The relationship between increases in motorway capacity and declines in urban rail passenger journeys: a case study of Sydney's M4 Motorway and Western Sydney Rail Lines

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1 Introduction: does the addition of urban motorway capacity cause mode shifting from the rail to road network and does this matter?

This paper examines the relationship between the addition of urban motorway capacity and declines in rail passenger journeys on parallel alignments. The research presented here forms part of a wider study that investigates outcomes from the expansion of urban motorway capacity in Sydney and the phenomenon of *induced traffic growth.*

Induced traffic growth is defined as new and additional road traffic movements that occur in response to increases in road capacity. By increasing road capacity, congestion and travel times are reduced, making travel by car more attractive. This generates a rapid succession of changes in travel behaviour across the surrounding network including *traffic reassignment*, *traffic redistribution*, *generated traffic* and passengers switching from parallel rail and public transport services, or *mode shifting*. This last response is the focus of this paper. Together, all form part of the composite effect called induced traffic growth (SACTRA 1994, p.53).

The effects of mode shifting and other travel behaviour responses are significant because they potentially undermine the primary benefit of supplying additional urban motorway capacity which is to reduce travel times (Thomson 1977; Downs 1992; Mogridge 1997). If road traffic volumes increase, travel time savings are quickly eroded and congestion returns. If public transport patronage falls and services sustain revenue losses, service levels may be cut, imposing additional costs on public transport users and operators (SACTRA 1994, pp.128–129). Investigating responses to urban motorway development, such as mode shifting, is therefore important as it assists in gauging whether or not additional motorway capacity has been an effective policy response for reducing congestion.

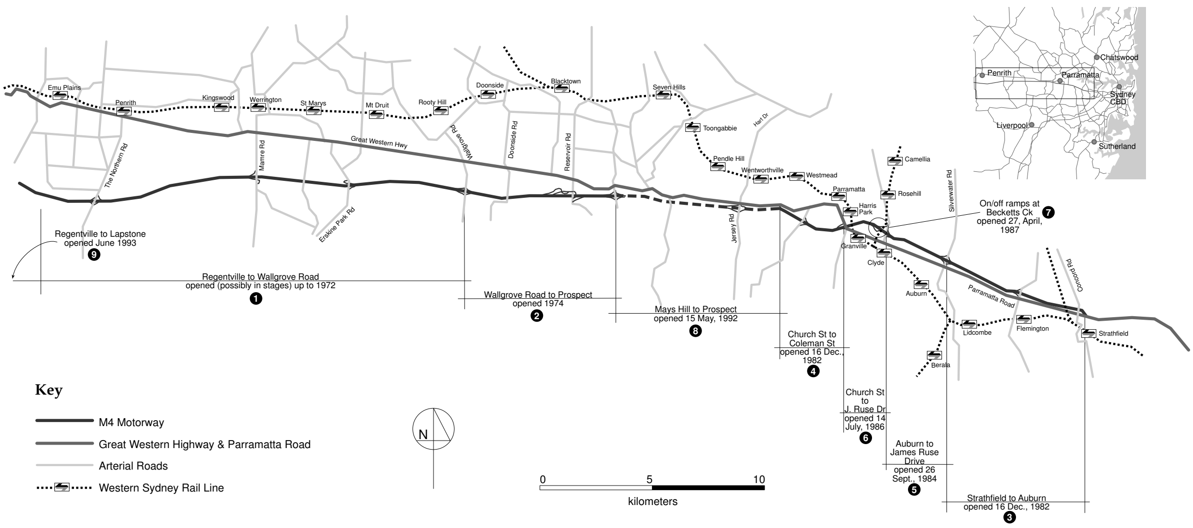


Figure 1. M4 Motorway, Great Western Hwy and Western Sydney Rail alignments

Specifically, this paper focuses on changes to rail passenger journey volumes on two key lines on Sydney's CityRail system before and after opening of the M4 Motorway section from Mays Hill to Prospect in May 1992. Figure 1 shows the relative alignments of the M4 Motorway and the Western Sydney Rail Line (WSRL). Together, these two trunk routes provide access for long distance commuting along Sydney's western axis.

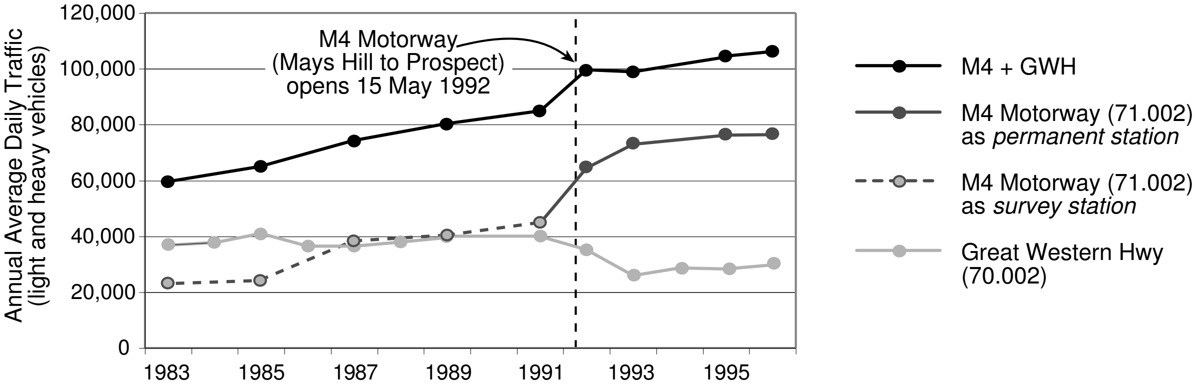


Figure 2. Annual Average Daily Traffic counts for the M4 Motorway and Great Western Hwy (1983 – 1996)

As can be seen in Figure 2, Annual Average Daily Traffic (AADT) volumes for the M4 Motorway increased dramatically after opening of the motorway section from Mays Hill to Prospect. A decline in traffic volumes took place on the Great Western Highway (GWH), which is an arterial road that also runs parallel to the M4 Motorway as shown in Figure 1. This indicates traffic reassignment. But despite this, combined AADT volumes for the M4 and GWH show a jump of around 18,000 movements. As will be shown in the proceeding analysis, some of the increase appears to be the result of mode shifting from the Western Sydney and Richmond Rail Lines.

The changes in rail passenger journeys will be examined in some detail in this case study using time series regression analysis to gauge the significance of mode shifting. But to begin, a brief review of the literature is presented, summarising in theoretical terms why mode shifting might take place after the addition of urban motorway capacity and under what conditions it becomes problematic.

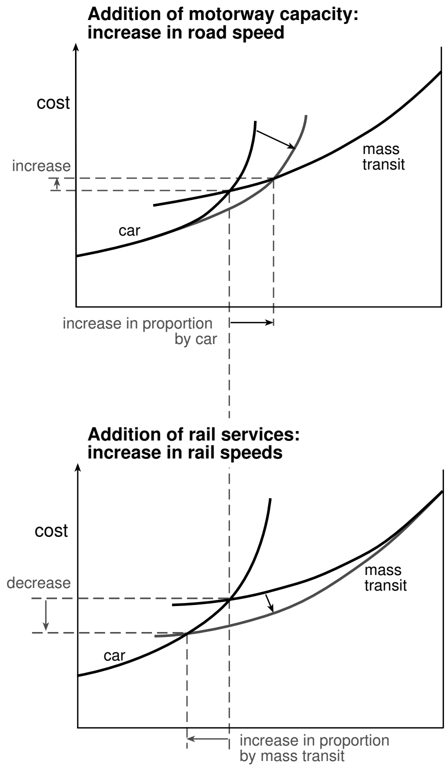
2 Theoretical background: mode shifting in response to additional urban motorway capacity

The most influential body of work that focussed on the effects of induced traffic growth was a report entitled *Trunk roads and the generation of traffic* (SACTRA 1994). The *Standing Advisory Committee on Trunk Route Assessment* (SACTRA) was commissioned by the UK government to investigate whether or not the addition of motorway capacity generated additional road traffic, and whether or not this created a significant problem. The report spawned a wide-ranging discussion both internationally and in the UK, prompting many new empirical studies of the effects of urban road building as well as revisiting previous theoretical explanations for what happens in the wake of adding new motorway capacity to congested urban networks. The investigation briefly addressed the issue of additional road trips from mode shifting, referring to a body of work called the *Mogridge conjecture* (SACTRA 1994, p.128).

2.1 The Mogridge conjecture and the Downs-Thomson paradox

The Mogridge conjecture — named after Martin Mogridge who lead a team of four researchers — was triggered by the observation that average travel speeds for the London conurbation had remained roughly the same for several decades (Mogridge 1990a, p.12). The four tried to identify a mechanism that could be responsible for this phenomenon, finding it in previous work by Downs (1962) and Thomson (1977) which they subsequently called the *Downs-Thomson paradox* (Mogridge et al. 1987).

The argument arising from these contributions states that in congested areas an equilibrium mechanism exists between travel by private car and travel by public transport. When motorway capacity is added to a congested urban road network, some passengers on parallel public transport routes will switch to the new or upgraded road until speeds on the new route are reduced and brought into equilibrium with those on the old routes. Or in other words, commuters and public transport passengers will shift between alternate routes and public transport options until no further travel time advantage can be found.



Source: Mogridge, MJH. 1997, 'The self defeating nature of road capacity policy: a review of theories, disputes and available evidence' in *Transport Policy*, Vol.4, No.1, p.9.

Figure 3. The Downs-Thomson paradox: comparing marginal cost outcomes of adding road capacity vs. mass transit improvements

The final outcome from mode shifting under these conditions has been defined as a paradox because in some cases the marginal cost of trips after the system has settled at a different point of equilibrium may be higher than before the investment in new motorway capacity. Because public transport is subject to commercial constraints, as passenger numbers decline, revenue is lost, raising the possibility of fare increases or service cuts to offset the consequent increases in the marginal cost of providing public transport trips. This causes another round of diversion from public transport and increases in road traffic congestion. The first graph in Figure 3 illustrates this outcome, the second illustrates the converse — investment in mass transit to bring about increases in public transport speeds and reductions in the marginal cost of trips.

As Mogridge notes, the basic difference between car travel and public transport is that the former has high variable costs while the latter has low variable costs. This is because as more cars enter the network, travel times increase steeply, while time costs per passenger on fixed schedule mass transit systems remain much the same and largely independent of passenger volumes (Mogridge 1990b, p.9). Adjusting the system in a way that shifts travellers from a mode with high fixed costs to one with high variable costs overlooks key logistical features of the different modes.

With respect to the observation that triggered the Mogridge conjecture, it was concluded that average speeds in London had stayed the same because public transport speeds had remained relatively constant. In effect, the fixed schedule speed of the public transport network was working as a default speed for the entire transport network.

While the Downs-Thomson paradox is the central theoretical platform in the body of work called the Mogridge conjecture, the final collection of studies and papers draws on theories from a variety of researchers and argues for the central idea from a broad array of positions. For example, the case for there being an equilibrium mechanism between private car and public transport use is likened to the long accepted idea that an equilibrium mechanism is responsible for the assignment of road traffic between alternate road routes as outlined in Wardop's first principle (Mogridge et al. 1987, pp.285–286; Holden 1989). The Mogridge conjecture also provides empirical justification for the idea to an extent that neither Downs nor Thomson did in their original publications. Significantly, the primary form of empirical investigation pursued by Mogridge was analysis of travel speeds from travel survey data. He did not analyse time series data immediately before and after the addition of road space where mode shifting due to relative changes in travel speeds could be expected to be at its most stark.

At the time when SACTRA canvassed this argument, they concluded that it only applied to cases when capacity is added to radial routes in metropolitan areas and public transport has a significant share of the travel market so that mode shifting is more likely (SACTRA 1994, p.129). However, recent empirical studies have also shown declines in rail passenger journeys on interurban services after the introduction of high-speed roads (Bel 1997).

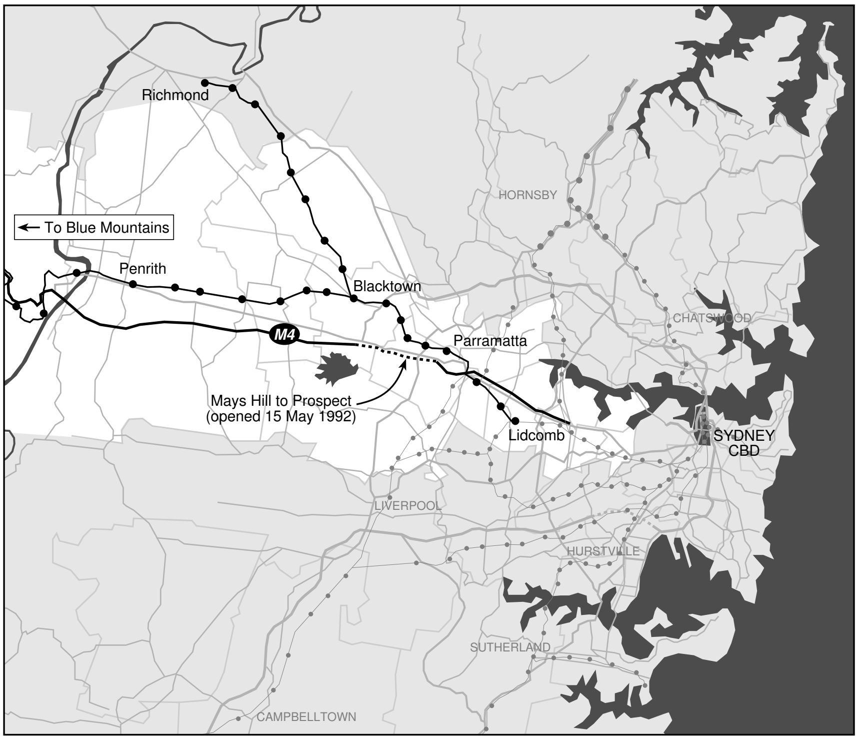
2.2 Induced traffic growth and mode shifting studies in Australia

There are surprisingly few empirical studies that address induced traffic growth and mode shifting in Australian cities. To date there have only been two (Luk & Chung 1997; Mewton 1997). Mewton confirmed that declines in rail passenger journeys took place on the Northern Suburbs Rail Line, coinciding with the opening of the Sydney Harbour Tunnel and Gore Hill Expressway (Mewton 1997, pp.40–42). Luk and Chung were unable to either confirm or refute mode shifting in their case study of a Melbourne Expressway owing to the unavailability of data (Luk & Chung 1997, p.19). StateRail have undertaken internal reports that confirm mode shifting due to motorway capacity increases (Kearnes 1994, p.2). These reports identified other possible causes for declines in passenger journeys over the period investigated in this study including the recession and changes to ticket types and fare structures. Time series regression was not used to distinguish these from mode shifting however.

3 Data: passenger journeys on the Sydney CityRail network

This section briefly outlines the data used for this analysis. As noted by Thomson, Sydney's transport network has topological features that make it well suited to testing for mode shifting and induced traffic growth. This is because the predominance of both radial road and rail trunk routes, and a strong city centre, mean that route substitution can occur easily for many trips owing to their concentration along key axes (Thomson 1977, pp.213–217).

Figure 4 shows the relative route alignments of the Western Sydney and Richmond Rail Lines and M4 Motorway. The position of the motorway section from Mays Hill to Prospect that was opened to traffic on 15 May 1992 is also shown. Rail stations highlighted in black indicate stations from which data were collected for inclusion in this study. Rail stations further to the west on the Blue Mountains rail line were also included but are not shown in this diagram. These have been listed at the bottom of Figure 4.



Western Sydney Rail Line stations include: Lidcombe, Auburn, Clyde, Granville, Harris Park, Parramatta, Westmead, Wentworthville, Pendle Hill, Toongabbie, Seven Hills, Blacktown, Doonside, Rooty Hill, Mt Druitt, St Marys, Werrington, Kingswood, Penrith, Emu Plains.

Blue Mountains Rail Line stations include: Lapstone, Glenbrook, Blaxland, Warrimoo, Valley Heights, Springwood, Faulconbridge, Linden, Woodford, Hazelbrook, Lawson, Wentworth Falls, Leura, Katoomba, Blackheath, Mt Victoria, Lithgow.

Richmond Rail Line stations include: Marayong, Quakers Hill, Schofields, Riverstone, Mulgrave, Windsor, Clarendon, East Richmond, Richmond.

Figure 4. Rail and motorway trunk routes in Sydney's western sector

The primary data used in this analysis are *estimated passenger journeys*. These have been calculated from records of rail ticket sales provided by RailCorp. Ticket sales are listed by their type and grouped according to their point of purchase. The point of purchase is assumed to be the station at which a passenger enters the CityRail network.

Ticket types conform to six generic categories. These include singles, returns, weeklys, monthlys, quarterlys and yearlys. The number of trips generated by single and return tickets is clear. In the case of periodical tickets, where ticket holders can undertake as many trips as they like within the nominated time-period, the average number of trips has been estimated through surveys carried out by RailCorp.

Table 1 sets out the number of trips attributed to each ticket type as per the survey findings.

Table 1. Trip rates for rail ticket types

Ticket type	Trip rate
Singles	1
Returns	2
Weeklys	11
Monthlys	45
Quarterlys	115
Yearlys	585

Figure 5 shows total estimated passenger journeys for Western Sydney Rail Line (WSRL) services. Estimated passenger journeys using single and return tickets and journeys using periodical tickets are also shown as is the point at which additional capacity on the M4 Motorway was opened.

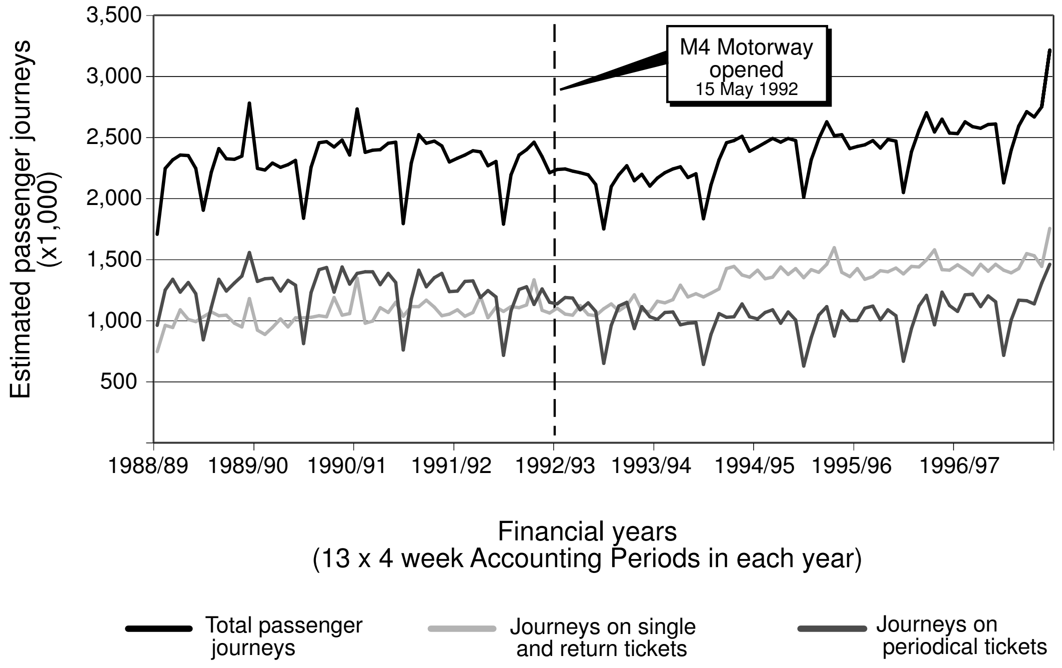


Figure 5. Estimated passenger journeys for Western Sydney and Blue Mountains rail services (1988/89 – 1996/97)

Prior to 1996/97, RailCorp collated rail ticket sales data according to 13 four-week periods, or Accounting Periods (APs). In this formation, regular seasonal and yearly, as well as long term cyclical, fluctuations can be seen. Each annual period for total and periodical tickets is characterised by a sharp decline in passenger journey numbers that coincides with the Christmas and summer holiday period. A longer-term trend can also be discerned however in total trips as well as those undertaken using singles and returns and periodical tickets. These trends do not correspond to regular yearly cycles and so their cause is not as immediately obvious. Two irregular data spikes appear at APs 13 and 27 in the time series. There is no explanation for these, but it is possible that they could be the product of data collation anomalies. There are also unusually low values at the start of the data series and unusually high values at the end.

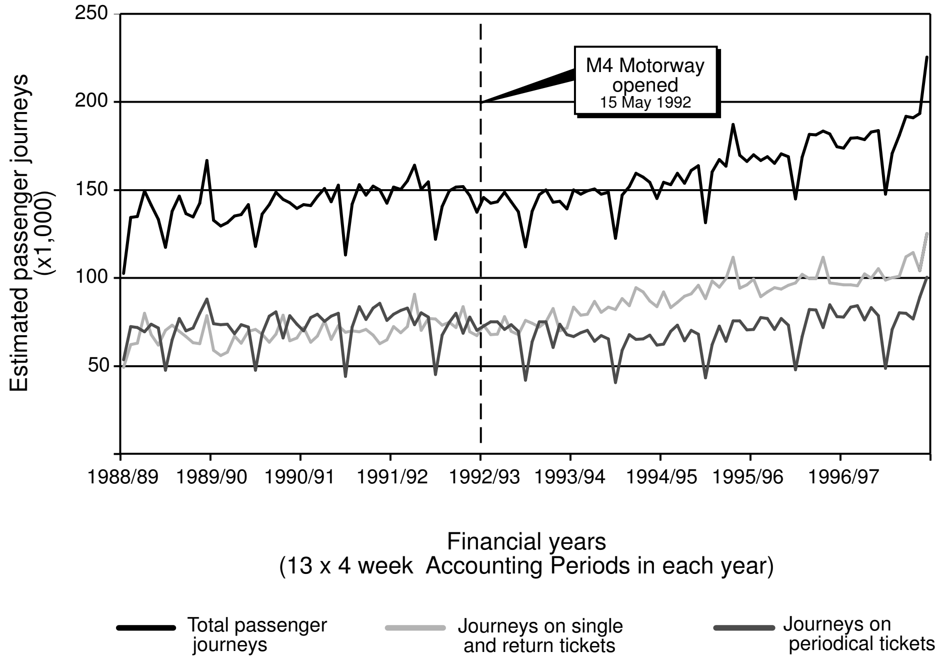


Figure 6. Estimated passenger journeys for Richmond rail services (1988/89 – 1996/97)

Figure 6 shows total estimated passenger journeys for Richmond Rail Line (RRL) services. Estimated passenger journeys using single and return tickets and journeys using periodical tickets is shown as for Figure 5. As with data for the WSRL, regular yearly fluctuations can be seen in addition to a long-term trend that does not conform to yearly cycles. The data spike at Accounting Period 13 can be seen, however the data spike occurring at Accounting Period 27 is not as prevalent in the RRL time series. As with the data for the WSRL, there are unusually low values at the start of the data series and unusually high values at the end.

Fluctuations in economic activity can influence longer-term changes in passenger volumes. At the time of opening the M4 Motorway from Mays Hill to Prospect, there was a downturn in general economic activity. It is important to distinguish this from mode shifting as a possible cause for the downturn in passenger journeys. This is why economic production data for the State of NSW was also collected for incorporation in the analysis. This was obtained from the Australian Bureau of Statistics (ABS). These data were calculated according to quarterly time periods.

4 Method: time series regression

The data for estimated passenger journeys were collated in parallel time series for 117 four-week APs between July 1988 and May 1997. This was done for total journeys on both the WSRL and RRL, as well as for journeys undertaken on periodical tickets and single and return tickets. Testing by different ticket types was done to assess whether the motorway attracted committed rail users who buy periodical tickets, or infrequent users who are more likely to purchase single and return tickets. It is also assumed that a higher portion of journey to work trips would be undertaken on periodical tickets.

State Domestic Product (SDP) data were also collated as a parallel series. Values for each quarter were repeated and listed in accordance with corresponding APs. Where APs did not correspond directly with quarterly periods, economic production values were used from the quarter whose time span most closely equated with the AP. Consequently there are three groups of APs with the same SDP value in the time series and one group of four APs with the same SDP value for each year.

Opening of the M4 Motorway section from Mays Hill to Prospect to traffic was represented by an indicator variable that changed from 0 to 1 at the time of opening. This approach models the opening as having an instantaneous effect, although it is quite possible, particularly with periodical tickets, that those passengers attracted off the rail and onto the road network did so over a time period around the opening.

As noted in Section 3, all passenger journey time series showed unusually low values in the first Accounting Period (July 1988) and unusually high values in the last (May 1997). Upon investigation, these were attributed to *end effects* of the construction of the time series and removed from further analysis.

The analysis started by removing the strong seasonal (annual) effect of period 13 in the data. Investigation of preliminary analyses showed that there were some isolated high values (particularly in June 1989), but since no specific cause for them could be identified, they were allowed for by applying exponential smoothing — single exponential smoothing with optimal ARIMA 0,0,1 model — to the series. Initially, linear regression was used to analyse the data. However, it was clear in many of the series that longer-term non-linear trends were present over and above the seasonal components. The seasonally adjusted and smoothed data were then analysed using the lowest-order polynomial model (cubic) that gave a reasonable fit to the data. The predictor variables SDP, month, month-squared, month-cubed and M4 were used in these models. The seasonally adjusted and smoothed data were then analysed using a polynomial (cubic) multiple regression with predictor variables *SDP*, *month*, *month-squared*, *month-cubed* and *M4*. This model was found to follow the trend more closely.

The smoothed time series was checked for autocorrelation using the Durbin-Watson test: in each case there was no evidence for autocorrelation

Analysis was undertaken with the primary aim of gauging two features of the time series. The first was whether the opening of the M4 Motorway section from Mays Hill to Prospect had a significant effect on passenger volumes on the WSRL and RRL by drawing passengers away from rail services. Significance was gauged by p-values. The second feature to be gauged was the likely scale of mode shifting. This volume was estimated by the coefficient of the indicator variable *M4* representing the change caused by the opening of the expressway.

5 Results: empirical evidence of a systematic relationship

Regressions for all coefficients of M4 are significant and negative. This indicates that the opening of the M4 Motorway section from Mays Hill to Prospect did correspond to a significant decline in the number of rail passenger journeys on the WSRL and the RRL, although of course it does not prove a causal link. This is broadly consistent with the Mogridge conjecture and Downs-Thomson paradox outlined in Section 2.

Table 2 shows the p-values (significance of each coefficient) from the regressions, as well as the R-square values (indicating the percentage of variability explained by the explanatory variables). It reveals that M4 is significant in all models, and estimates the amount of decline (in thousands of journeys) for each line and ticket type.

Table 2. P-values, R-square values and coefficients of M4 from cubic regressions

	RRLchtot	*RRLchsing*	*RRLchper*	*WSRLtot*	*WSRLsing*	*WSRLper*
SDP	0.15	0.25	0.57	<0.001	0.002	<0.001
month	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
month^2	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
month^3	0.94	<0.001	<0.001	0.70	<0.001	<0.001
M4	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
R^2	96%	97%	75%	79%	95%	97%
Coeff of M4 (x1000)	–12.5	–7.9	–4.7	–199	–132	–60

The loss of passenger journeys in the AP immediately after opening of the motorway section was in the order of 200,000 for the WSRL and 12,500 for the RRL, as shown in Table 2. This equates to just under 6,000 car trips per day from the WSRL if an average vehicle occupancy rate of 1.2 is used. The drop for the RRL is around 370.

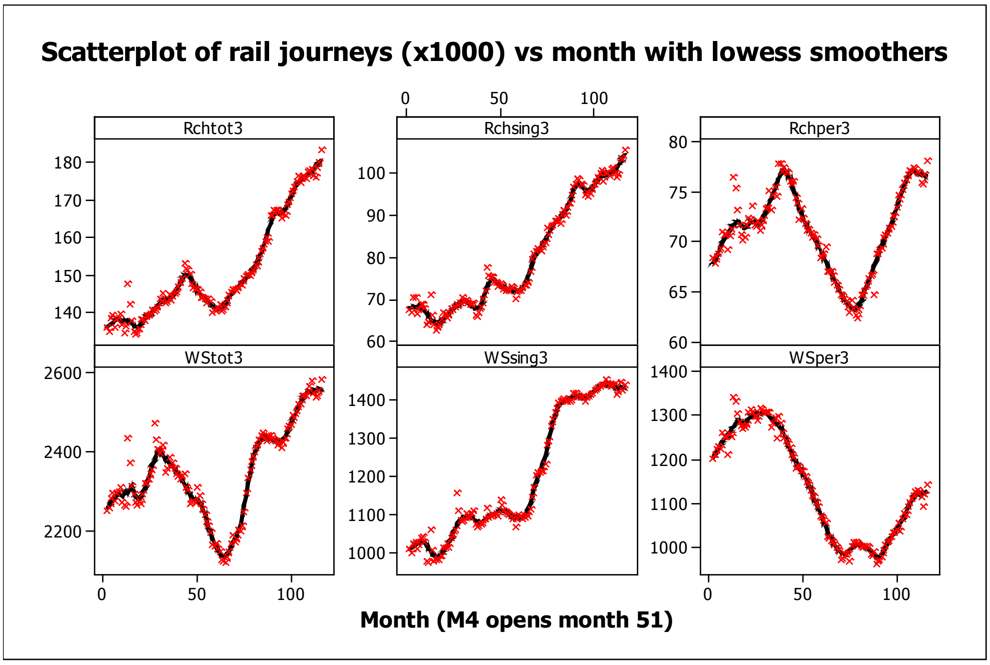


Figure 7. Rail passenger journeys vs. time with lowess[1] smoothers

Figure 7 shows the time series for the seasonally adjusted and exponentially smoothed data for total passenger journeys on the WSRL and RRL. Time series for passenger journey estimates for trips undertaken using singles and returns and periodical tickets are also shown. As can be seen there was a decline in passenger journeys in the weeks before the M4 opening during AP 51.

[1] A lowess smoother (or LOWESS) is a statistical procedure that fits a series of low-order polynomials to data using a form of *locally weighted regression* to produce a composite curve. Lowess curves are particularly useful for modelling complex system behaviour where no obvious theoretical model exists but where the structure is deterministic. By contrast linear, or high-order polynomial models, can overfit data, thereby removing important trends.

There are three points of interest in these time series data. The first is the apparent drop in passenger journeys before the opening of the motorway section. The second is the relatively rapid rate of growth in passenger journeys in the years after the motorway opening. The third point of interest is the greater degree of variation from the line of best in the period before the motorway opening by comparison with the period after opening.

All time series show declines in passenger journeys before the opening of the motorway. Historically, this period coincides with a general economic downturn. The SDP data used to account for this shows a flattening during this period, but not a decline. This aspect of the analysis may be better modelled using a different measure of economic activity. For example fluctuations in employment numbers may be more appropriate in this case, especially given the relationship between employment levels and the journey-to-work.

Another factor that helps to explain the decline prior to the motorway opening is the instigation of changes to ticket types and fare structures (Kearnes 1994, pp.7–8). This analysis has not incorporated these changes into the regression, however at the time StateRail noted that changes to the structure and price of weekly tickets may have encouraged some rail commuters to buy off-peak return and single tickets rather than periodicals. A record of the time at which these changes were introduced would help to clarify and distinguish declines in trip numbers due to ticket pricing changes from declines due to the recession and the motorway opening.

The pattern of decline for total passenger journeys on the WSRL and RRL after the motorway opening was similar. However passenger journeys for the WSRL showed a higher degree of variation from a cubic model. This variation can be seen in Figure 8. The stepwise nature of the estimates from the cubic model reflects the similar feature of the SDP data. This same pattern and variation from a cubic model can be seen in the time series regression for the RRL. This is shown in Figure 9.

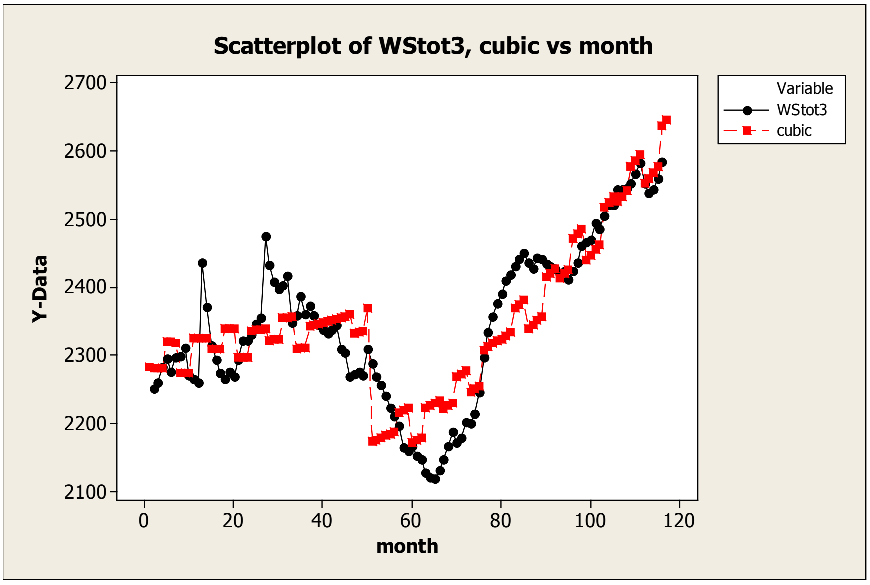


Figure 8. Total passenger journeys from rail stations on WSRL before and after M4 Motorway section opening

Significantly, passenger journey numbers increase not long after the motorway opening. Previous analysis of the M4 generated relatively crude data for fluctuations in service numbers on the WSRL (Zeibots 2003pp.42–44). Service numbers were increased for most stations in the years after the opening of the M4 Motorway. This would have the effect of reducing travel times by reducing waiting times. If a correlation between service improvements and growth in passenger numbers can be found then this would be consistent with the central argument of the Mogridge conjecture. As yet no data have been collated for changes in travel speeds on the rail network for this study, but clearly this will need to be done in future studies.

There are two phases of decline that can be seen in the time series after the motorway opening. The first is at the time of the motorway opening, the second is at AP 85. The data here are unable to provide a potential explanation for this second drop. There were no other motorway capacity increases on the M4 until August 1996. This second decline may have been caused by changes to service levels. Once again, a detailed examination of relative changes to travel speeds and service frequencies may shed some light on this aspect of the data. The second phase of decline on the RRL however does not appear to be as strong as it is on the WSRL.

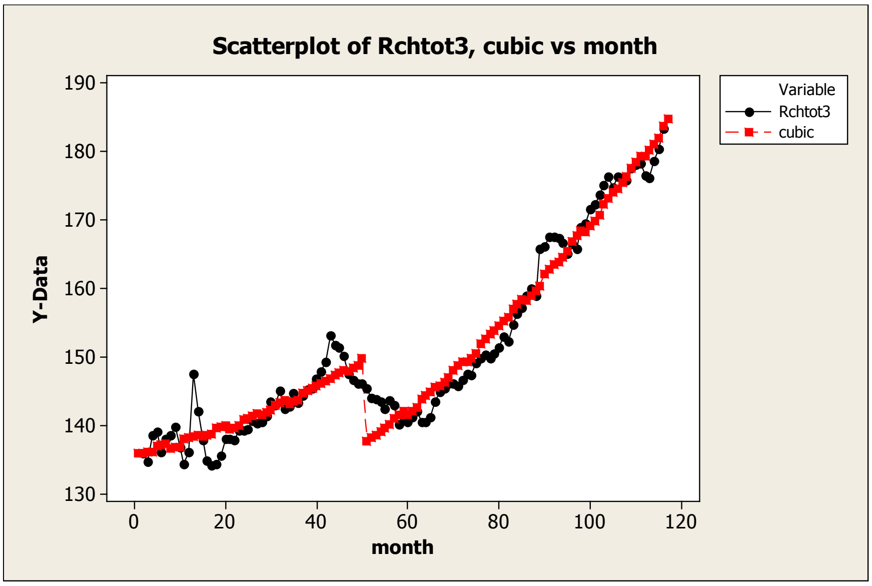


Figure 9. Total passenger journeys from rail stations on RRL before and after M4 Motorway section opening

For passenger journeys undertaken on the WSRL on single tickets (WSRLsing), the pattern was similar to that on the RRL, but again there was more variability from the cubic model, particularly after the opening of the M4 Motorway section.

For passenger journeys undertaken on the WSRL on periodical tickets (WSRLper), there was a falling trend before opening of the Mays Hill to Prospect section of the motorway, a significant drop and then a steep rise in the growth of passenger journeys. This is shown in Figure 10. Again, there was cyclic variability around the cubic model. What is particularly interesting about this is that the pattern occurs after the opening of the M4 from Mays Hill to Prospect but is not as prominent in the APs before the motorway opening.

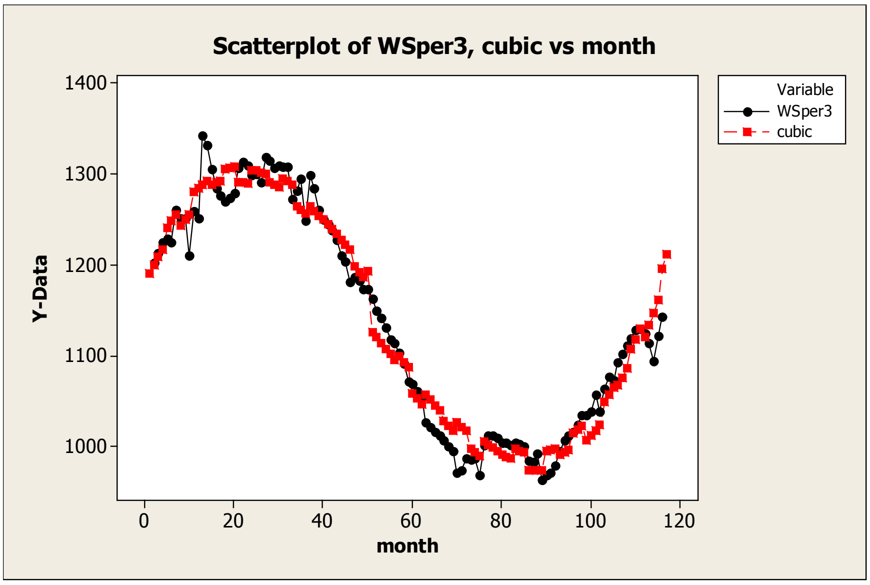


Figure 10. Passenger journeys from rail stations on WSRL using periodical tickets before and after M4 Motorway section opening

Total passenger journeys on the RRL (RRLtot) reveal a significant drop after opening of the Mays Hill to Prospect motorway section. This is followed by a rise that is significantly steeper than growth rates prior to the motorway section opening.

For passenger journeys on the RRL on single tickets (RRLsing), there is a smaller but still significant drop at M4, followed by a steeper rise in the period after the motorway section opening. For Richmond line periodicals (RRLper), there is a significant drop at the time of the motorway section opening followed by a steeper rise in the period after. However, the data in the period after display more variation from the cubic model, dropping first below and then above it. This could be due to seasonal fluctuations.

These patterns can be seen on the graphs of the seasonally adjusted and exponentially smoothed data shown in Figure 9 where the trends are indicated by a "lowess smoother", a line that follows the broad patterns in the data. The previous Figures (6, 7 and 8) have shown the data with cubic models superimposed.

The third general point of interest is that there appears to be more variation around the lowess curve before the motorway opening than for the period after opening shown in Figure 7. This suggests that trip types that would usually be responsible for wide fluctuations in passenger volumes had shifted to the road network. These could be trips to one off and special events.

6 Conclusion: mode shifting from rail to road after motorway opening confirmed

This paper provides a preliminary analysis of changes to rail passenger volumes before and after the addition of motorway capacity to Sydney's M4 Motorway in the western sector of the metropolitan area. The analysis has demonstrated that when new road capacity was added a statistically significant decline in passenger journeys on both the WSRL and RRL branch line occurred, coinciding with the motorway opening. While this analysis is unable to establish causality, it is likely that the declines are evidence of mode shifting from the rail network to the road network.

There were declines before the opening of the motorway section. It is likely that these were due to a combination of factors that include a downturn in the economy and changes to ticket types and fare structures. This analysis was unable to test for these but shows a clear need to in future analyses.

The rate at which passenger journeys grew after the opening of the motorway section could not be explained in this analysis. However there preliminary data for rail service levels indicates that there were increases in service numbers after the motorway opening and that these could provide an explanation for the increase in passenger numbers.

The results of this analysis support those reached by Mewton (Mewton 1997) and observations by StateRail, now RailCorp (Kearnes 1994) who have also examined the coincidental relationship between declines in passenger journey volumes and the addition of motorway capacity.

These results are broadly consistent with the explanation for mode shifting outlined in the Mogridge conjecture. Both the decline established in this analysis and the increase in passenger journeys after the motorway — if accompanied by service level improvements — provide evidence of an equilibrium mechanism at work. The extent of revenue losses to the rail operator and other public transport operators who provide feeder services to the rail trunk routes warrants further investigation. As does changes to service levels that may have followed the decline in passenger volumes.

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