MODELLING FREIGHT DEMAND

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ABSTRACT

Over the last 10 years, road freight in New Zealand has grown at approximately 1.3 times the rate of growth of real gross domestic product (RGDP) and that these two growth rates are strongly correlated. What this means is that, if the structure of the economy remains the same and average RGDP growth continues as it has done for the last 10 years, road freight volumes will double in 18 years.

Clearly freight growth of this magnitude is unsustainable in the long term at a number of levels including fossil-fuel consumption, greenhouse gas emissions, air quality related emissions, and congestion.

Although the model relating freight growth to RGDP growth provides a good fit to the observed data it is of limited use in developing strategies for a more sustainable freight system. Using this model the only mechanism available to reduce freight demand is to have negative RGDP growth but this is not an acceptable strategy in most economies.

To address this problem we have developed a more complex modelling framework that describes the relationships between economic growth and freight growth. In principle this framework can be applied to the economy as a whole, or to a specific region or to a sector and it describes mechanisms by which freight growth will be greater than economic growth.

INTRODUCTION

Over the last 10 years, road freight in New Zealand has grown at approximately 1.3 times the rate of growth of real gross domestic product (RGDP) and that these two growth rates are strongly correlated. What this means is that, if the structure of the economy remains the same and average RGDP growth continues as it has done for the last 10 years, road freight volumes will double in 18 years.

Clearly freight growth of this magnitude is unsustainable in the long term at a number of levels including fossil-fuel consumption, greenhouse gas emissions, air quality related emissions, and congestion.

This paper presents the development of a modelling framework that describes the mechanisms driving this freight growth. The eventual aim is to identify the key factors contributing to freight growth as a basis for developing strategies to control freight growth while maintaining acceptable levels of economic growth.

BACKGROUND

Previous work undertaken at TERNZ (Bolitho, Baas et al. 2003; Mackie, Baas et al. 2006a) has shown a strong correlation between the growth in road freight and the growth in RGDP. These studies used the vehicle-kms travelled (Vkt) derived from Road User Charges (RUCs)

purchased by heavy vehicles as a surrogate for freight volume. The correlation can be written as:

$$\frac{d\,Vkt}{Vkt} = \alpha\,\frac{d\,RGDP}{RGDP}$$

Eq. 1

This expression can then be integrated to give:

$$Vkt = K.RGDP^{\alpha}$$

Eq. 2

The analysis by Mackie used data for the period 1997-2005 and found a very good fit to this equation (r^2 = 0.996) with K = 0.0004 and α = 1.35. What this means is that the growth in road freight volume was 1.35 times the growth in RGDP. More recently we have repeated the analysis with additional data for 2006 and 2007 and the revised value of α was 1.31 with a slightly improved fit (r^2 = 0.997). Figure 1 shows the comparative growth between heavy vehicle-kms and RGDP while Figure 2 shows the model fit.
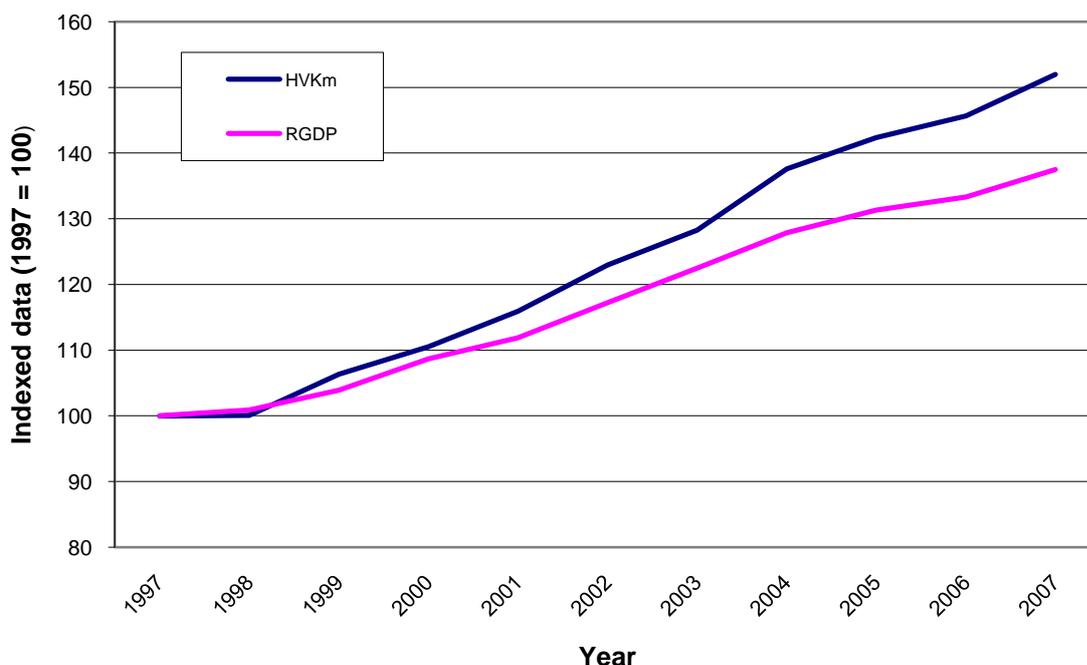

Figure 1. Growth in heavy vehicle-kms compared to growth in RGDP 1997-2007.

Implicit in this model is an assumption that vehicle productivity did not change over the time period spanned by the data, i.e. the relationship between Vkt and freight volumes has not changed. If there has been any change it is likely that the vehicles have become more productive, in which case the freight growth will have been greater than the Vkt growth.

This growth in road-freight is not the result of shifts to road from other transport modes. The data on rail freight movements for largely the same period show even higher growth rates (Mackie, Baas et al. 2006b). Moreover road freight makes up over 70% of the freight task by tonne-kms and 92% by tonnes moved (Richard Paling Consulting 2008) and

therefore dominates any statistics on freight demand. Thus the observed growth in road freight volume reflects the growth in overall freight demand.
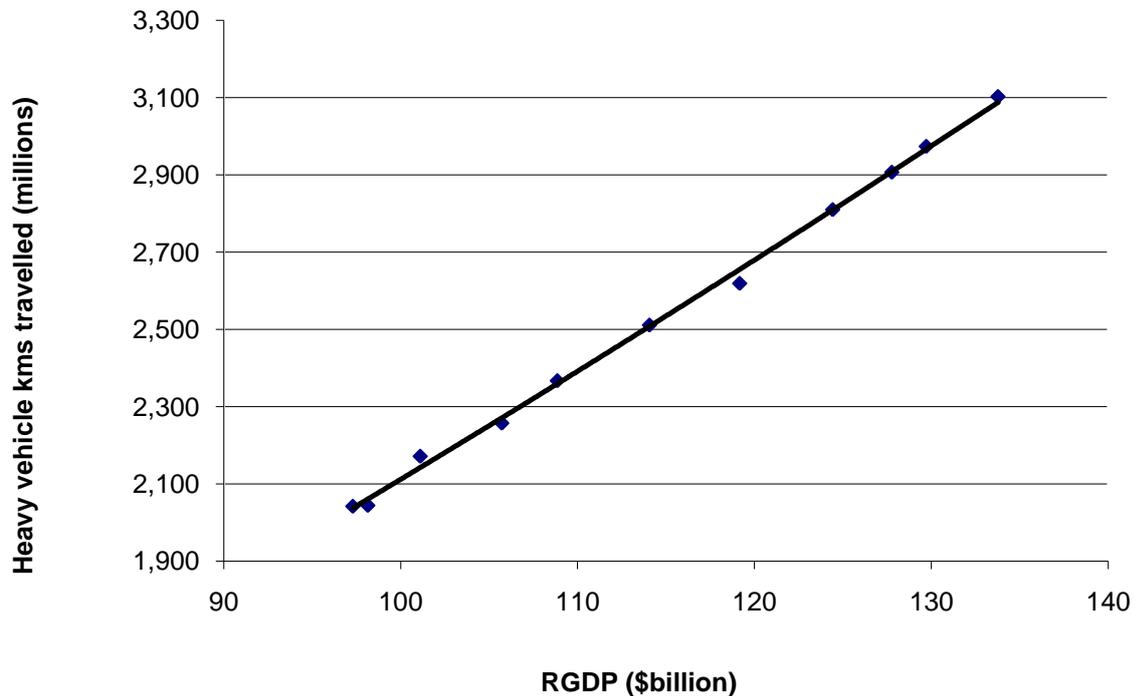

Figure 2. Heavy vehicle kilometres travelled vs RGDP (1997-2007).

Over the 10 year period analysed the growth in RGDP was 37.5% which is equal to an average annual rate of 3.2%. If we assume that the long term average annual rate of growth of RGDP will continue at 3% p.a. and that the relationship between RGDP and road freight does not change, then road freight volumes will double every 18 years. This is a compounding effect and thus in 36 years we would expect four times the current freight volume and so on.

The New Zealand Transport Strategy (Ministry of Transport 2008) predicts a rather more modest growth in road freight of 60% by 2040 although with a 120% increase in total freight. However, while the TERNZ model is based on "business as usual", i.e. existing trends continuing in the future, the NZTS projection is based on some significant changes in freight transport occurring. It assumes that there will be substantial modal shifts from road to coastal shipping and rail as well as some decoupling of freight growth from RGDP growth. It also assumes that RGDP growth in the future will be substantially less than it has been over the last ten years.

This pattern of freight growth exceeding RGDP growth is not unique to New Zealand. In Australia it has been predicted that the road freight task will double between 2000 and 2020 (BTRE 2006). This is based on 2.7% p.a. RGDP growth and a multiplier of 1.24. Their model also includes a factor for freight rates. In Europe they have observed an average freight growth of more than 1.2 times the growth in RGDP over the 25 countries in the European Union (ERF - IRF BPC 2007). On the other hand, in the USA, the freight task grew by only 0.62 times RGDP between 1980 and 1991 (Cambridge Systematics Inc 1997) demonstrating

that it is possible to achieve economic growth without a disproportionate growth in the freight task. The idea of decoupling freight growth from economic growth is very attractive from a sustainability point-of-view and there were indications that it was achieved for road freight in the UK between 1998 and 2004. However, an analysis of the data (McKinnon 2007) indicates that, although there may have been a modest decoupling effect, most of the reduction in road freight volumes could be explained by two factors that do not represent a reduction in the freight, namely, an increased market share captured by foreign truck operators (who do not appear in the road freight statistics) and a modal shift to rail and water.

Although some in the transport industry see this projected growth in freight demand positively and take the view that we should plan to accommodate it, in the long term it is unsustainable at a number of levels:

- Freight transport is relatively energy intensive and relies heavily on oil-based fossil fuels for this energy. If freight grows faster than RGDP, this implies that the economy is becoming more energy intensive and more dependent on non-renewable energy. (There is no evidence to suggest that the increase in energy used for freight is being offset by energy use reductions elsewhere in the system).

- There is some evidence to suggest that the international demand for oil is approaching the available supply capacity. If this happens there is likely to be a rapid rise in the price and quite possibly restrictions on availability. The price volatility associated with perceptions of the risk of supply shortages was demonstrated in 2007-8 when the price of crude oil doubled in a year and then, in the following six months, dropped back to less than one third of the peak value. The effects of restricted supply were last seen in New Zealand in the 1970s when the Organisation of Petroleum Exporting Countries (OPEC) reduced its production to force prices up. Rationing of private car use through "carless" days, bans on weekend sales of petrol and a reduced open road speed limit were imposed. Increased freight demand makes the economy more vulnerable.

- To meet its Kyoto Protocol commitments the government has undertaken to reduce the per capita greenhouse gas emissions from transport to half the 2007 levels by 2040 (Ministry of Transport 2008). Clearly, doubling the freight task every 18 years using a transport system based on fossil fuels would make this extremely difficult to achieve.

- The air quality in some of our major urban centres (notably Auckland and Christchurch) is already of some concern with some 500 premature deaths per annum attributed to air pollution from motor vehicles (Fisher, Kjellstrom et al. 2007).

- Similarly congestion is a concern is some major urban centres resulting in pressure on the government to invest in costly new infrastructure. Large increases in road freight demand will exacerbate this problem.

The model presented above provides an accurate fit to the current "business as usual" situation but provides no insight into how we can develop a less freight-intensive economy. The only mechanism provided for reducing freight growth is reducing RGDP growth. In this paper we develop a framework for modelling the relationship between freight demand and economic activity that identifies the factors that result in freight growing faster than RGDP and provides some insights into how this might change.

MODELLING FRAMEWORK

The modelling framework proposed here can be used to model freight at the national, regional or sectoral economy levels. For each economic entity the model structure remains the same but the coefficient and variable values will change.

Assume that the economic entity produces P tonnes of output. If each tonne of output has an average net value of $v /tonne, then RGDP is given by

$$RGDP = P \times v$$
Eq. 3

For national or regional economies the outputs include a wide range of products which may be very diverse with values ranging over several orders of magnitude. Nevertheless there is an average value and Eq. 3 can be applied. For some sectors such as information technology the weight of output is very small and hence the value per tonne is very high. Furthermore the output is not normally measured in tonnes. It will be difficult to calibrate the model for these sectors but as they are not usually major contributors to freight generation, the effect of not being very accurate will not have much effect on the overall levels of freight predicted.

The rate of change of RGDP with respect to time is given by

$$\frac{dRGDP}{dt} = P.\frac{dv}{dt} + v.\frac{dP}{dt}$$
Eq. 4

The relative change in RGDP over some time interval, *dt,* is

$$\frac{dRGDP}{RGDP} = \frac{dv}{v} + \frac{dP}{P}$$
Eq. 5

That is, the relative change in RGDP is equal to the relative change in the value per tonne of goods produced plus the relative change in the quantity of goods produced.

Now consider the freight demand associated with producing these goods. The output, P, is transported to end-users. Let the average distance for this trip be s_1 kms. For each unit of output, there are α_2 units of intermediate products which are transported an average distance of s_2 kms. Furthermore for each unit of output, there are α_3 units of raw materials which are transported an average distance of s_3 kms. Thus the total freight movement, *F*, generated (in tonnes-kms) is:

$$F = P.s_1 + P.\alpha_2.s_2 + P.\alpha_3.s_3$$
$$= P(s_1 + \alpha_2.s_2 + \alpha_3.s_3)$$
Eq. 6

Using the same approach as for RGDP, the relative change in freight over a time, dt, is

$$\frac{dF}{F} = \frac{dP}{P} + \frac{d(s_1 + \alpha_2.s_2 + \alpha_3.s_3)}{(s_1 + \alpha_2.s_2 + \alpha_3.s_3)}$$

Eq. 7

Substituting for P from Eq. 5

$$\frac{dF}{F} = \frac{dRGDP}{RGDP} - \frac{dv}{v} + \frac{d(s_1 + \alpha_2.s_2 + \alpha_3.s_3)}{(s_1 + \alpha_2.s_2 + \alpha_3.s_3)}$$

Eq. 8

The quantity $s_1 + \alpha_2.s_2 + \alpha_3.s_3$ is the average tonne-kms of freight per tonne of output. We will call this quantity freight intensity or FI. The equation then becomes:

$$\frac{dF}{F} = \frac{dRGDP}{RGDP} - \frac{dv}{v} + \frac{dFI}{FI}$$

Eq. 9

Thus the relative change in freight demand is equal to the relative change in RGDP minus the relative change in value per unit of output plus the relative change in freight intensity. Freight intensity is similar to the transport intensity quantity which is used in other studies. Transport intensity, TI, is usually defined as the amount of transport per unit of GDP. In terms of freight demand,

$$TI = \frac{P(s_1 + \alpha_2.s_2 + \alpha_3.s_3)}{P.v}$$

Eq. 10

Thus

$$TI = \frac{FI}{v}$$

Eq. 11

Differentiating and normalising

$$\frac{dFI}{FI} = \frac{dTI}{TI} + \frac{dv}{v}$$

Eq. 12

Thus Eq. 9 can be rewritten as

$$\frac{dF}{F} = \frac{dRGDP}{RGDP} + \frac{dTI}{TI}$$

Eq. 13

We can relate this back to the TERNZ freight growth model shown in Eq. 1. The original model found that *dF/F* was equal to 1.31 x *dRGDP/RGDP*. This implies that *dTI/TI* is currently equal to 0.31 x *dRGDP/RGDP*. In the short term we would expect the average value per unit output for the whole economy to stay approximately constant in real terms and thus *dv/v* = 0. Thus *dFI/FI* is also equal to 0.31 x *dRGDP/RGDP*

If we consider, say, the forestry sector it is clear that a relationship of the form shown in Eq. 13 would apply. When the demand for logs is low the harvesting will be done at the closest available forests because they have the lowest transport costs. Hence the TI would reduce amplifying the effect of the reducing RGDP. If demand increases more remote forests will need to be harvested and thus the average haul distance for logs increases often very substantially and hence TI also increases. Thus the TI moves in the same directions as the RGDP and amplifies its effect.

We can write the expression for Freight Intensity as follows.

$$FI = \sum_i \alpha_i . s_i$$

Eq. 14

Note that α_1 = 1. The index, i, identifies whether the freight relates to outputs (i=1), intermediate processes (i=2) or inputs (i=3). It then follows that:

$$\frac{dFI}{FI} = \frac{\sum_i \alpha_i . s_i . \frac{d\alpha_i}{\alpha_i}}{\sum_i \alpha_i . s_i} + \frac{\sum_i \alpha_i . s_i . \frac{ds_i}{s_i}}{\sum_i \alpha_i . s_i}$$

Eq. 15

That is, the relative change in freight intensity is equal to the weighted average of the relative change in freight volumes per tonne of output plus the weighted average of the relative change in distance travelled. The weighting reflects the proportion of freight movement associated with the variable being changed. For example, if we consider a sector with a high value output where the amount of inputs and intermediate freight is much larger than the amount of output freight. Then, even a quite large change in the freight distance for outputs (s_1) will have only a small effect of freight intensity, while a change in the freight distance for inputs will have a much greater effect on freight intensity.

We can expand the detail in the model by splitting the freight movements into import/export (to or from a port), intra-regional and inter-regional. We do this by introducing a new index, j, with values from 1 to 3 corresponding to the three categories.

$$\frac{dFI}{FI} = \frac{\sum_i \sum_j \alpha_{ij} . s_{ij} . \frac{d\alpha_{ij}}{\alpha_{ij}}}{\sum_i \sum_j \alpha_{ij} . s_{ij}} + \frac{\sum_i \sum_j \alpha_{ij} . s_{ij} . \frac{ds_{ij}}{s_{ij}}}{\sum_i \sum_j \alpha_{ij} . s_{ij}}$$

Eq. 16

In Eq. 16, α_{ij} is the amount of freight in process i with origin/destination j per tonne of output. s_{ij} is the average distance travelled in process i with origin/destination j. Because both i and j can assume values from 1 to 3 both α and s can be represented by 3 x 3 arrays.

This is illustrated in the table below.

	Import/Export	Intra-Regional	Inter-regional
Output	α_{11}, s_{11}	α_{12}, s_{12}	α_{13}, s_{13}
Intermediate	α_{21}, s_{21}	α_{22}, s_{22}	α_{23}, s_{23}
Input	α_{31}, s_{31}	α_{32}, s_{32}	α_{33}, s_{33}

To implement the model we need to determine the current values of α and s and to determine the factors that drive changes in α and s. Relationships between the rates of change in α and s and key driving factors such as fuel price, exchange rate, population etc still need to be developed.

AN EXAMPLE APPLICATION

Applying the modelling framework requires data to calibrate it and obtaining this data can be challenging. In this section we will illustrate the process by applying the framework to the dairy sector. The dairy sector is a relatively simple case to analyse because more than 95% of its production is exported and about 95% of the milk is processed by a single company.

The most recent year for which we have detailed data is 2006-07. In that year 15,134 Ml of milk was produced (Livestock Improvement Corporation Limited 2007). 2.099Mt of dairy products were exported (Richard Paling Consulting 2008). Domestic consumption was calculated using the per capita consumption rates for 2005 given by (International Dairy Federation 2007) and the 2007 population figures from Statistics New Zealand. The results were 0.392Mt of liquid milk and 0.108Mt of butter, cheese and other dairy products. Thus the total amount of output product produced by the industry was 2.599Mt. This is P in the modelling framework.

In the data for the dairy industry presented by Paling (2008) the country is divided into seven regions. Using these same seven regions and the freight figures given by Paling we can derive the table of α_{ij} values for the modelling framework. This is shown in Table 2 below. Note that α x P gives the amount of freight in each of the categories. It is notable that the amount of milk going into the system (bottom row of the table) is approximately six times as large as the amount of final product.

Table 2. Modelling framework α values for the dairy industry.

	Import/Export	Intra-Regional	Inter-regional
Output	0.81	0.15	0.04
Intermediate	0.00	1.01	0.06
Input	0.00	5.84	0.15

From the movements we can derive the average distance for each category of freight. These are shown in Table 3. 96% of dairy exports go through six ports. For each of these ports it is reasonably obvious which processing facilities will supply them and thus the average distance can be calculated. The inter-regional movements are similarly dominated by a small number of links and so the distance can be estimated easily. The intra-regional

movements are primarily the milk tanker movements. The data provided by Paling (2008) indicates an average loaded travel distance of 88km. However, tankers collecting milk can, at best achieve 50% utilisation and thus this implies an average trip length in excess of 176km.   Fonterra's 2004 annual report (Fonterra 2004) presents data that shows an average trip length of 130km. Assuming 46% utilisation this gives an average loaded distance of 60km. This is the figure that has been used.

Table 3. Modelling framework distance, s, values.

	Import/Export	Intra-Regional	Inter-regional
Output	114	60	121
Intermediate	0	60	204
Input	0	60	121

If we multiply the α and s values together we get the relative contribution of each freight component to the freight intensity of the industry. This is shown in Table 4. From this it is clear that the largest contribution to freight intensity in the dairy industry comes from the collection of milk, even though the average distance travelled is the smallest.

Fonterra has recognised this and in their 2007 annual report (Fonterra 2007) they describe a milk concentration plant that they are building which they expect will reduce their annual vehicle-kms by 1.5 million. This plant only serves one catchment area supplying one dairy factory and yet will save about 2% of the total vehicle-kms travelled by tankers.

Table 4. Modelling framework contributions to freight intensity for the dairy industry.

	Import/Export	Intra-Regional	Inter-regional
Output	92.1	9.0	5.0
Intermediate	0.0	60.3	12.6
Input	0.0	350.6	18.6

CONCLUSIONS

A modelling framework has been developed that describes the mechanisms by which freight grows more quickly than RGDP. To illustrate its application it has been calibrated for the dairy industry in New Zealand.

Further work is required to identify and quantify the factors that will change the model parameters. Once this is done the model will provide a tool for analysing the impacts of policy initiatives to reduce the freight intensity of the economy while maintaining acceptable levels of growth.

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