A STRUCTURAL EQUATION MODEL OF COMMERCIAL VEHICLE OWNERSHIP

Toka S. Mostafa and Matthew J. Roorda, University of Toronto
Taha H. Rashidi, University of New South Wales, Sydney

Introduction

Behavioural freight transportation modelling has recently emerged as an approach to enhance the quality of freight and logistics decision assessments. Business establishments, including both shippers and logistics service providers, have been identified as the agents interacting to develop the complex system of goods and service truck movements. Decisions of business establishments resulting in shipment generation and goods movement within and between urban areas have been identified and modelled (Roorda et al., 2010).

One of the essential decisions a company needs to make is whether to own its private vehicle fleet or outsource the shipment operations to other companies. If a firm decides to own its private fleet, the questions arise of how many and what type of vehicle.

In the literature, there had been almost no efforts to model firm vehicle ownership. This paper presents a structural modelling approach for commercial vehicle ownership that considers three vehicle types: cars, pickups and vans, and trucks. The structural modelling tests the hypothesis that there are complementary relationships between the ownership of cars, pickups/vans and trucks. This paper starts by presenting an overview of previous research efforts in related areas, followed by a description of the method. Data analysis, model structure, and model interpretations are presented next.

Vehicle Ownership Modelling

Business establishment fleet ownership can be treated using two approaches: normative and behavioural. The first approach deals with ownership as an optimization problem that aims to minimize an establishment's operations cost by treating vehicle ownership as a vehicle routing problem. The second approach replicates the behavioural pattern of vehicle ownership given some information about the decision-makers.

Behavioural household vehicle ownership modelling has been widely introduced both at the aggregate and the disaggregate level (Choo et al., 2004; de Jong et al., 2004, 2009; Hensher et al., 2002). However, no previous efforts have been published to capture the behaviour of business establishments regarding fleet vehicle ownership, except for (Rashidi et al., 2012).

This paper describes commercial fleet size and composition decisions using multivariate regression analysis in the form of a structural equation model.

Method: Structural Equation Modelling (SEM)

SEM is a statistical method that is used to represent complex relationships between a set of independent variables and a set of dependent variables. SEM is also a means for multivariate regression analysis, with the special consideration of defining error terms for the derived models as well as the correlation between error terms of the unobserved variables. One basic component of SEM is the structural model, which allows the evaluation of potential relationships between the dependent and independent variables. The structural model can be visualized in the form of a diagram, in which arrows represent the causality relationship between variables and arrowheads point to the affected variables (dependent variables); see Figure 1.

SEM differs from multivariate regression in that it allows the quantification of the effect of unobserved variables (latent variables) that are believed to have a direct relationship to the independent variables and are influenced by measured (exogenous) variables. This is done by hypothesizing a specific model structure and statistically evaluating the resulting model. For instance, a set of observed geographical characteristics where companies are located, such as proximities to major roads and land use characteristics collectively have a relationship with another latent variable that indicates the geographical suitability of the company locations. The SEM allows the statistical evaluation of such hypothesis (with or without latent variable structures) throughout some statistical measures such as coefficient of determination R^2 (see Figure 1).

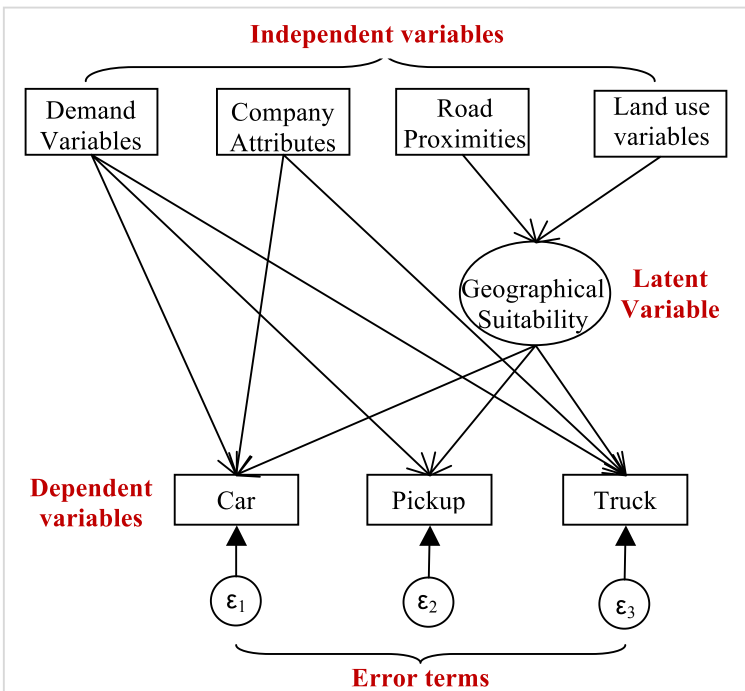


Figure 1. Schematic example of a tested model structure with a latent variable

In addition, SEM has Simultaneous Equation Modelling capabilities, in which dependent variables are considered to have an effect on dependent variables. For instance, in commercial vehicle ownership, the truck ownership dependent variable can have a relationship (either substitution or complementary) with ownership of pickups/vans and cars. The simultaneous equation modelling capability of the SEM enables statistical testing of such relationships. For example, Equation 1 shows a set of structural equations that models three dependent variables; y_1, y_2 and y_3 using a set of explanatory variables represented in the vector X. SEM allows for simultaneous consideration of the effect of other dependent variables, Y, and quantification of the error terms (ε) associated with each equation.

$$
\begin{aligned}
y_1 &= \alpha_1 + \beta_1 X + \gamma_1 Y + \varepsilon_1 \\
y_2 &= \alpha_2 + \beta_2 X + \gamma_2 Y + \varepsilon_2 \\
y_3 &= \alpha_3 + \beta_3 X + \gamma_3 Y + \varepsilon_3
\end{aligned} \tag{1}
$$

Data Sources

Two different variable sets are considered: company-related attributes and geographic characteristics of census tracts in which the company is located. Company attributes from approximately 2,000 establishments were collected from three surveys that used the same survey instrument: The Regional of Peel Commercial Travel Survey (2009), the Region of Durham Commercial Travel Survey (2010) and the Greater Toronto and Hamilton Area Commercial Travel Survey (2012). More than 2,000 companies belonging to different industrial classes were contacted to collect information about their daily shipment activities.

The survey data include basic information about the companies such as the number of employees, the number of years in business and the industrial class. The data set also includes estimates of company goods and service demand such as previous years inbound and outbound shipment values.

Census tract attributes were developed in a GIS analysis. Companies were geocoded using ArcGIS to identify the census tracts. External GIS data, available at the University of Toronto map and data library, with geographical attributes of the census tracts such as land use information and road characteristics, were linked to the (see Table 1 for the variables that were included in the final model).

Data Analysis

Three types of vehicles are considered for this modelling exercise; cars, pickups and vans, and trucks. Only companies that at least own one unit of any of the three vehicle types are considered, and companies with zero ownership are excluded. Figure 2 presents the sample distribution of vehicle ownership for manufacturing and construction industrial classes as examples.

Model Structure

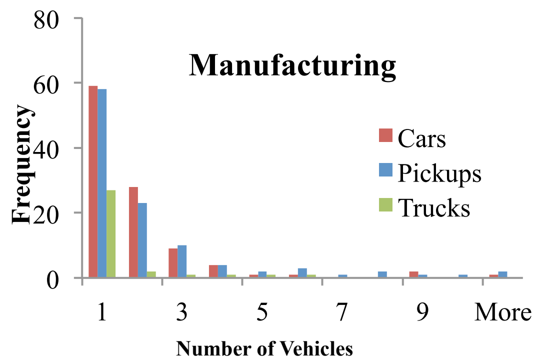
Various model structures have been tested. Some of them considered latent variables (like the one showed in Figure 1) and others with direct relations between independent and dependent variables. The final model structure is a multivariate regression structure where the three dependent variables (cars, pickups/vans and trucks) are directly affected by the set of independent variables, with simultaneous effect between the dependent variables, and no latent effects are found to be significant (Figure 3). The SEM program in STATA 12 software was used for this modelling exercise.

Model Results and Interpretations

Table 1 summarizes the parameter estimates for the final model. All the reported variables are statistically significant at least at an 80% confidence level.

It can be inferred from the model that there is a substitution relationship between pickup/van and truck ownership explained by the negative sign of the parameter coefficient in the pickup/van model. This means that the more trucks a company owns, the fewer pickups/

vans it owns. Each 14 owned trucks would reduce the number of owned pickups/vans by one. On the other hand, a complementary relationship exists between car and pickup/van ownership, and between car and truck ownership. The model results indicate that for each owned car there is, on average, a 0.4 increase in the number of owned pickups/vans, and for each owned truck there is, on average, a 0.27 increase in the number of cars owned.



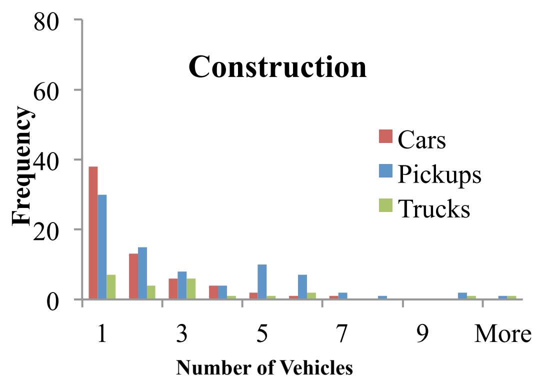


Figure 2. Vehicle ownership distribution for manufacturing and construction industrial classes

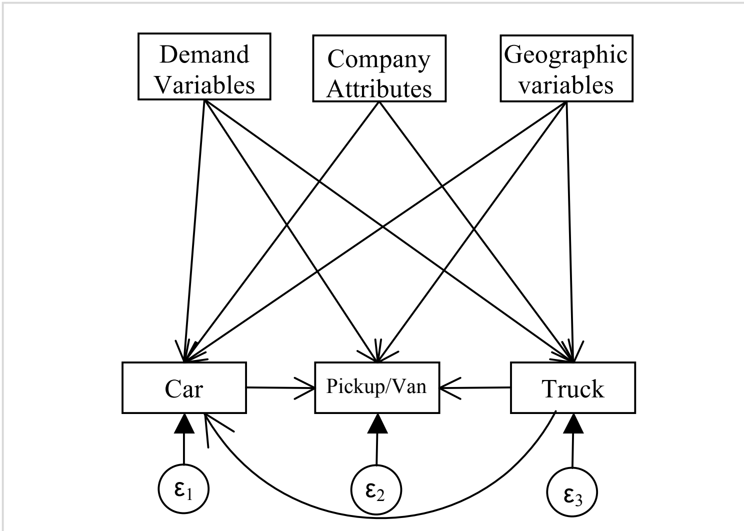


Figure 3. Final model structure

Companies belonging to construction industrial class are more inclined to own pickups/vans rather than cars. This can be explained by the nature of the construction business, which involves the operation of other special types of vehicles (e.g. dump trucks and concrete mixers) that are typically contracted to specialized companies, and the use of pickups/vans is favored to facilitate visits to construction sites. Also, professional and technical services companies have a greater tendency to own trucks.

The overall demand variation (whether the demand for goods/services varies by time of the year or not) seems to have a positive influence over the ownership of trucks. In addition, service providers tend to own more vans for lower service values, and this tendency decreases with the increase of the provided services. Conversely, when the value of the outbound shipments increases, the tendency of owning more trucks increases with a decreased ownership of cars, which might make some sense.

Most geographical characteristics, such as proximity to different roadways, and density of land use types within census tracts were not found to have statistically significant effects on vehicle ownership at 80% confidence level. However, the regions in which companies are located have a significant and intuitive effect. Companies located in the Region of Peel are more likely to own trucks, companies located in Durham Region are less likely to own cars, and companies located in the city of Toronto are less likely to own pickups or vans.

Table 1. Model results

Variable Name	Passenger Car		
	Coef.	**SE**	**Z**
Constant	0.27	0.54	0.49
Log number of years in business	-0.25	0.18	-1.33
Log number of employment	0.71	0.18	4.06
Industry Class			
Manufacturing	0.61	0.48	1.28
Passenger car ownership			
Pickup/van ownership			
Truck/tractor ownership	0.27	0.06	4.38
Demand varies? (1 yes, 0 No)	-	-	-
Value of provided services			
greater than $5M	-2.25	0.95	-2.36
Value of inbound shipments			
greater than $5M	4.99	0.99	5.07
Value of outbound shipments			
greater than $5M	-2.78	0.88	-3.17
Census tract characteristics			
In Durham region (Yes/No)	-0.96	0.41	-2.32
In Peel Region (Yes/No)	-	-	-
In the city of Toronto (Yes/No)	-	-	-

Variable Name	Pickup/van		
	Coef.	SE	Z
Constant	0.21	0.21	-1.00
Log number of years in business	-	-	-
Log number of employment	0.31	0.08	3.89
Industry Class			
Manufacturing	-	-	-
Construction	1.00	0.28	3.56
Office and service	-0.33	0.20	-1.63
Others	1.63	0.35	4.62
Passenger car ownership	0.41	0.01	29.80
Pickup/van ownership			
Truck/tractor ownership	-0.07	0.03	-2.41
Demand varies? (1 yes, 0 No)	-	-	-
Value of provided services			
between $500K and $999K	0.55	0.28	1.97
between $1M and $455M	0.47	0.25	1.89
greater than $5M			
Value of inbound shipments			
greater than $5M	-	-	-
Value of outbound shipments			
between $500K and $999K	-	-	-
between $1M and $5M	0.54	0.23	2.31
greater than $5M	-	-	-
Census tract characteristics			
In Durham region (Yes/No)	-	-	-
In Peel Region (Yes/No)	-	-	-
In the city of Toronto (Yes/No)	-0.60	0.24	-2.46

Variable Name	Trucks		
	Coef.	**SE**	**Z**
Constant	-1.08	0.29	-3.69
Log number of years in business	0.16	0.09	1.77
Log number of employment	0.25	0.09	2.76
Industry Class			
Manufacturing	-0.52	0.26	-2.05
Construction	-	-	-
Office and service	-	-	-
Utilities	-1.20	0.36	-3.37
Professional and tech. services	1.47	0.33	4.44
Others	1.29	0.38	3.38
Passenger car ownership	-	-	-
Pickup/van ownership	-	-	-
Truck/tractor ownership	-	-	-
Demand varies? (1 yes, 0 No)	0.36	0.18	1.96
Value of inbound shipments			
greater than $5M	-	-	-
Value of outbound shipments			
between $500K and $999K	0.49	0.31	1.59
between $1M and $5M	0.46	0.26	1.78
greater than $5M	2.44	0.35	6.98
Census tract characteristics			
In Durham region (Yes/No)	-	-	-
In Peel Region (Yes/No)	0.68	0.23	2.96
In the city of Toronto (Yes/No)	-	-	-

Goodness of Fit

The coefficient of determination (R^2) is used to evaluate the model, as shown in Table 2. Four R^2 values are reported; three are for the individual evaluation of the models for each vehicle type, and one is for the combined performance of the three models. The R^2 value indicates a better fit in the case of the pickup and van ownership (*0.49*), than for cars (*0.07*) and trucks (*0.13*). A greater variety of company attributes would help to better model the vehicle ownership behaviour.

Table 2. Coefficient of determination R^2

Dependent variables	R-squared
Car ownership	0.07
Pickup/van ownership	0.49
Truck ownership	0.13
Overall	0.23

Conclusions

In this paper, a structural equation modelling approach is used to model commercial vehicles ownership for three vehicle types. The model takes into account the simultaneous effect between dependent variables. The results reveal two complementary relationships: one between pickup and car, and the other between car and truck ownership. A substitution relationship between pickup/van and truck ownership also exists. The model represents differences in commercial vehicle ownership by companies in different industries, in different regions, and of different scales of operation, as measured by employment, inbound and outbound goods shipments and services.

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