Regionalisation of the National Land Transport Demand Model

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Abbreviations and acronyms

GDE	gross domestic expenditure
GDP	gross domestic product
IRD	New Zealand Inland Revenue
km	kilometre(s)
NLTDM	National Land Transport Demand Model
NZHTS	New Zealand Household Travel Survey (Ministry of Transport)
NZIER	New Zealand Institute of Economic Research
RLTDM	Regional Land Transport Demand Model
Transport Agency	New Zealand Transport Agency
VKT	vehicle kilometres travelled

Contents

Executive summary

Objective: enhance a national demand model for regional analysis

This report presents research undertaken to convert the New Zealand Transport Agency's National Land Transport Demand Model (NLTDM) to a Regional Land Transport Demand Model (RLTDM).

The RLTDM is intended to be used to construct quantitative long-term (30 year) regional transport planning scenarios.

Scope: socio-demographic and transport demand projections in 12 regions

The model contains considerable socio-demographic detail in order to connect long-term transport demand to primitive drivers of demand such as numbers of people in a region and their age or industrial composition of a region. This is similar to the previous NLTDM.

The RLTDM provides projections of transport demand by region. There are 12 regions in the model rather than the 16 areas usually defined as regions in New Zealand. Gisborne and Hawke's Bay are combined in a single region and an 'Upper South Island region' is used containing Nelson, Tasman, Marlborough and the West Coast.

The RLTDM can be used to conduct deterministic scenarios or to measure uncertainty associated with future transport demand given observable historical drivers of uncertainty in the economy and demographically.

Four key model developments covering migration, travel demand, mode choice and freight

This research resulted in four developments to the NLTDM to make it fit for purpose for constructing regional scenarios:

- improved modelling of inter-regional migration flows
  - based on origin-destination age-specific migration probabilities
  - included because inter-regional migration is a crucial source of regional population uncertainty
- intra-regional density effects, land use and transport demand (congestion)
  - captured through the use of canonical but stylised relationships between population growth and density and functional relationships to congestion and costs of travel
- regional mode of travel choices
  - based on regionalised conditional logit models of discrete choice
- inter-regional freight flows
  - based on introducing origin–destination matrices for freight flows.

A sample of key results

The purpose of this report is first and foremost to document the technical details of the RLTDM model developments for those who intend to use the model. Some of those details are a little arcane and not for a general audience.

Nonetheless, many of the findings in this report will be of general interest for people trying to understand transport demand in New Zealand and across New Zealand's regions. Not all of these are novel, but we present them here for sake of completeness.

Results of regional travel demand analysis

Analysis of journeys by household and by region showed:

- regional sensitivity to costs of travel reflects a number of underlying factors including population composition and relative incomes
- people who live alone (often retired people) and solo parent families tend to be more income constrained than most and exhibit greater sensitivity to travel costs than other households
- households in Northland are the most sensitive to changes in travel costs and people in Taranaki and Auckland are the least sensitive
- in densely populated and urban regions, where speeds are relatively low, increased speeds have a positive effect on number of journeys
- in rural areas where speeds are relatively high, an increase in speeds reduces the number of journeys.

Key drivers of changes to travel demand include:

- a 10% increase in average costs of travel (dollars per km) is associated with a 0.3% reduction in travel demand, though this value varies according to shares of costs in household budgets (incomes) and over time as costs rise and fall
- a 10% increase in the percentage of people unemployed yields a 0.1% reduction in travel demand nationally holding all else constant while controlling for differences in density across regions – impacts are larger in more densely populated regions
- a 10% increase in population density is associated with a 0.8% increase in travel demand, holding all else constant but controlling for differences in unemployment and travel speeds across regions – impacts are larger in less densely populated areas
- a 10% increase in travel speed is associated with a 14% increase in travel demand, holding all else constant while controlling for differences in density across regions.

Results of mode choice modelling

Analysis of mode choice resulted in a finding that when cost increases are isolated in one mode or another consumers find a substitute to that mode, but changes are not large. For example, a 10% increase in the cost of driver travel per dollar of household income causes an average 0.2% reduction in driver trips.

When driver trips reduce, most of the change is caught in increased passenger trips. The proportionate change in passenger trips (0.4%) is similar to the proportionate increase in public transport (bus and train) use but passenger volumes are a much larger absolute share accounting for 26% of journeys compared with 2% for public transport.

Some key regional results include:

- stronger mode substitution in urban areas such as Auckland and Wellington where:
  - population density is higher
  - public transport accessibility is higher

- overall sensitivity to changes in costs appear largest in regions with lower incomes
- mode choice in Wellington stands out as being remarkably unresponsive to changes in travel costs.

Results of regional freight flow analysis

Population size appears to be the most important driver of freight tonne-km flows with a 10% increase in population associated with a 16.8% increase in freight flows.

This impact is smaller than the impact of a 10% increase in share of services in gross domestic product (GDP) but a 10% increase in services share of GDP is generally harder to come by than a 10% increase in population.

There is a negative relationship between GDP at origin and gross freight flows. This is a little counterintuitive but it may reflect the fact that on balance the growth margin in New Zealand industry is in services and that when a region is growing it is increasing its ability to service its own needs.

Abstract

Research was undertaken to convert a National Land Transport Demand Model to a Regional Land Transport Demand Model. The new is intended to be used to construct quantitative long-term (30 year) regional transport planning scenarios. Model development undertaken included a series of regional and spatial econometric models covering: intra-regional density effects, land use and transport demand (congestion); regional mode of travel choices; inter-regional freight flows by origin and destination; and calibration of regional migration based on age- and location-specific propensities to migrate.

1 Introduction

This report presents the results of research undertaken to enhance the existing National Land Transport Demand Model (NLTDM) (Stephenson and Zheng 2013) with the overall objective of producing a Regional Land Transport Demand Model (RLTDM).

1.1 Objective

The NLTDM contains models of regional land transport demand but these models are mainly used to take account of the effects of regional variations on aggregate national demand. Thus the NLTDM is not as well equipped as it might be for region-specific analyses. The objective of this research is to build more refined regional models and thus to produce a model with improved capability to conduct regional analysis.

Two main weaknesses of the NLTDM for regional analysis, addressed by this research, are:

- limited region-specific detail on household travel demands and travel demands by mode within regions
- cursory treatment of the difference between where freight transport originates and where it ends up.

Much of the research presented in this report thus focuses on improving these aspects of the NLTDM.

That said, the research agenda was not constrained to only these issues, and improvements to supporting economic and demographic models were also investigated.

The RLTDM will be used to (a) project demand trends for transport by mode by region and (b) conduct scenario analysis of the structural impact on demand of major changes to demand drivers such as fuel prices, industry activity, incomes and inter-regional migration.

Scenarios were specified by the New Zealand Transport Agency ('the Transport Agency'). They were primarily qualitative and constructed around a handful of possible mega- or meta-trends. From discussion with officials the key trends of interest to the Transport Agency, summarised in figure 1.1 were identified.

1.2 Approach

The overall approach followed in developing the RLTDM was broadly the same as for the NLTDM. This limited the scope of model development in terms of new analytical and solution techniques.

The general approach of the NLTDM was to break transport demands down into three different components. For this work we add a fourth dimension:

- **trends** and patterns due to path dependencies, eg:
  - population growth, age structure and location
  - economic growth
- deviations from trend path dependencies due to relative price and income effects, eg:
  - fuel price shocks
  - income effects

- temporal interdependencies, eg:
  - co-movement of industry growth
  - transmission of shocks over time.
- spatial interdependencies, eg:
  - migration
  - freight flows.

The over-arching approach is best described as 'simulation' analysis. It differed from 'constrained optimisation' and 'equilibrium' techniques used elsewhere to model regional transport and economic dynamics.[1]

The implications of our approach were minimal in the context of developing the NLTDM for region-specific analysis. The simulation approach did, however, preclude borrowing from some of the models used elsewhere such as regional equilibrium and optimisation models. These tend to be more detailed and are best described as 'bottom-up' models typically focused on integrating land-use and transport decisions.[2] Our simulation method was more of the 'top-down' variety.[3]

There are nine broad components or sub-models which make up the overall model. These are reflected in figure 1.1 showing amendments made to the NLTDM in the course of this research. These are broadly sequential. They start with the most primitive components, population and regional population, and move progressively towards greater degrees of detail, uncertainty and assumptions.

1.3 Key developments and report structure

The results of the research, in terms of improvements to the NLTDM, are summarised in figure 1.1. Additions are highlighted in red underlined text and where major parts of the NLTDM have been removed these elements are indicated with strikethrough.

This report focuses on the main developments undertaken to produce the RLTDM. The more straightforward amendments (such as changes to the number of industries in the model) are not discussed further here.

The research resulted in four developments[4]:

1 Inter-regional migration, based on origin-destination age-specific migration probabilities

2 Intra-regional density effects, land use and transport demand (congestion) – captured through the use of canonical but stylised relationships between population growth and density and functional relationships to congestion and costs of travel

3 Regional mode of travel choices based on regionalised conditional logit models of discrete choice

[1] We explored several alternative modelling methods and frameworks but all of these would have been extremely costly to implement as implementation would have required a complete departure from the methods in the NLTDM.

[2] See for example Jin et al (2013) and Bain et al (2011).

[3] Examples of this sort of approach for evaluating long term policy are most frequently found in the applied economics literature (see Barnes et al 2011) as opposed to the transport and planning literatures. The reason for this would seem to be the more prescriptive traditions which exist in planning and engineering.

[4] The focus for model development was decided by the research steering group.

4 Inter-regional freight flows, based on introducing origin–destination matrices for freight flows.

The rest of this report steps through each of the above areas of development in a separate section. The discussion is somewhat technical and in places very descriptive (eg sections on data) so as to document the work undertaken. The report does not document those aspects of the RLTDM that remain unchanged from the NLTDM.

Each section begins with a description of the NLTDM components that have been developed and why. This is followed by a non-technical summary of development methods and some key results for readers not interested in the detail.

The bulk of each section consists of the final sets of analytical results arising from the developments and used in the RLTDM. In addition, tables of analytical results are added to the appendices to this report. These are important context for the main or 'final' results of the analysis.

The regional dimensions used in this report mirror those used in the NLTDM where Gisborne and Hawke's Bay are combined in a single region and an 'Upper South Island region' is used containing Nelson, Tasman, Marlborough and the West Coast. These aggregations are also used by Statistics New Zealand for surveys where small samples limit disaggregation, such as for the Household Economic Survey[5].

Even with a reduced number of regions (12 instead of the official 16 administrative regions) there is still considerable variation between regions which makes inference and model building quite challenging. That is, models which fit densely populated urban regions reasonably well are not easily used to describe regions with highly variable geographies and small populations yielding limited data points. This is unavoidable because variation in economic activity within most regions is larger than across regions.

[5] www.stats.govt.nz/browse_for_stats/people_and_communities/Households/household-economic-survey-info-releases.aspx

Figure 1.1 RLTDM model dimensions*

Population	Growth and incomes	HH vehicle demand	Freight demand	Prices	Vehicle fleet	VKT and cost	HH travel
Outputs Population by age and sex Households, by type Average age of households Number of people per household Labour force Long-run employment **Scope** Ages 0 to 100 years 6 Household types: alone, one parent, two parent, couple, multi-person, multi-family 12 regions: Northland, Auckland, Waikato, Bay of Plenty, Gisborne-Hawke's Bay, Taranaki, Manawatu-Wanganui, Wellington, Upper South Island, Canterbury, Otago, Southland **Input assumptions and key statistical models** Migration modelled via region-specific origin-destination migration probabilities plus a VAR model for calibrating uncertainty Age-specific mortality and fertility Living arrangement type rates (LATRs) Labour force participation rates Long-run unemployment rates	**Outputs** GDP by industry and region HH incomes by type and region **Scope** As for population plus 16 industries to align with Statistics NZ regional GDP industries. **Input assumptions and key statistical models** National and industry multifactor productivity growth Trend growth in industry GDP Historical covariance between industries in economic activity (VAR model) Relationship between GDP per capita and HH incomes	**Outputs** Vehicles per household by region and HH type **Scope** As for population plus forecast probability a HH will own 0, 1, 2, 3 or more vehicles **Input assumptions and key statistical models** Generalised linear model (logistic) of conditional probabilities (by HH type) of vehicle ownership based on income, average age, population density and a Wellington dummy (re-estimated on 2013 data)	**Outputs** Freight volumes by mode, industry, and region Road freight tonne-kilometres **Scope** 8 industries and 12 regions and three modes: rail, sea, road **Input assumptions and key statistical models** Trends in freight and freight intensity (value of freight input per unit of GDP by industry) based on industry GDP plus regional freight flows, origin and destination, modelled by gravity-style spatial interaction models.	**Outputs** Taxes Fuel price at pump Vehicle price trends NLTF revenue **Scope** NZ Scope for adding local taxation scenarios **Input assumptions** Long-run exchange rate Inflation (CPI) ETS costs Oil prices	**Outputs** Number of vehicles by age, type, technology, and size **Scope** Ages 0 to 30 Types: light passenger, light commercial, motorcycle, heavy commercial, bus Technology: Petrol, diesel, hybrid, electric, and plug-in hybrid Sizes based on engine cc rating: 5 light sizes, 2 motorcycle sizes, 9 heavy sizes and 3 bus sizes **Input assumptions and key statistical models** Fuel efficiency Age of import Registrations of alternative fuel vehicles Number of registrations that are new vehicles Scrappage rates	**Outputs** VKT by non-private passenger vehicles by vehicle type and age Emissions by vehicle type and age Cost per kilometre of travel, by vehicle type Tax revenue from transport Model tracks implied PT subsidies on regional basis **Scope** Vehicles as for vehicle fleet. **Input assumptions and key statistical models** VKT by vehicle age Travel behaviour and congestion impacts on fuel consumption Emissions factors	**Outputs** Passenger kilometres by public transport and private passenger vehicle Passenger vehicle VKT **Scope** Regions Passenger transport mode **Input assumptions and key statistical models** ~~Regional distributions of VKT~~ ~~Regional vehicle ocupancy trends~~ ~~Age distributions in propensity to use public transport~~ ~~VKT cost and income elasticities~~ ~~PT fuel price and income elasticities~~ Panel model of household travel by region and by household type based on household survey data. Mixed logit mode choice model predicting mode choices by region by household by age.

*Items in red and underlined are amendments to the NLTDM. Other aspects are common to the NLTDM and RLTDM models

2 Inter- regional migration

2.1 Populations and migration in the NLTDM

The most important structural aspect of the NLTDM is the projection of underlying population growth, age and household composition and location by region. This part of the model includes significant detail to accommodate a wide range of possible scenarios about demographics and living arrangements.

Key outputs of this part of the model are:

- national and regional populations by age and sex
- numbers of households by household type, by region
- average age of households
- number of people per household
- labour force
- long-run employment.

We used a modified cohort component method where population was broken down by size and age and evolved according to a transition matrix *T* plus net migration (*i-m*):

$$p_t = T.p_{t-1} + i_t - m_t \quad \text{(Equation 2.1)}$$

$$T = \begin{bmatrix} F_1 & \cdots & F_i & \cdots & F_k \\ P_1 & 0 & 0 & \cdots & 0 \\ 0 & \ddots & 0 & \cdots & 0 \\ 0 & 0 & P_i & \cdots & 0 \\ 0 & 0 & 0 & P_{k-1} & 0 \end{bmatrix}$$

Where *F* is age-specific fertility rates and *P* is the probability of a person shifting from one age group at time *t* to the next age group at time *t+1*. *T* evolves with time with:

- changes in age-specific fertility rates based on autoregressive time series forecasts
- changes in age-specific mortality rates based on Statistics New Zealand's (2009) medium scenarios.

In the NLTDM net migration was initially held constant, using Statistics New Zealand's population projection assumptions, but was subject to both scenarios and stochastic dimensions (see below).

The stochastic dimension of the population model is applied at a fairly aggregated level (following the approach of Dunstan (2011)[6]) to net migration – which underpins most of the uncertainty in population growth amongst the age groups of particular interest to us.

Net migration was modelled as an ARIMA (1,0,1) process:

$$N_t = \rho.N_{t-1} + \theta.\varepsilon.N_{t-1} + \varepsilon.N_t + \mu.N_t \quad \text{(Equation 2.2)}$$

[6]) We note that since our model was constructed Statistics New Zealand has begun publishing official stochastic population projections.

For the purposes of stochastic projections the error (ε) is sampled randomly from a normal distribution (with standard errors from historical estimation). We assumed that the age profile of migrants was the same as the average over the past 10 years.

2.2 Key results of model development

A fixed propensity model of origin–destination migration flows was constructed. This model was developed to improve the way the model accounts for inter-regional labour market adjustments and population growth and therefore regional differences in transport demand.[7]

During the course of the research we considered a range of modelling approaches including quasi spatial equilibrium approaches incorporating economic growth and house prices as determinants of migration and affected by migration. These approaches were discarded because they limited the ability of model users to interact with the model and impose scenarios.

The final model captures persistent pattern and differences in migration rates across regions and age-groups, for example:

- people aged 15 to 25 have the highest propensity to emigrate
- urban regions (Auckland, Wellington, Canterbury) have:
  - the lowest rates of emigration (see figure 2.1)
  - the highest rates of international immigrant arrivals (eg table 2.1)
- Auckland is the destination of nearly half of all migrants, domestic and international
- inward migrants to New Zealand are, on average, older than outward migrants from New Zealand.

The model uses mean observed migration rates, by region and age group, from the 2006 and 2013 censuses. This is supplemented with data on mean migration rates, by region and age group from Statistics New Zealand's International Travel and Migration data[8].

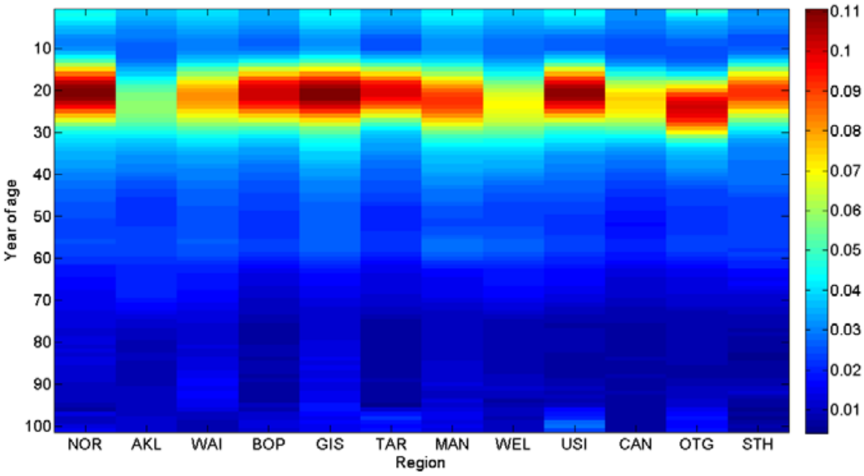
A mean over the two census period is used because migration rates differed significantly in the 2006 and 2013 censuses.

[7] Other minor adjustments were made to the model. For example, the NLTDM was limited to ages 0 to 90 while the RLTDM was extended to include 0 to 100 years of age.

[8] www.stats.govt.nz/browse_for_stats/population/Migration/international-travel-and-migration-info-releases.aspx

Figure 2.1 Probability of emigration, conditional on age and region of residence

Average over migration rates for 2001–2006 and 2008–2013



Abbreviations: NOR = Northland, AKL = Auckland, WAI = Waikato, BOP = Bay of Plenty, GIS = Gisborne and Hawke's Bay, TAR = Taranaki, MAN = Manawatu-Wanganui, WEL = Wellington, USI = Upper South Island (Nelson, Marlborough, Tasman, West Coast), CAN = Canterbury, OTG = Otago, STH = Southland
Source: Author's calculations, Statistics New Zealand Census

Table 2.1 Probability an international migrant arrives in a region

	Age group								
Region	0-15	16-25	26-35	36-45	46-55	56-65	66-75	76-85	86+
Northland	0.02	0.02	0.02	0.02	0.03	0.03	0.02	0.03	0.03
Auckland	0.48	0.43	0.41	0.41	0.41	0.43	0.49	0.46	0.48
Waikato	0.07	0.06	0.06	0.06	0.06	0.06	0.06	0.05	0.06
Gisborne-Hawke's Bay	0.03	0.02	0.03	0.03	0.03	0.03	0.02	0.03	0.03
Bay of Plenty	0.05	0.04	0.04	0.05	0.05	0.05	0.05	0.04	0.05
Taranaki	0.02	0.02	0.02	0.02	0.02	0.02	0.01	0.01	0.01
Manawatu-Wanganui	0.04	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03
Wellington	0.10	0.09	0.11	0.10	0.10	0.09	0.09	0.08	0.08
Upper South Island	0.03	0.02	0.03	0.03	0.03	0.03	0.03	0.03	0.03
Canterbury	0.12	0.12	0.12	0.11	0.10	0.10	0.08	0.11	0.11
Otago	0.04	0.04	0.04	0.03	0.03	0.03	0.02	0.02	0.02
Southland	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01

Source: Author's calculations, Statistics New Zealand International Travel and Migration

2.3 Migration model

The migration model is specified in three parts:

1. Trend growth in international inward migration rates (annual inward migration as a share of the resident population in the previous year)
2. Trend growth in rates of outward migration
3. Propensity for a migrant to choose a particular region.

2.3.1 Inward migration from overseas

Trend growth (α^m) in international immigration rates (m_t) is a constant value based on historical averages. A time-varying deflator (β_t^m) is used to smooth the adjustment (mean reversion) of migration flows rather than let the model leap to historical averages. The number of immigrants ($M_{i,t}$) by age (i) over time (t) is based on a set of fixed probabilities, $P(i = j|M),$ observed on average over the past 15 years:

$$m_t = m_{t-1}.\frac{\alpha^m}{\beta_t^m} + \epsilon_t^m$$
$$M_{i,t} = P(i = j|M).m_t.p_{t-1}$$ (Equation 2.3)

Where p_{t-1} is the resident population of New Zealand in the previous year and ϵ_t^m is a period-specific random normal shock assumed to be normally distributed with zero mean and standard deviation evaluated in a vector error correction model discussed below.[9]

2.3.2 Outward migration from regions

The model of emigration rates is similar to the international immigration model but age- and region-specific values enter the model from the outset and growth rates for outward migration rates are fixed by default ($\alpha_i^e = 1, \forall i$):

$$e_{i,t}^r = e_{i,t-1}^r.\frac{\alpha_i^e}{\beta_t^i} + \epsilon_t^i$$
$$E_{i,t}^r = e_{i,t}^r.p_{i,t-1}^r$$ (Equation 2.4)

Age- and region-specific emigration flows ($E_{i,t}^r$) are dependent on age- and region-specific probabilities of migration and the number of people of that age in the region in the previous year ($p_{i,t-1}^r$).

The value ϵ_t^i is a random normal shock assumed to be normally distributed with zero mean and standard deviation evaluated in a vector error correction model discussed below.

2.3.3 Modelling choice of migrant destination

Migrant choice of destination ($M_{i,t}^d$) is based on fixed probabilities of destination choice given the age and origin region of the migrant:

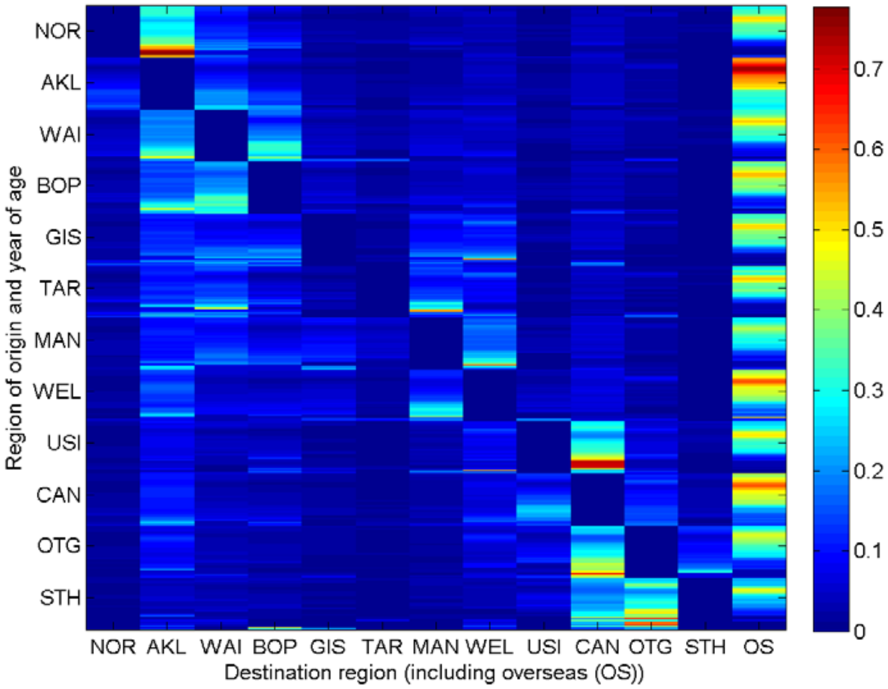
$$M_{i,t}^d = P(d = j|r,i).E_{i,t}^r + P(d = j|i).M_{i,t}$$ (Equation 2.5)

The destination probabilities are summarised in figure 2.3.

[9] Note that, because the above process is a random walk with drift, shocks are cumulative. However, the size of effects on population size is ambiguous because rates of immigration and emigration are proportionate to domestic population sizes so increasing inward migration also increases outward migration. This is why we use a vector error correction model to evaluate migration trends and to parameterise the stochastic component of the model.

Figure 2.3 Migrant destinations given origin and age

Probability of choosing a destination to migrate to, given origin and age within origin. There are 101 years of age in the data and 12 regions and thus 1212 categories on the left axis. Region labels on the vertical axis are aligned to the middle (50th) year of age for the region.



Source: Author's calculations, Statistics New Zealand Census

2.3.4 Model of stochastic component

The stochastic (random) component of the model is based on a simple vector error correction model relating economic activity (gross domestic expenditure (GDE) per capita), outward migration and inward migration.

This sort of model is used because it captures the simultaneity or endogeneity of all three variables. That is, GDE per capita is modelled as a function of people arriving and leaving, and people arriving and leaving is modelled as a function of GDE. The model is:

$$\Delta y_t = A.y_{t-1} + \sum_{i=1}^{3} B.\Delta y_{t-i} + \epsilon_t \qquad \text{(Equation 2.6)}$$

Where y_t is a vector of observations of three variables: GDE per capita, immigrant arrivals and immigrant departures. The matrix A contains the parameters reflecting long-term equilibrium (cointegrating) relationships between variables. The matrix B reflects parameters governing the adjustment of the system back towards equilibrium.

The model is estimated on annual data for 1988 to 2013. The estimated parameters are shown in table 2.2. The model itself is of only secondary interest in the sense that it is being used to set aside predictable sources of changes in migration and to identify the scale of 'truly' random aspects.

Note that the random component of migration in the RLTDM can be defined by users. The purpose of this model then is to judge what the reasonable order of magnitude is for such parameters.

Give the residuals (vector of error terms or ϵ_t) from fitting the model we find that the:

- standard deviation for the arrival rate is 0.044
- standard deviation for the departure rate is 0.076.

Table 2.2 Model used to parameterise migration rate uncertainty

Cointegrating eq:	**Parameter**		
LN(DEPARTURE_RATE(-1))	1		
LN(ARRIVAL_RATE(-1))	3.37		
	0.28		
LN(GDE(-1)/POP(-1))	-3.45		
	0.24		
C	5.35		
Error correction:			
	Difference in LN(DEPARTURE_RATE)	Difference in LN(ARRIVAL_RATE)	Difference in LN(GDE/POP))
Cointegrating equation	-0.09	-0.65	0.04
Standard error	0.28	0.16	0.05
Difference in LN(DEPARTURE_RATE(-1))	0.26	0.07	-0.08
Standard error	0.36	0.21	0.07
Difference in LN(DEPARTURE_RATE(-2))	-0.26	0.21	0.02
Standard error	0.33	0.19	0.06
Difference in LN(DEPARTURE_RATE(-3))	0.25	0.17	-0.03
Standard error	0.35	0.21	0.06
Difference in LN(ARRIVAL_RATE(-1))	-0.10	1.37	-0.03
Standard error	0.55	0.32	0.10
Difference in LN(ARRIVAL_RATE(-2))	0.08	0.42	-0.14
Standard error	0.44	0.26	0.08
Difference in LN(ARRIVAL_RATE(-3))	0.30	0.79	0.01
Standard error	0.60	0.35	0.11
Difference in LN(GDE(-1)/POP(-1))	3.90	1.07	0.32
Standard error	1.46	0.85	0.27
Difference in LN(GDE(-2)/POP(-2))	-2.85	3.53	0.41
Standard error	2.46	1.44	0.45
Difference in LN(GDE(-3)/POP(-3))	1.46	-0.48	-0.65
Standard error	2.49	1.46	0.46
C	-0.03	-0.08	0.02
Standard error	0.07	0.04	0.01
R-squared	0.56	0.86	0.46
Adj. R-squared	0.12	0.72	-0.07

3 Intra- regional household travel, density and congestion effects

3.1 Travel demand in the NLTDM

Travel demand projections in the NLTDM began with a national level estimate of growth in travel per vehicle ($\frac{\mathrm{VKT_{i,j,t}}}{VEH_{i,j,t}}$) by type of vehicle (*i*), by region (*j*) and over time (*t*) as a function of model user-assigned parameters (α_i, β_i) describing sensitivity of travel demand to price and income changes:

$$\Delta\left(\frac{\mathrm{VKT_{i,j,t}}}{VEH_{i,j,t}}\right) = \alpha_i \Delta COST_{i,j,t} + \beta_i . \Delta\mathrm{INCOME_{i,j,t}} \quad \text{(Equation 3.1)}$$

In the RLTDM sensitivity of travel demand to changes in travel costs and incomes is fixed, reflecting the parameter estimates described in the next sub-section.

The NLTDM did include some regional differentiation in travel demands not dissimilar to regional distinctions (fixed effects) in the development discussed below. For example, the NLTDM used differences in vehicle kilometres travelled (VKT) per vehicle (VEH) by region (*j*) and over time (*t*) and vehicle occupancy by region, relative to the national average (VKT_{NZ}/VEH_{NZ}), to capture the different effects of population growth on travel demands in different regions:

$$VKT_{j,t} = \frac{VKT_j/VEH_j}{VKT_{NZ}/VEH_{NZ}} . \frac{VKT_{NZ,t}}{VEH_{NZ,t}} . VEH_{j,t} \quad \text{(Equation 3.2)}$$

Regional variations in population composition were also considered in the NLTDM. Age-specific distributions of probabilities of being a driver were then applied to obtain age-adjusted region-specific estimates of VKT. The resulting value of VKT by region was then multiplied by regional estimates of average occupancy per vehicle to obtain projected passenger kilometres. Occupancy numbers were held constant by default in the absence of other data.

This approach allowed for constant structural regional differences which affect national travel demands, such as inherently higher vehicle kilometres travelled in regions that are sparsely populated or lower growth in VKT for regions which have older populations.

The developments discussed in this chapter allow for changing regional (structural) demand differences over time according to changes in relative incomes, population density, employment, travel speeds and household composition.

Demand by mode has been separated into an entirely separate model of mode choice (described in the next section).

3.2 Summary of models and results

The new approach to modelling household travel demands is a significant change from the way travel demand was modelled in the NLTDM. The development discussed here goes one step back up the chain and models demand for a generic ‘travel’ commodity.

We have constructed a model for predicting region-specific household travel demands. The model has two parts: a model of journeys per household per year and a model of distance per journey per household per year.

Key results of the model are summarised in tables 3.1 and 3.2. Full results of the model are explained in section 3.3.

The model uses socio-demographic and travel characteristics to explain journeys and distances travelled per journey.

The purpose of the model is to:

- project travel demand by region
- provide a mechanism for capturing effects of population density and congestion on travel demand.

The model predicts travel demand for each household and region and over time, but the summary results in tables 3.1, 3.2 and 3.3 only examine average results for each type of household and average results for each region. This is done because there are 72 combinations of households and regions so there is not space to present them all in a summary.

3.2.1 Model of journeys per household

The number of journeys per household per year are explained by (see table 3.1):

- dollars per km of travel per dollar of household income
  - reflects average out-of-pocket[10] costs of travel across all modes (explained further in section 4.3.4) and average household income for each year (see section 4.3.5), type of household and region (792 observations)
  - increases in costs of travel or reductions in income reduce numbers of journeys
  - people who live alone (often retired people) and solo parent families tend to be more income constrained than most and exhibit greater sensitivity to travel costs than other households
  - households in Northland are the most sensitive to changes in travel costs and people in Taranaki and Auckland are the least sensitive
  - regional sensitivity to costs of travel reflects a number of underlying factors including population composition and relative incomes
- population density (people per km^2)
  - a 10% increase in density reduces number of journeys by 0.9%
- average age
  - a 10% increase in age reduces number of journeys by 9%
- percent of people unemployed

[10] The data we have for modelling household travel and mode choices accounts for most components of so-called 'generalised cost of travel' including time measures, income measures and out-of-pocket costs. Unfortunately parking costs are omitted because of difficulties constructing a consistent and reasonable region-level dataset. In the context of a panel model this means that effects of regional differences in parking costs will be wrapped up in region-specific differences captured in different constants (fixed effects).

- an increase in unemployment has a negative effect on journeys
- higher levels of unemployment are associated with larger negative effect on journeys and increased density reduces negative effects on journeys

- average travel speed
  - this variable will be used to capture effects of congestion on travel demand
  - effects of changes to average speed vary according to current average speeds and population density
  - in densely populated and urban regions, where speeds are relatively low, increased speeds have a positive effect on number of journeys
  - in rural areas where speeds are relatively high, an increase in speeds reduces the number of journeys.

3.2.2 Model of distance per journey

The average distance travelled per journey is explained by (see table 3.2):

- dollars per km of travel per dollar of household income
  - increases in out-of-pocket costs of travel or reductions in income reduce distance travelled per journey, though the effect is small (0.08% reduction for a 10% increase in income-weighted cost)
  - variations in effects by region and household are similar to the results in the model of journeys with more income constrained households exhibiting greater sensitivity to travel costs than other households
  - households in Northland are the most sensitive to changes in travel costs and people in Taranaki and Auckland are the least sensitive
- percent of people unemployed
  - in less densely populated regions an increase in unemployment increases the distance travelled per journey but in more densely populated regions (Auckland, Bay of Plenty, Wellington, Canterbury) there is a negative effect of increased unemployment on distance per journey
- average travel speed
  - increased travel speeds cause reasonably large increases in distances travelled per journey – a 10% increase in speed induces a 13% increase in average distance travelled per journey.

3.2.3 Implications of models for travel demand

Average distance per journey is multiplied by the number of journeys to yield travel demand by region and by household type.

The main drivers of changes to travel demand are summarised in table 3.3 and show:

- a 10% increase in average costs of travel (dollars per km) is associated with a 0.3% reduction in travel demand, though this value varies according to shares of costs in household budgets (incomes) and over time as costs rise and fall
- a 10% increase in the percentage of people unemployed yields a 0.1% reduction in travel demand nationally holding all else constant while controlling for differences in density across regions

  - impacts are larger in more densely populated regions
- a 10% increase in population density is associated with a 0.8% increase in travel demand, holding all else constant but controlling for differences in unemployment and travel speeds across regions
  - impacts are larger in less densely populated areas
- a 10% increase in travel speed is associated with a 14% increase in travel demand, holding all else constant while controlling for differences in density across regions.

All of these results are relative to the scale of change seen in the data historically. This means, for example, that while a 14% increase in travel demand might seem large it should be considered in the context of fairly limited historical variations in average travel speeds. In the data a 10% change in average travel speeds would lift the region with the slowest travel speeds up to the average travel speed. Thus, a 10% or 20% increase in travel speeds is a fairly dramatic increase.

The model is based on data from the New Zealand Household Travel Survey (NZHTS) www.transport.govt.nz/research/travelsurvey/. Some of the density effects reflect farm travel not captured by the NZHTS.

Table 3.1 Summary results of model predicting journeys by household and by region

Results of a panel model based on 11 years (2004–2014) and 72 cross-sections and data from the NZHTS. Level values are averages for 2004–2011.

	Dependent	Explanatory variables					Percent change in journeys per household given a 10% increase in				
Group	Average number of journeys per year, per household	Dollars per km per dollar of house-hold income	Populat-ion density (people per km²)	Ave-rage age	Percent of people un-employed	Ave-rage travel speed	Dollars per km per dollar of household income	Population density (people per km²) given un- employment and speed	Ave-rage age	Percent of people un-employed, given density	Average travel speed, given population density
Alone	1,317	0.0005	276	60	2.6	23.5	-0.45	0.56	-9.03	-0.50	1.56
Couple, no kids	3,006	0.0002	246	57	1.3	28.0	-0.24	1.06	-9.03	-0.25	1.20
Two parent family	4,358	0.0002	246	23	1.8	28.1	-0.18	1.09	-9.03	-0.34	1.20
One parent family	2,224	0.0005	262	21	6.8	22.3	-0.48	0.51	-9.03	-1.29	1.40
Multi-person household	6,342	0.0002	232	34	5.9	24.3	-0.23	0.75	-9.03	-1.12	1.03
Multi-family household	13,550	0.0002	254	36	4.3	27.8	-0.16	1.12	-9.03	-0.82	1.30
Northland	4,368	0.0004	101	36	5.5	29.1	-0.42	1.30	-9.03	-1.05	-1.53
Auckland	4,505	0.0003	1,217	35	3.9	23.5	-0.25	0.59	-9.03	-0.74	6.13
Waikato	4,778	0.0003	110	36	4.1	27.9	-0.26	1.13	-9.03	-0.77	-1.27
Bay of Plenty	4,676	0.0003	410	37	3.6	25.8	-0.27	0.88	-9.03	-0.69	2.78
Gisborne–Hawke's Bay	4,311	0.0003	240	36	4.6	24.7	-0.29	0.77	-9.03	-0.88	1.13
Taranaki	5,276	0.0003	212	36	4.3	26.2	-0.25	0.95	-9.03	-0.83	0.75
Manawatu–Wanganui	4,431	0.0003	178	36	4.0	26.5	-0.26	0.96	-9.03	-0.77	0.20
Wellington	6,126	0.0003	647	36	3.5	24.2	-0.28	0.68	-9.03	-0.67	4.18
Upper South Island	4,273	0.0004	94	36	2.8	25.9	-0.38	0.86	-9.03	-0.53	-1.75
Canterbury	4,966	0.0003	442	35	2.7	23.3	-0.27	0.53	-9.03	-0.51	3.01
Otago	4,766	0.0003	272	36	3.0	22.4	-0.29	0.43	-9.03	-0.58	1.51
Southland	4,061	0.0003	181	35	3.4	28.0	-0.28	1.12	-9.03	-0.64	0.25

Source: Author's calculations, Ministry of Transport NZHTS

Table 3.2 Summary results of model predicting average distance per journey

Results of a panel model based on 11 years (2004–2014) and 72 cross-sections and data from the NZHTS. Level values are averages for 2004–2011.

	Dependent	Explanatory variables				Percent change in journeys per household given a 10% increase in		
Group	**Average distance per journey, per household**	**Dollars per km per dollar of household income**	**Population density (people per km²)**	**Percent of people unemployed**	**Average travel speed**	**Dollars per km per dollar of household income**	**Percent of people unemployed**	**Average travel speed**
Alone	7.9	0.0005	276.1	2.6	23.5	-0.08	0.01	13.34
Couple, no kids	9.9	0.0002	245.8	1.3	28.0	-0.04	0.01	13.34
Two parent family	8.6	0.0002	245.8	1.8	28.1	-0.03	0.02	13.34
One parent family	6.5	0.0005	262.2	6.8	22.3	-0.09	0.04	13.34
Multi-person household	8.4	0.0002	232.4	5.9	24.3	-0.04	0.06	13.34
Multi-family household	9.0	0.0002	254.1	4.3	27.8	-0.03	0.03	13.34
Northland	10.6	0.0004	101.4	5.5	29.1	-0.07	0.21	13.34
Auckland	8.2	0.0003	1216.5	3.9	23.5	-0.04	-0.18	13.34
Waikato	11.4	0.0003	110.2	4.1	27.9	-0.04	0.14	13.34
Bay of Plenty	10.0	0.0003	409.9	3.6	25.8	-0.05	-0.03	13.34
Gisborne–Hawke's Bay	8.7	0.0003	240.0	4.6	24.7	-0.05	0.04	13.34
Taranaki	9.2	0.0003	212.3	4.3	26.2	-0.04	0.06	13.34
Manawatu–Wanganui	8.6	0.0003	177.8	4.0	26.5	-0.05	0.08	13.34
Wellington	8.4	0.0003	646.8	3.5	24.2	-0.05	-0.09	13.34
Upper South Island	8.6	0.0004	94.2	2.8	25.9	-0.07	0.11	13.34
Canterbury	8.0	0.0003	442.3	2.7	23.3	-0.05	-0.03	13.34
Otago	8.2	0.0003	271.6	3.0	22.4	-0.05	0.02	13.34
Southland	10.2	0.0003	180.6	3.4	28.0	-0.05	0.06	13.34

Source: Author's calculations, Ministry of Transport NZHTS

Table 3.3 Summary results of model predicting total travel demand

Results of a panel model based on 11 years (2004–2014) and 72 cross-sections and data from the NZHTS. Level values are averages for 2004–2011.

	Dependents			Percent change in travel demand given a 10% increase in			
Group	**Average distance travelled per household per year (km)**	**Average number of households**	**Aggregate travel demand (billions of km)**	**Dollars per km, given household income**	**Percent of people unemployed, given density**	**Density, given number of people employed and speed**	**Average travel speed, given population density**
Alone	10,438	328,777	3.31	-0.52	-0.10	0.47	16.45
Couple, no kids	29,729	425,018	12.36	-0.27	-0.05	0.94	16.19
Two parent family	37,578	488,300	17.90	-0.21	-0.07	0.87	16.44
One parent family	14,530	160,581	2.08	-0.47	-0.21	0.35	16.25
Multi-person household	53,146	54,235	2.54	-0.25	-0.21	0.50	17.71
Multi-family household	121,543	96,143	11.35	-0.19	-0.15	0.82	17.15
Northland	46,148	57,211	1.94	-0.26	-0.08	1.25	12.29
Auckland	36,740	485,070	14.94	-0.23	-0.12	0.58	20.41
Waikato	54,319	146,651	5.86	-0.24	-0.09	1.18	12.08
Bay of Plenty	46,681	100,284	3.02	-0.29	-0.09	0.91	16.64
Gisborne–Hawke’s Bay	37,389	72,273	2.23	-0.26	-0.12	0.83	14.69
Taranaki	48,767	40,709	1.39	-0.23	-0.07	1.14	14.36
Manawatu–Wanganui	38,222	85,322	2.42	-0.25	-0.06	1.11	13.55
Wellington	51,463	178,151	5.96	-0.26	-0.11	0.74	18.22
Upper South Island	36,786	65,284	2.11	-0.35	-0.07	0.82	11.78
Canterbury	39,579	209,852	6.25	-0.26	-0.10	0.67	16.54
Otago	39,212	77,364	2.25	-0.28	-0.08	0.59	15.02
Southland	41,502	34,882	1.18	-0.25	-0.07	1.29	14.02
New Zealand	31,901	1,553,054	49.54	-0.25	-0.10	0.81	16.60

Source: Author’s calculations, Ministry of Transport NZHTS

3.3 Model

Equation 3.3 describes the model. The activities explained by the model are journeys per year (*J*), average distance per journey (*DJ*) and distance per year (*D*). Lower-case values represent variables after transformation by natural logarithm.

$$
\begin{aligned}
J_{h,r,t} &= e^{\alpha_{h,r}+\alpha_t+\beta X_{h,r,t}+\epsilon_{h,r,t}+} \\
DJ_{h,r,t} &= e^{\theta_{h,r}+\theta_t+\delta Y_{h,r,t}+\psi_{h,r,t}} \\
j_{h,r,t} &= \ln(J_{h,r,t}) = \alpha_{h,r} + \alpha_t + \beta X_{h,r,t} + \epsilon_{h,r,t} \\
dj_{h,r,t} &= \ln(DJ_{h,r,t}) = \theta_{h,r} + \theta_t + \delta Y_{h,r,t} + \psi_{h,r,t} \\
d_{h,r,t} &= j_{h,r,t} + j_{h,r,t} \\
D_{h,r,t} &= e^{(j_{h,r,t}+dj_{h,r,t})} + \epsilon_{h,r,t} + \psi_{h,r,t} \\
&\epsilon_{h,r,t} \sim N(0,\sigma^2),\ \psi_{h,r,t} \sim N(0,\sigma^2), Cov[\epsilon_{h,r,t}, \psi_{h,r,t}] = 0
\end{aligned}
\qquad \text{(Equation 3.3)}
$$

The panel cross sections are households (*h*) and regions (*r*). The models include cross-section specific constants (fixed effects $\theta_{h,r}$ and $\alpha_{h,r}$) and time period effects common to all cross sections in a given year (θ_t and α_t).

The explanatory variables described in the preceding summaries of results are captured in matrices $X_{h,r,t}$ (equation 3.4) and $Y_{h,r,t}$ (equation 3.5). The explanatory variables are log transformed (speed, density, ages), and ratios (costs relative to income and unemployment) and interaction terms are included:

$$
X_{h,r,t} = [\frac{cost_{h,r,t}}{income_{h,r,t}}, \ln(density_{h,r,t}), \ln(ages_{h,r,t}),
\frac{unemployed_{h,r,t}}{people_{h,r,t}}, \frac{unemployed_{h,r,t}}{people_{h,r,t}}.\ln(density_{h,r,t}),
\ln(speed_{h,r,t}), \ln(speed_{h,r,t}).\ln(density_{h,r,t})] \qquad \text{(Equation 3.4)}
$$

$$
Y_{h,r,t} = [\frac{cost_{h,r,t}}{income_{h,r,t}}, \frac{unemployed_{h,r,t}}{people_{h,r,t}}, \frac{unemployed_{h,r,t}}{people_{h,r,t}}.
\ln(density_{h,r,t}), \ln(speed_{h,r,t})] \qquad \text{(Equation 3.5)}
$$

Table 3.4 summarises estimation results and gives a full list of fixed effects.

Table 3.4 Household travel demand models – estimation results

Dependent variable: journeys per household				
Method: Panel least squares				
Sample: 2004 2014				
Periods included: 11				
Cross-sections included: 72				
Total panel (balanced) observations: 792				
Fixed effects and period effects included				
Variable	Coefficient	Std error	t-Statistic	Prob
C	16.1	3.3	4.92	0.00

Dependent variable: journeys per household				
Cost/income	-9,477	1,352	-7.01	0.00
ln(density)	-0.9	0.6	-1.65	0.10
Ln(ages)	-0.9	0.2	-5.48	0.00
Unemployed/population	-1.9	0.9	-2.11	0.04
(Unemployed/population).ln(density)	0.3	0.2	1.26	0.21
ln(speed)	-1.6	0.9	-1.73	0.08
ln (speed). ln(density)	0.3	0.2	1.94	0.05
R-squared	0.755	Durbin-Watson stat		1.96
Dependent variable: distance per household				
Method: Panel least squares				
Sample: 2004–2014				
Periods included: 11				
Cross-sections included: 72				
Total panel (balanced) observations: 792				
Fixed effects and period effects included				
Variable	Coefficient	Std error	t-Statistic	Prob
C	-2.23	0.36	-6.24	0.00
Cost/income	-1,667	1,266	-1.32	0.00
Unemployed/population	1.94	0.82	2.35	0.04
(Unemployed/population).ln(density)	-0.34	0.17	-1.94	0.21
ln(speed)	1.33	0.11	12.11	0.08
R-squared	0.60	Durbin-Watson stat		2.18

3.3.1 Out-of-sample fit

The model was tested for forecast performance and overall fit by fitting the models on a subset of the data for 2004 to 2012 and using that model to predict travel demands for 2013 and 2014.

The results of the out-of-sample fit show a very large skew in the errors for a handful of observations. The errors also show a small downward bias (tendency to predict less demand), once the right skewed results are disregarded.

The propensity to under-predict demand appears to be due to instability in travel demand relationships in recent years but, as discussed in the next section, further analysis suggests this is dissipating.

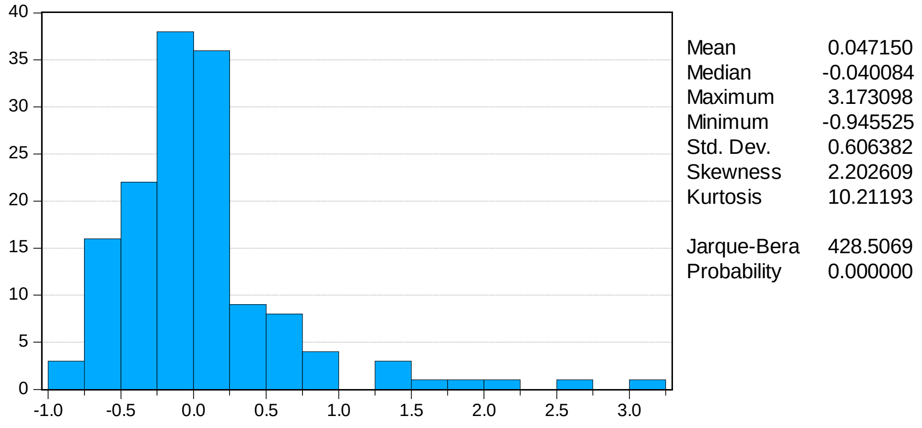
The long right tail of errors, ie large under-prediction of 'actuals', appears to be due to estimation error of actuals. The highly under-predicted values all relate to smaller rural areas (Gisborne), sole parent households, and multi-family and multi-person households for which living arrangements vary a great deal. These groups are not sampled very widely in the household survey and the end result is that measurement or sample error ends up in model residuals. The data set included four missing values: Northland multifamily households in 2004 and 2006 (to maintain a balanced panel we assumed these values were equal to the values recorded for Northland multifamily households in 2005 and 2007 respectively) and Taranaki sole occupant and multifamily households in 2007 (to maintain a balanced panel we assumed it was equal to the value recorded for those households in 2008).

Many of the very large prediction errors are not large in the context of data variance. The 4th and 5th largest prediction errors, for example, are for multi-person households in Gisborne (64% mean error, 2013–2014) and for sole parent families in Southland (50% mean error, 2013–2014).

More generally, travel demand by household and region has a standard deviation which is 98.8% of the mean, consequently prediction errors at the cross-section level which are 50% or 100% of actual, in any given year, are not necessarily large.

Figure 3.1 Out- of- sample errors

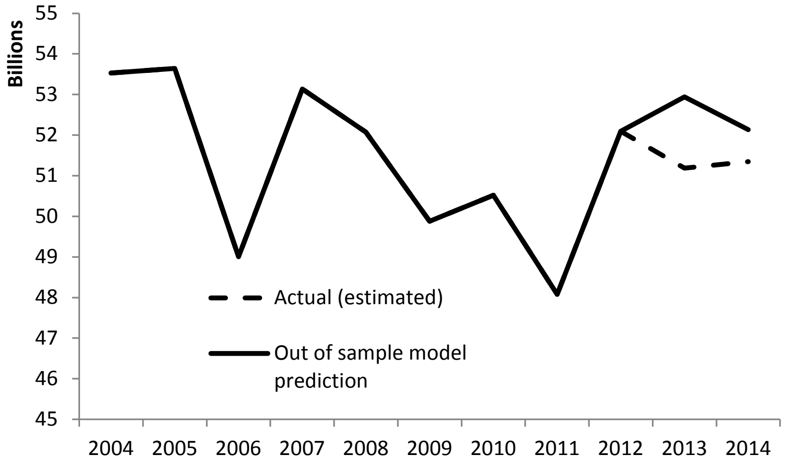
Actual less predicted travel demand as a proportion of actual



In aggregate the model does, nonetheless, exhibit an out-of-sample propensity towards under-predicting travel demand. To further investigate the model fit an analysis of coefficient stability was carried out to see if structural breaks had occurred in the data and underlying economic relationships.

Figure 3.2 Total travel demand out- of- sample error

Household travel demand, kilometres



3.3.2 Recursive coefficients

Stability of parameter estimates were tested using eight successive data sub-samples. The results indicate instability in cost and economic (unemployment) parameters while constants, density, speed, and age parameters are generally more stable (on average).

Table 3.5 Recursive coefficient estimates

Model of journeys per household								
Sample	Constant	Cost	Density	Ages	Unemployed	Unemployed.Density	Speed	Speed.Density
2004 to 2007	11.1	-7,341	-0.1	-1.0	-1.0	0.2	0.1	0.0
2005 to 2008	15.6	-7,961	-0.7	-0.9	-4.4	0.9	-1.3	0.2
2006 to 2009	15.7	-10,797	-0.9	-0.4	-4.9	0.8	-2.0	0.3
2007 to 2010	16.1	-10,496	-1.2	-0.3	-3.3	0.7	-2.3	0.4
2008 to 2011	16.9	-48,272	-0.8	-1.4	-5.7	1.1	-1.4	0.3
2009 to 2012	15.1	-5,399	-1.1	-0.5	-2.1	0.2	-1.6	0.4
2010 to 2013	25.6	6,001	-3.1	-0.6	-2.1	0.4	-4.5	0.9
2011 to 2014	14.6	12,334	-0.6	-0.8	-1.6	0.1	-0.9	0.1
Model of distance per journey								
Sample	Constant	Cost	Unemployed	Unemployed.Density	Speed			
2004 to 2007	-4.9	-1,215	1.0	-0.2	1.6			
2005 to 2008	-3.3	-1,131	-0.4	0.0	1.1			
2006 to 2009	-3.5	-3,713	-0.3	0.0	1.1			
2007 to 2010	-3.5	-4,119	1.3	-0.4	1.1			
2008 to 2011	-2.9	-15,140	3.0	-0.6	0.8			
2009 to 2012	-4.4	-11,942	3.0	-0.5	1.2			
2010 to 2013	-4.9	-9,718	3.0	-0.4	1.4			
2011 to 2014	-4.6	-1,199	2.9	-0.4	1.3			

4 Regional household mode shares

4.1 NLTDM mode choices

In the NLTDM, private travel demand by vehicle (described in chapter 3) was supplemented with a model of public transport boardings, assumed to grow at the regional level according to regional population growth changes in average vehicle travel costs, and growth in average household incomes (Stephenson and Zheng 2013).

The NLTDM also included a mechanism for 'arbitrarily raising the number of boardings in a region to accommodate exogenous shifts in preferences or increased accessibility of public transport' (Stephenson and Zheng 2013, p51).

In this development mode shares are modelled independently of travel demands. Factors affecting mode choice are modelled explicitly on a region-by-region basis and the ability to arbitrarily shock mode demands is removed.

4.2 Key results

We have modelled mode choice for each region of New Zealand using data from the NZHTS. The key results of our econometric analyses of mode choice are summarised in tables 4.1, 4.2 and 4.3.

The results in table 4.1 are elasticities of mode share use, averaged across all regions. The elasticities are percentage changes in mode share for a proportionate percentage change in the explanatory factors we used to model mode choice.

The results show, for example, that a 10% increase in age is associated with a 7.2% increase in the share of journeys by driving. For the starting mode share for driving in table 4.1 (69.3%) this implies a 5% (7.2% x 69.3) increase in the share of journeys by driving.

The elasticities are illustrative only. They are evaluated for the average person for each region and vary depending on the initial level of mode share and the initial level of explanatory variables.

Age is the explanatory variable with the strongest impact on mode choice followed by number of cars available to a household. Increases in these variables increase driver journeys and reduce journeys by other modes.

That said, a 10% change in average age of the population is less likely to occur than, for example, a 10% change in costs of travel.

Two mode-specific variables have been included in the model: cost of travel and average journey time. The cost variable is the typical cost per kilometre of travel divided by household income. An across-the-board increase in travel acts like an across-the-board reduction in income and this causes a reduction in driver and bus journeys and an increase in passenger journeys and walking and cycling.

Table 4.1 Mode share elasticities

Percent change in mode share divided by percent change in explanatory factor

Explanatory factors	Drive	Passenger	Bus	Train	Cycle	Walk
Initial average mode share (percent)	0.69	0.26	0.01	0.00	0.02	0.02
Increase in age	0.72	-1.75	-1.42	-0.13	-1.05	-0.92
Increase in number of cars	0.18	-0.34	-0.82	-0.15	-1.08	-0.74
Increase in travel time - all modes	0.07	0.09	0.10	0.17	-0.41	-3.85
Increase in share of journeys at peak	0.03	-0.10	0.42	0.24	-0.03	0.02
Reduction in cost of bus travel	0.00	0.00	-0.07	0.00	0.00	0.00
Increase in time travelled by drivers	-0.01	0.01	0.02	0.01	0.01	0.01
Increase in cost of driving	-0.02	0.04	0.04	0.02	0.04	0.04
Reduction in income	-0.004	0.01	-0.02		0.02	0.02

Note: These elasticities are illustrative only. They are evaluated for the average person for each region and vary depending on the initial level of mode share and the initial level of explanatory variables.

If cost increases are isolated in one mode or another then consumers substitute away from that mode though changes are not large. For example, a 10% increase in the cost of driver travel per dollar of household income causes an average 0.2% reduction in driver trips. Most of the shift away from driver trips is caught in passenger trips. The proportionate change in passenger trips (0.4%) is similar to the proportionate increase in public transport (bus and train) use but passenger volumes are a much larger absolute share accounting for 26% of journeys compared with 2% for public transport.

Journey time captures both preferences for faster modes on longer journeys and substitution away from modes that have increased in journey time (ie holding journey distance constant). For example, if journey times are increased across the board, consumers shift their journeys away from active modes. If, however, travel times increase for a particular mode, such as driving, then consumers shift demand in favour of other modes.

Regional variations in mode choice behaviour are summarised in tables 4.2 and 4.3. Table 4.2 shows how mode shares change when the cost of driving increases.

Some key regional results include:

- stronger mode substitution in urban areas such as Auckland and Wellington where
  - population density is higher
  - public transport accessibility is higher
- overall sensitivity to changes in costs appear largest in regions with lower incomes
- mode choice in Wellington stands out as being remarkably unresponsive to changes in travel costs.

A complete set of model results (elasticities) is provided in table B.1 in appendix B.

Table 4.2 Change in mode shares when the cost of driving increases

Percent change (*delta*) in mode share in response to a 10% increase in driving cost

Region	Drive	Passenger	Bus	Train	Cycle	Walk
Northland	-1.71	1.68	0.02	0.00	0.00	0.02
Auckland	-1.10	0.81	0.15	0.01	0.01	0.10
Waikato	-0.85	0.76	0.03	0.00	0.04	0.02
Bay of Plenty	-1.49	1.30	0.08	0.00	0.07	0.04
Gisborne–Hawke's Bay	-0.14	0.11	0.00	0.00	0.01	0.01
Taranaki	-1.77	1.55	0.03	0.00	0.09	0.10
Manawatu–Wanganui	-1.87	1.68	0.05	0.00	0.05	0.10
Wellington	-0.11	0.09	0.01	0.00	0.00	0.00
Upper South Island	-1.01	0.73	0.02	0.00	0.08	0.17
Canterbury	-1.98	1.47	0.15	0.00	0.27	0.10
Otago	-0.50	0.43	0.02	0.00	0.02	0.03
Southland	-1.26	1.16	0.04	0.00	0.00	0.06

Table 4.3 Change in mode shares when income falls

Change in mode shares given a 10% reduction in purchasing power

Region	Drive	Passenger	Bus	Train	Cycle	Walk
Northland	-0.86	0.84	0.00	0.00	0.00	0.02
Auckland	-0.34	0.49	0.07	0.00	0.02	0.14
Waikato	-0.44	0.37	0.00	0.00	0.04	0.02
Bay of Plenty	-0.78	0.64	0.01	0.00	0.08	0.05
Gisborne–Hawke's Bay	-0.08	0.05	0.00	0.00	0.01	0.01
Taranaki	-0.97	0.74	-0.01	0.00	0.11	0.12
Manawatu–Wanganui	-1.01	0.81	0.02	0.00	0.06	0.12
Wellington	-0.01	0.06	-0.01	0.00	0.01	0.01
Upper South Island	-0.52	0.36	-0.15	0.00	0.10	0.21
Canterbury	-1.14	0.68	0.02	0.00	0.32	0.12
Otago	-0.25	0.22	-0.03	0.00	0.02	0.04
Southland	-0.62	0.58	-0.04	0.00	0.00	0.07

4.3 Mode choice data

4.3.1 NZHTS data

The data used to model mode choice comes from the NZHTS for each year from 2004 to 2014.[11] The data extract used for this project covered:

[11] For information on the survey see www.transport.govt.nz/research/travelsurvey/detailedtravelsurveyinformation/, Abley and Douglass (2008) and Milne et al (2011).

- journeys
- journey distance and timing
- number of trip legs per journey
- mode of travel
- speed of travel
- region of residence and a flag for whether a person lives in an urban or rural area within a region
- purpose of trip
- vehicle type and availability
- personal and household characteristics such as age and income.

The data did not include detailed spatial information beyond region and urban/rural areas – to maintain data confidentiality and because the ultimate objective is generalised regional mode choice modelling.

Journeys were chosen as the unit of account to simplify the analysis as opposed to more granular trip level data. The predominant mode of travel across a chain of trips has been used by the Ministry of Transport to classify the mode of travel by journey.

The data was transformed and augmented with several additional calculations to deal with:

- cost and income variables
- matching categories to those used in the NLTDM
- default speeds by mode.

These are discussed further below. Sample (unweighted) summary statistics of the model data are provided in table D.2 in appendix D.

4.3.2 Household types

Household categories in the NZHTS do not align with the categories commonly used by Statistics New Zealand and which are used in the NLTDM. To adapt the survey categories to categories that would align with the NLTDM, the concordance in table 4.4 was used.

Table 4.4 Households in survey

Household survey	Survey code	Model category
Alone	1	Alone
Couple	2	Couple
Other adults only	3	Multi-person
Family	4	Two parent
Adult family	5	Multifamily
Adult with others	6	Multifamily
One parent	7	One parent

4.3.3 Default travel times and speeds

To estimate consumer response to travel times we used the NZHTS to construct 'typical' speeds by region and by mode and by time of travel. This was done to construct a measure of consumer expectations of travel by mode. The alternative would be to use actual travel times but this is the result of a choice (or choices) as opposed to a factor considered before making a choice.

Travel speeds were based on duration and distance calculations provided by the Ministry of Transport.

The default travel times used in the modelling are summarised in table 4.5.

Table 4.5 Default travel speeds

Example, across all regions, average kilometres per hour 2004–2013

		Bus	Cycle	Drive	Other	Passenger	Taxi	Train	Walk	Average
Weekday	All times	20.2	11.8	29.9	7.6	30.1	20.2	29.0	4.6	26.2
	Offpeak	20.3	11.9	29.7	6.4	30.5	20.4	27.9	4.6	26.2
	Peak	20.0	11.6	30.1	9.2	29.6	19.6	29.9	4.7	26.3
Weekend	All times	19.7	11.6	29.8	8.1	30.4	20.1	27.6	4.6	26.2
	Offpeak	20.2	11.8	29.6	6.1	30.7	20.0	25.9	4.6	26.1
	Peak	19.1	11.3	30.1	11.2	30.0	20.6	28.8	4.7	26.4
Average	All times	19.9	11.7	29.9	7.9	30.3	20.2	28.3	4.6	26.2

Source: Author's calculations, Ministry of Transport NZHTS

4.3.4 Travel costs

Calculation of travel costs were based on:

- matching NLTDM travel cost data[12], which varies by vehicle type (eg cc rating), to vehicle information from the NZHTS and assuming that all driver and passenger journeys are carried out using the most fuel efficient vehicle available to the household[13]
- estimating average cost per kilometre of public transport travel using Transport Agency farebox recovery data and then adjusting farebox 'prices' to account for discounts provided to young people and people over 65.

Around 60% of travel is generally by people who (given their age and where they live) receive discounts.[14] To adjust for this we assume:

$$\frac{Farebox}{passengerkm} = 0.4. AdultFare + 0.6\ .(1 - Discount). Adultfare$$
$$= Adultfare. (0.4 + 0.6. (1 - Discount))$$ (Equation 4.1)

$$AdultFare = \frac{Farebox}{passengerkm} . \frac{1}{0.4 + 0.6. (1 - Discount)}$$

Data on discounts is not readily available so we:

- constructed a data set on discounts based on menu prices on the websites of the main providers of public transport in the main centres of each region

12 See Stephenson and Zheng (2013, p50).

13 The travel survey records information on vehicles available to the household but not the particular characteristics of each vehicle used for each trip or journey.

14 All regions employ the same age categories for discounts (child, student and over 65) but not all regions offer the same discounts. For example some regions do not include discounts for peak travel by people over 65 while others do.

- assumed constant discount percentages over time in the absence of alternative sources of information
- assumed that definitions of on-peak and off-peak travel had also remained stable over time – principally for the purposes of determining when free travel applies to SuperGold Card holders.

Table 4.6 Public transport use by age

Averages 2011–2014. Estimated national totals.

Age	Millions of hours per year	100s of millions of kilometres per year	Share of hours	Share of distance
<5	0	0	0%	0%
<15	14	3.0	22%	20%
<25	23	5.1	35%	34%
<35	7	1.6	11%	11%
<45	7	1.6	11%	11%
<55	6	1.5	9%	10%
<65	4	1.2	6%	8%
<75	2	0.6	3%	4%
>74	2	0.5	3%	3%

Source: Ministry of Transport NZHTS

Average estimated discounts used in the modelling, for each region, are summarised in table 4.7. Our estimates ignore peak and off peak differences in discounts except for the SuperGold Card discount.

Table 4.7 Estimated public transport discounts

Excludes SuperGold Card. Fare as percent of full fare.

Region	Child discount	Student	Pensioner
Northland	66.7	66.7	66.7
Auckland	61.2	60.3	0.0
Waikato	66.7	0.0	66.7
Bay of Plenty	60.0	60.0	60.0
Gisborne	49.7	66.0	49.7
Hawke's Bay	49.7	66.0	49.7
Taranaki	60.0	60.0	60.0
Manawatu–Wanganui	60.0	72.0	72.0
Wellington	75.0	74.7	74.7
Nelson	60.0	80.0	0.0
Marlborough	60.0	80.0	0.0
Canterbury	50.0	50.0	0.0
West Coast	60.0	80.0	0.0
Otago	68.5	83.2	83.2
Southland	67.9	0.0	67.9

Source: Author's calculations, public transport operator web-sites

4.3.5 Household incomes

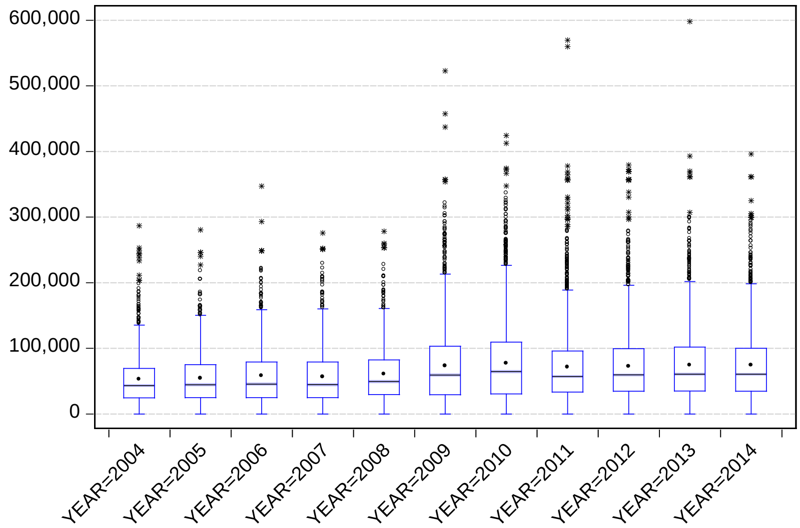
For our analysis, we used household incomes as a measure of household purchasing power. This variable was constructed by summing over incomes for each household member in the NZHTS.

Information on (reported) incomes in the NZHTS is based on income bands selected by households and these bands have changed over time. To use these bands for a quantitative income measure, which is necessary for evaluating purchasing power, we had to select a value from each income band. As incomes are generally distributed unevenly across bands we fitted gamma distributions to Inland Revenue income data and then found the median (50th percentile) value within each band according to that gamma distribution. These values are laid out in appendix D, table D.1 and the distribution of household incomes which result are summarised in box plots in figure 4.1.

There is a distinctive shift in sample income distributions in the series between 2008 and 2009, corresponding to the timing of a change in survey sampling used for the NZHTS and changes to income categories.

Figure 4.1 Estimated income distributions

Dollars of income per household



Note: Boxes show spans from 25th to 75th quartiles. Lines are medians. Dots are means. Stars are outliers. Lines show range of values from 5th to 95th percentiles.

Source: Author's calculations, Inland Revenue, Ministry of Transport NZHTS

4.4 Mode choice models

The model of mode choices is:

$$P^r_{n,i,t} = \int L^r_{n,i,t}(\beta^r_n) f(\beta).d(\beta) \qquad \text{(Equation 4.2)}$$

The term on the left, $P^r_{n,i,t}$, is the region-specific (*r*) probability of a person or household (n) choosing a particular model of travel given a particular choice situation (*i*) and time period. The unit of account is journeys.

The right-hand terms comprise logit probabilities $L^r_{n,i,t}$ conditional on a so-called ‘mixing distribution’ which is a random variable, $f(\beta)$, summarising taste variation. A single logit probability is replaced by a weighted average of many logit probabilities with the weights determined by the mixing distribution.

Mode choices are:

- cycle
- drive
- passenger
- walk
- bus
- taxi (in Auckland and Wellington only)
- train (in Auckland and Wellington only).

Trains and taxis were excluded for regions outside Auckland and Wellington for computational reasons. In principle a resident of any region may travel by these modes – albeit not always locally – but in most regions these were not cited by survey participants so they could not be included.

Choice situation information included:

- time of day – a dummy for on- and off-peak (defined loosely as journeys commencing on week days between 7am and 9am and 3pm to 7pm)
- number of cars available in the household
- regional population density – used to capture changes over time and differences within regions only in so far as the variable varies by broad area type – major urban, urban, rural.

Individual-specific information included in the model was:

- age
- household type (a dummy ordered from less complex to more complex household structures).

A single alternative-specific variable was included – average cost per km of travel relative to household income.

Mode-specific choice parameters included:

- time taken to complete the journey given a particular mode (calculated ex-ante using regional mode average speeds for the particular time of day that the choice was being made – referred to as ‘mode time’)
- a constant average market share or fixed propensity to choose a particular mode.

The variables assumed to exhibit random taste variation were:

- average cost
- constant terms on public transport modes (bus and train).

The rationale for assuming random variation in response to average costs is that some people may implicitly value their time less than others – for reasons not otherwise captured in the model, such as enjoying reading on the bus or perhaps they are less time constrained than other travellers.

Preferences for public transport were modelled as random to account for the fact that the data was drawn from choice situations where public transport was simply not available but this was not otherwise captured in the model.

Thirty-six models were estimated: three for each time period for each region (12). Time periods analysed were:

- 2004 to 2007
- 2008 to 2011
- 2012 to 2014.

Note that the sample sizes were much improved for the latter two time periods.

At the centre of the model are the logit probabilities. On an assumption of linear utility the choice probabilities, for a given region and time period are:

$$L_{n,i} = \frac{e^{\beta' x_{n,i}}}{\sum_j e^{\beta' x_{n,j}}} \quad \text{(Equation 4.2)}$$

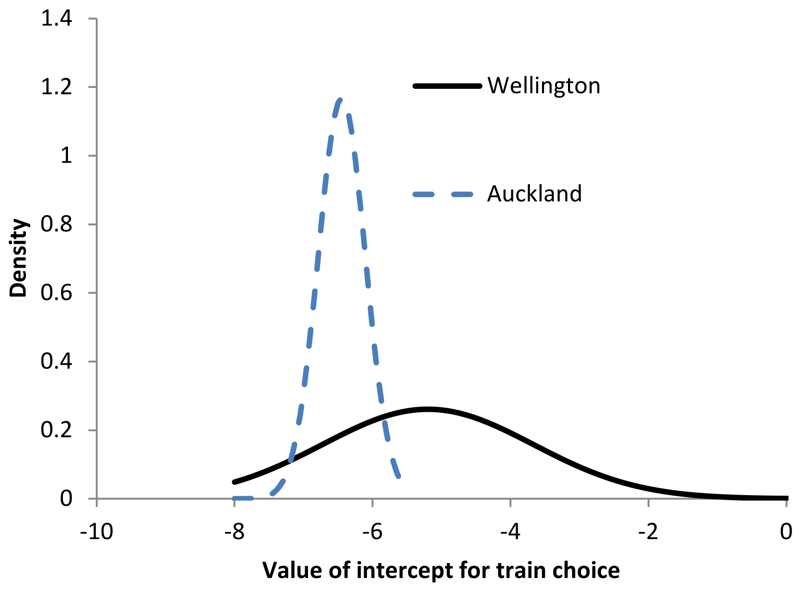
In practical terms, the mixing function varies and weights these logit probabilities.

In the final analysis, non-trivial mixing functions were used for the Auckland and Wellington models, where normal distributions are used. For other regions the mixing functions did not improve the fits of the models. Consequently simple multinomial logit was used – equivalent to assuming a uniform distribution for the mixing function.

The variables for which mixing distributions were applied were those variables assumed to exhibit random taste variation (cost and fixed probability of choosing to use travel by bus). The results of the estimations show, for example, wider variation in preferences for (intercepts associated with) train travel in Wellington than in Auckland. This is shown in figure 4.2 which shows the modelled distribution over the intercepts for choice of journey by train. Note that the variation shown captures factors not otherwise captured in the modelling and this includes availability of trains as a mode choice. Also, the central tendencies in the distributions, unlike the spreads in figure 4.2, cannot be easily compared as their interpretations depend on all other values in the models.

While there is noticeably wider variance in choices of train travel in Wellington than in Auckland the same is not true for bus travel. This suggests that the variance in Wellington is related to a combination of intensive use of rail, limited to corridors of high capacity.

Figure 4.2 Variance in preferences for train travel



For modelling purposes the predicted probabilities for mode choices were combined into household-specific market shares to match the household specific travels and construct weighted average mode shares.

Final model fits are for the period 2011–2014. One exception to this was the model for Otago for which we chose the period 2010–2012. This is the only period for which the Otago models had intuitively appealing negative signs for the travel cost coefficients. That is, the only period in which people reduced travel demand when costs increased.

The Otago model was not the only model to exhibit positive coefficients on travel costs. Stability tests, consisting of successive estimates of subsamples, showed instability in model coefficients and a number of instances of positive travel-cost coefficients. We presume this was related to small samples – particularly in the periods prior to 2008.

Aggregate travel demand by mode, region and year ($T_{n,m,r,t}$) is modelled as a function of mode shares by journey and household type and region over time ($P^r_{n,m,t}$), journeys by region and household type ($J_{n,r,t}$), and average distances per mode – which are taken to be fixed over time (see table 4.8)[15]:

$$T_{n,m,r,t} = \frac{\sum_t D_{n,m,r,t}}{\sum_t J_{n,m,r,t}} . \sum_n^N P^r_{n,m,t} \cdot J_{n,r,t}$$ (Equation 4.3)

[15] This assumption, that average distance per mode is the same over time, is quite restrictive. The effects of the assumption are ambiguous but further research should consider marginal distances per mode when distance per journey changes.

Table 4.8 Average distance per journey by mode

	Bus	Cycle	Drive	Passenger	Train	Walk
Northland	13.6	1.5	11.4	14.4		0.8
Auckland	12.2	7.2	9.9	10.3	16.3	1.1
Waikato	19.4	3.6	11.8	13.4		0.9
Bay of Plenty	11.6	1.8	9.7	12.1		0.9
Gisborne–Hawke's Bay	20.7	3.4	8.8	10.1		0.8
Taranaki	12.1	2.6	9.8	14.6		0.8
Manawatu–Wanganui	17.1	4.3	10.2	11.4		0.9
Wellington	10.4	5.5	9.7	11.5	32.8	0.8
Upper South Island	17.1	3.2	9.7	12.0		0.9
Canterbury	11.8	4.2	9.0	10.6		1.0
Otago	12.3	3.7	7.9	9.9		0.9
Southland	16.8	3.4	9.9	14.1		0.7

5 Origin- destination freight flows

5.1 Freight in the NLTDM

Freight demand in the NLTDM was modelled as a weighted sum of regional industry GDP with weights reflecting common freight intensity by industry with adjustments to account for distances of freight travelled in some regions.

Demand was attributed to a single region – rather than as an explicit inter-regional flow – based on where the demand for the freight (or end user) ultimately resided.

In other words, regional freight demand was modelled explicitly but the origin and destination of freight were not. For example, growth in freight demand in the manufacturing industry may come from Auckland but the goods may have been shipped from, for example, the Port of Tauranga or the Port of Auckland.

The purpose of this part of the model development was to account for spatial dependencies in freight flows so that, for example, a scenario of increased demand in Wellington would be able to immediately consider spill-over implications (if any) for other regions.

5.2 Summary of model results

A model of freight origin-destination was constructed. The model is similar to a conventional gravity-style model (where flows decrease with distance) but is augmented to account for spatial dependence of:

- flows from neighbouring origins (origin-dependence)
  - on the assumption that strength of freight flows from, for example, Auckland to Bay of Plenty may be associated with the strength of flows from Waikato to the Bay of Plenty
- flows to neighbouring destinations (destination-dependence)
  - on the assumption that strength of freight flows to, for example, Auckland from Bay of Plenty may be associated with strength of flows from Waikato to Auckland
- flows from neighbouring origins to neighbouring destinations (origin-destination dependence)
  - on the assumption that strength of freight flows to Auckland from Bay of Plenty may be associated with strength of flows from Gisborne to Waikato (ie occur due to similar and correlated drivers).

Key results of the models are provided below by way of examples of a response of freight flows into, out of, and within Auckland due to a 10% shift (independently) of each of the explanatory factors in the model.

Two models have been fitted explicitly: a model of tonne-km of freight (see table 5.1) and a model of tonnes of freight (see table 5.2). In addition, the results of the two models are combined to produce an implicit estimate of implications for freight distances per tonne of freight shipped.

Population size appears to be the most important driver of freight tonne-km flows with a 10% increase in population associated with a 16.8% increase in freight flows. This impact is smaller than the impact of a 10% increase in share of services in GDP but a 10% increase in services share of GDP is generally harder to come by than a 10% increase in population.

The negative relationship between GDP at origin and gross freight flows is a little counterintuitive but it may reflect the fact that on balance the growth margin in New Zealand industry is in services and that when a region is growing it is increasing its ability to service its own needs.

Table 5.1 Predictors of freight tonne- km flows

Example using shocks occurring in the Auckland region. Base estimate is model fitted.

Flow	Factor	Outward	Inward	Net	Within	Gross
Auckland freight	Base estimate (millions of tonne-km)	2,931	2,077	5,008	1,153	6,161
Base estimate	Shares of total (%)	47.6	33.7	81.3	18.7	100.0
Response to 10% shocks (% response)						
Origin	Services share of GDP	-23.0	-23.0	-23.0	-6.0	-19.8
Destination	Services share of GDP	-5.8	-5.8	-5.8	-1.4	-5.0
Origin	Primary sector share of GDP	-9.7	-9.7	-9.7	-2.4	-8.3
Destination	International trade volumes	0.7	0.8	0.8	0.2	0.6
Origin	Population	19.6	19.6	19.6	4.3	16.8
Destination	Population	5.8	5.8	5.8	1.3	4.9
Origin	GDP	-26.1	-26.1	-26.1	-6.9	-22.5
Destination	Land area	3.3	3.3	3.3	0.8	2.8
Destination	Distance	-3.4	-3.4	-3.4	-0.8	-2.9
Intra-regional	GDP per capita	-0.5	-0.8	-0.6	-27.1	-5.6
Intra-regional	Services share of GDP	-0.4	-0.7	-0.5	-22.7	-4.7

Also, the origin–destination flows we are predicting are inter-regional – they do not include overseas trade. Thus it may also be that economic growth leads to increased imports. This would seem to be supported by negative relationships between regional GDP per capita and freight flows.

These effects are all estimated using a single year of freight data so it is only picking up systematic differences and drivers of freight flows across regions and not across time.

The explanatory factors (variables) used to describe freight flows are, broadly:

- industry composition of regional economies
  - in terms of shares of primary, manufacturing and services sector shares of GDP in each region
  - intended to capture the idea that services industries generally require less freight and that primary sectors are expected to consume larger freight volumes relative to value added (GDP) than manufacturing sectors
  - more detailed breakdowns are possible but we have insufficient observations of freight flows to accommodate a more detailed breakdown
- international trade volumes
  - the sum of port (including airport) import and export tonnage
  - intended to capture the influence that major ports have on freight flows
- population
  - intended to help capture consumptive demands and scale effects on freight flows
- aggregate size of regional economies
  - measured by GDP

  - to capture any economic scale effects
- land area of each region
  - to capture the extent to which spatial scales drive kilometres travelled and are also expected to limit inward and outward freight flows from a region
- distance between regions – influencing how far freight flows travels
- GDP per capita
  - applying only to intra-regional flows
  - intended to help capture relative income and consumption demand across different regions.

The explanatory variables differ by location with explanatory variables used to describe demand (pull) factors at the freight destination and production (push) factors at the origin. Intra-regional flows are also treated by separate explanatory variables.

The freight tonne-km model and the freight tonne flow model have the same directions of effect on each of the explanatory factors.

The influence of the port freight flows is surprisingly limited. This perhaps reflects a combination of the overall small share that import and export of goods has these days plus the fact that port volumes are correlated with other measures of economic activity (except in the Waikato) and geographical characteristics – so perhaps it offers limited additional explanatory power. A similar finding was reported in Byett et al (2015).

Table 5.2 Predictors of freight tonne flows

Example using shocks occurring in the Auckland region. Base estimate is model fitted.

Flow	Factor	Outward	Inward	Net	Within	Gross
Auckland freight	Base estimate (millions of tonnes)	8,962	8,569	17,531	36,483	54,014
Base estimate	Shares of total (%)	47.6	33.7	81.3	18.7	100.0
Response to 10% shocks (% response)						
Origin	Services share of GDP	-25.7	-25.9	-25.8	-9.4	-14.7
Destination	Services share of GDP	-8.6	-8.7	-8.7	-2.9	-4.8
Origin	Primary sector share of GDP	-9.4	-9.5	-9.4	-3.2	-5.2
Destination	International trade volumes	0.7	0.8	0.8	0.3	0.4
Origin	Population	26.7	26.9	26.8	8.0	14.1
Destination	Population	8.5	8.5	8.5	2.7	4.6
Origin	GDP	-28.3	-28.6	-28.4	-10.5	-16.3
Destination	Land area	3.5	3.5	3.5	1.1	1.9
Destination	Distance	-7.9	-7.9	-7.9	-2.7	-4.4
Intra-regional	GDP per capita	-1.1	-1.4	-1.3	-24.8	-17.1
Intra-regional	Services share of GDP	-1.0	-1.3	-1.1	-22.4	-15.5

Table 5.3 Changes to distance per tonne of freight

Example using shocks occurring in the Auckland region. Base estimate is model fitted.

Flow	Factor	Outward	Inward	Net	Within	Gross
Auckland freight	Base estimate (millions of tonnes)	327	242	286	32	114
Base estimate	Shares of total (%)	286.7	212.5	250.4	27.7	100.0
Response to 10% shocks (% response)						
Origin	Services share of GDP	3.6	3.9	3.8	3.7	-6.0
Destination	Services share of GDP	3.1	3.2	3.1	1.6	-0.2
Origin	Primary sector share of GDP	-0.3	-0.2	-0.3	0.8	-3.3
Destination	International trade volumes	0.0	0.0	0.0	-0.1	0.2
Origin	Population	-5.6	-5.8	-5.7	-3.4	2.3
Destination	Population	-2.5	-2.5	-2.5	-1.3	0.3
Origin	GDP	3.1	3.4	3.2	3.9	-7.5
Destination	Land area	-0.2	-0.2	-0.2	-0.3	0.9
Destination	Distance	4.8	4.9	4.8	1.9	1.5
Intra-regional	GDP per capita	0.6	0.6	0.6	-3.1	13.9
Intra-regional	Services share of GDP	0.6	0.6	0.6	-0.4	12.8

5.3 The model

Following the approach set out in Le Sage and Pace (2008), the model is:

$$k = \rho_1 W_o k + \rho_2 W_d k - \rho_1 \rho_2 W_o W_d k + \alpha + X_d \beta_d + X_o \beta_o + D\gamma + \epsilon \quad \text{(Equation 5.1)}$$

$$t = \rho_1 W_o t + \rho_2 W_d t - \rho_1 \rho_2 W_o W_d t + \alpha + X_d \beta_d + X_o \beta_o + D\gamma + \epsilon$$

Where: k is a vector of origin to destination tonne-km flows; t is a vector of origin to destination tonne flows; X_d is a matrix of destination characteristics; X_o is a matrix of origin characteristics; D is vector of distances between origins and destinations; W_o is an origin-specific spatial weight matrix; W_d is a destination-specific spatial weight matrix.

The independent variables (X) are same for both the tonne-km and tonne flow models.

The spatial weights matrices are contiguity matrices – reflecting whether regions neighbour each other. Rows normalised to sum to 1. An example is provided in table 5.4. This shows, for example, that the Waikato region borders five other regions (see sum of rows in top matrix) and that the normalised weight matrix thus applies a weight of 0.2 to the intersection between Waikato and its border regions.

Table 5.4 Illustration of weight matrices

Segment of the contiguity matrix						
	Northland	Auckland	Bay of Plenty	Waikato	Gisborne...	Sum of rows
Northland	0	1	0	0	0	1
Auckland	1	0	1	1	0	2
Bay of Plenty	0	0	0	1	1	2

Segment of the contiguity matrix						
Waikato	0	1	1	0	0	5
Gisborne...	0	0	1	0	0	1
Segment of the row- normalised contiguity matrix						
	Northland	Auckland	Bay of Plenty	Waikato	Gisborne...	Sum of rows
Northland	0	1	0	0	0	1
Auckland	1	0	0.5	0.5	0	1
Bay of Plenty	0	0	0	0.5	0.5	1
Waikato	0	0.2	0.2	0	0	1
Gisborne...	0	0	1	0	0	1

The reason we used contiguity rather than distance-based weight matrices was because estimated freight flows between regions fall away in a rapid and almost discrete fashion and so it was appropriate to exclude far-flung regions from inclusion in the spatial lags.[16]

The explanatory variables and corresponding coefficients (ie $\rho, \alpha, \beta_d, \beta_o, \gamma$) in the estimated model are summarised in tables 5.5 and 5.6. Note that the estimator for the spatial lag coefficient is the combined value for the ρ_1 and ρ_2.

The final model specification was chosen after specifying a single very general model and gradually removing predictors that were not statistically significant (see appendix C) for the most general specification that we started with). The final model was one for which all predictors were significant in the tonne flow model and all but one predictor (services share of GDP at flow destination) was significant. The decision was made to favour symmetry between the two models as this would be practically useful when constructing scenarios.

The final specification has only 13 predictors compared with a candidate of 30. It did not have the best fit of the models – either in terms of R-squared measures or model error – but did provide a reasonable fit in terms of an R-squared of 0.84 for the tonne flow model and 0.64 for the tonne-km flow model.

There was no opportunity to test out-of-sample model fit because we had only one year of (comparable) data on origin–destination freight flows – from the *National freight demand study* (Deloitte 2014).

All the models tested exhibited what appeared to be large errors on one dimension or another. That is, most models accurately predicted one flow or another such as freight flows into one region. A few models were accurate overall but exhibited large errors for particular large regional flows.

By way of example, two matrices of model errors are shown in tables 5.7 and 5.8.

The first table is results from the final tonne flow model. The diagonal (intra-regional) flows are in red, highlighting that these are the vast majority of flows in tonnes and the values which matter most to overall model error. Indeed some of the larger errors on the off-diagonals only seem large because they are percentage changes off a small base.

[16] More generally, the low value of trade between some regions suggests that these models could usefully be estimated with Tobit formulation (or similar) that better deals with low or zero flows. In the models shown here the only way this was dealt with was to use log transformation to restrict the predicted values to positive values and we used small positive values where published data on flows were ostensibly zero – because it is highly unlikely that they are actually zero.

The model errors in tables 5.7 and 5.8 are from the best fitting model of tonne flows when measured in terms of overall model error. Our final model had an overall model error of -13% while the model reflected in table 5.8 had an overall arithmetic error of -6%. While the fit was better overall, the model was not preferred as it had a number of insignificant coefficients and several more explanatory variables than the final model – so fewer degrees of freedom. The final choice between these and other models was a matter of judgement in trading off between the various attributes.

There are at least three main potential reasons for the magnitude of these errors:

- error in freight flows statistics
- large idiosyncratic variation in freight flows
- incorrect model specification.

There are empirical reasons to believe the first two sources of error have an influence. These sources of error are not problematic in the sense that they unavoidable and simply represent a limit to available information.

The last source of error – model misspecification – is much more undesirable. We have tested a range of models and are comfortable with the models chosen but we cannot be 100% sure that model misspecification is not an important source of error.

The main reason we believe there are errors in the *National freight demand study* flows is that the flow data from the study are estimates. Like all estimates, they will include errors. One hopes that the errors in the estimates are unbiased – so average out to zero – but the study method appears to be deterministic so it did not consider the nature (eg distribution) of errors in the estimates. To our knowledge no formal models were used to construct the estimates or test assumptions. Estimated flows were compared to traffic flow data as a sense-check but as far as we can see there was no formal assessment of the conceptual model underlying the data from the study. Consequently we do not have a good sense of the scope for systematic error in the estimates.[17]

We also have strong reason to believe that freight flows are quite volatile (ie have large idiosyncratic errors) given, for example, the research of Jewell et al (2011) which, over several years, attempted to measure and model and forecast freight flows and had limited success, or at least reported wide variation in modelling results when attempting to estimate and understand freight flows.

We cannot be certain whether estimation error dominates the error in our models or if the model error reflects true underlying freight volatility. This points to an avenue for future research, focusing not on the predictability of freight flows but rather the extent of any unpredictability or volatility.[18] This would be particularly interesting to understand given that aggregate freight tonne-km trends are quite stable (see, for example, freight indicator statistics released by the Ministry of Transport).[19]

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[17] We can observe, however, that the origin-destination flows are remarkably symmetric. We suspect that if a more formal statistical model of flow dynamics had been employed, this would not be the case.

[18] Strictly speaking statistical modelling does focus on explaining model 'residuals' or errors. The suggestion here is that research focuses more on modelling the variance in errors and on the physical or economic mechanics that might drive that variance.

[19] Available at www.transport.govt.nz/ourwork/tmif/freighttransportindustry/ft007/.

Table 5.5 Tonne flow model statistics

2012 freight flow data

Dependent = tonnes/GDP			
Flow	**Factor**	**Coefficient**	**t- stat**
Origin	Average	-11.86	-3.06
Origin	Services	-2.67	-4.68
Destination	Services	-0.81	-2.16
Origin	Primary sector	-0.88	-4.15
Destination	Trade volumes	0.07	3.95
Origin	Population	2.10	4.72
Destination	Population	0.72	5.58
Origin	GDP	-3.00	-7.79
Destination	Area	0.31	2.95
Destination	Distance	-0.73	-5.54
Intra-regional	Average	30.68	2.86
Intra-regional	GDP per capita	-2.90	-2.83
Intra-regional	Services	-2.58	-2.64
Spatial lags	W_j	0.14	6.08
	R-squared	0.84	
	Model std error	0.46	

The origin–destination flow model is used to calibrate inter-regional freight flow shares, but not absolute freight flows. Absolute flows follow the same basic industry-centric methods as in Stephenson and Zheng (2013) but flow directions and distances are explicitly modelled using regional shares of flows:

$$k_{r,t} = \frac{OD_{r,t}}{\sum_r OD} \cdot \sum_{i}^{I} y_{i,t} \cdot \alpha_{i,t}$$ (Equation 5.2)

Table 5.6 Tonne- km flow model statistics

2012 freight data

Dependent = tonne_km/GDP			
Flow	**Factor**	**Coefficient**	**t- stat**
Origin	Average	-8.56	-2.21
Origin	Services	-2.35	-4.10
Destination	Services	-0.54	-1.43
Origin	Primary sector	-0.92	-4.30
Destination	Trade volumes	0.07	4.02
Origin	Population	1.61	3.61
Destination	Population	0.50	3.88
Origin	GDP	-2.73	-7.06

Dependent = tonne_km/GDP			
Flow	**Factor**	**Coefficient**	**t- stat**
Destination	Area	0.29	2.78
Destination	Distance	-0.31	-2.92
Intra-regional	Average	31.50	2.92
Intra-regional	GDP per capita	-3.25	-3.16
Intra-regional	Services	-2.65	-2.69
Spatial lags	W_j	0.11	2.90
	R-squared	0.64	
	Model std error	0.47	

Where tonne-km by region over time ($k_{r,t}$) is a function of industry GDP (y_i), freight intensity by industry ($\alpha_{i,t}$) and a region's share of modelled origin–destination freight flows.

There is presently no adjustment for mode shares – with all modes expected to maintain historical mode shares – as in as in Stephenson and Zheng (2013).

Table 5.7 Model errors – final model of tonne flows

Model percent error. Total model percentage error for all flows is -13%.

	Northland	Auckland	Waikato	Bay of Plenty	Gisborne–Hawke's Bay	Taranaki	Manawatu-Wanganui	Wellington	Upper South Island	Canterbury	Otago	Southland	Total
Northland	38.5	14.3	174.0	-68.6	-18.8	60.9	310.0	-64.5	-33.0	-65.1	-68.1	-78.7	21.4
Auckland	90.0	- 5.2	-17.7	-56.1	19.0	34.9	-53.6	-62.9	222.0	-53.7	54.8	165.7	-9.6
Waikato	123.2	-52.4	- 26.4	-78.6	42.1	20.6	200.4	96.9	9.4	84.8	24.3	-15.1	-31.9
Bay of Plenty	8.7	-34.5	-65.3	- 19.7	213.5	168.5	-0.8	131.5	47.5	148.8	30.5	15.2	-18.5
Gisborne–Hawke's Bay	128.6	183.8	30.9	-4.4	11.6	58.3	-53.9	130.2	74.5	110.5	-1.2	-32.3	13.8
Taranaki	-10.5	138.5	-38.2	-35.2	-45.2	33.7	29.9	126.8	-9.3	47.4	-5.1	-36.3	27.5
Manawatu–Wanganui	229.0	105.2	195.9	55.3	-66.5	-70.4	48.5	-46.5	115.1	227.9	98.9	31.2	10.9
Wellington	42.9	-67.5	-2.7	203.0	-1.2	64.0	-55.3	8.8	112.9	176.5	49.5	-4.3	0.4
Upper South Island	-34.2	-23.4	-24.6	-38.5	4.4	-8.5	50.5	196.9	- 29.5	-63.5	-92.4	18.1	-44.4
Canterbury	7.6	-75.8	16.6	66.2	-19.3	36.0	-16.0	41.1	-75.0	- 43.2	-69.7	-69.7	-45.9
Otago	-33.9	-18.4	-36.7	-29.6	-56.3	-29.3	2.8	54.1	130.4	13.5	- 27.3	-53.8	-24.9
Southland	-17.4	4.8	-19.1	16.2	-44.1	-11.3	26.8	84.5	185.6	71.5	-45.1	- 32.9	-28.0
Total	141.9	90.8	73.9	70.2	109.0	114.0	116.3	96.5	71.9	59.7	54.1	65.1	-17.0

Table 5.8 Model errors from tonne flow model with smallest overall errors

Model percent error. Details of model are in appendix C.

	Northland	Auckland	Waikato	Bay of Plenty	Gisborne–Hawke's Bay	Taranaki	Manawatu–Wanganui	Wellington	Upper South Island	Canterbury	Otago	Southland
Northland	**58%**	56%	258%	-59%	17%	103%	368%	-58%	-8%	-60%	-59%	-74%
Auckland	87%	**9%**	-2%	-52%	41%	43%	-56%	-64%	254%	-58%	57%	155%
Waikato	85%	-51%	**- 3%**	-80%	43%	9%	141%	59%	3%	43%	7%	-31%
Bay of Plenty	-23%	-46%	-71%	**- 17%**	202%	106%	-31%	66%	22%	69%	-5%	-18%
Gisborne–Hawke's Bay	71%	142%	8%	-13%	**9%**	24%	-66%	78%	59%	57%	-17%	-47%
Taranaki	-22%	140%	-39%	-38%	-43%	**20%**	21%	107%	-3%	29%	-8%	-42%
Manawatu–Wanganui	158%	84%	157%	35%	-67%	-73%	**- 8%**	-54%	120%	171%	81%	11%
Wellington	9%	-72%	-20%	155%	-6%	40%	-64%	**- 6%**	134%	139%	40%	-17%
Upper South Island	-44%	-27%	-30%	-42%	15%	-11%	40%	218%	**- 27%**	-66%	-92%	11%
Canterbury	29%	-68%	50%	117%	23%	82%	6%	100%	-61%	**- 36%**	-53%	-56%
Otago	-30%	-6%	-29%	-23%	-42%	-18%	12%	85%	206%	37%	**- 18%**	-34%
Southland	-20%	12%	-17%	22%	-32%	-6%	26%	102%	245%	89%	-23%	**- 28%**

6 Conclusions and recommendations

6.1 Conclusions

The purpose of this report is mostly descriptive. The objective was first and foremost to document the technical details of the RLTDM model developments for those who intend to use the model. Nonetheless, some general concluding observations can be made drawing on recurring themes throughout the research. Lessons learned also suggest directions for further research into transport demand in New Zealand and New Zealand regions.

The results of the research can be grouped into three themes.

1 Discontinuity. Analysis of travel demands shows a major structural break associated with the global financial crisis and recession in New Zealand in 2008–2009. The most striking aspect of this structural break is that despite five or more years of economic recovery the effects of that discontinuity are still evident in data on transport demand. This finding is also not restricted to transport demand but was also observed in the course of our analysis of regional migration.

2 Volatility. Whether analysing freight flows or analysing travel behaviour there are significant amounts of volatility in activity at a regional level. This is not generally surprising because many regions are very small and this smallness naturally causes volatility. The extent of volatility in freight demands was, however, very surprising.

3 Demographics are destiny. Age, position in the life-course and population cohort sizes all have profound implications for travel demands. This too is not a novel observation, but it was reinforced in this research where age played a particularly important role in explaining changes in travel demands.

In our opinion, policy should proceed with careful regard for the role of compositional demographic changes in driving human activity and observed aggregate outcomes.

The importance of demographics and the discontinuity we observe in travel demands both suggest that observations of travel demand in recent years are potentially poor indicators of future trends. In addition to the long-lived effects of a once in a century recession, the New Zealand population in the past five years was characterised by the largest cohort ever to live in New Zealand and that cohort was 15–20 years old with all the age-specific demands and behaviours that come with that age group.

On its own, this suggests that the positive public transport patronage trends of recent years were a creature of coincident demographics and economic misfortune (coupled with an over 50% increase in cost of travel). Yet, on the other hand, the persistence of structural breaks means changes in demands require careful attention.

6.2 Recommendations

The themes described above suggest two directions for future research. The first is that research on freight patterns should include further examination of unpredictability or volatility freight flows and the causes of this volatility.

The second recommendation is that New Zealand-specific research into travel behaviour include decomposition of travel behaviour and ongoing monitoring of travel behaviour at the level of the individual to tray and understand if trends are transitory or long lived.

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Appendix A: Travel demand estimation results

Table A.1 Fixed effects from travel demand panels

Region	Household	Journeys per household	Distance per journey
Northland	Alone	-0.51	0.01
Northland	Couple, no kids	0.45	0.05
Northland	Multi-person household	-0.47	-0.07
Northland	Multi-family household	1.11	0.04
Northland	One parent family	-0.92	0.08
Northland	Two parent family	-0.19	-0.03
Auckland	Alone	-0.97	0.09
Auckland	Couple, no kids	-0.16	0.11
Auckland	Multi-person household	0.65	0.23
Auckland	Multi-family household	1.63	0.07
Auckland	One parent family	-1.01	-0.02
Auckland	Two parent family	-0.32	0.06
Waikato	Alone	-0.46	0.17
Waikato	Couple, no kids	0.35	0.22
Waikato	Multi-person household	0.18	0.11
Waikato	Multi-family household	1.25	0.13
Waikato	One parent family	-0.82	0.14
Waikato	Two parent family	-0.07	0.02
Bay of Plenty	Alone	-0.56	0.32
Bay of Plenty	Couple, no kids	0.36	0.24
Bay of Plenty	Multi-person household	-0.54	-0.13
Bay of Plenty	Multi-family household	0.68	0.18
Bay of Plenty	One parent family	-0.71	0.08
Bay of Plenty	Two parent family	-0.35	-0.16
Gisborne–Hawke's Bay	Alone	-0.38	-0.09
Gisborne–Hawke's Bay	Couple, no kids	0.27	-0.03
Gisborne–Hawke's Bay	Multi-person household	-0.33	0.11
Gisborne–Hawke's Bay	Multi-family household	1.25	0.04
Gisborne–Hawke's Bay	One parent family	-0.68	-0.20
Gisborne–Hawke's Bay	Two parent family	-0.17	0.02
Taranaki	Alone	-0.26	-0.01
Taranaki	Couple, no kids	0.52	0.00
Taranaki	Multi-person household	0.42	-0.18
Taranaki	Multi-family household	0.91	-0.07

Region	Household	Journeys per household	Distance per journey
Taranaki	One parent family	-1.06	-0.37
Taranaki	Two parent family	-0.06	-0.12
Manawatu–Wanganui	Alone	-0.33	0.07
Manawatu–Wanganui	Couple, no kids	0.30	-0.07
Manawatu–Wanganui	Multi-person household	0.33	-0.30
Manawatu–Wanganui	Multi-family household	0.92	-0.11
Manawatu–Wanganui	One parent family	-1.09	-0.29
Manawatu–Wanganui	Two parent family	-0.18	-0.15
Wellington	Alone	-0.27	0.12
Wellington	Couple, no kids	0.36	0.08
Wellington	Multi-person household	0.14	0.22
Wellington	Multi-family household	1.20	0.08
Wellington	One parent family	-1.08	-0.16
Wellington	Two parent family	-0.23	-0.04
Upper South Island	Alone	-0.30	-0.07
Upper South Island	Couple, no kids	0.55	0.05
Upper South Island	Multi-person household	0.01	-0.02
Upper South Island	Multi-family household	1.25	0.05
Upper South Island	One parent family	-0.69	-0.21
Upper South Island	Two parent family	-0.04	-0.01
Canterbury	Alone	-0.39	0.09
Canterbury	Couple, no kids	0.21	0.02
Canterbury	Multi-person household	0.78	0.11
Canterbury	Multi-family household	1.15	-0.01
Canterbury	One parent family	-1.21	-0.14
Canterbury	Two parent family	-0.15	-0.03
Otago	Alone	-0.19	0.10
Otago	Couple, no kids	0.36	0.13
Otago	Multi-person household	0.40	0.29
Otago	Multi-family household	1.11	0.06
Otago	One parent family	-1.20	-0.18
Otago	Two parent family	-0.17	-0.03
Southland	Alone	-0.41	-0.16
Southland	Couple, no kids	0.30	0.12
Southland	Multi-person household	-0.21	-0.06
Southland	Multi-family household	0.93	-0.11
Southland	One parent family	-1.01	-0.42
Southland	Two parent family	-0.16	-0.06

Appendix B: Mode choice model results

B1 Mode share model results

Table B.1 Mode share elasticities

Percentage change in mode share given a percentage change in explanatory variable

Measure	Region	Bus	Cycle	Drive	Pas-senger	Walk	Train
Base case mode share	Northland	0.003	0.000	0.693	0.302	0.003	
	Auckland	0.018	0.005	0.670	0.265	0.033	0.004
	Waikato	0.009	0.011	0.741	0.233	0.006	
	Bay of Plenty	0.018	0.014	0.690	0.270	0.008	
	Gisborne–Hawke’s Bay	0.010	0.027	0.692	0.254	0.017	
	Taranaki	0.005	0.017	0.679	0.281	0.018	
	Manawatu–Wanganui	0.007	0.008	0.713	0.257	0.015	
	Wellington	0.032	0.014	0.672	0.258	0.013	0.005
	Upper South Island	0.007	0.028	0.661	0.246	0.058	
	Canterbury	0.024	0.044	0.674	0.241	0.017	
	Otago	0.011	0.013	0.662	0.293	0.020	
	Southland	0.008	0.001	0.738	0.241	0.013	
Income	Northland	0.004	0.067	-0.012	0.028	0.068	
	Auckland	0.042	0.042	-0.005	0.018	0.042	0.008
	Waikato	-0.001	0.038	-0.006	0.016	0.038	
	Bay of Plenty	0.004	0.058	-0.011	0.024	0.059	
	Gisborne–Hawke’s Bay	-0.001	0.005	-0.001	0.002	0.005	
	Taranaki	-0.013	0.067	-0.014	0.026	0.067	
	Manawatu–Wanganui	0.032	0.077	-0.014	0.032	0.077	
	Wellington	-0.003	0.005	0.000	0.002	0.005	0.001
	Upper South Island	-0.211	0.037	-0.008	0.015	0.037	
	Canterbury	0.008	0.073	-0.017	0.028	0.073	
	Otago	-0.024	0.018	-0.004	0.007	0.019	
	Southland	-0.046	0.057	-0.008	0.024	0.057	
Driving cost	Northland	0.056	0.056	-0.025	0.056	0.056	
	Auckland	0.084	0.030	-0.016	0.030	0.030	0.030
	Waikato	0.033	0.033	-0.011	0.033	0.033	
	Bay of Plenty	0.048	0.048	-0.022	0.048	0.048	
	Gisborne–Hawke’s Bay	0.004	0.004	-0.002	0.004	0.004	
	Taranaki	0.055	0.055	-0.026	0.055	0.055	
	Manawatu–Wanganui	0.065	0.065	-0.026	0.065	0.065	
	Wellington	0.003	0.003	-0.002	0.003	0.003	0.003

Measure	Region	Bus	Cycle	Drive	Pas-senger	Walk	Train
	Upper South Island	0.030	0.030	-0.015	0.030	0.030	
	Canterbury	0.061	0.061	-0.029	0.061	0.061	
	Otago	0.015	0.015	-0.008	0.015	0.015	
	Southland	0.048	0.048	-0.017	0.048	0.048	
Bus cost	Northland	-0.064	0.000	0.000	0.000	0.000	
	Auckland	-0.104	0.002	0.002	0.002	0.002	0.002
	Waikato	-0.039	0.000	0.000	0.000	0.000	
	Bay of Plenty	-0.053	0.001	0.001	0.001	0.001	
	Gisborne–Hawke’s Bay	-0.007	0.000	0.000	0.000	0.000	
	Taranaki	-0.079	0.000	0.000	0.000	0.000	
	Manawatu–Wanganui	-0.045	0.000	0.000	0.000	0.000	
	Wellington	-0.007	0.000	0.000	0.000	0.000	0.000
	Upper South Island	-0.252	0.002	0.002	0.002	0.002	
	Canterbury	-0.064	0.002	0.002	0.002	0.002	
	Otago	-0.042	0.000	0.000	0.000	0.000	
	Southland	-0.103	0.001	0.001	0.001	0.001	
Journey time	Northland	0.048	-1.225	0.006	0.030	-4.596	
	Auckland	0.194	0.081	0.112	0.120	-3.391	0.164
	Waikato	0.062	-0.352	0.026	0.043	-4.276	
	Bay of Plenty	0.080	-1.241	0.046	0.073	-4.304	
	Gisborne–Hawke’s Bay	0.108	-0.213	0.071	0.082	-3.739	
	Taranaki	0.086	-0.589	0.073	0.087	-3.633	
	Manawatu–Wanganui	0.088	-0.385	0.057	0.073	-3.679	
	Wellington	0.072	-0.058	0.051	0.072	-4.411	0.166
	Upper South Island	0.189	-0.045	0.170	0.185	-2.736	
	Canterbury	0.100	-0.179	0.070	0.093	-3.819	
	Otago	0.105	-0.555	0.081	0.107	-3.894	
	Southland	0.083	-0.174	0.042	0.071	-3.767	
Driving time	Northland	0.017	0.017	-0.008	0.017	0.017	
	Auckland	0.056	0.003	-0.003	0.003	0.003	0.003
	Waikato	0.009	0.009	-0.003	0.009	0.009	
	Bay of Plenty	0.015	0.015	-0.007	0.015	0.015	
	Gisborne–Hawke’s Bay	0.008	0.008	-0.004	0.008	0.008	
	Taranaki	0.008	0.008	-0.004	0.008	0.008	
	Manawatu–Wanganui	0.012	0.012	-0.005	0.012	0.012	
	Wellington	0.008	0.008	-0.004	0.008	0.008	0.008
	Upper South Island	0.007	0.007	-0.004	0.007	0.007	
	Canterbury	0.015	0.015	-0.007	0.015	0.015	

Measure	Region	Bus	Cycle	Drive	Pas-senger	Walk	Train
	Otago	0.024	0.024	-0.012	0.024	0.024	
	Southland	0.022	0.022	-0.008	0.022	0.022	
Age	Northland	-2.945	-4.246	0.734	-1.648	-1.099	
	Auckland	-0.830	-0.538	0.757	-1.736	-0.829	-0.485
	Waikato	-1.383	-0.645	0.655	-1.979	-0.894	
	Bay of Plenty	-1.224	-1.292	0.721	-1.671	-0.895	
	Gisborne–Hawke's Bay	-2.095	-0.803	0.786	-1.908	-0.994	
	Taranaki	-0.917	-1.027	0.784	-1.745	-1.062	
	Manawatu–Wanganui	-1.741	-1.572	0.665	-1.685	-1.072	
	Wellington	-0.678	-0.364	0.760	-1.836	-0.675	0.218
	Upper South Island	-1.335	-0.372	0.723	-1.655	-0.879	
	Canterbury	-0.861	-0.185	0.676	-1.718	-0.776	
	Otago	-1.153	-0.837	0.731	-1.507	-0.913	
	Southland	-1.894	-0.753	0.664	-1.917	-0.958	
Household type	Northland	-0.211	44.075	0.092	-0.202	-0.749	
	Auckland	0.952	-0.051	-0.011	-0.066	0.158	0.680
	Waikato	-0.407	-0.535	0.103	-0.290	0.069	
	Bay of Plenty	0.006	-0.895	0.069	-0.134	0.069	
	Gisborne–Hawke's Bay	-0.126	-0.846	-0.025	0.182	-0.303	
	Taranaki	0.959	-0.194	0.111	-0.283	0.146	
	Manawatu–Wanganui	0.439	-0.579	0.073	-0.230	0.552	
	Wellington	0.371	0.769	0.076	-0.280	-0.063	-0.295
	Upper South Island	0.518	0.170	0.068	-0.186	-0.136	
	Canterbury	0.553	0.216	0.047	-0.242	0.215	
	Otago	-0.887	0.396	0.001	0.000	0.183	
	Southland	-0.074	-0.817	0.149	-0.461	0.179	
Car availability	Northland	-2.016	-8.015	0.090	-0.177	-1.201	
	Auckland	-0.966	-0.630	0.223	-0.366	-0.865	-0.117
	Waikato	-0.304	-0.645	0.062	-0.138	-0.695	
	Bay of Plenty	-1.346	0.608	0.125	-0.239	-0.737	
	Gisborne–Hawke's Bay	-0.663	-0.596	0.231	-0.510	-0.448	
	Taranaki	-0.520	-1.155	0.249	-0.491	-0.455	
	Manawatu–Wanganui	-0.588	0.183	0.170	-0.439	-0.366	
	Wellington	-1.218	-0.915	0.199	-0.260	-0.585	-0.192
	Upper South Island	-0.613	0.311	0.161	-0.282	-0.715	
	Canterbury	-1.243	-0.152	0.183	-0.322	-0.536	
	Otago	-0.412	-2.004	0.313	-0.527	-1.068	
	Southland	0.072	-0.001	0.118	-0.295	-1.259	

Measure	Region	Bus	Cycle	Drive	Pas-senger	Walk	Train
Journeys at peak times	Northland	0.525	-0.084	0.044	-0.106	0.130	
	Auckland	0.212	1.467	0.007	-0.104	0.126	0.181
	Waikato	0.251	0.141	0.040	-0.143	-0.021	
	Bay of Plenty	0.341	-0.275	0.050	-0.136	0.005	
	Gisborne–Hawke's Bay	0.429	0.009	0.022	-0.069	-0.126	
	Taranaki	0.631	0.108	0.044	-0.121	-0.069	
	Manawatu–Wanganui	0.304	-0.007	0.038	-0.111	-0.065	
	Wellington	0.669	-0.422	-0.062	0.065	0.509	0.295
	Upper South Island	0.474	0.013	0.032	-0.083	-0.079	
	Canterbury	0.099	0.061	0.039	-0.127	-0.044	
	Otago	0.489	0.236	0.027	-0.082	-0.115	
	Southland	0.650	-1.603	0.040	-0.139	-0.028	

B2 Econometric models

Variables that are specific to a choice situation or individual include coefficients for each mode except one mode which is set to 0 (in this case Drive), so results can be interpreted. This is true except for cost per km and typical time travelled by each mode ('modetime') as these variables naturally vary across choices so identification of mode-specific effects is not an issue.

The 'hh' variable suffixes in the table below reflect a factor capturing household type.

The 'ave_cost_per_inc' variable is average cost of travel per km divided by household income. The coefficient on this mode is assumed to have a constant mean but to vary according to a normal distribution with estimated standard deviation on that distribution captured by the 'sd.ave_cost_per_inc' variable. The intercepts for bus and train travel are also assumed to vary according to a normal distribution.

The 'peak' variable is the share of journeys undertaken during peak times.

Table B.2 Mixed logit choice models for Auckland

	Coefficient for each sample				Significant ==1		
Var	**pre2008**	**2008–2011**	**2012–2014**	**Ave**	**pre2008**	**2008–2011**	**2012–2014**
Bus:(intercept)	-0.83	-1.98	-1.91	-1.57	1.00	1.00	1.00
Cycle:(intercept)	-0.36	-1.43	-4.12	-1.97	0.00	1.00	1.00
Other:(intercept)	-0.16	-2.30	-2.55	-1.67	0.00	1.00	1.00
Passenger:(intercept)	2.97	2.56	2.62	2.72	1.00	1.00	1.00
Taxi:(intercept)	-3.14	-3.73	-7.61	-4.83	1.00	1.00	0.00
Train:(intercept)	-7.17	-7.24	-4.92	-6.45	1.00	1.00	1.00
Walk:(intercept)	3.53	3.25	3.71	3.50	1.00	1.00	1.00
ave_cost_per_inc	-0.10	-0.02	-0.22	-0.12	1.00	0.00	1.00
Bus:age	-0.05	-0.04	-0.04	-0.05	1.00	1.00	1.00

	Coefficient for each sample				Significant ==1		
Var	**pre2008**	**2008-2011**	**2012-2014**	**Ave**	**pre2008**	**2008-2011**	**2012-2014**
Cycle:age	-0.05	-0.03	-0.03	-0.04	1.00	1.00	1.00
Other:age	-0.04	-0.04	-0.03	-0.03	1.00	1.00	1.00
Passenger:age	-0.07	-0.07	-0.07	-0.07	1.00	1.00	1.00
Taxi:age	-0.04	0.00	0.00	-0.01	1.00	0.00	0.00
Train:age	-0.06	-0.03	-0.03	-0.04	1.00	1.00	1.00
Walk:age	-0.04	-0.04	-0.04	-0.04	1.00	1.00	1.00
Bus:hh	0.18	0.14	0.29	0.21	1.00	1.00	1.00
Cycle:hh	-0.09	-0.11	-0.01	-0.07	0.00	1.00	0.00
Other:hh	0.33	-0.09	0.07	0.10	1.00	0.00	0.00
Passenger:hh	0.01	0.00	-0.02	0.00	0.00	0.00	1.00
Taxi:hh	0.16	0.04	-0.14	0.02	1.00	0.00	1.00
Train:hh	0.42	0.26	0.22	0.30	1.00	1.00	1.00
Walk:hh	0.12	0.05	0.06	0.08	1.00	1.00	1.00
Bus:cars	-0.71	-0.59	-0.60	-0.63	1.00	1.00	1.00
Cycle:cars	-0.29	-0.10	-0.41	-0.27	1.00	0.00	1.00
Other:cars	-0.67	-0.12	-0.23	-0.34	1.00	0.00	1.00
Passenger:cars	-0.41	-0.32	-0.28	-0.34	1.00	1.00	1.00
Taxi:cars	-0.52	-0.58	-0.71	-0.60	1.00	1.00	1.00
Train:cars	-0.06	-0.36	-0.16	-0.19	0.00	1.00	1.00
Walk:cars	-0.48	-0.42	-0.52	-0.47	1.00	1.00	1.00
Bus:dens	0.00	0.00	0.00	0.00	1.00	1.00	0.00
Cycle:dens	0.00	0.00	0.00	0.00	1.00	1.00	1.00
Other:dens	0.00	0.00	0.00	0.00	1.00	0.00	0.00
Passenger:dens	0.00	0.00	0.00	0.00	1.00	0.00	1.00
Taxi:dens	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Train:dens	0.00	0.00	0.00	0.00	0.00	1.00	0.00
Walk:dens	0.00	0.00	0.00	0.00	1.00	0.00	0.00
Bus:peak	0.85	0.59	0.50	0.65	1.00	1.00	1.00
Cycle:peak	0.24	0.03	0.02	0.10	0.00	0.00	0.00
Other:peak	-0.50	-0.30	-0.29	-0.36	1.00	1.00	0.00
Passenger:peak	-0.28	-0.37	-0.48	-0.38	1.00	1.00	1.00
Taxi:peak	-1.40	-0.06	-0.29	-0.58	1.00	0.00	0.00
Train:peak	1.27	0.65	1.24	1.05	1.00	1.00	1.00
Walk:peak	0.21	-0.03	-0.21	-0.01	1.00	0.00	1.00
Drive:modetime	-0.10	-0.05	-0.04	-0.06	1.00	1.00	1.00
Bus:modetime	0.04	0.07	0.06	0.06	0.00	1.00	1.00
Cycle:modetime	-2.41	-1.07	-0.29	-1.25	1.00	1.00	1.00
Other:modetime	-5.43	-0.02	0.03	-1.81	1.00	0.00	0.00

	Coefficient for each sample				Significant ==1		
Var	pre2008	2008–2011	2012–2014	Ave	pre2008	2008–2011	2012–2014
Passenger:modetime	0.00	0.01	0.00	0.00	0.00	1.00	0.00
Taxi:modetime	-0.52	-0.28	-0.35	-0.38	0.00	0.00	0.00
Train:modetime	0.75	0.55	0.30	0.53	1.00	1.00	1.00
Walk:modetime	-37.29	-34.05	-33.59	-34.98	1.00	1.00	1.00
sd.Bus:(intercept)	0.09	0.17	-0.02	0.08	0.00	0.00	0.00
sd.Train:(intercept)	-2.20	1.39	-0.21	-0.34	1.00	1.00	0.00
sd.ave_cost_per_inc	0.09	-0.01	0.11	0.06	1.00	0.00	1.00

Table B.3 Mixed logit mode choice models for Wellington

	Coefficient for each sample				Significant ==1		
Var	pre2008	2008- 2011	2012- 2014	Ave	pre2008	2008- 2011	2012- 2014
Bus:(intercept)	-2.35	-1.96	-1.37	-1.57	1.00	1.00	1.00
Cycle:(intercept)	-1.62	-0.87	-1.75	-1.97	1.00	1.00	1.00
Other:(intercept)	-0.48	-4.66	-3.53	-1.67	0.00	1.00	1.00
Passenger:(intercept)	2.18	2.67	2.64	2.72	1.00	1.00	1.00
Taxi:(intercept)	-1.32	-3.09	-2.18	-4.83	0.00	1.00	1.00
Train:(intercept)	-6.12	-4.95	-4.52	-6.45	1.00	1.00	1.00
Walk:(intercept)	3.56	3.87	3.80	3.50	1.00	1.00	1.00
ave_cost_per_inc	-0.11	0.00	-0.03	-0.12	0.00	0.00	0.00
Bus:age	-0.04	-0.04	-0.04	-0.05	1.00	1.00	1.00
Cycle:age	-0.04	-0.03	-0.03	-0.04	1.00	1.00	1.00
Other:age	-0.02	-0.04	-0.03	-0.03	1.00	1.00	1.00
Passenger:age	-0.06	-0.07	-0.07	-0.07	1.00	1.00	1.00
Taxi:age	-0.03	-0.02	-0.02	-0.01	1.00	1.00	1.00
Train:age	-0.03	-0.01	-0.01	-0.04	1.00	1.00	1.00
Walk:age	-0.04	-0.04	-0.04	-0.04	1.00	1.00	1.00
Bus:hh	0.32	0.19	0.08	0.21	1.00	1.00	1.00
Cycle:hh	0.23	-0.11	0.19	-0.07	1.00	0.00	1.00
Other:hh	-0.22	0.06	-0.05	0.10	1.00	0.00	0.00
Passenger:hh	0.04	-0.03	-0.10	0.00	1.00	1.00	1.00
Taxi:hh	0.15	0.17	0.05	0.02	0.00	1.00	0.00
Train:hh	0.12	0.07	-0.11	0.30	0.00	0.00	1.00
Walk:hh	0.01	0.02	-0.04	0.08	0.00	0.00	1.00
Bus:cars	-0.94	-0.71	-0.75	-0.63	1.00	1.00	1.00
Cycle:cars	-0.40	-0.60	-0.58	-0.27	1.00	1.00	1.00
Other:cars	-0.95	-0.66	-0.38	-0.34	1.00	1.00	1.00
Passenger:cars	-0.34	-0.34	-0.23	-0.34	1.00	1.00	1.00
Taxi:cars	-1.07	-1.41	-1.08	-0.60	1.00	1.00	1.00

	Coefficient for each sample				Significant ==1		
Var	**pre2008**	**2008-2011**	**2012-2014**	**Ave**	**pre2008**	**2008-2011**	**2012-2014**
Train:cars	-0.52	-0.42	-0.20	-0.19	1.00	1.00	1.00
Walk:cars	-0.54	-0.54	-0.40	-0.47	1.00	1.00	1.00
Bus:dens	0.00	0.00	0.00	0.00	1.00	1.00	1.00
Cycle:dens	0.00	0.00	0.00	0.00	0.00	0.00	1.00
Other:dens	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Passenger:dens	0.00	0.00	0.00	0.00	0.00	0.00	1.00
Taxi:dens	0.00	0.00	0.00	0.00	0.00	1.00	0.00
Train:dens	0.00	0.00	0.00	0.00	1.00	1.00	0.00
Walk:dens	0.00	0.00	0.00	0.00	1.00	1.00	1.00
Bus:peak	0.63	0.92	0.61	0.65	1.00	1.00	1.00
Cycle:peak	0.77	-0.04	-0.05	0.10	1.00	0.00	0.00
Other:peak	0.23	0.25	0.55	-0.36	0.00	0.00	1.00
Passenger:peak	-0.32	-0.34	-0.41	-0.38	1.00	1.00	1.00
Taxi:peak	-0.66	-1.02	-1.22	-0.58	0.00	1.00	1.00
Train:peak	1.57	1.14	0.97	1.05	1.00	1.00	1.00
Walk:peak	-0.16	-0.27	-0.29	-0.01	1.00	1.00	1.00
Drive:modetime	-0.07	-0.11	-0.06	-0.06	0.00	1.00	1.00
Bus:modetime	-0.17	0.08	0.03	0.06	0.00	1.00	0.00
Cycle:modetime	-4.36	-1.05	-0.72	-1.25	1.00	1.00	1.00
Other:modetime	0.04	0.05	0.06	-1.81	0.00	1.00	1.00
Passenger:modetime	0.04	0.08	0.04	0.00	0.00	1.00	1.00
Taxi:modetime	-1.04	-1.02	-2.21	-0.38	0.00	1.00	1.00
Train:modetime	1.20	0.76	0.76	0.53	1.00	1.00	1.00
Walk:modetime	-43.04	-38.48	-50.45	-34.98	1.00	1.00	1.00
sd.Bus:(intercept)	0.21	0.05	-0.05	0.08	0.00	0.00	0.00
sd.Train:(intercept)	2.00	1.16	1.43	-0.34	1.00	0.00	1.00
sd.ave_cost_per_inc	0.04	0.03	0.00	0.06	0.00	0.00	0.00

Table B.4 Simple multinomial logit choice models by region

Period 2011–2014, except for Otago which is 2010–2011

Variable	Values	Northland	Waikato	Bay of Plenty	Gisborne–Hawke's Bay	Taranaki	Manawatu–Wanganui	Upper South Island	Canterbury	Otago	Southland
Cycle:(intercept)	Coeff	-33.02	0.40	0.69	0.85	4.19	0.86	0.12	-0.71	0.34	-0.35
	Std error	6,263.73	0.78	0.85	0.79	1.27	1.14	0.88	0.30	0.91	2.29
Drive:(intercept)	Coeff	-0.78	1.68	0.37	0.52	3.72	1.96	2.26	0.87	0.24	2.12
	Std error	-0.01	0.53	0.59	0.58	1.06	0.80	0.69	0.22	0.62	0.96
Passenger:(intercept)	Coeff	1.55	4.11	2.65	3.01	6.77	4.44	4.56	3.28	2.50	4.93
	Std error	0.92	0.53	0.58	0.57	1.06	0.79	0.69	0.22	0.63	0.97
Walk:(intercept)	Coeff	3.88	4.90	4.14	4.51	7.25	4.64	5.98	4.08	4.10	5.93
	Std error	1.03	0.58	0.66	0.64	1.11	0.86	0.75	0.25	0.68	1.07
ave_cost_per_inc	Coeff	-0.30	-0.17	-0.26	-0.02	-0.41	-0.34	-0.20	-0.36	0.38	-0.26
	Std error	0.31	0.13	0.13	0.20	0.25	0.36	0.11	0.09	0.19	0.31
Cycle:age	Coeff	-0.05	0.02	0.00	0.04	0.00	0.01	0.03	0.02	0.01	0.04
	Std error	33.39	0.01	0.01	0.01	0.02	0.02	0.01	0.00	0.01	0.03
Drive:age	Coeff	0.10	0.05	0.05	0.08	0.04	0.06	0.05	0.04	0.05	0.08
	Std error	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.00	0.01	0.01
Passenger:age	Coeff	0.04	-0.02	-0.01	0.01	-0.02	0.00	-0.01	-0.03	-0.01	0.00
	Std error	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.00	0.01	0.01
Walk:age	Coeff	0.06	0.01	0.01	0.03	0.00	0.02	0.01	0.00	0.01	0.03
	Std error	0.02	0.01	0.01	0.01	0.01	0.01	0.01	0.00	0.01	0.01
Cycle:hh	Coeff	5.56	-0.04	-0.31	-0.23	-0.35	-0.32	-0.11	-0.10	0.02	-0.24
	Std error	1,276.74	0.15	0.18	0.15	0.22	0.25	0.16	0.05	0.16	0.48
Drive:hh	Coeff	0.10	0.15	0.02	0.03	-0.25	-0.11	-0.14	-0.14	0.10	0.07
	Std error	0.19	0.11	0.11	0.11	0.17	0.17	0.12	0.04	0.11	0.18
Passenger:hh	Coeff	0.00	0.04	-0.05	0.09	-0.38	-0.21	-0.23	-0.23	0.08	-0.12

Variable	Values	Northland	Waikato	Bay of Plenty	Gisborne-Hawke's Bay	Taranaki	Manawatu-Wanganui	Upper South Island	Canterbury	Otago	Southland
	Std error	0.19	0.11	0.11	0.11	0.17	0.17	0.13	0.04	0.11	0.19
Walk:hh	Coeff	-0.18	0.14	0.02	-0.05	-0.24	0.03	-0.21	-0.10	0.10	0.08
	Std error	0.20	0.11	0.13	0.11	0.18	0.18	0.13	0.04	0.12	0.20
Cycle:cars	Coeff	-6.92	-0.16	1.04	0.04	-0.34	0.36	0.46	0.54	0.12	-0.03
	Std error	1,475.86	0.22	0.24	0.25	0.36	0.36	0.24	0.09	0.31	0.45
Drive:cars	Coeff	1.16	0.17	0.81	0.49	0.38	0.36	0.38	0.70	0.95	0.02
	Std error	0.26	0.14	0.18	0.18	0.28	0.26	0.20	0.07	0.22	0.19
Passenger:cars	Coeff	1.03	0.08	0.62	0.09	0.01	0.07	0.17	0.46	0.63	-0.16
	Std error	0.25	0.14	0.18	0.18	0.28	0.26	0.20	0.07	0.22	0.20
Walk:cars	Coeff	0.48	-0.18	0.35	0.12	0.03	0.11	-0.05	0.36	0.55	-0.62
	Std error	0.28	0.15	0.19	0.20	0.30	0.28	0.21	0.07	0.23	0.24
Cycle:peak	Coeff	-1.55	-0.27	-1.61	-1.07	-1.43	-0.80	-1.31	-0.10	-0.91	-5.72
	Std error	1,270.08	0.40	0.47	0.40	0.69	0.60	0.46	0.15	0.45	819.04
Drive:peak	Coeff	-1.22	-0.53	-0.75	-1.03	-1.61	-0.68	-1.26	-0.16	-0.44	-1.42
	Std error	0.03	0.28	0.27	0.31	0.59	0.41	0.37	0.11	0.30	0.48
Passenger:peak	Coeff	-1.61	-0.99	-1.24	-1.27	-2.08	-1.08	-1.60	-0.61	-0.76	-1.85
	Std error	0.03	0.29	0.27	0.31	0.59	0.41	0.37	0.12	0.30	0.48
Walk:peak	Coeff	-1.00	-0.68	-0.87	-1.42	-1.93	-0.96	-1.59	-0.39	-0.76	-1.58
	Std error	0.04	0.30	0.30	0.33	0.61	0.44	0.38	0.13	0.32	0.52
Bus:modetime	Coeff	0.05	0.07	0.03	0.11	0.00	0.06	0.04	0.03	-0.22	0.04
	Std error	0.05	0.03	0.05	0.03	0.11	0.08	0.07	0.03	0.13	0.04
Cycle:modetime	Coeff	-6.38	-3.06	-7.89	-2.17	-3.54	-3.02	-1.77	-1.73	-1.72	-1.71
	Std error	654.80	0.98	1.54	0.77	1.11	1.45	0.66	0.22	0.69	0.87
Drive:modetime	Coeff	-0.15	-0.07	-0.12	-0.10	-0.09	-0.12	-0.08	-0.12	-0.04	-0.26
	Std error	0.01	0.04	0.06	0.05	0.06	0.05	0.05	0.02	0.06	0.08

Variable	Values	Northland	Waikato	Bay of Plenty	Gisborne-Hawke's Bay	Taranaki	Manawatu-Wanganui	Upper South Island	Canterbury	Otago	Southland
Passenger:modetime	Coeff	-0.01	0.01	0.01	0.00	0.01	0.00	0.01	0.00	0.02	0.00
	Std error	0.00	0.01	0.02	0.00	0.01	0.00	0.01	0.00	0.02	0.02
Walk:modetime	Coeff	-49.61	-44.31	-40.84	-42.64	-44.52	-45.27	-40.51	-36.45	-40.02	-50.23
	Std error	0.03	2.37	2.38	2.53	3.14	3.36	0.82	1.04	2.22	4.70

Table B.5 Model coefficient stability – cost coefficient example

Coefficient on average cost per kilometre of travel from models on individual years

Year	Northland	Waikato	Bay of Plenty	Gisborne-Hawke's Bay	Taranaki	Manawatu-Wanganui	Upper South Island	Canterbury	Otago	Southland
2004	0.31	0.44	-1.22	0.40	0.43	0.91	-0.32	-0.08	0.92	-2.26
2005	-1.75	-0.28	2.12	-0.78	0.06	0.00	-0.29	-0.80	-0.12	-2.21
2006	0.31	-1.49	0.09	-0.43	0.80	0.51	-0.51	0.00	0.30	-1.00
2007	0.12	0.18	0.06	0.52	0.92	-0.87	0.10	-0.21	0.08	1.57
2008	-0.95	0.42	-0.06	0.71	-1.60	-0.90	-0.75	0.79	0.18	1.37
2009	0.23	0.14	0.32	0.05	0.27	0.51	-0.12	0.21	0.34	0.54
2010	-0.89	0.10	0.25	0.68	-0.32	0.90	0.18	0.14	-0.07	0.26
2011	-0.91	-0.73	0.10	-0.34	-0.43	-0.73	-0.09	-0.11	-0.10	-0.18
2012	-0.62	0.20	-0.28	-0.56	0.13	1.19	-0.14	-0.37	0.34	-1.82
2013	-0.77	-0.09	-0.12	0.66	-0.66	-1.72	-0.65	-0.43	0.58	0.27
2014	0.48	-0.63	-0.38	-0.17	-0.70	-0.48	0.18	-0.30	0.23	0.78

Appendix C: Freight flow models and data

Table C.1 Tonne flow model with smallest overall errors

Overall error of -6%

Flow	Factor	Coeff	t- stat
Origin	Average	-24.21	-2.93
Origin	Manufacturing	-1.25	-1.57
Origin	Services	-4.27	-3.32
Destination	Services	-1.00	-2.03
Origin	Primary sector	-1.01	-2.38
Destination	Primary sector	-0.26	-0.81
Origin	Trade volumes	0.49	1.99
Destination	Trade volumes	0.16	1.69
Origin	Population	3.28	3.96
Destination	Population	0.54	2.15
Origin	GDP	-3.80	-5.53
Origin	Export volume	-0.47	-1.94
Destination	Import volume	-0.10	-1.00
Origin	Area	0.32	1.77
Destination	Area	0.36	3.11
Destination	Distance	-0.85	-6.22
Intra-regional	Average	32.09	2.99
Intra-regional	GDP per capita	-3.08	-2.97
Intra-regional	Services	-2.65	-2.74
Intra-regional	Trade volumes	0.06	0.75
Intra-regional	Export volume	-0.05	-0.76
Spatial lags	W_j	0.13	5.77
	R-squared	0.86	
	Model std error	0.44	

Table C.2 Most general freight model

Tonne freight flow version

Flow	Factor	Coefficient	t- stat
Origin	Average	-32.1	-2.7
Origin	Manufacturing	-1.4	-1.7
Destination	Manufacturing	-0.7	-0.9
Origin	Services	-4.5	-3.5
Destination	Services	-2.1	-1.6
Origin	Primary sector	-1.1	-2.6
Destination	Primary sector	-0.5	-1.1
Origin	Trade volumes	0.7	2.1
Destination	Trade volumes	0.4	1.1
Origin	Population	3.4	4.1
Destination	Population	1.3	1.6
Origin	GDP	-3.9	-5.7
Destination	GDP	-0.7	-1.0
Origin	Export volume	-0.6	-2.2
Destination	Export volume	-0.2	-0.6
Origin	Import volume	-0.1	-0.7
Destination	Import volume	-0.1	-1.2
Origin	Area	0.4	2.0
Destination	Area	0.5	2.6
Destination	Distance	-0.9	-6.0
Intra-regional	Average	25.0	1.6
Intra-regional	Population	0.0	0.0
Intra-regional	GDP per capita	-2.4	-1.1
Intra-regional	Manufacturing	0.6	0.2
Intra-regional	Services	-2.1	-0.5
Intra-regional	Primary sector	0.1	0.1
Intra-regional	Trade volumes	0.1	0.6
Intra-regional	Export volume	-0.1	-0.2
Intra-regional	Import volume	0.0	0.0
Intra-regional	Area	0.2	0.3
Spatial lags	W_j	0.1	4.7
	Rsqr	0.9	0.0
	SigE	0.4	0.0

Appendix D: Data tables

Table D.1 Income – fitted values by income band recorded in the NZHTS

Fitted using gamma distributions fitted to personal income data reported by the IRD – excludes income from tax credits

	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013
L	–	–	–	–	–	–	–	–	–	–	–
M	5,794	5,815	5,825	5,798	5,794	5,792	5,836	5,861	5,859	5,890	5,875
N	12,457	12,461	12,465	12,465	12,468	12,470	12,477	12,480	12,480	12,484	12,486
P	17,441	17,444	17,448	17,450	17,453	17,456	17,461	17,464	17,464	17,467	17,470
R	24,706	24,716	24,734	24,746	24,759	24,772	24,790	24,802	24,802	24,811	24,825
S	34,675	34,684	34,702	34,716	34,731	34,744	34,760	34,770	34,771	34,778	34,794
U	58,574	58,607	58,678	58,743	58,804	58,859	58,914	58,952	58,957	58,978	59,047
T	44,658	44,667	44,685	44,700	44,715	44,729	44,743	44,753	44,755	44,761	44,777
J	54,647	54,656	54,674	54,690	54,705	54,719	54,733	54,743	54,744	54,750	54,767
K	64,640	64,648	64,666	64,683	64,699	64,713	64,726	64,736	64,737	64,742	64,760
W	81,729	81,796	81,950	82,097	82,233	82,356	82,467	82,547	82,558	82,599	82,757
Q	121,522	121,958	123,081	124,319	125,536	126,739	127,809	128,643	128,780	129,179	131,229
V	116,148	116,302	116,674	117,048	117,388	117,700	117,965	118,159	118,189	118,281	118,695
H	171,244	171,663	172,764	174,001	175,204	176,391	177,413	178,214	178,350	178,717	180,742
X	27,800	28,476	29,795	30,856	32,117	33,385	35,052	36,248	36,371	37,188	39,257
Z	27,800	28,476	29,795	30,856	32,117	33,385	35,052	36,248	36,371	37,188	39,257
Stdev	23,456	23,965	25,134	26,296	27,508	28,711	29,948	30,877	31,007	31,523	33,537

Table D.2 Choice model data descriptive statistics

Sample for 2012–2014 observations

id (observation id)	**choice (choice flag)**	**age (age)**	**hh_inc (household income)**
Min. : 281006	Mode :logical	Min. : 0.00	Min. : 3303
1st Qu.: 648523	FALSE:825097	1st Qu.: 20.00	1st Qu.: 50651
Median : 803514	TRUE :117871	Median : 40.00	Median : 82683
Mean : 801837	NA's :0	Mean : 38.69	Mean : 92240
3rd Qu.: 950518		3rd Qu.: 55.00	3rd Qu.:119527
Max. :1172568		Max. :105.00	Max. :597974
hh (household type)	**dens (density)**	**reg (region)**	**peak (journey at peak)**
Min. :1.000	Min. : 1.456	Min. : 1.000	Min. :0.0000
1st Qu.:2.000	1st Qu.: 8.292	1st Qu.: 3.000	1st Qu.:0.0000
Median :3.000	Median : 436.818	Median : 7.000	Median :0.0000
Mean :3.387	Mean : 525.616	Mean : 6.522	Mean :0.3764
3rd Qu.:5.000	3rd Qu.: 770.360	3rd Qu.:10.000	3rd Qu.:1.0000
Max. :6.000	Max. :1389.863	Max. :12.000	Max. :1.0000
ave_cost_perk (average cost per kilometre)	**ave_cost_per_inc (average cost per kilometre relative income)**	**speed**	**modetime (typical journey duration by mode)**
Min. :0.00000	Min. : 0.00000	Min. : 0.00184	Min. : 0.000
1st Qu.:0.03587	1st Qu.: 0.00191	1st Qu.: 10.20267	1st Qu.: 0.081
Median :0.19551	Median : 0.18861	Median : 17.88477	Median : 0.216
Mean :1.10169	Mean : 1.83833	Mean : 19.71243	Mean : 2.276
3rd Qu.:1.71555	3rd Qu.: 1.50747	3rd Qu.: 27.20194	3rd Qu.: 0.600
Max. :5.00000	Max. :151.38841	Max. :194.43912	Max. :24987.148
time (journey duration)	**cars**	**dist (distance)**	**purp (journey purpose)**
Min. : 0.0000	Min. :0.000	Min. : 0.000	HOME : 1504
1st Qu.: 0.0833	1st Qu.:1.000	1st Qu.: 1.277	OTH :223352
Median : 0.1667	Median :2.000	Median : 3.275	SHOP :235304
Mean : 0.2787	Mean :2.099	Mean : 9.082	SOCL :265944
3rd Qu.: 0.3333	3rd Qu.:2.000	3rd Qu.: 8.823	STUDY: 50680
Max. :25.0667	Max. :9.000	Max. :626.595	WORK :166184

Source: Author's calculations, IRD, Ministry of Transport NZHTS, Statistics New Zealand