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Panel data analysis of public transport patronage growth– an innovative econometric approach

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Abstract

This paper presents an econometric methodology designed to examine, understand and explain patronage growth rates at both the network level and corridor level (i.e. by bus route, bus corridor or train line).

This econometric methodology has three distinguishing features:

(1) we employ a seasonal difference model (i.e. we focus on explaining patronage growth rates rather than patronage levels)

(2) we analyse patronage data that has been disaggregated by corridor, using a corridor-level panel data model

(3) we follow a comprehensive set of stages designed to ensure that any findings are thorough and robust.

This econometric methodology has two key benefits. The first is that the methodology assists in isolating and disentangling the contributions of various explanatory variables. The second benefit is that the methodology provides a systematic and scientific means of 'post-evaluating' the pay-offs from network changes and service improvements.

This econometric methodology was developed by DMK Consulting and employed in a research project commissioned and supported by the NZ Transport Agency. This research project produced an econometric analysis of public transport patronage growth for a selection of New Zealand cities, including Auckland, Wellington, Hamilton and Tauranga. The primary objective of the research was to examine and explain historical trends in patronage growth and, in doing so, provide up-to-date public transport elasticities.

This paper uses a few examples from that research report to demonstrate the benefits of this econometric methodology.

1.Introduction

This paper presents an econometric methodology developed by DMK Consulting and employed by Kennedy (2013) in a research project for the NZ Transport Agency.

Section 2 presents a review of the related research literature.

Section 3 describes the econometric methodology. We use an innovative approach – a corridor level panel data model – to examine, understand and explain patronage growth rates at both the network level and corridor level (i.e. by bus route, bus corridor or train line).

Section 4 explains the first benefit of the econometric methodology: it is a tool that isolates and disentangles the impacts of a number of explanatory variables.

Section 5 explains the second benefit of the econometric methodology: it can provide a scientific and systematic 'post-evaluation' of the passenger growth generated by service improvements and network changes.

Section 6 presents the conclusions and implications of this project.

Section 7 presents acknowledgements.

2. Literature Review

2.1 Review of New Zealand Literature

The econometric methodology presented here was applied by Kennedy (2013) in an econometric analysis of public transport patronage growth for a selection of New Zealand cities including Auckland, Wellington, Hamilton and Tauranga. The primary objective of the research was to examine and explain historical trends in patronage growth and, in doing so, provide up-to-date public transport elasticities. The full report can be obtained from www.nzta.govt.nz/resources/research/reports/518/docs/518.pdf

Prior to Kennedy (2013) there had been a limited number of econometric analyses of public transport patronage within New Zealand.

Wallis and Kennedy (2008) carried out econometric analysis of passenger growth for Wellington city buses during the period between 2000 and 2007. Various models were used to estimate the impact of fares, petrol prices, and other factors on passenger growth. Employment also made a positive contribution to peak passenger numbers.

Wang (2011) carried out an econometric analysis of local bus and rail services for Auckland, Wellington and Christchurch during the period between 1996 and 2008. A dynamic model was fitted to estimate the relationships between patronage and various explanatory variables including service levels, fares, petrol prices, income, and car ownership.

In his peer review of Wang (2011), Colman (2009) raised concerns regarding the direction of causation between patronage and service levels, as it was unclear whether improved services generated more patronage, or whether higher demand for patronage encouraged provision of more services. He also raised concerns about short time periods and other statistical issues but acknowledged that some of these issues were caused by data constraints that were beyond the author's control.

2.2 Review of Econometric Modelling Methods

The econometric models most commonly employed in the international literature are partial adjustment models (PAMs) and error correction models (ECMs). Both of these models attempt to estimate the long-run relationships between public transport patronage and explanatory variables.

Unfortunately, both PAMs and ECMs were inappropriate for our analysis as they require data for a reasonable length of time in order to estimate the long-run relationships mentioned above. The data available to us were relatively short, covering time periods ranging from 4 to 8 years.

Kennedy and Wallis (2006) developed seasonal difference models and demonstrated that they were a useful alternative to the more commonly employed PAMs and ECMs. Seasonal difference models were applied to public transport patronage analysis by Wallis and Kennedy (2008). The advantages of seasonal difference models are discussed in more detail in Section 3, but one of the key advantages is that, unlike PAMs and ECMs, seasonal difference models produce valid estimates even over short time periods.

3. Econometric Methodology

The econometric methodology presented here involves understanding as much as possible about passenger growth and decline at the corridor-level (i.e. by train line or bus corridor). Data from all of these corridors is then bundled together and an econometric tool (called a panel data model) is used to determine the drivers of passenger demand across the whole network, while also controlling for any explanatory variables unique to particular corridor, such as maintenance disruptions or line-specific service improvements.

The three most distinguishing features of the econometric methodology adopted for this research project are that we:

(1) employed a seasonal difference model

(2) analysed patronage data that had been disaggregated by corridor

(3) developed a comprehensive set of stages designed to ensure that any findings were thorough and robust.

These features are discussed, respectively, in sections 3.1, 3.2 and 3.3.

3.1 Seasonal Difference Model

In Kennedy (2013) we reviewed the international literature relating to econometric modelling of public transport patronage and concluded that the preferred modelling approach was a seasonally differenced model.

In effect, this means that our modelling approach seeks to explain passenger growth rates rather than passenger numbers.

In a seasonal difference model, the dependent variable is the percent change[1] in patronage between a given quarter (e.g. 2007–Q1) and the same quarter in the previous year (e.g. 2006–Q1). The explanatory variables are the percent change in real petrol prices, fares, service levels, etc between the same two quarters.

The seasonal difference model can be represented using Equation 3.1.

$$\Delta_{SD}P_t = \propto + \beta\Delta_{SD}X_t + e_t \qquad \text{(Equation 3.1)}$$

where: $\Delta_{SD}P_t \approx$ % change in patronage between quarter t and quarter t-4

$\Delta_{SD}X_t \approx$ % change in explanatory variable/s between quarter t and quarter t-4

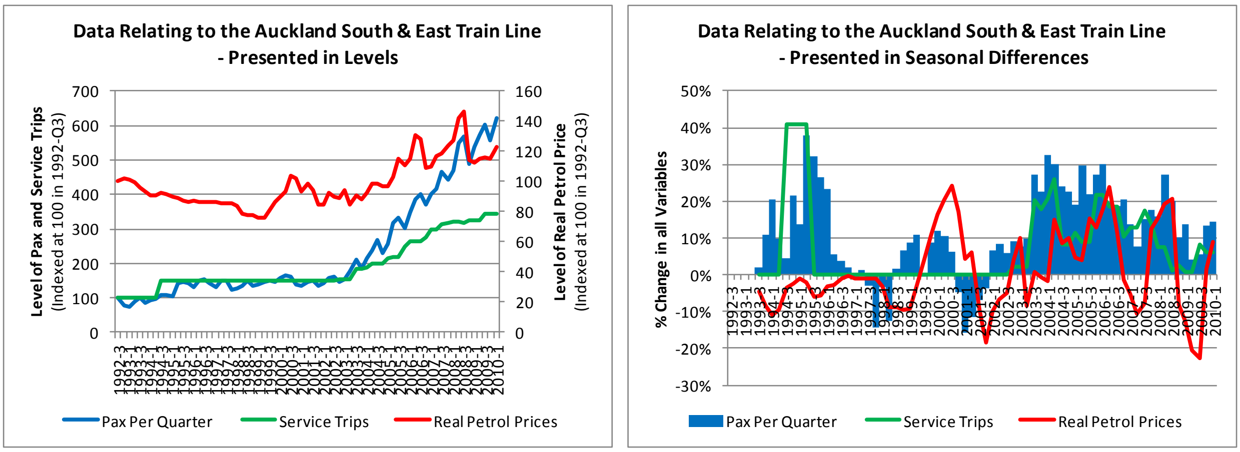
e_t= error term

The following advantages of seasonal difference models were identified by Kennedy (2013):

- Compared with more commonly employed models like simple regression models or partial adjustment models, seasonal difference models have a lower risk of producing ‘spurious’ or invalid results. Econometric theory implies that, as a rule, regression models of variables through time will provide more trustworthy estimates if the data shows a tendency to revert to a mean (ie ‘stationarity’). As the example in figure 3.1 demonstrates, this mean-reverting property is clearly lacking in the type of data employed in more common models, but it does become plausible after seasonal differencing.

[1]Strictly speaking, seasonal difference models are regressions using the seasonal differences of log-transformed levels of patronage, real petrol prices, real fares, service levels etc. However, the seasonal difference of a log-transformed variable is approximately the same as a % change in that variable.

Figure 3.1 Illustration of how seasonal differencing is required for 'stationarity'



- Seasonally differenced models simplify the analytical process because the process of calculating percentage change between, say, 2007–Q1 and 2006–Q1, filters away any seasonal patterns from the data in a clean and straightforward manner.
- Seasonal difference models are less likely to be affected by multicollinearity because, although explanatory variables may be highly correlated when expressed in levels, the % changes in those variables are usually less strongly correlated.
- Seasonal difference models impose less restrictive assumptions about the impact of explanatory variables on the dependent variables. In contrast, partial adjustment models assume that explanatory variables have an impact that declines exponentially through time and, furthermore, that the ratio of long-run to short-run impacts is the same for all explanatory variables.
- Seasonal difference models can produce valid findings even when the time series has covers relatively short time periods.

3.2 – Corridor Level Analysis

Kennedy (2013) notes that most econometric analyses of public transport patronage use regression models to explain patronage at the level of a city, urban area, or network.

However, we anticipated considerable benefits in using a panel data model to analyse passenger data that was disaggregated down to the level of the corridor (i.e. bus route, bus corridor or train-line).

The main advantage of the corridor-level panel data approach is that it enables us to distinguish *corridor-specific explanatory variables* from *generic explanatory variables*:

- *corridor-specific explanatory variables* relate to a specific bus route, bus corridor, or train line (e.g. timetable changes to a single route, line maintenance on a single line)
- *generic explanatory variables* have a similar effect across all corridors (e.g. petrol prices, fares, employment growth, etc).

The seasonal difference model shown in Equation 3.1 was modified, as shown in Equation 3.2 below, to accommodate a panel data approach:

$$\Delta_{SD}P_{ti} = \propto_i + \beta\Delta_{SD}X_t + \gamma_i\Delta_{SD}Z_{ti} + e_{ti} \qquad \text{(Equation 3.2)}$$

where: $\propto_i$ = time trend on each route/corridor/line i

$\Delta_{SD}P_{ti} \approx$ % change in patronage between quarter t and quarter t–4 for route/corridor/line i

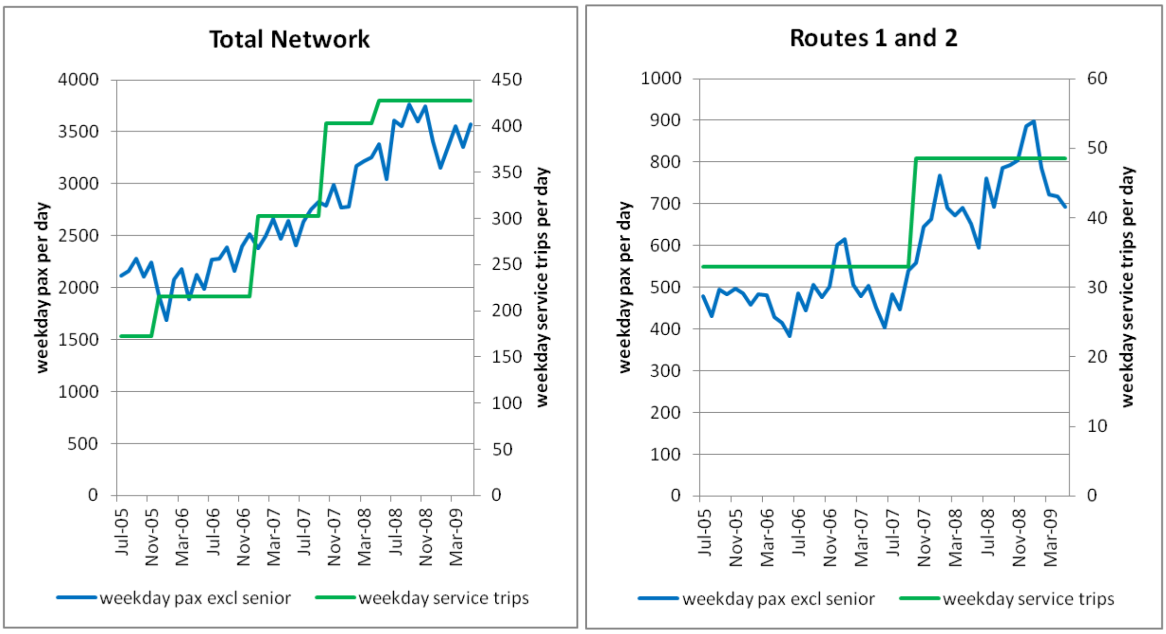
$\Delta_{SD}X_t \approx$ % change in *generic explanatory variable/s* (petrol prices, retail sales, etc) between quarter t and quarter t–4

$\Delta_{SD}Z_{ti} \approx$ % change in *corridor-specific explanatory variable/s* (service improvements, line maintenance, etc) between quarter t and quarter t–4 for route/corridor/line i

e_{ti} = error term

A corridor-level panel data approach enables us to control more accurately for the influence of these corridor-specific explanatory variables. For example, consider the series of service timetable improvements on the Tauranga bus network between 2005 and 2009. Figure 3.2 shows that the relationship between the number of service trips and patronage is difficult to ascertain if we only look at it from a network level.

Figure 3.2 Illustration of the benefit of panel data analysis



However, if we separate Routes 1 and 2 from the rest of the network then we can clearly see the impact of the doubling of frequency on routes 1 and 2 in Nov-07. A corridor-level panel data model facilitates this greater clarity.

There have been a few recent studies that apply a panel data approach to public transport analysis, but most do this at the level of county, urban area, or city. Dargay and Hanly (2002) fitted a panel data model to bus patronage disaggregated by county within England. Bresson et al (2004) fitted a panel data model to French patronage data disaggregated by urban area. Zhang et al (2012) used a panel data mode to Chinese patronage data disaggregated by city.

We are only aware of one other study that fitted a panel data model disaggregated by corridor: NERA (2003) used a panel data disaggregated by distance rail 'flows' between major urban centres. That study does not appear to have controlled for corridor-specific events and factors in the manner proposed by this paper.

3.3 – Stages of the Econometric Methodology

The econometric methodology consists of a series of stages designed to ensure that any findings are based on thorough analysis:

1. *Data collection and data manipulation* – the analytical process begins with data collection. The data then has to be checked and manipulated into a form that is suitable for econometric analysis.
2. *Graphical analysis* – we believe it is important to look at the data and make sense of it intuitively before proceeding onto econometric analysis. We generate graphs of passenger growth by corridor, and seek to explain and understand any trends or anomalies in the data. The observations here feed into the models tested in stages 4 to 7.
3. *Data analysis* – there are a number of statistical problems that can potentially undermine the validity of the econometric analysis. We examine the data for presence of these problems and respond accordingly where there is evidence of a problem.
4. *Model building process* – the process of building models for passenger growth involves fitting general models and testing the contribution made by the possible explanatory variables, removing those that look suspect or indeterminate, and whittling the model down to its core components.
5. *Diagnostic analysis* - the preferred model will still not be statistically valid unless the residuals of the model meet certain criteria. We examine the residuals of each individual line, in which we look for evidence of autocorrelation, non-normality or omitted variables.

4. Key benefit 1 – Disentangling and isolating explanatory variables

Transport planners want to understand what causes passenger numbers to grow or decline. By understanding the drivers of growth they can implement appropriate policies and plans to enhance that growth. Similarly, by identifying the causes of declines they can implement policies and plans to mitigate those declines and hopefully reverse them.

Unfortunately, identifying the drivers of growth and decline is challenging because there is a wide array of influences on passenger growth and decline. The Auckland rail network is a good example of this challenge.

Figure 4.1 shows year-on-year patronage growth on the Auckland rail system between 2001 and 2010, as well as various key explanatory variables.

Figure 4.1 – Total patronage growth on the Auckland rail system (2001-2010)

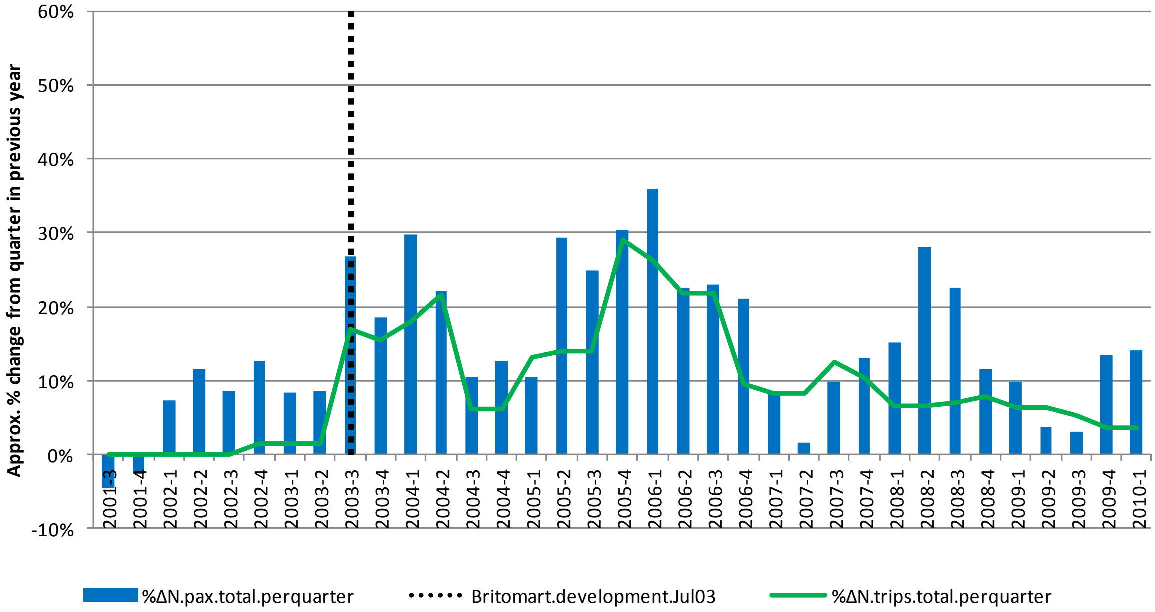


Figure 4.1 shows that the period between 2001 and 2010 was associated with high and volatile rates of patronage growth. The exact causes of this growth were difficult to ascertain.

In 2003-Q3, the Britomart station development was completed, creating train lines with a direct route into the Auckland CBD. It appears that this contributed to high rates of patronage growth from that point onwards.

Unfortunately (from a statistical perspective) the Britomart station development was also accompanied by a number of service timetable improvements. This made it difficult to disentangle the 'Britomart' effect from the 'service timetable' effect.

The task becomes even more challenging once other economic influences (fare increases, petrol price volatility, the global financial crisis, economic recession, etc) and a number of miscellaneous events (double-tracking construction, line maintenance, etc) are added in.

However, we found that a panel data model helped us isolate and disentangle some of those explanatory variables because we were able to distinguish between generic explanatory variables and line-specific explanatory variables, as shown by Table 4.1.

Table 4.1 Generic v line-specific explanatory variable

Generic explanatory variables	Line-specific explanatory variables	Comment on line-specific explanatory variables
• Real petrol prices • Real train fares • Real retail sales • Employment • Student discount • SuperGold • Stagecoach bus labour strike • Network signalling problem • Easter impact	• The Britomart development	The Britomart development had a positive impact on both lines, but the impact was greater for the Southern and Eastern lines
	• Service timetable improvements	The timing and magnitude of service changes differed across lines by timing and magnitude
	• Project Boston	Project Boston was the first stage of double-track construction on the Western line. This construction project limited services and had a negative impact on patronage.
	• Line maintenance	There were a number of line maintenance projects during Dec-08 and Jan-10 and these appear to have had an impact on patronage that differed by line

	• Changeover anomaly	There were anomalies in the data arising from the 'changeover' from the old operator (Tranz Metro) to a new one (Connex) on 22 August 2004. These anomalies in the data differed by line.

Figures 4.2 and 4.3 illustrate how line-specific explanatory variables have an impact that is unique to particular lines:

- The Project Boston double tracking construction project only affected the Western Line
- The completion of the Britomart development had a positive impact on both lines, but the impact was greater on the Southern and Eastern Lines.The post-Britomart time-trend was estimated to be 10% p.a. for the Southern and Eastern lines, compared to 15% p.a. for the Western line
- The timing and magnitude of service timetable improvements differed by line. On the Western line there were two notable service changes in 2005-Q4 and 2008-Q3. In contrast, the Southern and Eastern line only had one service change in 2006-Q4
- The timing and magnitude of service timetable improvements in Figures 4.2 and 4.3 show up as more 'lumpy' and discontinuous than in Figure 4.1 (where patronage is aggregated across all time periods and lines). These discontinuinities makes it easier for us to estimate the impact of these service improvements

Figure 4.2 – Interpeak patronage growth on the Western Line (2001-2010)

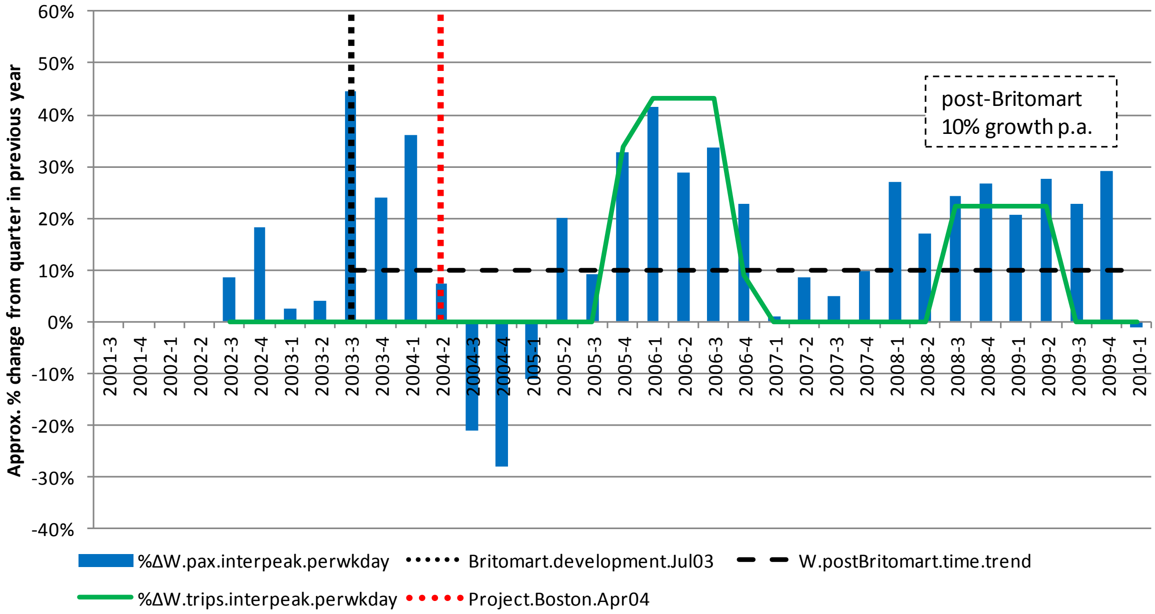
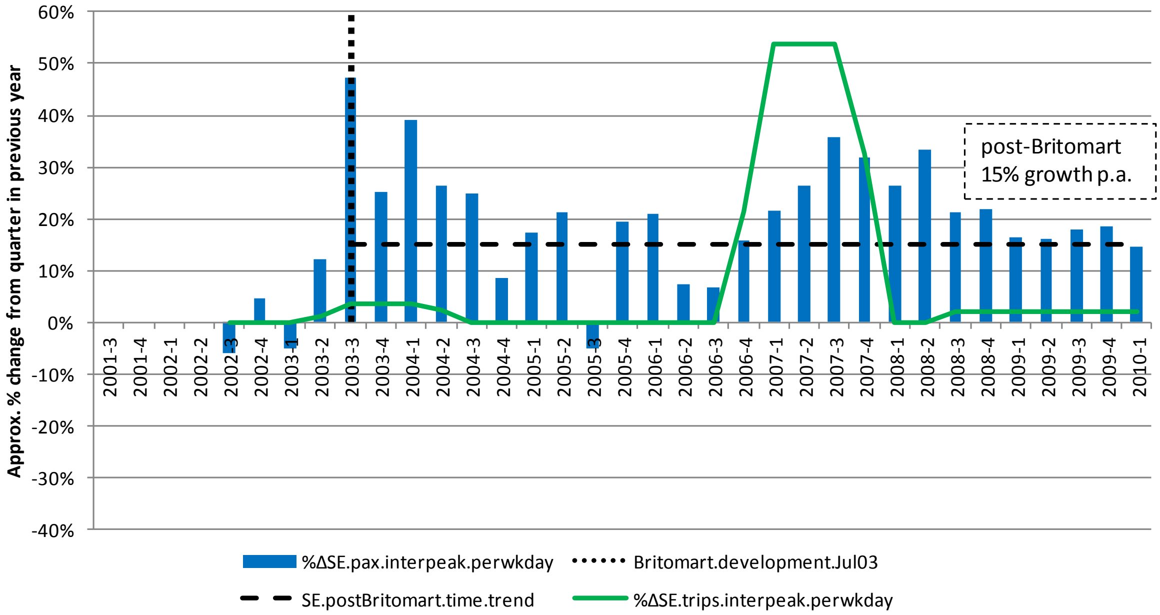


Figure 4.3 – Interpeak patronage growth on the Southern and Eastern Lines (2001-2010)



A line-specific panel data model exploits this uniqueness and uses it to estimate the impact of these line-specific explanatory variables. For the interested reader, these estimates are shown in Table A.1 of the Annex.

A line-specific panel data model also estimates the impact of generic explanatory variables more accurately because it controls for the line-specific explanatory variables mentioned above. Again, for the interested reader, these estimates are shown in Table A.2 of the Annex.

By combining our estimates for both line-specific and generic explanatory variables, we were able to tell a more complete 'story' about the drivers of patronage growth on a given network:

- The completion of Britomart generated a sustained period of high growth from 2003 through to recent years. Britomart was accompanied by more train services and an improved service timetable, and this clearly contributed to the observed growth. The service elasticity was +0.4 for weekday inter-peak and evening rail service improvements, +0.3 for Saturday rail service improvements, and +0.5 for the introduction of Sunday rail service improvements.

- But the more significant driver appears to have been some combination of the less tangible improvements associated with Britomart (i.e., greater convenience for commuters, publicity, and general enhancement of facilities).

- The real fare elasticity was -0.9. Therefore, a 10% increase in real fares caused a 9% fall in patronage (during the peak) and hence only a 1% increase in revenue.

- There was strong evidence of complex and non-linear responses to petrol prices, for example the crossing of the $2.00 nominal petrol price in 2008 was associated with a 'jump' in patronage. After controlling for that 'threshold effect', the real petrol price cross-elasticity was 0.0- to +0.2; this indicates that general petrol price moves had a modest impact on patronage in Auckland, with a 10% increase in real petrol prices causing a 0-2% increase in patronage.

- Employment growth appeared, as expected, to have a positive impact on peak-time passengers and a negative impact on inter-peak passengers. The employment elasticity estimates were, respectively, +1.2 and -1.2.

The findings above give a taste of what can potentially be achieved with the econometric methods presented here. There is considerable data already available that was not exploited by our research. We can see the econometric methodology being modified further to produce an even more comprehensive and insightful 'story'.

5. Key Benefit 2 – 'Post-evaluation' of service and network changes

In the author's opinion, the current practice in regard to public transport planning puts disproportionate emphasis on 'pre-evaluation'; that is, research and modelling of the theoretical patronage gains from proposed public transport investments.

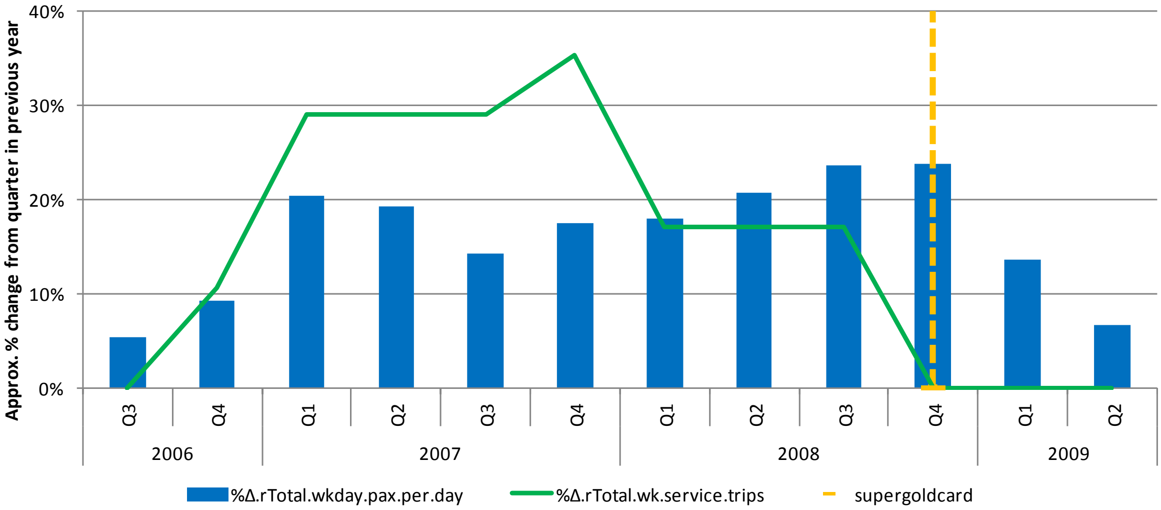
There is relatively little emphasis on 'post-evaluation' of the effectiveness of these investments, and use of this feedback to guide future investments. There are occasional attempts to evaluate the patronage generated by service changes of particular interest, but these attempts are usually somewhat ad hoc. Furthermore, findings are usually kept 'in-house'.

In Section 4 we note that our econometric methodology produces insight and increases accuracy because it enables us to control for corridor-specific explanatory variables.

However, the econometric methodology can also be modified to provide a systematic 'post-evaluation' of service and network changes. We have demonstrated how this can be done using an analysis of the Tauranga bus network.

Figure 5.1 shows patronage growth on the Tauranga bus network from 2005-2009.

Figure 5.1



Tauranga exhibited high patronage growth rates between 2005 and 2009. This was, in part, due to a number of interesting service improvements during this period:

- Frequency was doubled from hourly to half-hourly across a number of routes
- Hours of operation were extended on one route
- Some existing routes were removed and replaced by an 'orbiter' style service
- A new route was introduced.

Our analysis of the Tauranga bus network followed the same process as was described in Section 4. We used a panel data model to estimate coefficients for route-specific explanatory variables (see Table A.3) and generic explanatory variables (see Table A.4).

In an extension of the Tauranga bus network, we took the elasticities estimated in Table A.3 and used them to 'post-evaluate' the patronage benefits arising from each service improvement. This 'post-evaluation' analysis is shown in Table 5.1.

A 'post-evaluation' analysis like that shown in Table 5.1 can be used to assess the effectiveness of historic investments, and can guide future investments toward initiatives that maximise value for money. For example, consider the following insights from Table 5.1:

- The service change with the highest pay-off (in terms of passengers per service trip) was a simple one: the introduction of two extra morning services and one additional evening service. This had a pay-off of 14.6 passengers per service trip
- The introduction of a new route had a higher payoff than most improvements to existing services: 9.0 passengers per service trip
- The doubling of service frequency had a consistent impact across all routes in the sense that the service elasticity was +0.4 on average and generally ranged from +0.3 to +0.5. However, the pay-off in terms of passengers per service was higher on services with higher initial loading levels. For example, Route 9 with only 146.9 passengers had a pay-off of only 4.7 while Routes 1&2 with 566.6 passengers had a pay-off of 7.1
- The introduction of express services had a payoff of only 6.3 passengers per service trip if we only look at the effect after 1 year. However, after two years, this pay-off had increased to 10.3 passengers per service trip.

Table 5.1 'Post-evaluation' of Tauranga bus network changes and timetable improvements

Service Changes	Service trips per day		Elasticity calculations			Impact on weekday pax		
	Before	After	% change in service trips	% change in pax generated by new service trips	Estimated service elasticity	Pax per day (before)	Additonalpax generated per day	Additional pax generated per new service trip
Doubling of weekday frequency from hourly to 30 min								
Matua-Brookfield (4&5), Dec 06	24	36	50%	7%	0.17	341.6	24.4	**2.0**
Windermere Ohauiti (8), Dec 06	11.38	23.7	108%	45%	0.51***	182.5	82.9	**6.7**
Welcome Bay (9), Dec 06	12	23	92%	35%	0.46***	146.9	51.2	**4.7**
Bethlehem Brookfield (10), Oct 07	12	22	83%	28%	0.41***	153.9	43.4	**4.3**
Extension of hours (Additional depatures on route 9 at 6.05am, 6.40am and 7.15pm)								
Welcome Bay (9), Oct-07	23	25	9%	15%	1.65***	198.1	29.2	**14.6**
Doubling of weekday frequency from hourly to 30 min + Extension of hours (Additional departures on Route 1 at 8.30am and 7.15pm, additional departure on Route 4 at 7.15pm)								
Mount-Bayfair (1&2), Oct 07	33	49	48%	20%	0.46**	566.6	111.4	**7.1**
Matua-Brookfield (4&5), Oct 07	36	49	36%	10%	0.32'	366.0	37.9	**2.9**
Introduction of express service:								
Papamoa (6), Dec 06, immediate impact (0–4 qtrs)	11.75	25.5	117%	21%	0.25*	402.4	86.0	**6.3**
subsequent impact (5–8 qtrs)	11.75	25.5	117%	11%	0.14	488.4	56.0	**4.1**
cumulative impact (0–8 qtrs)	11.75	25.5	117%	35%	0.39	402.4	142.0	**10.3**
Transition to orbiter-type service:								
Greerton (7), Oct–07	30	35	17%	-6%	-0.37	468.8	-26.0	**-5.2**
Introduction of new service:								
The Lakes (12), Oct 07	0	12	n/a	n/a	n/a	0.0	107.9	**9.0**

6. Conclusions and Implications

This paper presents an econometric methodology designed to examine, understand and explain patronage growth rates at both the network level and corridor level (i.e. by bus route, bus corridor or train line).

The three most distinguishing features of the econometric methodology adopted for this research project are that we

(1) employed a seasonal difference model (i.e. we focused on explaining patronage growth rates rather than patronage levels).

(2) analysed patronage data that had been disaggregated by corridor, using a corridor-level panel data model.

(3) developed a comprehensive set of stages designed to ensure that any findings were thorough and robust.

There were two key benefits from this econometric methodology. The first benefit was that corridor-level analysis enabled us to isolate and disentangle the contributions of various explanatory variables. The second benefit was that the methodology also provided a systematic and scientific means of 'post evaluating' the pay-offs from network changes and service improvements.

In Kennedy (2013) we were able to demonstrate that this econometric methodology can produce relatively detailed and insightful analyses of patronage growth. Such analyses were produced for public transport networks in Auckland (bus and rail), Wellington (bus and rail), Hamilton (bus only) and Tauranga (bus only). In this paper, we use a few examples from the Auckland rail network to provide a taste of those analyses.

We have also modified our analyses of the Tauranga bus network to show how the econometric methodology can produce 'post-evaluations'. Such 'post-evaluations' will enable more evidence-based transport planning.

We will continue our development of the econometric methodology presented here. We believe that with further refinement of the methodology, and more detailed analysis of existing data, opportunities exist for even more insight into passenger growth.

These opportunities will only grow as new technologies like smart-cards and real-timeinformation generate a data-rich environment. In our opinion, econometric methodologies such as those presented here will need to be refined and honed so that transport planners are able to benefit fully from this new environment.

7. Acknowledgements

We thank the Australasian Transport Research Forum 2013 for providing us with the opportunity to present this paper and the ideas herein.

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- Ken McLeod (Auckland Transport) for recording and collaborating an impressive and comprehensive dataset of detailed data relating to the history of the Auckland rail network, and for providing insight into important issues and events on that network.
- Gary Malony and Emlyn Hatch (Bay of Plenty Regional Council) for compiling a wide array of data and documentation relating to patronage and service
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Although the contributions of all these organisations and people are acknowledged, the responsibility for any errors or omissions arising out of this research lie entirely with the author.

References

Bresson, G, J Dargay, J-L Madre and A Pirotte (2004) Economic and structural determinants of the demand for public transport: an analysis on a panel of French urban areas using shrinkage estimators. *Transportation Research Part A: Policy and Practice 38*, no.4: 269–285.

Colman, A (2009) *Comment: appraisal of factors influencing public transport patronage*. Referee report from Andrew Coleman, Motu Economic and Public Policy Research.

Dargay, JM and M Hanly (2002) The demand for local bus services in England, *Journal of Transport Economics and Policy 36,* no.1: 73–91.

Kennedy, D (2013) Econometric models for public transport forecasting. *NZ Transport Agency research report 518*. 407pp.

Kennedy, D and I Wallis (2006) 'Impacts of fuel price changes on New Zealand transport', *Land Transport New Zealand Research Report 331*. 138pp.

NERA (2003) *Research on long term fare elasticities, a final report for the Stategic Rail Authority, London*. 97pp.

Wallis, I and D Kennedy (2008) '*Go Wellington' patronage analysis*. Ian Wallis Associates, Report to NZ Bus Limited. 31pp.

Wang, J (2011) Appraisal of factors influencing public transport patronage. *NZ Transport Agency research report 434.* 176pp.

Zhang, D, X Yang, J Teng, J Ann, G Chen and R Cai (2012) Socioeconomic development and urban public transit, ridership in China: panel data model based empirical analysis. *TRB 2012 Annual Meeting*, 28pp.

Annex

Table A.1 – Auckland rail - Estimates for line-specific explanatory variables

Line-specific time-trends		Weekday			Weekend
		Peak	Interpeak	Evening	
Pre-Britomart time trends	Southern and eastern	5%	8%	-1%	12%
	Western	5%	16%**	12%	18%‘
Post-Britomart time trends	Southern and eastern	9% ***	15%***	10%**	18%***
	Western	5%*	10%***	8%*	14%***
Line-specific events		**Weekday**			**Weekend**
		Peak	**Interpeak**	**Evening**	
Temporary opening effect of Britomart (southern and eastern)					74%***
Temporary opening effect of Britomart (western)					83%***
First year of Britomart (southern and eastern)		R	37%***	17%*	11%
First year of Britomart (western)		RI	28%***	RI	RI
Project Boston construction (western, Apr 04)		RI	-17%***	-11%‘	-22%*
Changeover anomaly (southern and eastern)		10%**	15%*	9%	27%*
Changeover anomaly (western)		8%**	9%‘	1%	13%
Line maintenance (southern and eastern, Dec 08)		-5%	-4%	-8%	RI
Line maintenance (western, Dec 08)		-2%	-4%	-22%*	-42%**
Line maintenance (southern and eastern, Jan 10)		-3%	-3%	-6%	RI
Line maintenance (western, Jan 10)		-19%***	-14%'	-24%*	-39%*
Service elasticities		**Weekday**			**Weekend**
		Peak	**Interpeak**	**Evening**	
Weekday service timetable improvements	Short-run (0-1 years)	0.15	0.34***	0.36***	
	Medium run (1-2 years)	0.55***	0.10	RI	
Saturday service timetable improvements					0.28‘
Introduction of Sunday services					0.48
Sunday service timetable improvements					RI

Note regarding statistical significance: *** → 0.1%, ** → 1%, * → 5%, ‘ →10%,

RI denotes ‘removed due to implausible sign’

Table A.2 Auckland rail – Estimates for generic explanatory variables

Economic Elasticities	Weekday			Weekend
	Peak	Interpeak	Evening	
Real rail fare elasticity	-0.89***	RI	-0.13	RI
Real petrol price cross-elasticity	0.08	RI	0.52*	0.48
$2.00 petrol price threshold dummy	RI	RI	17%	CIH
Real retail sales cross-elasticity	-0.15	-0.71	2.31***	0.21
Employment cross-elasticity	1.19*	-1.15*	-0.36	-1.19
Miscellaneous Events	**Weekday**			**Weekend**
	Peak	**Interpeak**	**Evening**	
Increase in tertiary student discount	3%	8%	21%‘	RI
Introduction of SuperGold Card dummy (Oct 08)		RI	RI	CIH
Stagecoach Bus labour strike (May 95)	2%	RI	5%	5%
Network signalling problem (Apr 07)	-3%	-1%	-9%	-3%
Easter dummy	-3%‘	0%	0%	-6%

Note regarding statistical significance: *** → 0.1%, ** → 1%, * → 5%, ‘ →10%,

RI denotes ‘removed due to implausible sign’ and CIH denotes ‘coefficient implausibly high’

Table A.3 Tauranga bus - Estimates for route-specific explanatory variables

Route-specific Service Elasticities		Weekday
Doubling of frequency from hourly to 30 min + extension of hours:	Mount-Bayfair (1&2), Oct 07	0.46**
	Matua-Brookfield (4&5), Oct 07	0.32‘
Doubling of frequency from hourly to 30 min	Matua-Brookfield (4&5), Dec 06	0.17
	Windermere Ohauiti (8), Dec 06	0.51***
	Welcome Bay (9), Dec 06	0.46***
	Bethlehem Brookfield (10), Oct 07	0.41***
Extension of hours:	Welcome Bay (9), Oct 07, Dec 06	1.65***
Introduction of express service:	Papamoa (6), Dec 06, SR impact (0–4 qtrs)	0.25*
	MR impact (5–8 qtrs)	0.14
Transition to orbiter-type service:	Greerton (7), Oct 07	-0.37
Cannibalisation Rates		**Weekday**
Proportion of patronage on new Lakes (12) service (introduced May 08) that was 'cannibalised' off other routes:	Greerton (7)	-9%
	Windermere Ohauiti (8)	RI
	Pyes Pa (11)	-11% '
Route Specific Event		**Weekday**
Route change relating to Pillans Rd	Belvedere Brookfield (3), Oct 06	16%***

Note regarding statistical significance: *** → 0.1%, ** → 1%, * → 5%, ‘ →10%,

RI denotes ‘removed due to implausible sign’

Table A.4 Tauranga bus - Estimates for generic explanatory variables

Economic Elasticities	**Weekday**
Real petrol price	0.25*
Real retail sales (Tauranga city)	0.06
Employment (Tauranga city)	1.22***
Miscellaneous Events	**Weekday**
Nominal $2.00 petrol price threshold	8%
Introduction of SuperGold Card (Oct 08)	16%***
Easter/Jazz Festival	RI

Note regarding statistical significance: *** → 0.1%, ** → 1%, * → 5%, ‘ →10%,
RI denotes ‘removed due to implausible sign’