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The optimal shipment size and truck size choice – The allocation of trucks across hauls

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ABSTRACT

There has been a growing interest in understanding how firms allocate their trucks across hauls, and how this allocation changes under various economic environments. This study investigates how variations in route/haul, carrier and vehicle characteristics affect the optimal vehicle size choice and the associated choice of shipment size. We show that the two choices are derived from the same optimization problem. There can be a continuum of shipment sizes, but decision-makers in freight transport have to choose from a limited number of vehicle alternatives. Therefore, we use a discrete–continuous econometric model where shipment size is modeled as a continuous variable, and vehicle size/type choice as a discrete variable. The results indicate that when faced with higher demand, and during longer trips firms are more likely to use heavier vehicles and ship in larger quantities which suggest that firms are realizing economies of scale and economies of distance. The study also discusses the effect of vehicle operating cost on the vehicle selection process and its policy implications.

1. Introduction

The demand for freight transport service has been growing rapidly, and is predicted to grow in the future. There has also been a proliferation of just-in-time inventory (JIT) practices, resulting in increased overall freight transport activity. From the side of policy makers, this growth has brought attention to the issues of allowing higher capacity vehicles on the roads, and the impact these vehicles have on safety, the environment, and efficiency.[1] As freight volume increases, it is expected that transport services will be provided by higher-capacity vehicles. Inventory practices such as JIT, however, suggest that part of the growth in volume may have to be met by increasing service frequency.

These trends in freight transportation raise interesting research questions. At a basic level, we can ask how freight operators choose a vehicle for a haul. It is also important to know how the pattern of vehicle use or vehicle size choice changes with policy interventions (such as a change in the permissible payload or road-pricing) or external shocks (such as an increase in fuel price). Answers to these questions help to clarify the implications of vehicle use patterns on traffic

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[1] The US Congress recently debated a transportation bill that would increase the weight of trucks allowed on highways from 80,000 to 97,000 lb (American Energy and Infrastructure Jobs Act of 2012). The congress did not pass the bill; and it suggested that further studies on the impact of heavy-duty trucks are needed to implement the bill, among others. The EU has also been considering similar measures (TML, 2008; Christidis and Leduc, 2009; OECD, 2011; Significance and CE, 2010). In many emerging economies, leading truck manufacturers are also expecting the demand for medium and heavy-duty trucks to increase (Daimler, 2011; Mathyssek, 2009).

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congestion, pavement deterioration, pollution and safety. This clarification becomes all the more important when we consider that different vehicles have different impacts on these externalities.

The objective of this study is to investigate how variations in route/haul, carrier and vehicle characteristics affect the optimal vehicle size choice in trucking. Previous studies have mainly focused on mode choice as opposed to the process by which firms make vehicle choices (the main topic here).[2] This study addresses two important issues in the economics of freight demand analysis. First, it outlines a conceptual framework based on shipment size optimization theory to identify the main determinants of firms' choice of vehicle and shipment size. Second, it provides a framework for modeling the interdependence between quantity shipped and vehicle choice using a discrete–continuous econometric model developed by Dubin and McFadden (1984). For model estimation, a unique dataset from the Danish heavy trucks trip diary was used. The dataset has detailed one-week operational information on a trip-by-trip basis for about 2500 trucks in 2006 and 2007.

The results show that the main determinants of vehicle size choice are vehicle operating cost, vehicle age and carrier type. As operating cost increases, the probability of heavier vehicles being chosen also increases, while higher total cost leads to a gradual shift towards smaller vehicles. These seemingly contradictory effects of cost have important policy implications. For instance, in the face of policies (or exogenous shocks) which raise the variable cost of trucking operations (e.g. road pricing or increase in fuel price) firms prefer to use heavier vehicles. On the other hand, policies or other changes which increase fixed costs and therefore total cost (e.g. registration tax, permits, licenses, etc.) make firms use smaller vehicles.

In conformity with the predictions of shipment size optimization theory, we find that trip distance and total freight demand to have significant positive effects on shipment size choice. These findings suggest that firms realize economies of distance by using heavier vehicles for longer trips and economies of scale by hauling larger quantities. Commodity-type fixed effects and the density of a cargo were also shown to affect shipment size decisions. In general, the results imply that increases in freight volume and today's widespread business practice of sourcing products from distant places will lead to increased demand for higher capacity vehicles. The desire to have flexible and frequent services, however, may dampen this tendency to some extent.

The rest of the paper is organized as follows. Section 2 gives a brief background to theoretical and econometric studies on freight modeling. Section 3 develops the conceptual framework based on shipment size optimization theory; Section 4 presents a discrete–continuous econometric model that jointly estimates shipment size and vehicle size choice; Section 5 describes the data and presents the empirical results; Sections 6 concludes and summarizes the paper.

2. Background

This study is based upon and further contributes to several studies. It is well-documented in the literature that shipment size determines the choice of mode/vehicle and vice versa (see for example, McFadden et al., 1986; Inaba and Wallace, 1989; Abdelwahab and Sargious, 1992; Holguín-Veras, 2002; Johnson and de Jong, 2011). In addition to recognizing this simultaneous decision process, these studies show that various haul, carrier, and commodity characteristics are important factors that affect the decision on the optimal shipment size and vehicle size.

The basic assumption of econometric studies of freight mode/vehicle choice is that mode/vehicle choice entails simultaneous decisions on how much to ship and by what mode, which implies the use of a discrete–continuous econometric framework.[3] McFadden et al. (1986) and Abdelwahab and Sargious (1992) provide the most complete formulation of the firm's simultaneous choice of mode and shipment size. However, the applicability of their models is rather limited when decision makers have to choose from more than two mode alternatives. Inaba and Wallace (1989) use a switching regression technique, arguing that shipment size and mode/destination choice are derived from the same optimization problem. Their analysis improved upon the approach of McFadden et al. by including spatial competition in the firm's decision and providing estimates of unconditional freight demand for more than two mode/destination choices. The econometric model of Inaba and Wallace, which is based on Lee (1982), assumes independent error structure across alternatives. Violation of this assumption would, therefore, seriously compromise the results and applicability of their model as a forecasting tool.

Recently, Holguín-Veras (2002) and Johnson and de Jong (2011) used an indirect approach to address the simultaneity problem. They model the discrete choice component (vehicle class choice in Holguín-Veras and mode choice in Johnson and de Jong) as the structural equation of interest, replacing actual shipment with prediction from a shipment size auxiliary regression. This approach is an interesting one when the main focus is the vehicle/mode choice because it is possible to apply advanced discrete choice models that overcome the IIA problem that most selection models suffer from. But, unlike McFadden et al. (1986), this approach does not allow for testing for simultaneity bias.

The current study uses a basic econometric model developed by Dubin and McFadden (1984) to address the simultaneity bias in the context of a discrete–continuous choice. Their model relaxes the procedure suggested by Lee (1982), which imposes a strong assumption about the covariance between the error terms in the selection and the outcome equations. We model the vehicle size/type choice process as a discrete choice, and the decision on shipment quantity as a continuous variable. Furthermore, as an alternative model specification for the main results, the paper presents estimates based on the indirect approach suggested by Holguín-Veras (2002) and Johnson and de Jong (2011).

[2] Our modeling framework can also be applied in freight mode choice which is formally and economically similar to the vehicle choice problem.

[3] An alternative sometimes is discrete-discrete (by classifying shipment sizes to a number of size classes), as in Windisch et al. (2010).