approach is taken when attributing specific reductions to particular countermeasures.

In this analysis we have attempted to include other confounding factors which may have effected the numbers of head injured bicyclists. Variables such as numbers of Random Breath Tests, and Speed Camera Traffic Infringement Notices (TINs), which have been found in previous analyses to significantly reduce numbers of serious casualty crashes (Cameron, et al, 1994b), did not appear to have a significant effect on monthly numbers of injured bicyclists admitted to hospital. Numbers of head injured pedestrians was seen as a surrogate variable for road safety improvements, most relevant to unprotected road users generally—this variable was also seemingly unrelated to numbers of head injured bicyclists.

The Bicycle Injury Data Investigation (Carr and Cameron, 1995) examined trends in coding practices in both Hospital Admissions data and TAC data. The results (which are in the Bicycle Injury Data Investigation report) show that there has been a distinct increase in the total number of head injuries from all activities causing injury, since the introduction of Casemix. When this increase was taken into account, it had a statistically significant explanatory role in the modelling of numbers of head injured bicyclists.

This analysis used a slightly different approach to previous analyses by modelling *numbers* of head injured bicyclists, rather than *proportions* of injured bicyclists who had head injuries. This enabled a more sophisticated time series analysis model to be employed, which included a variety of modelling possibilities which would not be available when modelling proportions or rates. In each modelling approach there are always assumptions which need to be carefully and critically investigated. With the modelling of proportions of head injured, for example, there is the implicit assumption that explanatory factors have the same effect on both numbers of head injured, and numbers of non-head injured; on the other hand, when analysing proportions of head injured, the numbers of non-head injured works as a surrogate for other improvements in road safety.

In this analysis of *numbers* of head injured, we were unable to include any reliable measures of exposure, and thus it is impossible to distinguish between reductions due to helmet wearing and reductions solely due to possible reductions in exposure. There has been some evidence recently (Mead, 1993; Ratcliffe, 1992) that the introduction of mandatory helmet wearing laws, has led to decreases in overall numbers of bicyclists; Finch et al (1993) showed that exposure for teenagers was reduced in Victoria as a result of the helmet wearing law. The modelling results were however very encouraging. Overall in Victoria, the post helmet wearing law period has seen a substantial (39.5%) reduction in the number of head injured bicyclists admitted to hospital. From the analysis method used (including other explanatory factors), it is fair to assume that the major part of this reduction is attributable to the introduction of the helmet wearing law. Similarly for Melbourne (34.3%) and motor vehicle involved crashes (45.3%), there were also substantial reductions in numbers of head injured bicyclists admitted to hospital.

This project also looked at changes in bicyclists' injury severity (given that the bicyclist is injured). Here a clear pattern emerged—the proportion of highest severity level (AIS=5: critical) remained more or less unchanged by the introduction of mandatory helmet wearing, but the proportion of serious AIS severity levels (3: serious, 4: severe) showed distinct drops after the law was introduced. These reductions were particularly pronounced when looking at head injuries: overall the proportion of serious AIS levels (3: serious, and 4: severe) showed a 39.8% reduction in the post-law period, while for motor vehicle involved cases, the proportion of serious AIS levels showed a 45.9% reduction post-law.

This analysis has confirmed the substantial reductions being made in both number and severity of bicyclist injuries since the introduction of the mandatory helmet wearing law. This has hopefully dispelled doubts about benefits of helmet wearing raised as a result of what has shown to be data anomalies (changes in coding practices) which surfaced in the previous analysis.

5. References

Abraham, B (1987). Application of intervention analysis to a road fatality series in Ontario. Journal of Forecasting, 6, 211-219.

Bhattacharyya, MN, and Layton, AP (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.

Box, GEP (1976). Science and statistics. Journal of the American Statistical Association, 71, 791-799.

Box, GEP, and Tiao, GC (1975). Intervention analysis with applications to economic and environmental problems. Journal of the American Statistical Association, 70, 70-79.

Cameron, MH, Vulcan, P, Finch, CF, and Newstead, SV (1994a). Mandatory bicycle helmet use following a decade of helmet promotion in Victoria, Australia—an evaluation. Accident Analysis and Prevention, 26, 327-337.

Cameron MH, Newstead, SV, and Vulcan, P (1994b). Analysis of reductions in Victorian road casualties, 1989 to 1992. Proceedings of the 17th ARRB Conference, Part 5, 165-182.

Carr DJ, and Cameron, MH (1995). Bicycle injury data investigation. Preliminary draft report, Melbourne: Monash University Accident Research Centre: April, 1995.

Finch, CF, Heiman, L, and Neiger, D (1993). Bicycle use and helmet wearing rates in Melbourne, 1987-1992. The influence of the helmet wearing law. Report No. 45, Melbourne: Monash University Accident Research Centre: February, 1993.

Haque, MO (1990). Preliminary evaluation of the Victorian zero blood alcohol content legislation at alcohol times: An Australian case study in intervention analysis. Communications in Statistics, A, 19, 3881-3899.

Harvey, AC, 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, A, 149, 187-210.

Hastie, TJ, & Tibshirani, RJ (1986). Generalized additive models (with discussion). Statistical Science, 1, 297-318.

Hastie, TJ, & Tibshirani, RJ (1990). Generalized Additive Models. London: Chapman & Hall.

Healy, DJ (1986). Trends in helmet usage rates and bicyclist numbers sustaining head injury—July 1981 to December 1985. Road Traffic Authority, Report No. GR/86/11.

Hipel, KW, & McLeod, AI (1994). Time Series Modelling of Water Resources and Environmental Systems. Amsterdam: Elsevier.

Janssen, EG, and Wismans, JSHM (1985). Experimental and mathematical simulation of pedestrian-vehicle and cyclist-vehicle accidents. Proceedings of the 10th International Technical Conference on Experimental Safety Vehicles, Oxford, July 1985.

Lassarre, S, and Tan, SH (1982). Evaluation of safety measures on the frequency and gravity of traffic accidents in France by means of intervention analysis. In "Time Series Analysis: Theory and Practice, Vol. 1", O.D. Anderson (Ed), Elsevier/N. Holland, 297-306.

MacKenzie, EJ, Steinwachs, DM, Shankar, BS, and Turney, SZ (1986). An ICD-9CM to AIS conversion table: Development and application. Proceedings of the 30th Annual Conference of the American Association for Automotive medicine, 135-151. Norton Grove, Illinois: AAAM.

Mead, P (1993). Bike Helmet Survey Results, CTRAC, PO Box 3207, Alice Springs, October 1993.

Newstead, SV, Cameron, MH, and Gantzer, S (1994). Bicyclist head injuries in Victoria three years after the introduction of mandatory helmet use. (in preparation).

Ratcliffe, P (1993). Bicycling in the ACT—a survey of bicycle riding and helmet wearing in 1992. ACT Department of Urban Services, Canberra, 1993.

Ray, SC (1989). Legal control of drunken driving: A time series study of California data. International Journal of Forecasting, 5, 515-522.

Stewart, JR (1985). Estimation of the effects of changes in drinking and driving on alcohol-related automobile crashes. American Statistical Association, Proceedings of Social Statistics Section, 438-442.

TTM Consulting Pty Ltd (1994). Bicycle helmet usage rates in Victoria: March 1994. VicRoads, Report No. GR 94-6.

Walker, MB (1992). Law compliance among cyclists in New South Wales, a third survey, April 1992. Road Traffic Authority Network Efficiency Strategy Branch, 1992.

Weiss, AA (1992). The effects of helmet use on the severity of head injuries in motorcycle accidents. Journal of the American Statistical Association, 87, 48-56.

6. Appendix

6.1 Healy head injury definition

The following is a list of ICD-9CM N-codes from the Healy (1986) head injury definition. The N-codes Healy used were only 4-digit codes; in the case of 800, this includes all ICD-9CM N-codes from 800.00-800.99, while 873.0 includes all ICD-9-CM N-codes from 873.00-873.09.

N-Code	Description
800	Fracture of vault of skull
801	Fracture of base of skull
803	Other and unqualified skull fractures
850	Concussion
851	Cerebral laceration and contusion
852	Subarachnoid, subdural, and extradural hemorrhage injury
853	Other and unspecified intracranial hemorrhage
854	Intracranial injury of other and unspecified
872	Open wound of ear
873.0	Open wound of scalp, without mention of compl.
873.1	Open wound of scalp, complicated
873.8	Other and unspecified open wound of head with complication
873.9	Other and unspecified open wound of head, com.

6.2 MacKenzie head injury definition

The following is a list of ICD-9CM N-codes from the MacKenzie et al (1986) head injury definition. In the case of 800, this includes all ICD-9CM N-codes from 800.00-800.99, while 854.0 includes all ICD-9CM N-codes from 854.00-854.09.

N-Code	Description
800	Fracture of vault of skull
801	Fracture of base of skull
803	Other and unqualified skull fractures
804	Multiple fractures involving skull or face
850	Concussion
851	Cerebral laceration and contusion
852	Subarachnoid, subdural, and extradural hemorrinjury
853	Other and unspecified intracranial hemorrhage
854.0	Intracranial injury of other and unspecified mention of open intracranial wound
854.1	Intracranial injury of other and unspecified intracranial wound, with state of consciousness
951	Injury to other cranial nerve(s)
952.0	Cervical spinal cord injury without evidence bone injury
957.0	Injury to superficial nerves of head and neck

6.3 Exploratory Analysis

In the field of statistical analysis there are numerous techniques which provide possibilities to *explore* the data in question, without being confined by the sometimes rigid assumptions that various statistical inference tests impose. These include, for example, descriptive analyses and graphical comparisons. One of these graphical comparisons which has emerged recently and has a very wide frame of reference is the method of generalized additive models introduced by Hastie & Tibshirani (1986, 1990). The GAMFIT program software from these authors fits a variety of models (Gaussian, Binomial, Poisson, Gamma, and Cox) using cubic smoothing splines. The details of this method are beyond the scope of this report, but can be simplistically explained by the case of two factors.

If one has measured on two factors, such as numbers of head injured bicyclists and numbers of Random Breath Tests, one can graphically depict these data in a so-called *scatterplot* by graphing a point for each pair of data values—this gives a simple idea how these two *variables* are related. There are several methods available to *smooth* (or trim) this spread over the graph, giving some idea of the *average relationship*. Hastie & Tibshirani (1990) have proposed a method which allows not only *smoothing* of a relationship between two possibly related factors, but simultaneously *smoothing* the pairwise relationships between a number of factors and a particular factor under question.

The advantage of this method is that no pre-conceived idea of the possible relationship between two variables, either linear or positive or some sort of threshold function is imposed on the data—the data simply *speak for themselves*. This method is not assumption-free and is only an approximation to the underlying *true* relationship which we can only hope to divulge.

In the analysis using the method by Hastie & Tibshirani (1990) the following variables were included to help explain the variation in the monthly time series of head injured bicyclists admitted to hospital from 1987/88 to 1993/94:

1. Injured bicyclists admitted to hospital without a head injury (non-head injured).
2. Random Breath Tests in Victoria previously found as a predictor for the reduction in road trauma in Victoria post-1989 (Cameron et al, 1994b).
3. Speed Camera TINs previously found as a predictor for the reduction in road trauma in Victoria post-1989 (Cameron et al, 1994b).
4. Pedestrian head injuries (surrogate for improvements in road safety for unprotected road user groups, such as bicyclists).
5. Bicycle helmet wearing rates (interpolated).
6. Relative rate of head injury of patients admitted to hospital in Victoria.
7. Trigonometrical seasonal variable, with maximum in February corresponding to the maximum in head injuries for bicyclists in Victoria.

Of these variables, bicycle helmet wearing rates and relative rate of head injury showed the lowest p-values, corresponding to the stronger relationships with numbers of head injured bicyclists.

The statistical significance is of less importance; this graphical approach may shed light on unusual relationships which are not linear.

Figure 6.1 shows the *smoothed* relationship between numbers of bicyclist head injuries and numbers of bicyclist non-head injuries (the dotted lines represent 95% confidence limits of the bold *smoothed curve*).

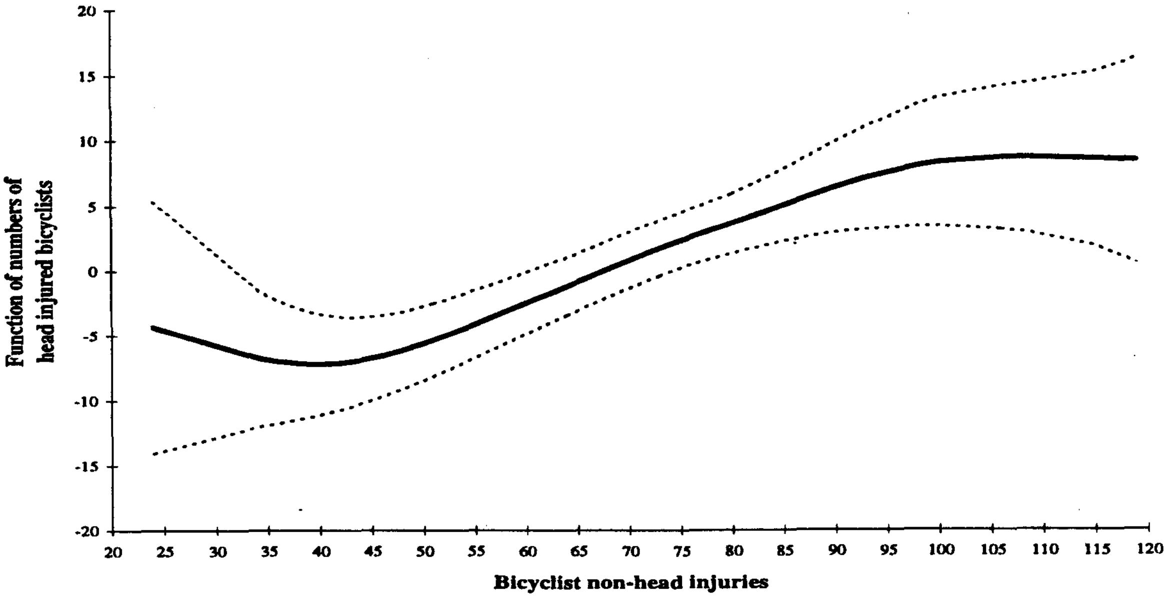

Figure 6.1: Numbers of bicyclist head injuries as a function of numbers of bicyclist non-head injuries 1987/88 to 1993/94.

This graph shows a weak positive relationship between numbers of head and non-head injured bicyclists. The relationship between these two variables can be seen visually by the joint seasonal pattern these two time series share (higher values tend to occur in warmer months, such as December and January). However at very low values, and also at extremely high values of non-head injured bicyclists, there is little or no relationship between the relative numbers. This can be seen in Figure 2.2, with the respective *peaks* and *troughs* of the non-head injured bicyclists not necessarily corresponding to *peaks* and *troughs* of the head injured bicyclists.

Figure 6.2 shows the *smoothed* relationship between numbers of bicyclist head injuries and numbers of Random Breath Tests (the dotted lines represent 95% confidence limits of the bold *smoothed curve*).

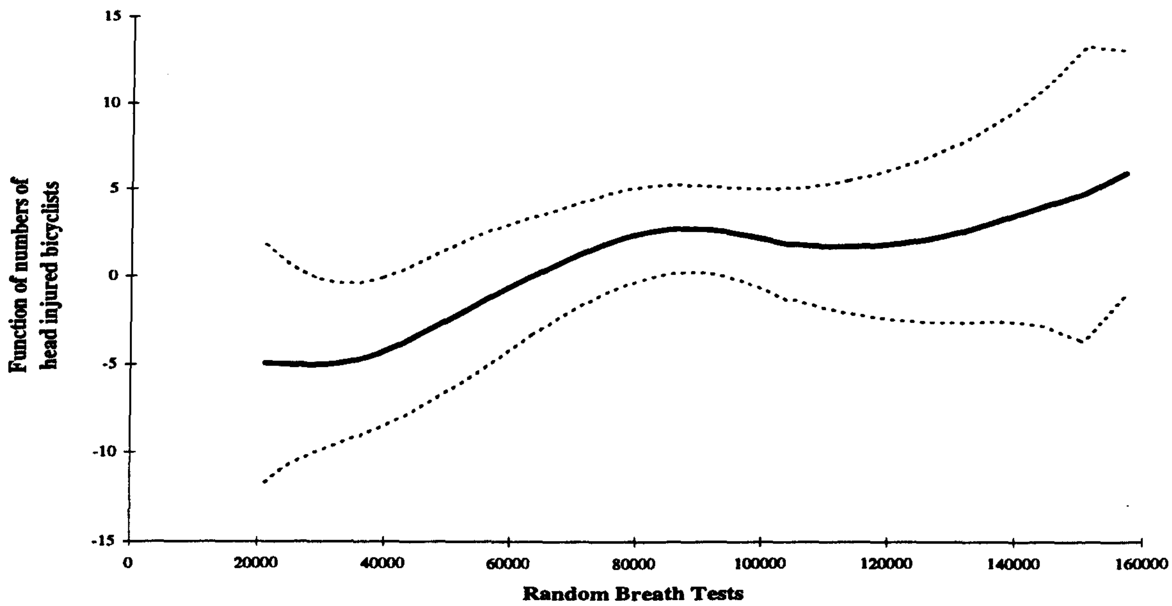

Figure 6.2: Numbers of bicyclist head injuries as a function of numbers of Random Breath Tests from 1987/88 to 1993/94.

This graph shows a relatively flat curve (slightly positive) with fairly wide confidence intervals. Due to the wide confidence intervals little or no significance can be given to the sign of the slope.

Figure 6.3 shows the *smoothed* relationship between numbers of bicyclist head injuries and numbers of Speed Camera TINs (the dotted lines represent 95% confidence limits of the bold *smoothed curve*).

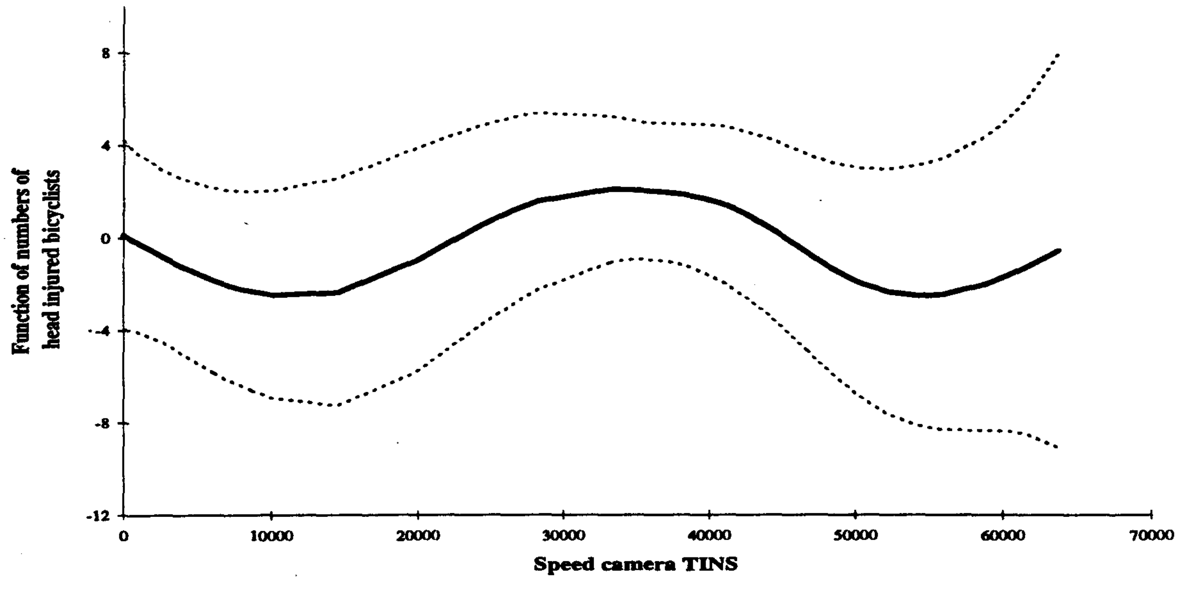

Figure 6.3: Numbers of bicyclist head injuries as a function of numbers of Speed Camera TINs from 1987/88 to 1993/94.

This graph shows that more or less no relationship between Speed Camera TINs and numbers of head injured bicyclists. Again the confidence intervals are very wide, which allows little to made in the way of conclusions.

Figure 6.4 shows the *smoothed* relationship between numbers of bicyclist head injuries and numbers of pedestrian head injuries (the dotted lines represent 95% confidence limits of the bold *smoothed curve*).

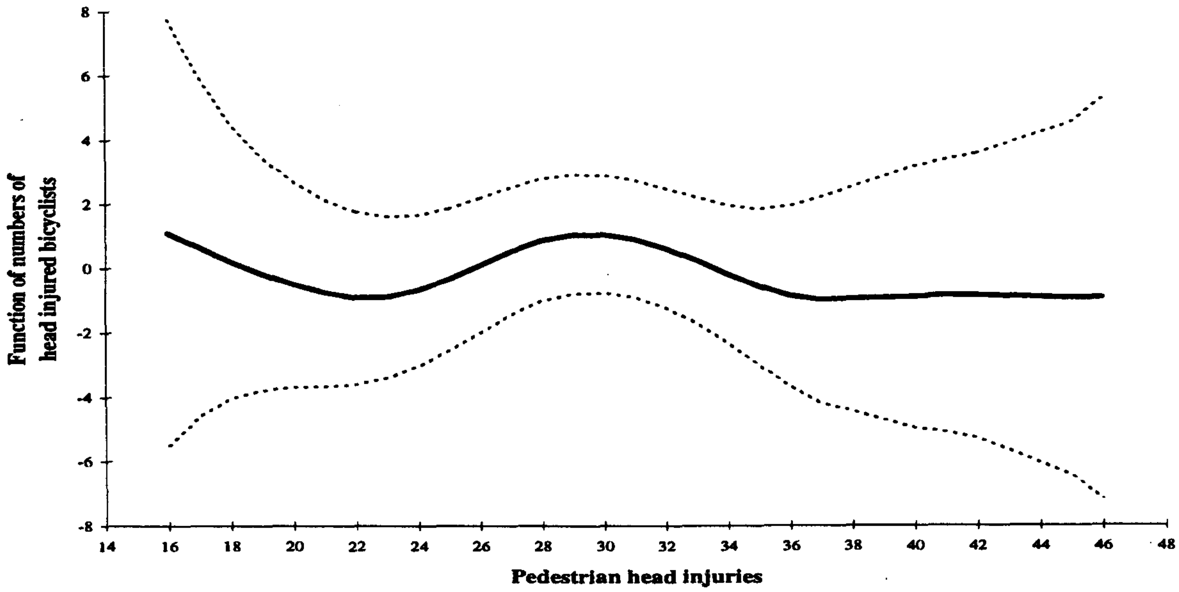

Figure 6.4: Numbers of bicyclist head injuries as a function of numbers of pedestrian head injuries 1987/88 to 1993/94.

This graph shows a relatively flat curve, which represents little or no relationship between numbers of head injured bicyclists and head injured pedestrians. Seeing that 4 out of the 7 years of data is post helmet wearing law, one would expect differences between the numbers of *protected* road users (bicyclists) and a group of *unprotected* road users (pedestrians).

Figure 6.5 shows the *smoothed* relationship between numbers of bicyclist head injuries and interpolated helmet wearing rates (the dotted lines represent 95% confidence limits of the bold *smoothed curve*). These helmet wearing rates are from Finch et al (1993). The original rates are yearly values—to obtain monthly values, the yearly data were interpolated, and then smoothed using several passes through a Hanning filter (Hipel, & McLeod, 1994).

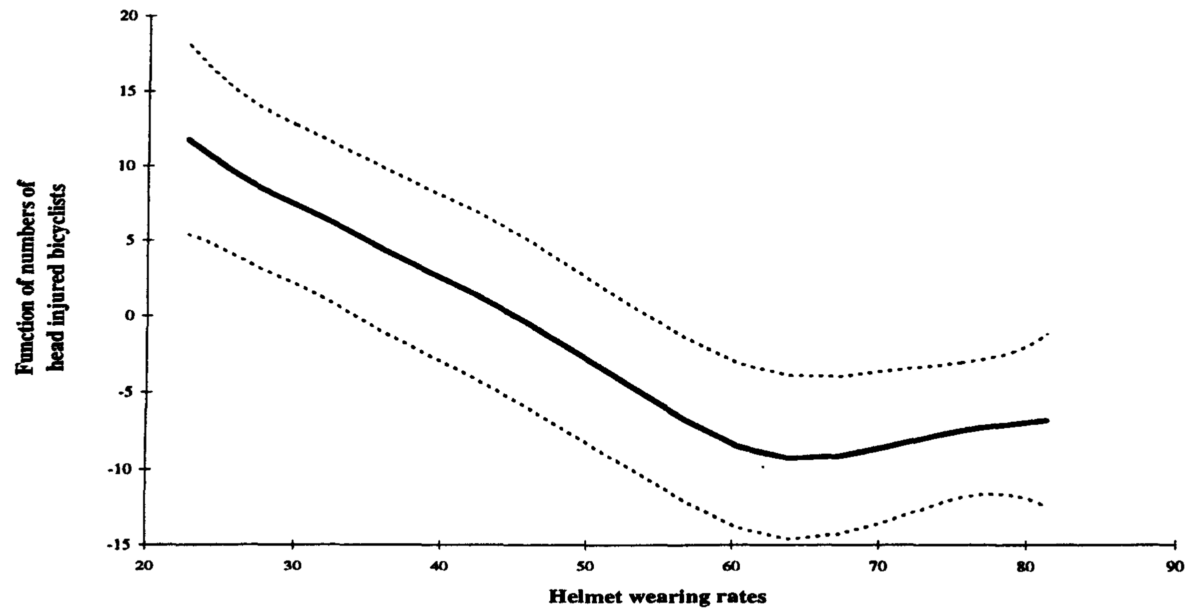

Figure 6.5: Numbers of bicyclist head injuries as a function of interpolated helmet wearing rates from 1987/88 to 1993/94.

This graph shows the distinct negative relationship between helmet wearing rates and numbers of head injured bicyclists. At higher helmet wearing rates (65% and above) there no longer seems to be a difference in numbers of head injured bicyclists—this may be explained by the fact that a certain number of crashes involving bicyclists, lead to head injury irrespective of helmet wearing (these become more apparent when overall numbers of head injured bicyclists are low).

Figure 6.6 shows the *smoothed* relationship between numbers of bicyclist head injuries and the relative rate of head injury in the Hospital Admissions data (monthly numbers of head injuries divided by the number of head injured in July 1987) (the dotted lines represent 95% confidence limits of the bold *smoothed curve*).

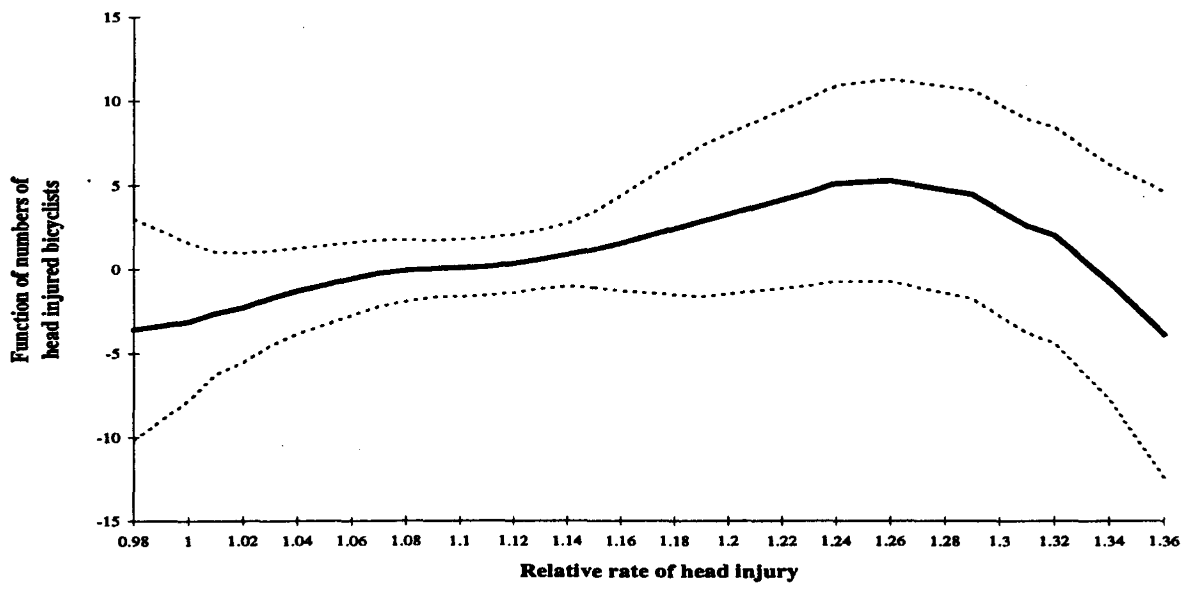

Figure 6.6: Numbers of bicyclist head injuries as a function of relative rates of head injury in the Hospital Admissions data from 1987/88 to 1993/94.

In general this graph seems to show that higher rates of head injury coding do correspond to slightly higher numbers of head injured bicyclists. The very wide confidence intervals on the right-hand side of the graph represent the fact that there are very few values of head injury coding above 1.18.

Figure 6.7 shows the *smoothed* relationship between numbers of bicyclist head injuries and the trigonometrical seasonal variable (the dotted lines represent 95% confidence limits of the bold *smoothed curve*).

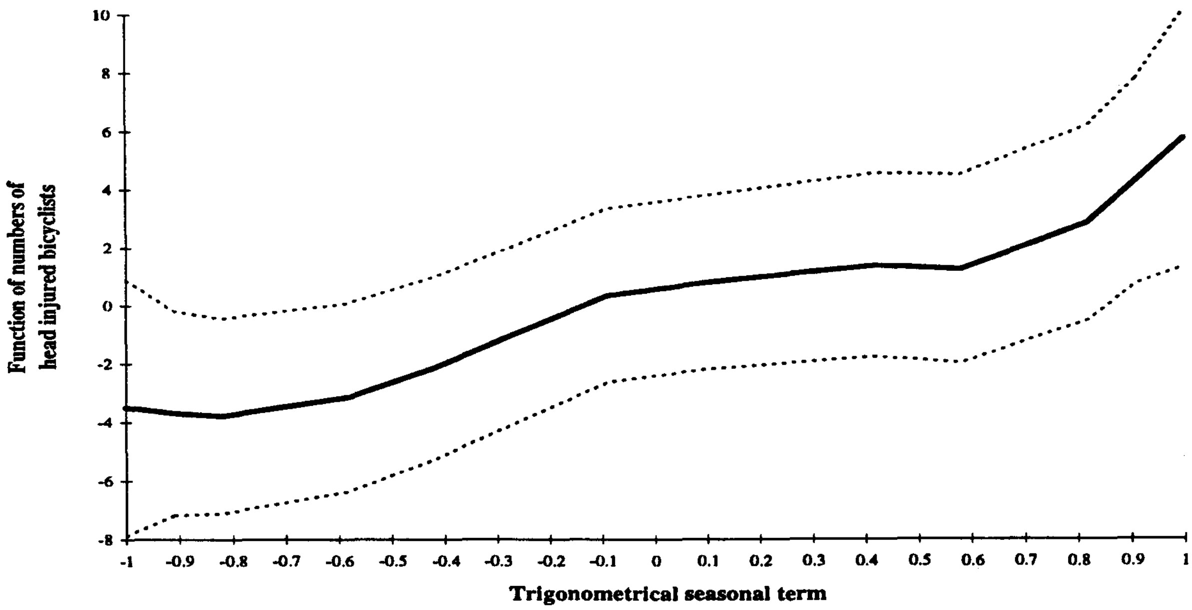

Figure 6.6: Numbers of bicyclist head injuries as a function of the trigonometrical seasonal variable from 1987/88 to 1993/94.

This graph seems to show that higher numbers of head injured bicyclists correspond to the months near February. The wide confidence intervals may be an indication that a trigonometrical seasonal term does not ideally represent the head injury seasonal variation.

6.4 Edited output of multivariate time series models

6.4.1 Hospital Admissions Data: Victoria - Numbers of bicyclist head injured

Observations 84

	Jan Jul	Feb Aug	Mar Sep	Apr Oct	May Nov	Jun Dec	TOTAL
1987							
	21.	33.	31.	37.	48.	49.	219.
1988	43.	60.	63.	46.	33.	26.	
	21.	21.	33.	39.	44.	50.	479.
1989	42.	38.	42.	40.	39.	20.	
	20.	19.	24.	29.	48.	50.	411.
1990	50.	48.	52.	31.	29.	26.	
	18.	10.	23.	24.	18.	22.	351.
1991	25.	42.	21.	36.	17.	11.	
	9.	19.	17.	15.	31.	30.	273.
1992	26.	35.	35.	26.	12.	13.	
	17.	17.	16.	22.	25.	31.	275.
1993	39.	25.	31.	27.	23.	14.	
	15.	22.	24.	26.	38.	37.	321.
1994	47.	38.	34.	22.	19.	20.	180.
AVGE	39.	41.	40.	33.	25.	19.	
	17.	20.	24.	27.	36.	38.	

Table Total- 2509.00 Mean- 29.87 Std. Dev.- 12.15

MODEL DEFINITION

Transformation log(y)
Regression Model Constant + LS1990.jul + Trigonometric Seasonal + User-defined
ARIMA Model ([7] 0 0)

MODEL ESTIMATION/EVALUATION
Exact ARMA likelihood estimation
Max total ARMA iterations 200
Max ARMA iter's w/in an IGLS iterati 40
Convergence tolerance 1.00E-05
Estimation converged in 8 ARMA iterations, 55 function evaluations

Regression Model

Variable	Parameter Estimate	Standard Error	t-value
Constant	2.0967	0.37198	5.64
LS1990.jul	-0.5024	0.05547	-9.06

Trigonometric Seasonal			
cos(2pi*1t/12)	0.3791	0.02659	14.26
sin(2pi*1t/12)	0.0206	0.02305	0.90
User-defined			
Rate of head injury	0.8988	0.32634	2.75

Chi-squared Tests

Regression Effect	df	Chi-Square	P-Value
Trigonometric Seasonal	2	206.43	0.00

ARIMA Model: ([7] 0 0)

Parameter	Estimate	Standard Errors
Nonseasonal AR		
Lag 7	0.3698	0.10195
Variance	0.33930E-01	

Likelihood statistics

Effective number of observations (nefobs)	84
Number of parameters estimated (np)	7
Log likelihood	22.3992
Transformation Adjustment	-277.9972
Adjusted Log likelihood (L)	-255.5979
AIC	525.1959
F-corrected-AIC	526.6696
Hannan Quinn	532.0361
BIC	542.2116

DIAGNOSTIC CHECKING

Sample Autocorrelation

Lag	1	2	3	4	5	6	7	8	9	10	11	12
ACF	0.02	-0.09	-0.19	0.15	-0.03	0.08	0.00	-0.02	-0.10	0.03	0.03	-0.09
SE	0.11	0.11	0.11	0.11	0.12	0.12	0.12	0.12	0.12	0.12	0.12	0.12
Q	0.05	0.79	3.97	5.89	5.99	6.64	6.64	6.70	7.66	7.76	7.87	8.71
DF	0	1	2	3	4	5	6	7	8	9	10	11
P	0.000	0.375	0.137	0.117	0.200	0.249	0.355	0.461	0.467	0.559	0.641	0.649
ACF	0.06	-0.02	-0.21	-0.12	0.19	0.00	-0.01	-0.16	0.17	-0.04	0.16	0.00
SE	0.12	0.12	0.12	0.12	0.13	0.13	0.13	0.13	0.13	0.13	0.13	0.14
Q	9.10	9.15	13.63	15.22	19.30	19.31	19.31	22.34	25.49	25.68	28.84	28.84
DF	12	13	14	15	16	17	18	19	20	21	22	23
P	0.694	0.762	0.478	0.436	0.253	0.311	0.373	0.267	0.183	0.219	0.149	0.186

ACF	0.04	-0.23	0.06	-0.03	0.08	0.03	0.05	-0.21	-0.08	0.05	0.13	-0.10
SE	0.14	0.14	0.14	0.14	0.14	0.14	0.14	0.14	0.15	0.15	0.15	0.15
Q	29.01	35.56	35.98	36.07	36.86	36.98	37.28	43.15	44.10	44.41	46.90	48.55
DF	24	25	26	27	28	29	30	31	32	33	34	35
P	0.220	0.079	0.092	0.114	0.122	0.147	0.169	0.072	0.075	0.089	0.069	0.064

If residuals are random, the Ljung Box Q should be distributed as chi-squared on df degrees of freedom

```
Histogram of the Standardized and Mean-Centered Residuals
 Standard
 Deviations     Frequency
      -3 +
         |
      -2 +
         |###########
      -1 +#####
         |##################
       0 +##################
         |########
       1 +##############
         |########
       2 +##
         |
       3 +

 One '#'= 1 observation[s]
```

Summary Statistics for the Unstandardized Residuals

Minimum	-0.346
Maximum	0.402
Median	-0.007
Robust Std Dev	0.198

6.4.2 Hospital Admissions Data: Melbourne - Numbers of bicyclist head injured

Observations 84

	Jan Jul	Feb Aug	Mar Sep	Apr Oct	May Nov	Jun Dec	TOTAL
1987							
	12.	16.	17.	21.	18.	24.	108.
1988	20.	26.	30.	25.	11.	17.	
	16.	9.	18.	20.	18.	27.	237.
1989	20.	18.	24.	17.	17.	11.	
	8.	10.	5.	18.	22.	24.	194.
1990	34.	21.	26.	13.	19.	15.	
	11.	5.	15.	12.	6.	12.	189.
1991	13.	24.	11.	26.	9.	4.	
	4.	13.	9.	9.	13.	18.	153.
1992	19.	11.	19.	16.	5.	8.	
	10.	8.	6.	12.	14.	13.	141.
1993	22.	11.	19.	18.	15.	5.	
	12.	16.	10.	20.	20.	17.	185.
1994	27.	22.	15.	12.	12.	10.	98.
AVGE	22.	19.	21.	18.	13.	10.	
	10.	11.	11.	16.	16.	19.	

Table Total- 1305.00 Mean- 15.54 Std. Dev.- 6.46

MODEL DEFINITION

Transformation log(y)
Regression Model Constant + LS1990.jul + Trigonometric Seasonal + User-defined
ARIMA Model ([7 12] 0 0)

MODEL ESTIMATION/EVALUATION
Exact ARMA likelihood estimation
Max total ARMA iterations 200
Max ARMA iter's w/in an IGLS iterati 40
Convergence tolerance 1.00E-05
Estimation converged in 6 ARMA iterations, 49 function evaluations

Regression Model

Variable	Parameter Estimate	Standard Error	t-value
Constant	1.1534	0.56771	2.03
LS1990.jul	-0.4194	0.07231	-5.80
Trigonometric Seasonal			
cos(2pi*1t/12)	0.3437	0.04214	8.16

sin(2pi*1t/12)	0.0413	0.03724	1.11
User-defined			
Rate of head injury	1.1749	0.50503	2.33

Chi-squared Tests

Regression Effect	df	Chi-Square	P-Value
Trigonometric Seasonal	2	66.65	0.00

ARIMA Model: ([7 12] 0 0)

Parameter	Estimate	Standard Errors
Nonseasonal AR		
Lag 7	0.2169	0.10514
Lag 12	-0.2044	0.10942
Variance	0.94908E-01	

Likelihood statistics

Effective number of observations (nefobs)	84
Number of parameters estimated (np)	8
Log likelihood	-20.7337
Transformation Adjustment	-221.9414
Adjusted Log likelihood (L)	-242.6750
AIC	501.3501
F-corrected-AIC	503.2701
Hannan Quinn	509.1674
BIC	520.7966

DIAGNOSTIC CHECKING

Sample Autocorrelation

Lag	1	2	3	4	5	6	7	8	9	10	11	12
ACF	-0.09	-0.16	0.11	0.05	-0.11	0.03	0.04	-0.07	-0.03	-0.12	0.03	-0.03
SE	0.11	0.11	0.11	0.11	0.11	0.12	0.12	0.12	0.12	0.12	0.12	0.12
Q	0.78	2.99	4.00	4.22	5.36	5.45	5.61	6.04	6.12	7.44	7.52	7.61
DF	0	0	1	2	3	4	5	6	7	8	9	10
P	0.000	0.000	0.045	0.121	0.147	0.244	0.346	0.418	0.526	0.490	0.583	0.667
ACF	-0.06	-0.11	0.09	0.08	-0.20	0.07	0.09	-0.11	0.16	0.03	0.00	0.01
SE	0.12	0.12	0.12	0.12	0.12	0.12	0.13	0.13	0.13	0.13	0.13	0.13
Q	7.99	9.27	10.15	10.83	14.95	15.54	16.51	17.78	20.54	20.67	20.67	20.70
DF	11	12	13	14	15	16	17	18	19	20	21	22
P	0.714	0.679	0.682	0.699	0.455	0.486	0.488	0.470	0.363	0.417	0.479	0.540

ACF	-0.03	-0.14	0.10	-0.13	-0.01	0.06	-0.04	-0.06	-0.02	0.15	-0.09	0.00
SE	0.13	0.13	0.13	0.13	0.13	0.13	0.13	0.13	0.13	0.13	0.14	0.14
Q	20.77	23.16	24.35	26.63	26.64	27.09	27.34	27.85	27.89	31.04	32.31	32.32
DF	23	24	25	26	27	28	29	30	31	32	33	34
P	0.595	0.510	0.500	0.429	0.483	0.514	0.554	0.578	0.627	0.515	0.501	0.550

If residuals are random, the Ljung Box Q should be
distributed as chi-squared on df degrees of freedom

Histogram of the Standardized and Mean-Centered Residuals

```
Standard
Deviations     Frequency
     -3 +
        |#
     -2 +###
        |#####
     -1 +#############
        |#############
      0 +##################
        |################
      1 +###########
        |####
      2 +
        |
      3 +
```

One '#'= 1 observation[s]

Summary Statistics for the Unstandardized Residuals

Minimum	-0.824
Maximum	0.617
Median	0.049
Robust Std Dev	0.338

6.4.3 Hospital Admissions data: Victoria (motor vehicle involved) - Numbers of bicyclist head injured

Observations 84

	Jan / Jul	Feb / Aug	Mar / Sep	Apr / Oct	May / Nov	Jun / Dec	TOTAL
1987							
	8.	14.	11.	12.	16.	12.	73.
1988	10.	21.	25.	13.	10.	9.	
	10.	7.	12.	14.	9.	10.	150.
1989	9.	12.	12.	8.	12.	12.	
	9.	8.	3.	10.	13.	13.	121.
1990	14.	15.	17.	5.	9.	12.	
	10.	3.	15.	8.	5.	8.	121.
1991	6.	17.	5.	7.	8.	5.	
	3.	7.	3.	5.	9.	8.	83.
1992	3.	9.	7.	7.	2.	5.	
	5.	3.	3.	5.	9.	12.	70.
1993	10.	5.	7.	6.	11.	2.	
	5.	11.	3.	8.	11.	16.	95.
1994	8.	18.	7.	7.	1.	6.	47.
AVGE	9.	14.	11.	8.	8.	7.	
	7.	8.	7.	9.	10.	11.	

Table Total- 760.00 Mean- 9.05 Std. Dev.- 4.48

MODEL DEFINITION

Transformation log(y)
Regression Model Constant + LS1990.jul + Trigonometric Seasonal
ARIMA Model (0 0 [6])(1 0 0)

MODEL ESTIMATION/EVALUATION
Exact ARMA likelihood estimation
Max total ARMA iterations 200
Max ARMA iter's w/in an IGLS iterati 40
Convergence tolerance 1.00E-05
Estimation converged in 9 ARMA iterations, 61 function evaluations

Regression Model

Variable	Parameter Estimate	Standard Error	t-value
Constant	1.7875	0.03624	49.33
LS1990.jul	-0.6035	0.05953	-10.14
Trigonometric Seasonal			
cos(2pi*1t/12)	0.2891	0.06033	4.79
sin(2pi*1t/12)	-0.0069	0.06036	-0.11

Chi-squared Tests

Regression Effect	df	Chi-Square	P-Value
Trigonometric Seasonal	2	22.97	0.00

ARIMA Model: (0 0 [6])(1 0 0)

Parameter	Estimate	Standard Errors
Seasonal AR		
Lag 12	-0.3915	0.12050
Nonseasonal MA		
Lag 6	0.2567	0.12100
Variance	0.17782E+00	

Likelihood statistics

Effective number of observations (nefobs)	84
Number of parameters estimated (np)	7
Log likelihood	-48.0139
Transformation Adjustment	-172.9722
Adjusted Log likelihood (L)	-220.9861
AIC	455.9723
F-corrected-AIC	457.4460
Hannan Quinn	462.8125
BIC	472.9880

DIAGNOSTIC CHECKING

Sample Autocorrelation

Lag	1	2	3	4	5	6	7	8	9	10	11	12
ACF	-0.08	0.00	-0.07	0.13	-0.16	-0.05	0.01	0.19	0.00	-0.14	0.01	0.00
SE	0.11	0.11	0.11	0.11	0.11	0.11	0.12	0.12	0.12	0.12	0.12	0.12
Q	0.56	0.56	1.01	2.51	4.89	5.14	5.14	8.54	8.54	10.33	10.34	10.34
DF	0	0	1	2	3	4	5	6	7	8	9	10
P	0.000	0.000	0.314	0.285	0.180	0.273	0.398	0.201	0.287	0.243	0.324	0.411
ACF	0.01	0.01	-0.13	-0.08	-0.09	-0.09	-0.19	0.07	0.11	-0.07	-0.10	0.06
SE	0.12	0.12	0.12	0.12	0.12	0.12	0.12	0.13	0.13	0.13	0.13	0.13
Q	10.35	10.37	12.11	12.76	13.56	14.53	18.41	18.90	20.18	20.78	21.87	22.29
DF	11	12	13	14	15	16	17	18	19	20	21	22
P	0.499	0.584	0.518	0.545	0.559	0.559	0.363	0.398	0.384	0.410	0.407	0.442
ACF	-0.16	0.02	-0.03	0.09	0.06	0.05	-0.12	0.06	0.05	0.17	0.00	0.01
SE	0.13	0.13	0.13	0.13	0.13	0.13	0.13	0.14	0.14	0.14	0.14	0.14
Q	25.52	25.58	25.72	26.69	27.17	27.53	29.62	30.21	30.51	34.76	34.76	34.77
DF	23	24	25	26	27	28	29	30	31	32	33	34
P	0.324	0.375	0.422	0.426	0.455	0.489	0.433	0.455	0.491	0.338	0.384	0.431

```
 If residuals are random, the Ljung Box Q should be
 distributed as chi-squared on df degrees of freedom

Histogram of the Standardized and Mean-Centered Residuals
 Standard
 Deviations     Frequency
 Outlier [##
      -3 +##
         |###
      -2 +##
         |##
      -1 +######
         |################
       0 +###################
         |################
       1 +#####
         |#####
       2 +#####
         |####
       3 +

 One '#'= 1 observation[s]
 Residuals with |t|>3.25
 Obs       t-value
 -----------------
 1992.jan    -3.56
 1994.may    -3.71

Summary Statistics for the Unstandardized Residuals
 Minimum                     -1.166
 Maximum                      0.839
 Median                       0.010
 Robust Std Dev               0.317
```