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Direct and cross elasticities for freight distribution access charges.

By

David A. Hensher, Andrew T. Collins,
John M. Rose and Nariida C. Smith[1*]

[1] Transport for NSW
*Nariida Smith was Sydney Office Manager for
GHD Meyrick when this study was undertaken.

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ABSTRACT:

The interest in reform of road user charges for freight distribution in many countries continues unabated, linked to a desire to improve economic efficiency as well as recognition of the declining revenue base from traditional sources, especially fuel excise. A critical input into the assessment framework used to identify the impact of alternative access charges on freight vehicle utilisation, by vehicle class, is a suite of direct and cross elasticities. This paper uses data collected in Australia in 2010-11 on alternative access charge regimes obtained from a stated choice experiment, used in estimation of mixed logit models calibrated on vehicle market shares, to derive matrices of direct and cross access charging elasticities that represent the relationship between an access charge (defined by combinations of distance, mass, and location), vehicle class choice, total kilometres, and tonne-kilometres carried in the vehicle class segments. The elasticities can be used to estimate the response of heavy vehicle operators (and shippers) to price signals under the different access charging schemes.

KEY WORDS: ***Freight elasticities, access charges, vehicle class, vehicle kilometres, tonne vehicle kilometres, stated choice.***

AUTHORS: **Hensher, Collins, Rose and Smith**

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CONTACT:

INSTITUTE of TRANSPORT and LOGISTICS STUDIES (C13)
The Australian Key Centre in Transport and Logistics Management

The University of Sydney NSW 2006 Australia

Telephone: +612 9114 1824
Facsimile: +612 9114 1722
E-mail: business.itlsinfo@sydney.edu.au
Internet: http://sydney.edu.au/business/itls

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1. Introduction

The Council of Australian Governments (COAG) Road Reform Plan was established in 2010 to investigate the feasibility of alternative heavy vehicle pricing models in order to move from the current average cost-recovery model towards a model based more upon economic efficiency. As part of the research program, the COAG Road Reform Plan identified the need for a feasibility study of alternative road funding and pricing reform options. The National Transport Commission (NTC) was tasked with developing and assessing a number of alternative heavy vehicle pricing model options, ranging from an improved status quo and distance based charges to distance-mass-location based charging, with the aim of better aligning prices charged with the actual cost of road wear imposed by heavy vehicles on the road network. Table 1 summarises the pricing regimes under consideration.

Table 1: Candidate access charging regimes

Regime	Variant	Explanation
Fuel based charges	PAYGO (current system)	Includes an annual registration fee and a fuel excise based charge.
	Flat charges	Similar to the current PAYGO system, this option would apply a fixed fuel excise for all heavy vehicles and a significantly lower registration fee. The new charge has been recalculated to better align fuel excise and the associated cost caused by heavy vehicles.
	Differentiated charges	Involves a flat fuel charge per litre differentiated for rigid vehicles without a trailer and other heavy vehicles.
Distance based charges	By vehicle	Charges all heavy vehicles using the same flat per kilometre charge.
	By module	Charges a differentiated rate for articulated vehicles and rigid vehicles. Additionally, considers the number of modules that each vehicle has. For example, if an operator had a truck and dog combination they would pay the rigid charge twice to reflect both the truck and trailer.
	By number of axles	Charges heavy vehicles based on the total number of axles the vehicle has. The more axles, the higher the charge the vehicle is required to pay.
	By axle group	Charges heavy vehicles according to the number and type of axles it has. Additionally, it also considers the type of axle groups that a vehicle has.
Distance-location		For each vehicle type, this option charges heavy vehicles based on the kilometres it has travelled and the road types that it has used. This option charges a different price for 5 major road (location) categories, which are freeways, major urban arterials, major rural arterials, local collector and local access.
Distance-mass		For each vehicle type, this option charges heavy vehicles based on the mass it carries and the kilometres it travels. The charge could be either based on nominated maximum mass or could be dynamically adjusted according to the actual load that is on the vehicle.
Distance-mass-location		Charges heavy vehicles according to the mass carried and road types used by the heavy vehicle. This option most aligns the price charged to the heavy vehicle and the associated cost of operating the vehicle.

Source: NTC advice. Note that all distance-location, distance-mass and distance-mass-location charges could be applied by vehicle, axle group, axle number and module.

A critical input into the assessment framework used to identify the impact of alternative access charges on freight vehicle utilisation is a suite of direct and cross elasticities. The focus of this paper is on deriving matrices of direct and cross access charging elasticities representing the relationship between an access charge, vehicle class choice, total kilometres, and tonne-kilometres carried. Although the primary focus is on road freight movements, we allow for rail in the profile of alternative modes.

The modelling framework used to deliver the requisite elasticities is the mixed logit choice model (see Hensher *et al.* 2005). The mixed logit model is rich enough to test for the presence of many sources of observed and unobserved heterogeneity in preference revelation in respect of a specific alternative and a specific attribute. It enables us to relax the independence of irrelevant alternatives (IIA) assumption and hence obtain meaningful and asymmetric cross elasticities.

Reviews of the freight demand elasticity literature are provided by Graham and Glaister (2004) in the context of road traffic demand, and de Jong *et al.* (2004, 2012), in the context of a broader freight modelling agenda. Graham and Glaister (2004) compiled 143 direct elasticities for road freight, and observed a mean of -1.07, a range of -7.92 to 1.92, and that 66 percent of elasticities lay between -1.3 and -0.5. Compiling various freight transport cost elasticities from Australia, Luk and Hepburn (1993) found short run direct elasticities to range from -0.55 to -0.33, and long run elasticities to range from -2.5 to -0.7. However, the studies considered by these papers varied in numerous respects, including in terms of models employed, commodities carried, and, crucially, definitions of price and demand. Graham and Glaister (2004) noted that such differences between studies is likely to explain the extensive variation in elasticity measures. Li *et al.* (2011) employed a random effects regression model to identify systematic sources of variation in direct elasticity measures. Some of their key findings include greater elasticity for tonne kilometres over tonnes, for transport by road, but a lesser elasticity on this dimension for rail; an overall greater elasticity for rail; and a lesser elasticity for time series data relative to cross-section and panel data.

Crucial to the construction of elasticities is the selection of which variables to include in the elasticity measure. In a freight context, quantity demanded is commonly measured in vehicle kilometres and tonnes kilometres, and is herein. Whilst the elasticity is typically with respect to a change in price such as a freight rate, it could also be with respect to such measures as generalised cost (e.g., Beuthe *et al.* 2001) or quality-of-service (e.g., Lewis and Widup 1982). In this study, we consider the impact of varying per kilometre access charges, which form the crucial component of the alternative pricing regimes detailed above. This in turn has implications for which freight options the elasticities should be derived. Mode of transport dominates the literature, with truck, rail and inland shipping common alternatives. However, a reasonable reaction to the introduction or variation of access charges is a shift between classes of heavy vehicles, especially if the charges are imposed in different ways across vehicle classes. Holguín-Veras (2002) derived elasticities for three classes of vehicle: pickups and small trucks, two and three axle trucks, and semitrailers. In this study, we estimate direct and cross access charging elasticities for 16 vehicle classes, as well as rail. To the best of our knowledge, no previous study has handled vehicle substitution to such a high level of detail.

The elasticities are obtained in a highly disaggregate manner through a stated choice survey. Given the complexity of real freight choice decisions, and a focus on evaluating behavioural response to a range of proposed access charging regimes, a stated choice task is selected as an appropriate way to obtain insights into how freight distribution and logistics companies might respond to alternative road user charging policies. A detailed description of how such a survey can be constructed is also a key part of this paper.

The paper is organised as follows. We begin with an overview of the context in which to collect data, emphasising the level of detail required if we are to be able to disaggregate elasticities to a level meaningful in assessing market heterogeneity in responses to alternative access charging regimes. This is followed by the design of the choice experiment, a brief summary of the mixed logit model, a descriptive profile of the data and the estimated models. The full suite of key elasticties are then presented and interpreted, followed by conclusions.

2. Study setting

The focus of the empirical inquiry is the distribution of freight, predominantly by heavy vehicles, varying in size from two-axle rigid to triple road trains, throughout Australia. The type of road (i.e., freeway, arterial or local) is also distinguished given its relevance to the setting of the access charge and anticipated differences in behavioural response.

To be of value in assessing the overall impacts of changes in pricing regimes on road freight demand, the methodological approach must be able to account for both the diversity of freight and the operators who carry it and shippers who dispatch it. The first task is to identify groupings of decision makers to be surveyed. Then, if the numbers of vehicles and amount of freight carried by each grouping can be assessed, the information can be used to deduce the overall impact of elasticities on transport and traffic with road pricing changes.

For the decision makers to be surveyed, we focus on the distribution companies. We include within this focus the logistics operations within medium and large enterprises which run the logistics business for the firm and the large and small third party logistics providers who provide total supply chain services for small to large businesses. For simplicity, these decision makers are referred to as "transport operators" or just "operators". We believe that the transport operator knows what is being moved, including the driver who is on the road making route decisions. How they negotiate the impost of costs with their customers downstream and/or upstream is "their call".

It is unlikely that all transport operators would respond in a similar way to price changes. However, there is also likely to be commonality of responses from similar types of operators. There can be many dimensions of grouping based on:

- *Characteristics of the firms*: such as geographical location of operation, type of operation, and size of firm;
- *Attributes of operational logistics*: such as vehicles used, types of routes used, trip frequency; and
- *Attributes of the freight*: such as what commodities are carried, whether they are mass or volume constrained, value of the goods, fragility and time sensitivity.

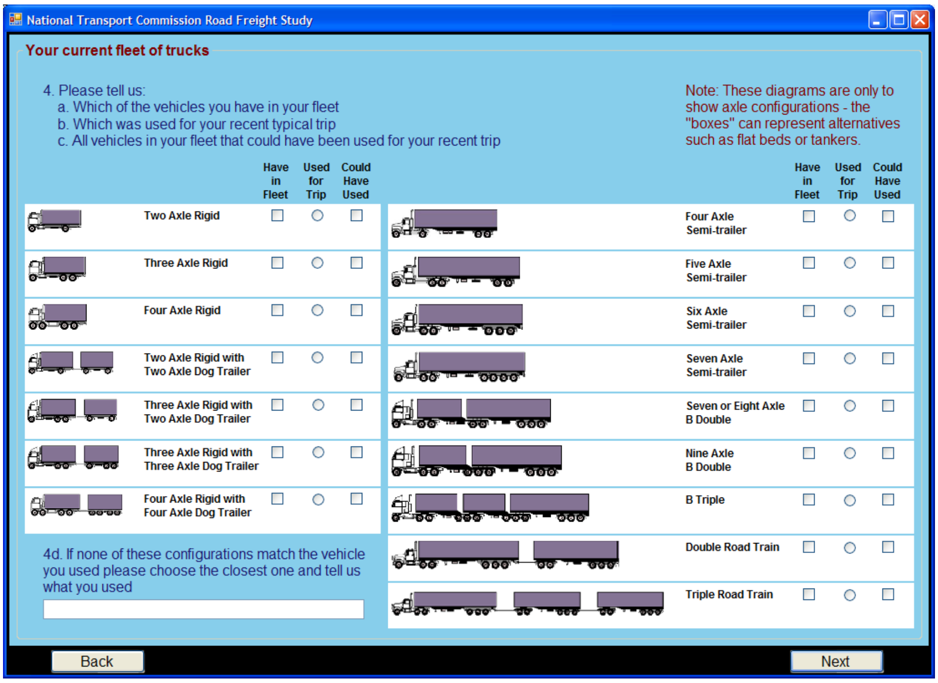
Consultation with industry (through extensive discussions at an industry workshop and expert interviews) confirmed that the commodity carried is likely to be a key determinant of response to price changes. Commodity serves a proxy for a multiplicity of other important variables and governs freight attributes, as well as being strongly linked to logistics requirements. Importantly, commodities determine a subset of suitable vehicles usually used for their carriage. The classes or categories of commodities includes contestable freight, sometimes carried by rail, or coastal shipping freight such as grain, but excludes heavy bulk goods such as iron ore. Although our primary focus is on road freight movements, the "vehicle used for carriage" considered in the study can be rail. A set of categories was developed based on a review of available freight activity information, as well as reference to Hassall (2008, 2009), that resulted in eight broad categories as shown in Table 2.

Table 2: Commodity categories used in the survey

Number	Commodity Category
1	Palletised, taut liner including refrigerated containers
2	Quarry and construction materials and solid waste
3	Package/parcel/carbonised/postal express packages
4	Petroleum, dangerous goods and other tankers and liquid waste
5	Containerised or wharf goods
6	Livestock
7	Forestry and bulk agriculture including grains
8	Automotive

Industry experts also suggested that the commodity category would also serve in most cases as a good proxy for the types of areas of operation and thus for the types of roads predominantly used. They believed it would be possible to distinguish between the types of freight mainly confined to rural highways and other freight more likely to all use rural local roads. Judicious selection of categories may also be able to encompass general areas of operation: urban, intercity, regional and remote. Broad regional distinctions were considered much more relevant than a state based categorisation. However, it was suggested that a full survey would need to include respondents in all states and in all capital cities so that the broader industry would perceive the survey as fair.

Access charging reforms can be responded to in many ways, including vehicle substitution, routing, and distribution paths with revised loading mixes of commodities. This capacity to adapt, given the ability to change operations, both in the short term and the long term, varies by commodity. Vehicle use substitution which can occur either from an existing fleet or as a new acquisition is likely to be a primary option for response to road price changes in a number of circumstances as shown in Australia, for example, by the increased use of B-doubles to reduce trip numbers during times of high fuel price. The commodity constrains vehicle choice, but all relevant vehicles must be considered. The range of vehicles is shown in Figure 1 using the Austroads classification of heavy vehicles.



National Transport Commission Road Freight Study

Your current fleet of trucks

4. Please tell us:
  a. Which of the vehicles you have in your fleet
  b. Which was used for your recent typical trip
  c. All vehicles in your fleet that could have been used for your recent trip

Note: These diagrams are only to show axle configurations - the "boxes" can represent alternatives such as flat beds or tankers.

	Have in Fleet	Used for Trip	Could Have Used
Two Axle Rigid	☐	○	☐
Three Axle Rigid	☐	○	☐
Four Axle Rigid	☐	○	☐
Two Axle Rigid with Two Axle Dog Trailer	☐	○	☐
Three Axle Rigid with Two Axle Dog Trailer	☐	○	☐
Three Axle Rigid with Three Axle Dog Trailer	☐	○	☐
Four Axle Rigid with Four Axle Dog Trailer	☐	○	☐

	Have in Fleet	Used for Trip	Could Have Used
Four Axle Semi-trailer	☐	○	☐
Five Axle Semi-trailer	☐	○	☐
Six Axle Semi-trailer	☐	○	☐
Seven Axle Semi-trailer	☐	○	☐
Seven or Eight Axle B Double	☐	○	☐
Nine Axle B Double	☐	○	☐
B Triple	☐	○	☐
Double Road Train	☐	○	☐
Triple Road Train	☐	○	☐

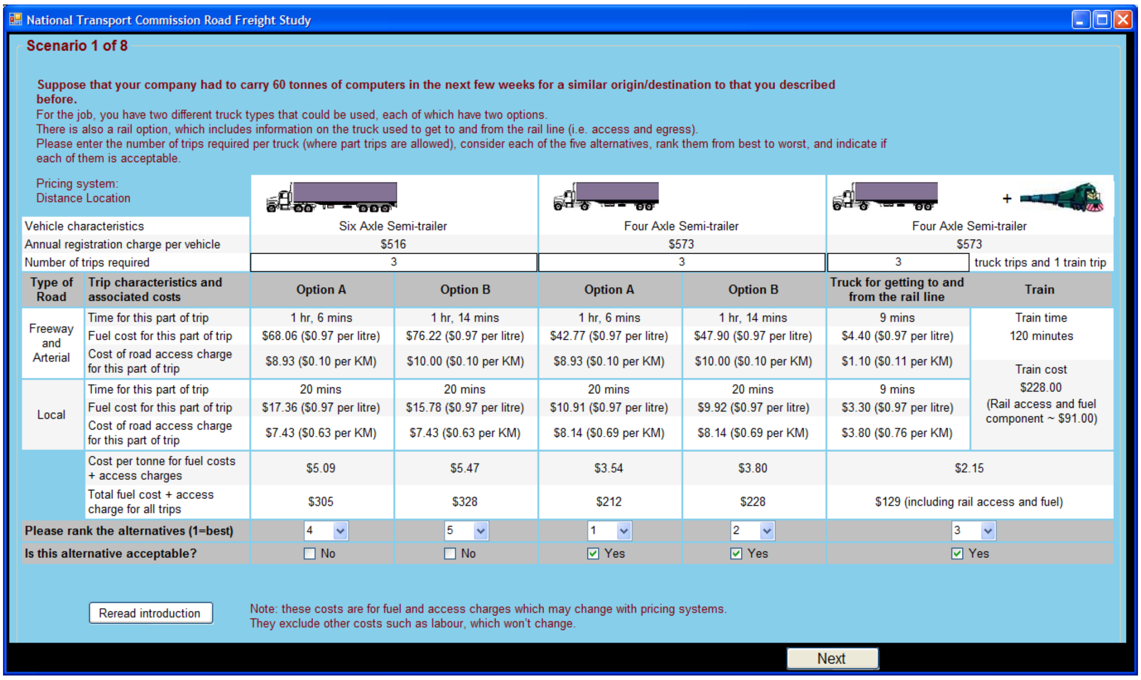
4d. If none of these configurations match the vehicle you used please choose the closest one and tell us what you used

Figure 1: Vehicle classes
(Note: Black and white in print)

This background provided essential information in designing a stated choice experiment, which we now discuss in detail.

3. Stated choice scenarios

The key component of the study was the series of stated choice scenarios presented to respondents. One possible scenario is depicted in Figure 2. In order to populate sensible hypothetical options, detailed information was required on the recent trip. This included the road types used: freeway, arterial and/or local, and for each, the distance travelled, average speed, and percentage of kilometres in urban areas. Fuel cost and consumption was collected for the trip as a whole. If the respondent indicated that the recent trip was either made by rail or could have been made by rail, an extra screen sought details of either their actual rail or their possible rail trip, plus information about road access and egress to/from the rail terminal.



Scenario 1 of 8

Suppose that your company had to carry 60 tonnes of computers in the next few weeks for a similar origin/destination to that you described before.
For the job, you have two different truck types that could be used, each of which have two options.
There is also a rail option, which includes information on the truck used to get to and from the rail line (i.e. access and egress).
Please enter the number of trips required per truck (where part trips are allowed), consider each of the five alternatives, rank them from best to worst, and indicate if each of them is acceptable.

Pricing system:
Distance Location

Vehicle characteristics		Six Axle Semi-trailer		Four Axle Semi-trailer		Four Axle Semi-trailer	
Annual registration charge per vehicle		$516		$573		$573	
Number of trips required		3		3		3	truck trips and 1 train trip
Type of Road	**Trip characteristics and associated costs**	**Option A**	**Option B**	**Option A**	**Option B**	**Truck for getting to and from the rail line**	**Train**
Freeway and Arterial	Time for this part of trip	1 hr, 6 mins	1 hr, 14 mins	1 hr, 6 mins	1 hr, 14 mins	9 mins	Train time 120 minutes
	Fuel cost for this part of trip	$68.06 ($0.97 per litre)	$76.22 ($0.97 per litre)	$42.77 ($0.97 per litre)	$47.90 ($0.97 per litre)	$4.40 ($0.97 per litre)	
	Cost of road access charge for this part of trip	$8.93 ($0.10 per KM)	$10.00 ($0.10 per KM)	$8.93 ($0.10 per KM)	$10.00 ($0.10 per KM)	$1.10 ($0.11 per KM)	Train cost $228.00 (Rail access and fuel component ~ $91.00)
Local	Time for this part of trip	20 mins	20 mins	20 mins	20 mins	9 mins	
	Fuel cost for this part of trip	$17.36 ($0.97 per litre)	$15.78 ($0.97 per litre)	$10.91 ($0.97 per litre)	$9.92 ($0.97 per litre)	$3.30 ($0.97 per litre)	
	Cost of road access charge for this part of trip	$7.43 ($0.63 per KM)	$7.43 ($0.63 per KM)	$8.14 ($0.69 per KM)	$8.14 ($0.69 per KM)	$3.80 ($0.76 per KM)	
	Cost per tonne for fuel costs + access charges	$5.09	$5.47	$3.54	$3.80	$2.15	
	Total fuel cost + access charge for all trips	$305	$328	$212	$228	$129 (including rail access and fuel)	
Please rank the alternatives (1=best)		4	5	1	2	3	
Is this alternative acceptable?		☐ No	☐ No	☑ Yes	☑ Yes	☑ Yes	

Note: these costs are for fuel and access charges which may change with pricing systems.
They exclude other costs such as labour, which won't change.

Figure 2: Illustrative stated choice scenario

(Note: Black and white in print)

The choice scenario screens presented the respondent with a choice between four truck alternatives, and where relevant, a fifth, train alternative. Each alternative was described by a set of attributes, where the levels of the attributes are a function of a number of responses provided earlier in the survey. The aim here was to boost the realism of the choice scenario, such that the respondent could relate to it. In addition, an experimental design, detailed below, was applied to create some variation across the alternatives and the choice scenarios, where this variation is essential to the estimation of the appropriate econometric models.

A number of rules determining the composition of the choice scenarios had to be developed to ensure that the pricing reform options were meaningful in the context of a recent trip. These included the allocation of pricing regimes and truck types to each of the choice scenarios, the formation of the base levels of the attributes, including the relevant inputs, formulas, any dependencies between the attribute levels, and the extent to which the base levels are modified by the experimental design. Figure 3 details the key links between the recent trip characteristics, the experimental design, and the choice scenario attributes. The choice scenario attributes align with those in Figure 2.

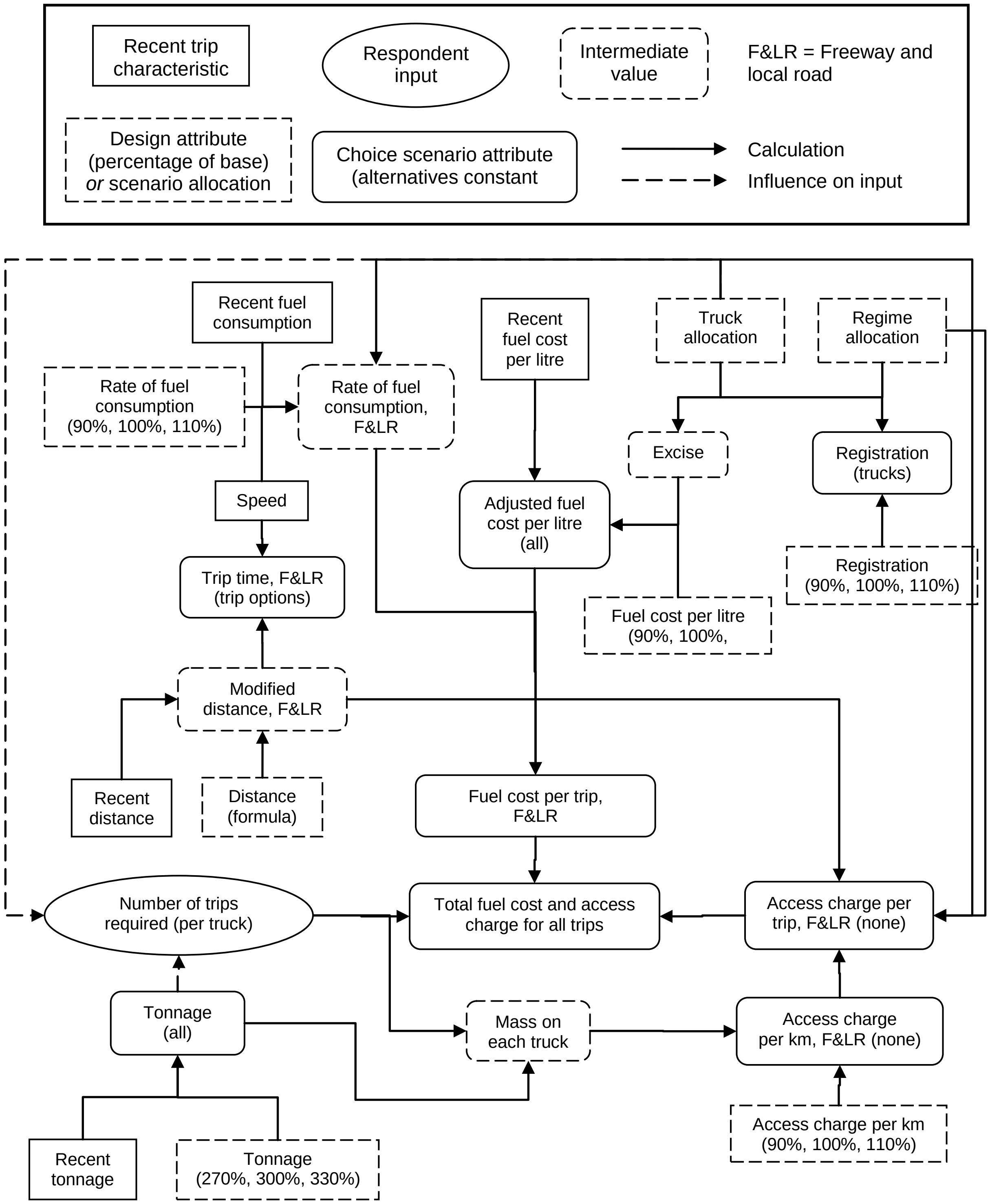


Figure 3: Key influences of recent trip characteristics and experimental design on choice scenario attributes. Note: excludes rail specific attributes.

Eight choice scenarios were shown. The first four were framed as decisions where only the existing fleet mix could be utilised. The second four allowed for different vehicles to be utilised. The pricing regimes varied across the initial four choice scenarios. One each of the following was presented to the respondent, with the order randomised:

- Fuel, with flat or differentiated charges;
- Distance: by vehicle, module, number of axles, or axle group;
- Distance-location or distance-mass; and
- Distance-mass-location.

Two trucks were presented to respondents, each with two route options. For the first four scenarios, one of the trucks was always the truck that was used for the recent trip; the other truck differed across choice scenarios, and was selected from the other trucks that could have been used for the recent trip (also obtained from previous questions), such that as much coverage as possible was obtained over the alternative trucks.

In the final four scenarios, the same pricing regimes were presented to the respondent, together with the same underlying experimental design. What differed was the truck selection process. The chosen truck from the equivalent scenario from the initial four scenarios was presented, with the other truck selected from the trucks that the respondent indicated they might use. Again, maximum coverage of the alternative trucks was ensured.

For each truck, two trip options were presented. Distance and speed could vary across the two options, which in turn impacted on trip time, fuel cost and access cost. However, the two trip option *A*s and two trip option *B*s had the same distance and speed. If the train alternative was presented, the truck obtained from the recent trip context was always presented for access and egress.

Each scenario presented the respondent with a certain tonnage that needed to be carried. The base tonnage was three times the tonnes carried in the recent trip. The actual tonnage varied across choice scenarios according to the experimental design, with the three candidate levels being 270, 300 and 330 percent of the recent tonnage. Such a large multiplier on the tonnage forced the respondent to make multiple trips. The number of trips required was asked in the choice scenario, where the number did not have to be an integer. That is, part trips were allowed, and the total fuel and access cost for all trips, detailed below, reflected this. The choice of the number of trips had very important ramifications, especially for pricing regimes that include mass, as the number of trips determines the mass per truck.

The base registration cost was retrieved from a lookup table, where the cost varied according to truck type and pricing regime. Three levels were used in the experimental design: 90, 100 and 110 percent of the base cost.

Trip time was a function of trip distance and trip speed. The trip speed was informed by the recent trip and not influenced by the experimental design. The freeway and arterial road speed was a weighted average of the speeds on each road type, where the distance travelled on each provides the weighting. The local speed was unweighted. If present, the train alternative retrieved the same values. Trip distance was also informed by the recent trip, where the distances on freeways and arterial roads were summed. The distance was modified by the experimental design in such a way as to prevent very large differences in distance when the distance was long, but also force differences over very small distances. The recent distance travelled (i.e., the base level) formed one of the levels and the other two levels were the base level plus and minus a function of the base level. This function, *f*, can be expressed as

$$f = \frac{1}{2\ln(base\_level + 5)}. \qquad (1)$$

The trip time in minutes was 60×distance/speed. Since the distance was influenced by the experimental design, the trip time exhibited sufficient variation and did not need to be influenced further by the design. Problems arose if the recent trip did not include any travel on local roads, or, less likely, travel was only on local roads and not on freeways or arterial roads. Rather than have no travel on these road types in the choice scenarios, travel of two kilometres was assumed on the road type that they did not recently travel on. Default speeds of 95km/hr for freeways, 65km/hr for arterial roads and 35km/hr for local roads were assumed.

The fuel cost was a product of both the fuel cost per litre, and the fuel consumption. The base fuel cost per litre was calculated as the price they paid for their recent trip, minus the current excise of 22.6 cents/litre, plus the excise for the pricing regime-truck pair provided in a lookup table. For most of the pricing regimes, the new excise was zero. This base fuel cost per litre was then influenced by the experimental design, with levels of 90, 100 and 110 percent of the recent cost. Only one experimental design adjustment was applied per choice scenario, so that the fuel cost logically remained constant within but varied across choice scenarios.

The fuel consumption rate for each alternative was a function of the speed of travel, the type of truck that the alternative represented, and the recent fuel consumption, where the last influence captured specific driving patterns associated with the recent trip. The fuel consumption rate in litres per kilometre was modified by the experimental design for each segment (i.e., freeway/arterial or local roads), then multiplied by the final distance for the corresponding segment and the fuel cost per litre to obtain the fuel cost for each segment.

The access charge rate per kilometre took into account how much of the recent trip was on freeways, urban arterial roads and rural arterial roads, for all pricing regimes with a location component. The pricing regimes with a mass component required how much load was carried on each truck, defined as the total load that needed to be carried in the scenario divided by the number of trips that the respondent specified that they needed for the alternative for which the access charge was being calculated. The rate was influenced by the experimental design. The access charge for each segment was just the access charge rate per kilometre, multiplied by the final distance for that segment.

In addition to the individual cost components for each road segment for a single trip (fuel cost and access charge), the total cost for all trips was presented. This number was divided by the total tonnes carried to get a cost per tonne carried.

The truck costs for train access and egress were calculated in the same way as for the truck alternatives, just using different responses in the survey. The recent trip train time was influenced by the experimental design, with levels of 90, 100 and 110 percent. The same levels were applied to the train cost, which was a function of the recent trip freeway and arterial distance, the commodity class carried, and the origin and destination states. Additionally, since this cost is not a fair comparison with truck alternatives, an estimate of the access and fuel component of this cost was calculated as 40 percent of the total train cost, and also shown to the respondent. The total train cost was this adjusted cost, plus the fuel and access charges for access and egress multiplied by the number of required access and egress trips.

The purpose behind conducting experiments is to determine the independent influence of different attributes on some observed outcome. In stated choice studies, this translates into the desire to determine the influence of the design attributes upon the choices that are observed to be made by sampled respondents undertaking the experiment. Rather than simply randomly assigning the attribute levels shown to respondents over the course of an experiment, experimental design theory has traditionally been applied to allocate the attribute levels to the alternatives in some systematic manner.

The choice experiment itself has a total of 23 attributes, with each attribute described by three levels. The full factorial consists of 31,381,059,609 choice scenarios. For the current study, we employed a balanced fractional factorial orthogonal array with 72 choice scenarios blocked into 18 subsets, with each respondent being assigned four choice scenarios each. The use of a fractional factorial orthogonal array allows each attribute to vary independently of all other attributes, and hence allows for an independent measure of each attribute's influence upon the observed choices. The experimental design influences have already been detailed, and are summarised in Table 3.

Table 3: Attributes and attribute levels

Attribute	**Variants**	**Attribute levels as percent of base level**
Registration	Truck 1, truck 2, truck for rail	90%, 100%, 110%
Rate of fuel consumption freeway	Option A, option B, train and truck	90%, 100%, 110%
Rate of fuel consumption local roads	Option A, option B, train and truck	90%, 100%, 110%
Distance travelled freeways and arterial roads	Option A, option B, train and truck	Formula, 3 levels
Distance travelled local roads	Option A, option B, train and truck	Formula, 3 levels
Fuel cost per litre	Constant for choice scenario	90%, 100%, 110%
Access charge	Truck 1, truck 2, truck for rail	90%, 100%, 110%
Train time	Train only	-90%, 100%, 110%
Train cost	Train only	90%, 100%, 110%
Tonnes carried	Constant for choice scenario	270%, 300%, 330%
Blocking column	Constant for respondent	1 to 18

4. The mixed logit model

The data obtained from the stated choice study is used in a mixed logit model to obtain relevant parameters that are used in the derivation of estimates of direct and cross access regime elasticities. In this section we provide a brief overview of the mixed logit model together with the elasticity formulae. Full details are given in Train (2003) and Hensher *et al.* (2005).

Assume that a sampled individual q (q=1,…,Q) faces a choice among J alternative access charging regimes in each of T choice situations. Individual q is assumed to consider the full set of offered alternatives in choice situation t and to choose the alternative with the highest utility. The utility associated with each alternative j as evaluated by each individual q in choice situation t, is represented in a discrete choice model by a utility expression of the general form in (2).

$$U_{qtj} = \boldsymbol{\beta}'_q \mathbf{x}_{qtj} + \varepsilon_{qtj} \ . \qquad (2)$$

$\mathbf{x}_{qtj}$ is the full vector of explanatory variables, including attributes of the alternatives, characteristics of the individual firm and descriptors of the decision context in choice situation t. The components $\boldsymbol{\beta}_q$ and ε_{qtj} are not observed by the analyst and are treated as stochastic influences. Individual firm heterogeneity is introduced into the utility function through $\boldsymbol{\beta}_q$. Thus,

$$\boldsymbol{\beta}_q = \boldsymbol{\beta} + \boldsymbol{\eta}_q, \qquad (3)$$

or $\beta_{qk} = \beta_k + \eta_{qk}$ where β_{qk} is the random coefficient associated with k=1,…,K attributes whose distribution over individual firms depends in general on underlying parameters, and $\boldsymbol{\eta}_q$ denotes a vector of K random components in the set of utility functions in addition to the J random elements in $\boldsymbol{\varepsilon}_{qtj}$.

The *mixed logit* class of models used in this study assumes a general distribution for β_{qk} and an IID extreme value type 1 distribution for ε_{qtj}. Denote the marginal joint density of $[\beta_{q1},\beta_{q2},..,\beta_{qK}]$ by $f(\boldsymbol{\beta}_q \,|\boldsymbol{\Omega})$ where the elements of $\boldsymbol{\Omega}$ are the underlying structural parameters of the distribution of $\boldsymbol{\beta}_q$, $(\boldsymbol{\beta},\boldsymbol{\Gamma})$. For a given value of $\boldsymbol{\beta}_q$, the *conditional* probability for choice j in choice situation t is multinomial logit, since the remaining error term is IID extreme value:

$$\mathrm{P}_{qtj}(\boldsymbol{\beta}_q|\mathbf{X}_{qtj}) = \exp(\boldsymbol{\beta}_q'\mathbf{x}_{qtj}) / \Sigma_j\exp(\boldsymbol{\beta}_q'\mathbf{x}_{qtj}). \tag{4}$$

The *unconditional* choice probability (4) is the expected value of the logit probability over all the possible values of $\boldsymbol{\beta}_q$, that is, it is integrated over these values, weighted by the density of $\boldsymbol{\beta}_q$.

$$P_{qtj}(\mathbf{X}_{qtj},\boldsymbol{\Omega}) = \int_{\boldsymbol{\beta}_q} P_{qtj}(\boldsymbol{\beta}_q \mid \mathbf{X}_{qtj})\, f(\boldsymbol{\beta}_q \mid \boldsymbol{\Omega})\, d\boldsymbol{\beta}_q . \tag{5}$$

The log likelihood function for estimation of the structural parameters is built up from these unconditional probabilities and can be approximated by simulation. The simulated log likelihood function is:

$$\log\mathrm{L}_\mathrm{S} = \sum_{q=1}^{Q} \log \frac{1}{R} \sum_{r=1}^{R} \prod_{t=1}^{T} \prod_{j}^{J} P_{qtj}^{Y_{qtj}}(\boldsymbol{\beta}_{rq} \mid \mathbf{X}_{qtj})\, f(\boldsymbol{\beta}_q \mid \boldsymbol{\Omega}), \tag{6}$$

where R is the number of draws in the simulation and Y_{qtj} is an indicator variable equal to 1 if respondent q was observed to choice alternative j in choice situation t, or 0 otherwise. The formula for calculating the mean elasticities for model is given in equation (7).

$$E\left[\frac{\partial \log P_{qtj}}{\partial \log x_{qtjk,l}}\right] = \frac{1}{Q}\sum_{q=1}^{Q} \int_{\boldsymbol{\beta}_q} [\delta_{j,l} - P_{qtj,l}(\boldsymbol{\beta}_q, \mathbf{X}_{lq})]\beta_{qk} x_{qtjk,l}\, d\boldsymbol{\beta}_q\ , \tag{7}$$

where j and l index alternatives, such that $\delta_{j,l} = 1$ if $j \neq l$ or 0 otherwise, x indexes the kth attribute and q indicates the individual. Using R simulated draws from the distribution of $\boldsymbol{\beta}_\mathbf{q}$, we obtain the simulated values of the means of the elasticities:

$$E\left[\frac{\partial \log P_{qtj}}{\partial \log x_{qtjk,l}}\right] = \frac{1}{Q}\sum_{q=1}^{Q} \frac{1}{R} \sum_{r=1}^{R} [\delta_{j,l} - P_{qtj,l}(\boldsymbol{\beta}_{q,r}, \mathbf{X}_{lq})]\beta_{qk,r} x_{qtjk,l} \tag{8}$$

5. Descriptive profile

The main computer assisted personal interview (CAPI) survey commenced in greater Sydney, Melbourne and Launceston (Tasmania) in January 2011 (preceded by a pilot conducted in October 2010). A staggered survey roll out process was planned allowing for any problems with either the interviewing process or the instrument to be picked up quickly. Perth then Adelaide commenced in February. The intended roll out to South East Queensland had to be abandoned due to flooding in Brisbane[1].

The CAPIs were demanding for the respondents and for the interviewers. Most interviews were conducted by extremely experienced interviewers who had previous experience with the transport industry. Overall 150 face to face interviews and 20 video interviews were completed. Ongoing modelling during the field work tested the sample until it was deemed sufficient to provide elasticity results at the desired level of confidence. Despite limitations on numbers of regional interviews, which in turn led to reduced numbers of interviews in some commodity groups and limited interviews in some states, elasticity results were robust due to similarity of

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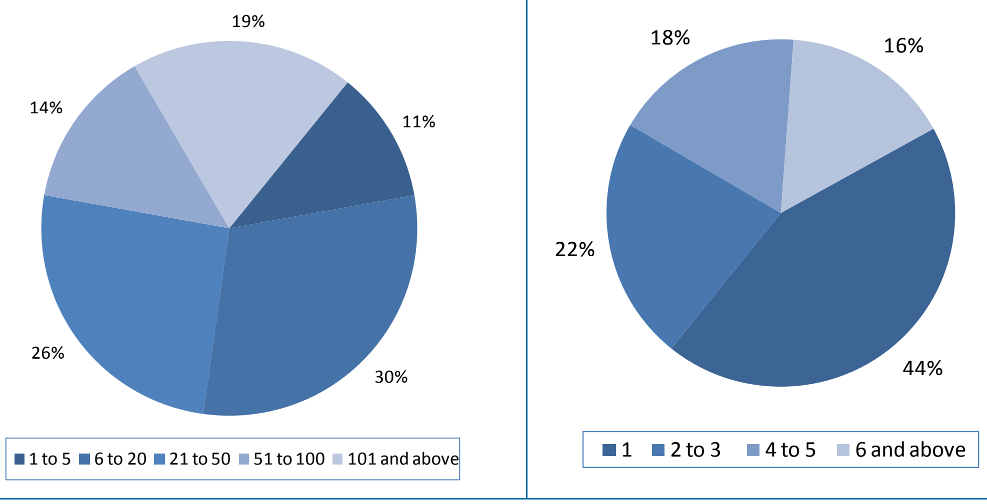
[1] We developed an innovative video interviewing process, using a telephone conferencing service which allowed computer screen sharing. Once established, the technique resulted in greater flexibility for the interviewer and much larger geographical coverage. Only achievement of an adequate sample size, combined with project completion deadlines, precluded more regional and remote interviews. The opportunity to develop a larger Queensland sample this way was hampered as a cyclone devastated North Queensland. The handful of Queensland interviews were therefore from the relatively unaffected areas around Rockhampton north of the floods and south of the cyclone.

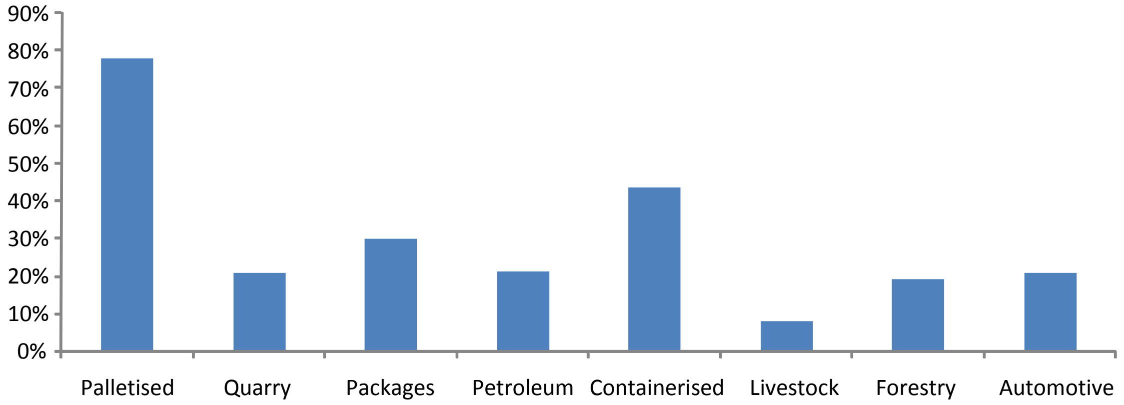
responses by vehicle type and road type across commodity groupings and locations (see details below).

The CAPI collected information on the overall characteristics of the respondent, firm and its freight task. In general, most respondents had significant experience in the freight industry. More than 50 percent of the respondents had more than 20 years of experience. Respondents with 10 years or less experience represented only 11 percent of the sample. Forty percent of the respondents identified themselves as the owner of the business, with the other 60 percent of respondents typically being managers or directors of the firm. Owners of small businesses (1-5 employees) represented around 10 percent of the respondents. Some informative profiles of the sample are given in Figure 4.

(a) Employees in the firm's logistics department **(b) Number of states that the firm operated in**



(c) Proportion of respondents that carry a certain commodity



Palletised = palletised, taut liner including refrigerated containers
Quarry = quarry and construction materials and solid waste
Packages = package/parcel/carbonised/postal express packages
Petroleum = petroleum, dangerous goods and other tankers and liquid waste
Containerised = containerised or wharf goods
Forestry = forestry and bulk agriculture including grains

(d) Proportion of respondents that own a certain vehicle class

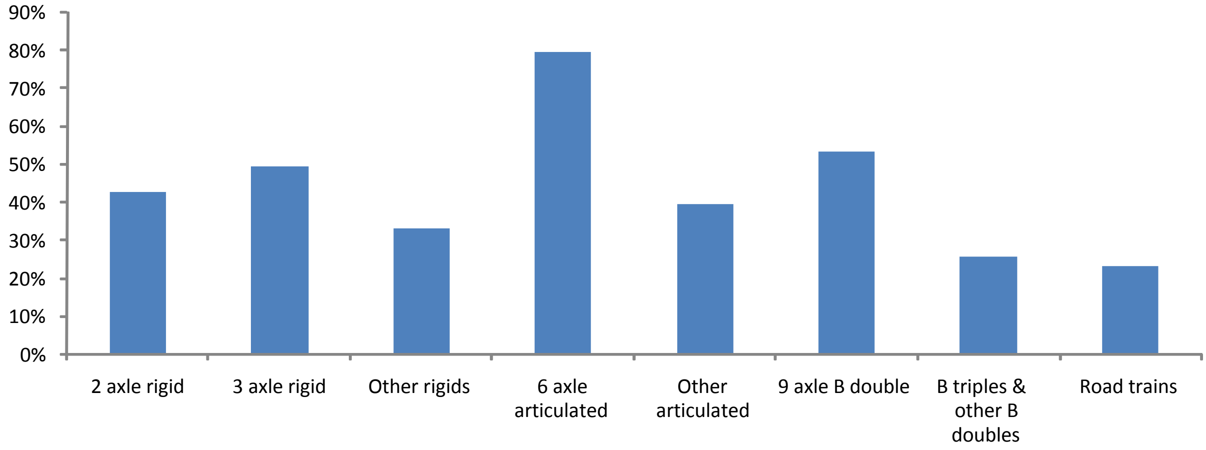
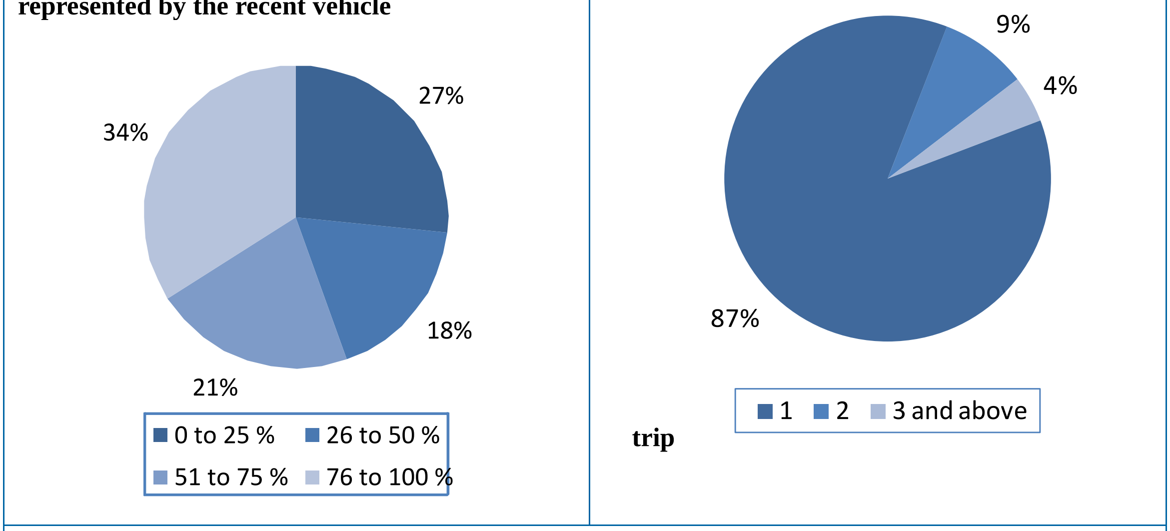


Figure 4: Profile of the Sample (Note: Black and white in print)

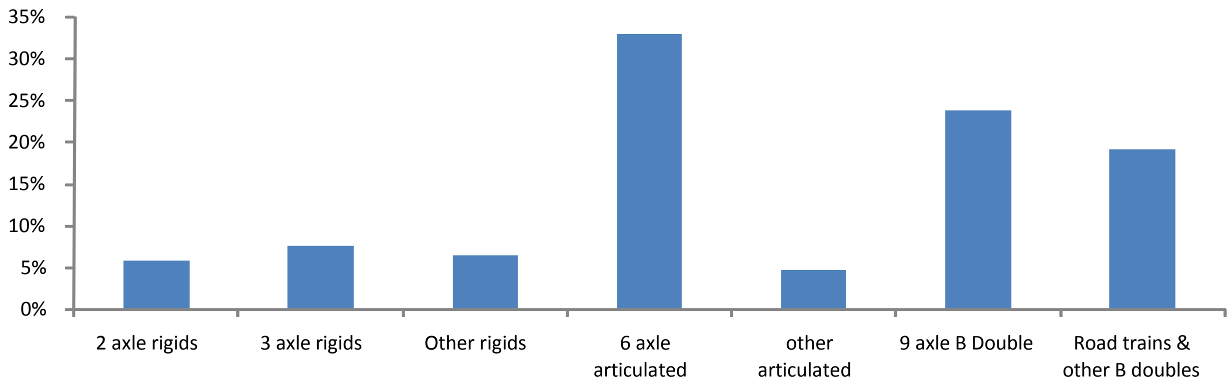
Respondents were required to select a vehicle that they had used in a recent trip. The main vehicles used in their recent trips included 6 axle articulated vehicle (33 percent), 9 axle B-double (24 percent), two axle (six percent) and three axle rigids (eight percent), and double (eight percent) and triple road trains (six percent). Figure 5 presents an overview of the sample profile of the recent trip.



(a) Percentage of the firm's operation represented by the recent vehicle

(b) Number of alternative vehicles for recent trip

(c) Vehicle used in recent trip



(d) Alternative vehicles mentioned by respondents – in existing fleet, and from all possible vehicles

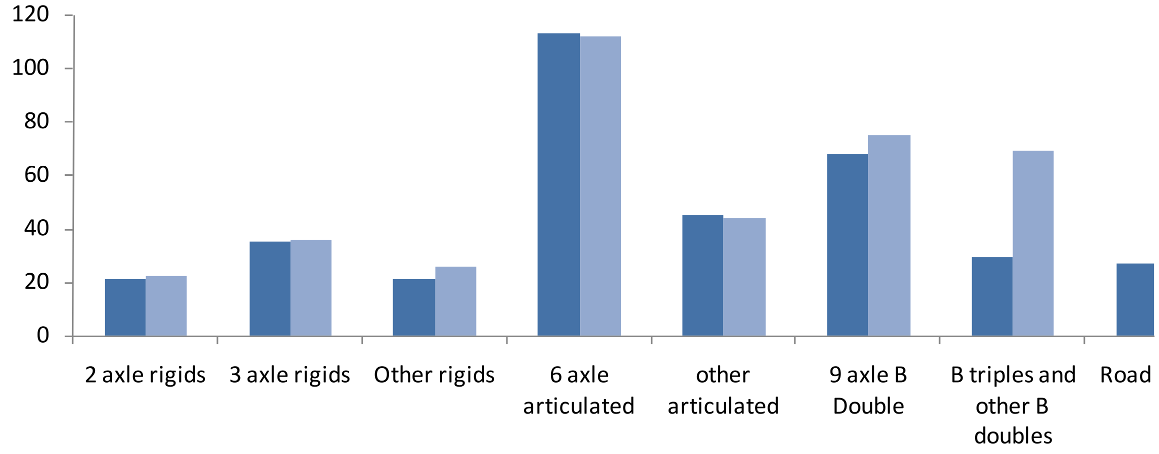


Figure 5: Profile of the recent typical trips
(Note: Black and white in print)

6. Model results

An extensive number of mixed logit models were estimated as the data accumulated during the survey deployment. The final models from which we calculated the suite of direct and cross elasticities are summarised below in Table 4.

Table 4: Summary of mixed logit models

Model	**M1**	**M2**	**M3**	**M4**	**M5**
Random parameters	Coefficients (*t*-ratios)				
Fuel cost per km ($/km)	-11.616 (-11.5)	-15.479 (-12.51)	11.721 (11.56)	-11.771 (-11.4)	-12.8989 (-12.30)
Access charge ($/km)	-7.735 (-2.65)	-12.563 (-3.68)	-7.5082 (-2.59)	-9.1663 (-2.83)	-
Non-random parameters					
Heavy vehicle category – Semi-trailer (1,0)[a]	-1.050 (-3.15)	-0.3743 (-0.91)	-1.0515 (-3.14)	-1.1957 (-3.55)	-0.7242 (-2.12)
Heavy vehicle category – B-Double (1,0) [a]	-0.0673 (-0.25)	0.1693 (0.49)	-0.0557 (-0.20)	-0.3580 (-1.30)	0.0634 (0.22)
Heavy vehicle category – Rigid (1,0) [a]	-3.424 (-6.33)	-2.968 (-4.72)	-3.4218 (-6.32)	-3.4360 (-6.31)	-2.9977 (-5.54)
Proportion of kms that are on freeways/arterials	-5.035 (-4.07)	-5.0514 (-2.29)	-5.4122 (-4.55)	-5.7943 (-4.55)	-5.6792 (-4.58)
Registration cost per km ($/km)	-4.920 (-0.80)	-0.3357 (-0.05)	-5.1647 (0.83)	-4.6857 (-0.76)	-7.7569 (-1.19)
Tonnes carried per trip	0.1619 (13.2)	0.2891 (15.3)	0.1629 (13.21)	0.20292 (13.30)	0.1840 (14.39)
Rail dummy (1,0)	1.052 (3.07)	1.4176 (3.75)	0.9294 (2.72)	1.1439 (3.35)	1.0924 (3.15)
Total vehicle kilometres per trip	-0.0012 (-4.57)	-		-	-0.0012 (-4.67)
Total kms on local roads per trip	-	-0.1104 (-7.18)	-	-	-
Total kms on freeways/arterials per trip	-	-0.0015 (-4.82)	-	-	-
Total vehicle tonne kilometres per trip	-	-	-0.01397 (-5.61)	-	-
Total vehicle tonne kms on local roads per trip	-	-	-	-0.1741 (-2.63)	-
Total vehicle tonne kms on freeways/arterials per trip	-	-	-	-0.0288 (-5.49)	-
Access charge – distance-location ($/km)	-	-	-	-	-13.9736 (-2.87)
Access charge – distance-mass ($/km)	-	-	-	-	-1.3634 (-3.11)
Access charge – distance-mass-location ($/km)	-	-	-	-	-10.496 (-4.83)
Model Fits					
Log-likelihood at zero			-4755.25		
Log-likelihood at convergence	-1489.44	-1433.03	-1483.61	-1481.48	-1457.94
McFadden ρ^2	0.687	0.696	0.688	0.689	0.693
Info. Criterion: AIC	2.205	2.138	2.196	2.195	2.162
Sample Size			1360		

a. Base level is B-triple and road train

The five model forms are required in order to deliver the range of direct and cross elasticities required. Model 1 handles total vehicle kilometres (VKM), and Model 2 disaggregates these kilometres by the two road types presented in the choice scenarios, freeway/arterial and local roads. Model 3 handles total tonne vehicle kilometres (Tonne VKM), with Model 4 disaggregating Tonne VKM by road type. Model 5 is a variation of Model 1, distinguished by separate parameter estimates for the three proposed access charging regimes. We cannot have both VKM and Tonne VKM in one model, any more than we can include VKM and separate variables for VKM on freeways/arterials and local roads.

For the random parameters, we have selected a quasi-constrained triangular distribution, in which the spread[2] estimate is constrained to equal the mean estimate for the random parameters, generating a range from zero to two times the mean estimate. This is an appealing way of capturing the random taste heterogeneity, avoiding complications handling heterogeneity at the extremes of unconstrained distributions.

The overall goodness-of-fit (McFadden ρ^2) is impressive. Typically discrete choice models have fits in the range 0.2 to 0.4 and hence we can conclude that all five models have explained a substantially improved amount of the variability in choice responses. This is especially worth noting given that we are using highly disaggregated data which has preserved far more variance in real behaviour than is typical in freight demand studies that aggregate data to levels, such as market shares, where the result is reduced variance to explain in modelling. With less variance to explain, one can easily get a greater overall statistical goodness-of-fit. A ρ^2 of between 0.687 and 0.696 is typically assumed to be equivalent (approximately) to over 90 percent of explained variance under (linear) R^2.

The statistical significance of individual parameter estimates is impressive with most explanatory variables having *t*-values greater than the 95 percent confidence level (t>1.96). There are exceptions, one notably being the registration cost per km. As might be expected it is a small amount and is statistically insignificant across all five models. Overall, these are very impressive models, identifying eight statistically significant influences in Models 1-3 and nine and ten significant influences respectively in Models 4 and 5.

The fuel cost and access charge variables are defined with random parameters that recognise the presence of preference heterogeneity across the sampled population. When we disaggregate the access charge by pricing regime (i.e., distance-location, distance-mass, and distance-mass-location), we did not find the random parameter specification was an improvement over three fixed parameters. Some degree of preference heterogeneity is being revealed between the three pricing regimes, although the difference is most pronounced between distance-mass and distance-location. One does however have to be careful in inferring too much from parameter estimates, since they are influenced by the numerical magnitude of each explanatory variable (although in this case they are in a common unit); what is more useful is the resulting elasticities that are driven by the incidence of specific charging regimes in the choice experiment.

7. Elasticity otputs

Elasticities can be derived from the models which show the relationship between a percentage change in the access charge ($/km) and:

- The probability of choosing a vehicle class for a trip;
- The percentage change in the VKM per trip by vehicle class;
- The percentage change in the Tonne VKM per trip by vehicle class; and

Additionally, several disaggregations are performed, including of the VKM and Tonne VKM by road type, and of the access charge by charging regime. The access charge is the additional charge per km above the registration and fuel costs. It does not include the fuel excise. Fuel excise is part of the fuel cost, and hence embedded in the fuel price elasticity. One very useful finding relates to the distinction between choice of vehicle class and choice of route given vehicle class. The choice experiment was constructed to recognise the real possibility that much of the substitution in response to the access charge would be *within vehicle class* in contrast to *between vehicle classes*. Consequently, in order to net out the within-class substitution between routes (if this is not required in the evaluation of the impact of the access charge on vehicle class

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[2] The spread is the standard deviation times $\sqrt{6}$.

switching, and associated VKM and Tonne VKM switching between classes), we have to first average the direct elasticities within vehicle class (across the two routes), and likewise for the two cross elasticities within vehicle class between the two routes, and take the difference.

The *net (or within-class route switching) direct elasticity effect* represents the vehicle class substitution response for VKM and Tonne VKMs. To calculate the amount of the switched VKM and Tonne VKM predicted to go to each of the other vehicle classes, we have to again average the cross elasticities (this time there are four such elasticities for each vehicle class that a vehicle class is switching to). Multiplying the resulting elasticities by the access regime percentage change and the base total trips or VKM or Tonne VKM, whatever is the relevant application, will provide estimates of the allocation of the switched activity to alternative vehicle classes.

The models are estimated as discrete choices between vehicle classes (and routes within vehicle classes). We are interested also in the relationship between VKM (or Tonne VKM) and access charges. This can be obtained within this framework under specific assumptions. The VKM (and Tonne VKM) elasticity with respect to access charge can be derived from the vehicle choice model as follows: the elasticity of the probability of vehicle class with respect to the access charge is defined as the ratio of the percentage change in the probability of choosing a vehicle class to the percentage change in the access charge, *ceteris paribus*. The elasticity of the probability of vehicle class with respect to VKM is defined as the ratio of the percentage change in the probability of choosing a vehicle class to the percentage change in VKM, *ceteris paribus. Holding the percentage change in the probability of vehicle class fixed* in both elasticity calculations, we are able to infer the ratio of the percentage change in VKM to the percentage change in the access charge, *ceteris paribus*. We have done this through a routine that imposes a constraint on the percentage change in the probability of vehicle class in calculating both initial elasticities used to derive the elasticities of interest.

Table 5 summarises the overall unweighted and weighted mean estimates for the segments of interest. The language "unweighted" refers to a simple averaging across all vehicle classes. An alternative approach is to obtain a weighted average using the market levels of activity. The weighted mean direct elasticities in Table 5 use weights from Table 6 for the relevant elasticities. Except for the fuel direct elasticity, all weighted mean direct elasticities are higher than the unweighted equivalent estimate. The probability of vehicle class elasticities are calculated both with respect to an access charge irrespective of access regime, and to each of the five key access regime charges. The VKM and Tonne VKM elasticities are calculated for all road types, and disaggregated by road type.

Table 5: Aggregate summary of direct elasticities with respect to access charge ($/km)

Elasticity Context	**Mean Direct Elasticity**	
	Unweighted	**Weighted (by)**
Probability of Vehicle Class		**(Laden trips)**
Overall	-0.539	-0.865
Fuel	-1.354	-0.847
Distance	-	-
Distance-Location (DL)	-0.154	-0.299
Distance-Mass (DM)	-0.008	-0.019
Distance-Mass-Location (DML)	-0.146	-0.208
Total VKM		**(VKM)**
Freeway/Arterial	-0.401	-0.556
Local Roads	-0.790	-1.751
All Roads	-0.387	-0.545
Total Tonne VKM		**(GTK)**
Freeway/Arterial	-0.398	-0.733
Local Roads	-0.067	-0.157
All Roads	-0.602	-1.099

Notes:

(i) The reason why the direct elasticities for Tonne VKM between road types are higher for freeway/arterial compared to local roads is that for some large direct elasticities, such as those for the heavier vehicles, the tonne kilometres carried on freeways/arterials is very high (which means in the elasticity formula it creates a large elasticity), and this appears to more than outweigh the influence of the Tonne VKM carried on vehicles which have smaller loads, and which are more likely to have a higher amount of local road activity. This does not occur for VKM since there are no large dominating elasticities for specific vehicle classes such as those for Tonne VKM.

(ii) We have been unable to obtain matrices for DL, DM and DML in context of VKM and Tonne VKM. The way forward might be to use the three matrices associated with vehicle class and to rescale the VKM and Tonne VKM matrices by the relative values in the vehicle class DL, DM and DML matrices.

Table 6: Market profile of activity in 2010

Vehicle class	**Code**	**Vehicle Kilometres (VKM)**	**Gross Tonne Kilometres (GTK)**	**Laden Trips**
Rail	Rail	-	-	-
Rigid 2 axle	R2	3 831 710 881	29 406 051 065	72 699 536
Rigid 3 axle	R3	1 212 375 212	23 000 749 963	32 449 962
Rigid 4 axle	R4	198 700 342	4 895 983 498	4 317 568
Trailer 2+2 axle	T22	390 129 522	5 537 441 246	5 515 008
Trailer 3+2 axle	T32	201 998 329	4 274 756 251	4 232 209
Trailer 3+3 axle, 4+4 axle	T33, T44	324 832 353	10 816 866 087	5 694 656
Semi trailer 4 axle	S4	192 396 579	3 963 433 194	2 034 530
Semi trailer 5 axle	S5	324 834 349	10 018 070 457	4 036 009
Semi trailer 6 axle	S6	3 023 591 231	109 121 120 628	24 640 565
Semi trailer 7 axle	S7	176 882 455	8 369 509 435	1 106 158
B triple	BT	168 873 085	10 104 337 754	170 996
B double 7 or 8 axle	BD7	242 787 450	12 827 148 342	4 049 974
B double 9 axle	BD9	1 519 857 761	90 939 039 785	1 538 961
Double road train	DRT	417 988 938	29 420 052 970	576 442
Triple road train	TRT	257 585 301	16 818 592 238	85 053
Total		**12 809 376 142**	**380 330 019 000**	**168 842 282**

Note: all values have been rounded to the nearest whole number. The totals were calculated from the precise values.

It is not easy establishing external support for the empirical evidence herein. We are unaware of any freight study that has looked at access charges in the level of detail herein (in respect of vehicle classes and range of pricing regimes). What we are able to do is provide some broad based evidence from one of the better studies, summarised in Table 7 in Small and Winston (1999) with the first and third rows being closest in comparison. In all cases price appears to be the freight rate so it is not strictly a comparable measure for fuel prices or access charges.

Table 7: Freight transport elasticities (Small & Winston, 1999, Table 2-2)

	Rail	**Truck**
Aggregate Mode Split Model, Price	-0.25 to -0.35	-0.25 to -0.35
Aggregate Model from Tanslog Cost Function, Price	-0.37 to -1.16	-0.58 to -1.81
Disaggregate Mode Choice Model, Price	-0.08 to -2.68	-0.04 to -2.97

Note: These elasticities vary depending on commodity group.

Despite obvious concerns about comparability, it is encouraging to see the mean estimate of elasticity for total tonne kilometres with respect to unweighted access charge of -0.602 in Table 5 being similar to evidence elsewhere (we might refer to it as in the ballpark). Beuthe *et al.* (2002) reviewed evidence on road freight demand direct elasticities and found that in aggregate demand studies the aggregate tonnes carried with respect to total cost is around -0.6 and the tonne-km equivalent is -1.1. Our closest estimate is -1.099 in Table 5, which is amazingly similar.

Tables 8, 9 and 10[3] provide the full matrices of direct and cross elasticities of VKM, Tonne VKM and vehicle class with respect to access charge ($/km)[4]. The elasticities are not disaggregated by pricing regime or road type[5]. Own price elasticities are emboldened. Cross price elasticities should be read horizontally. For example (Table 8) given a one percent increase in the price of a rigid 2 axle truck, the VKM for this vehicle class will decrease by -0.1253 percent while the VKM for a 3 axle rigid will increase by 0.0258 percent.

Table 8: Elasticity of vehicle class vehicle kilometres travelled with respect to access charge ($/km)

	Rail	**R2**	**R3**	**R4**	**T22**	**T32**	**T33**	**T44**	**S4**	**S5**	**S6**	**S7**	**BT**	**BD7**	**BD9**	**DRT**	**TRT**
Rail	**-0.0093**	0.0002	0.0002	0.0009	0	0	0	0	0	0.0002	0.0002	0	0.0003	0.0008	0.0004	0.0020	0.0003
R2	0.0002	**-0.1253**	0.0258	0.0002	0	0	0	0	0.0101	0	0.0022	0	0	0	0	0.0022	0
R3	0.0002	0.0258	**-0.1089**	0.0069	0.0001	0.0066	0.0004	0	0.0016	0.0045	0.0031	0	0	0	0	0	0
R4	0.0003	0.0001	0.0024	**-0.0461**	0.0004	0	0	0	0	0	0.0014	0	0	0	0	0	0
T22	0	0	0	0.0002	**-0.0214**	0	0.0003	0.0030	0	0	0	0	0	0	0	0	0
T32	0	0	0.0001	0	0	**-0.1107**	0	0	0	0	0	0	0	0	0	0	0
T33	0	0	0	0	0.0001	0	**-0.0093**	0	0	0	0	0	0	0	0	0	0
T44	0	0	0	0	0.0013	0	0	**-0.0396**	0	0	0	0	0	0	0	0.0009	0
S4	0	0.0011	0.0002	0	0	0	0	0	**-0.1620**	0.0019	0.0003	0	0	0	0	0.0025	0
S5	0.0018	0	0.0045	0	0	0	0	0	0.0177	**-0.1234**	0.0113	0	0	0.0011	0	0.0021	0
S6	0.0053	0.0054	0.0074	0.0094	0	0	0.0015	0	0.0058	0.0197	**-0.2272**	0.1703	0	0.0190	0.0256	0.0108	0.0088
S7	0	0	0	0	0	0	0	0	0	0	0.0198	**-0.6427**	0	0.0068	0.0001	0	0
BT	0.0417	0	0	0	0	0	0	0	0	0	0	0	**-1.3553**	0.0078	0.0148	0.0378	0.0725
BD7	0.0375	0	0	0	0	0	0	0	0	0.0006	0.0067	0.0206	0.0180	**-0.4310**	0.0121	0.0009	0.0071
BD9	0.0134	0	0.0001	0	0	0	0	0	0	0	0.0287	0.0010	0.1093	0.0635	**-0.3414**	0.0168	0.0217
DRT	0.0150	0.0016	0	0	0	0	0	0.0101	0.0172	0.0071	0.0033	0	0.0768	0.0249	0.0046	**-0.6542**	0.0808
TRT	0.0006	0	0	0	0	0	0	0	0	0	0.0031	0	0.1654	0.0069	0.0068	0.0909	**-1.1420**

Note: Definition of R2, R3, etc. is given in Table 6.

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[3] The full matrix tables of results (available on request) report an average elasticity estimate and an empirical standard deviation of the individual estimates of that elasticity. A "*t*-ratio" was obtained as the ratio of the average elasticity to the empirical standard deviation. It is important, however, to understand that an elasticity calculation has a number of estimates embedded in them of parameters and probabilities (see equation 7), and hence it is extremely complex (if not practically impossible) to derive standard errors that are required in testing a hypothesis about the elasticity. What we present as a t-ratio is based on the mean and a standard deviation; however the latter is not an estimator of the standard deviation of the sampling distribution. The delta method or Krinsky-Robb tests could be implemented to do that, but for elasticities, even from a simple multinomial choice model, it would take many months to program, if it could be done at all. On the other hand, we would not trust a hypothesis test for an elasticity even if the standard errors were computed by the delta method.

[4] We undertook extensive analysis to establish additional elasticity segments, and within the limits of 170 observations (each defined by eight choice scenarios), we were unable to disaggregate any further. The 1,360 observations is a sufficient sample for the specific analysis reported, given that the variance of interest is associated with the attributes in the choice experiment, which vary eight times for each individual firm interviewed.

[5] This disaggregation is available from the authors on request.

Table 9: Elasticity of vehicle class tonne kilometres travelled with respect to access charge ($/km)

	Rail	**R2**	**R3**	**R4**	**T22**	**T32**	**T33**	**T44**	**S4**	**S5**	**S6**	**S7**	**BT**	**BD7**	**BD9**	**DRT**	**TRT**
Rail	**-0.0109**	0.0001	0.0002	0.0006	0	0	0	0	0	0.0002	0.0002	0	0.0003	0.0010	0.0005	0.0031	0.0002
R2	0.0001	**-0.0280**	0.0048	0.0001	0	0	0	0	0.0040	0	0.0007	0	0	0	0	0.0006	0
R3	0.0002	0.0048	**-0.0280**	0.0023	0	0.0017	0.0001	0	0.0003	0.0012	0.0015	0	0	0	0	0	0
R4	0.0002	0	0.0008	**-0.0215**	0.0001	0	0	0	0	0	0.0008	0	0	0	0	0	0
T22	0	0	0	0.0001	**-0.0070**	0	0.0001	0.0010	0	0	0	0	0	0	0	0	0
T32	0	0	0	0	0	**-0.0279**	0	0	0	0	0	0	0	0	0	0	0
T33	0	0	0	0	0	0	**-0.0051**	0	0	0	0	0	0	0	0	0	0
T44	0	0	0	0	0.0004	0	0	**-0.0562**	0	0	0	0	0	0	0	0.0015	0
S4	0	0.0004	0	0	0	0	0	0	**-0.0487**	0.0006	0.0001	0	0	0	0	0.0008	0
S5	0.0015	0	0.0012	0	0	0	0	0	0.0053	**-0.0673**	0.0070	0	0	0.0008	0	0.0008	0
S6	0.0048	0.0017	0.0036	0.0057	0	0	0.0013	0	0.0015	0.0116	**-0.2436**	0.1702	0	0.0120	0.0416	0.0082	0.0192
S7	0	0	0	0	0	0	0	0	0	0	0.0197	**-0.7911**	0	0.0091	0.0001	0	0
BT	0.0410	0	0	0	0	0	0	0	0	0	0	0	**-3.3719**	0.0078	0.0137	0.0614	0.3108
BD7	0.0425	0	0	0	0	0	0	0	0	0.0004	0.0042	0.0274	0.0177	**-0.3920**	0.0109	0.0012	0.0148
BD9	0.0197	0	0.0001	0	0	0	0	0	0	0	0.0466	0.0007	0.0997	0.0574	**-0.4096**	0.0267	0.0469
DRT	0.0144	0.0005	0	0	0	0	0	0.0172	0.0052	0.0021	0.0025	0	0.1245	0.0369	0.0074	**-1.1411**	0.1967
TRT	0.0004	0	0	0	0	0	0	0	0	0	0.0067	0	0.7010	0.0144	0.0146	0.2210	**-2.8186**

Table 10: Elasticity of probability of choosing vehicle class with respect to access charge ($/km)

	Rail	**R2**	**R3**	**R4**	**T22**	**T32**	**T33**	**T44**	**S4**	**S5**	**S6**	**S7**	**BT**	**BD7**	**BD9**	**DRT**	**TRT**
Rail	**-0.4636**	0.0042	0.0054	0.0392	0	0	0	0	0	0.0203	0.0168	0	0.0569	0.0519	0.0104	0.0941	0.0087
R2	0.0035	**-0.5013**	0.1245	0.0076	0	0	0	0	0.0187	0.0004	0.0019	0	0	0	0	0.0013	0
R3	0.0042	0.1373	**-0.5798**	0.1180	0.0040	0.0038	0.0263	0	0.0128	0.0065	0.0096	0	0	0	0.0002	0	0
R4	0.0062	0.0015	0.0401	**-0.5707**	0.0026	0	0	0	0	0	0.0071	0	0	0.0001	0	0	0
T22	0	0	0.0009	0.0013	**-0.2717**	0	0.0027	0.0260	0	0	0	0	0	0	0	0	0
T32	0	0	0	0	0	**-0.0043**	0	0	0	0	0	0	0	0	0	0	0
T33	0	0	0.0023	0	0.0007	0	**-0.4828**	0	0	0	0	0	0	0	0	0	0
T44	0	0	0	0	0.0113	0	0	**-0.9381**	0	0	0	0	0	0	0	0.0227	0
S4	0	0.0033	0.0025	0	0	0	0	0	**-0.5494**	0.0019	0.0030	0	0	0	0	0.0025	0
S5	0.0152	0.0005	0.0104	0	0	0	0	0	0.0144	**-0.6406**	0.0773	0	0	0.0004	0	0.0019	0
S6	0.0295	0.0069	0.0302	0.0601	0	0	0.0058	0	0.0836	0.1579	**-0.7341**	0.1180	0	0.0454	0.0676	0.0178	0.0029
S7	0	0	0	0	0	0	0	0	0	0	0.0134	**-0.6448**	0	0.0102	0.0029	0	0
BT	0.0175	0	0	0	0	0	0	0	0	0	0	0	**-1.1302**	0.0062	0.0238	0.0231	0.0427
BD7	0.0412	0	0	0.0005	0	0	0	0	0	0.0004	0.0183	0.0536	0.0129	**-0.9127**	0.0217	0.0121	0.0027
BD9	0.0262	0	0.0009	0	0	0	0	0	0	0	0.0884	0.0320	0.1385	0.0949	**-0.7724**	0.0507	0.0045
DRT	0.0699	0.0023	0	0	0	0	0	0.3478	0.0284	0.0108	0.0085	0	0.0452	0.0214	0.0175	**-1.1563**	0.0833
TRT	0.0091	0	0	0	0	0	0	0	0	0	0.0017	0	0.1081	0.0033	0.0022	0.1116	**-0.8826**

Cross elasticities provide an understanding of the substitution between vehicle types given an increase in prices. An example of how vehicle kilometres could be switched from a 3 axle rigid to other vehicles is shown in Figure 6. An increase in price for a 3 axle rigid (R3) reduces the kilometres travelled by this vehicle type and therefore its share of the freight task. The reduction in freight vehicle kilometres by 3 axle rigids is expected to be picked up primarily by 2 axle rigids, which accounts for 53 percent of the reduction. The remainder of the freight kilometres will move to 4 axle rigids (29 percent), 5 axle semi-trailers (12 percent) and 6 axle semi-trailers (six percent). Using this methodology allows us to estimate the new fleet mix in terms of vehicle kilometres travelled assuming that the change in kilometres travelled is in effect the change in the freight task carried. In applying these vehicle switching elasticities, consideration is also given to productivity savings (or costs) from moving to a different vehicle type.

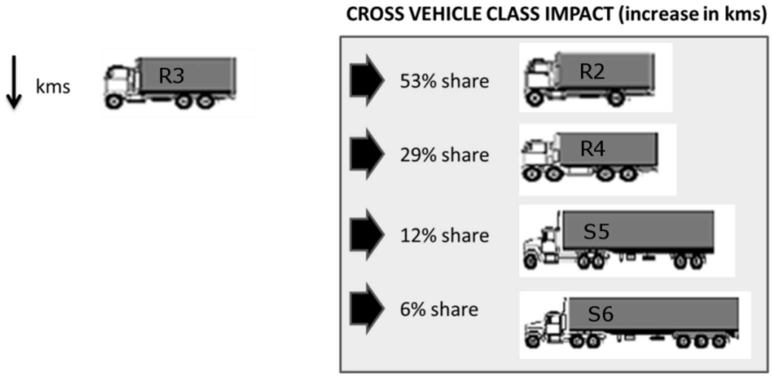

Figure 6: Substitution of vehicle kilometres – 3 axle rigid example

8. Conclusions

The main purpose of heavy vehicle pricing reform is to better align vehicle access pricing with the actual cost of road infrastructure provision. Pricing signals might then provide incentives to operators to change behaviour. However, the signal will only be effective if transport operators are able to respond to signals, through vehicle switching by moving to vehicles which impose less road cost, for example, using larger vehicles and hence making fewer trips; and route switching by moving to routes less subject to damage by heavy vehicles.

This paper has presented new empirical estimates of operators' direct price elasticities - their potential change in demand for travel in a particular vehicle on a particular route, as prices and regimes change. However, since the reform aims to drive switching behaviour there is a particular requirement for cross elasticities either between vehicle classes, between modes or between routes. For example, estimates of the likely impacts of rising costs of B-double access on demand for freight by rail or freight by truck trailer are needed.

This information is required before pricing reform is implemented as it is not possible to base elasticities on observed behaviour. The first two of these challenges required the development of new forms of stated preference experiments which account for a range of different operational situations when tailoring hypothetical scenarios to each operator's context. This in turn led to heterogeneity in responses that required the application of mixed logit models, recognising the need to capture sufficient detail to be able to derive elasticities of interest that account for the full range of contextual settings of recent intrastate and interstate trips in Australia.

The new empirical evidence values derived from this study accords with the results of analysis of qualitative data (not reported herein) based on operator opinions and attitudes. Thus, they provide quantitative measures of the messages which the operators wanted to provide to the National Transport Commission. Cross elasticities show quite clearly where there can be no substitution between some vehicles and also show where some substitution could occur with higher elasticities for showing propensity to switch. In line with operator comments, all schemes are relatively inelastic due the constraints limiting operational changes; however switching will occur where opportunities exist. This is in line with operators' ongoing efforts to make their operations efficient and to reduce costs. The data on current trips did however reveal that only 25% of trips have alternative routes. The Australian road network in regional areas often has only one road suitable for heavy vehicles. Even within urban areas, with well developed road infrastructure, route operational characteristics as well as weight and height restrictions reduce options. Local road use is in-elastic, in line with the proportion of this use which is "last mile" from the freight's initial origin or to its final destination.

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