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Shipment size modelling and the impact of latent class: comparison of French and German results

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Abstract. The heterogeneity of supply chains is an important challenge for analysing, understanding and modelling freight transport systems. This paper explores a solution based on a Total Logistics Cost approach and Latent Class Analysis in order to introduce efficiently (i.e. without adding too many degrees of freedom) relevant information in models of choice of shipment size. In doing so, the paper shows that handling and conditioning variables are at least if not more important than the activity of shippers to explain shipment size, thus confirming the results obtained by a recent study with a similar approach based on German data. Latent class segments incorporating this information are meaningful and intuitively acceptable, and significantly improve the models' explanatory powers. This implies that a segmentation based on conditioning and handling constraints presents good transferability.

1 Introduction

In order to understand and improve freight transport systems, it is necessary to understand the decisions taken by shippers, and their reasons. An important decision for a given shipper sending commodities towards a given receiver is shipment size, or shipment frequency, notably because this decision is closely related to the choice of transport mode and vehicle type.

The choice of shipment size is one of the decisions a shipper has to take when managing a supply chain. Supply chains are very heterogeneous: the nature of commodities, client characteristics, production cost structure, etc. vary a lot from one supply chain to another. This raises methodological questions regarding shipment size modelling: how to account for this heterogeneity? How can the transferability of shipment size models be improved? What data should be acquired and used to observe and model shipment size modelling?

This paper applies a methodology to capture heterogeneity in the choice of shipment size through Latent Class Analysis. This methodology was designed by [1]. The virtue of the LCA approach is that it allows to capture a lot of heterogeneity with a limited amount of information. Also, the paper presents a comparison of the results obtained by applying the methodology to two distinct datasets, issued from shipper surveys realised in France and Germany. Finally, the paper examines how the segmentation resulting from the LCA approach improves shipment size modelling compared to a classic segmentation based on commodity types.

2 Methodology and Data

This paper combines shipment size modelling based on a Total Logistics Cost approach and Latent Class Analysis. These concepts are presented here.

2.1 Total Logistics Cost and choice of shipment size

The choice of shipment size is seen as the result of a trade-off between inventory costs and transport costs [2]. Smaller, more frequent shipments help keep inventory and warehousing costs down, whereas larger, less frequent shipments are not as expensive to transport.

Formally, the model of choice of shipment size is based on a Total Logistics Cost formulation, itself derived from the Economic Order Quantity model. For shipment n, denote by $C_n(q_n)$ the Total Logistics Cost. Then:

$$C_n(q_n) = Q_n F_n / q_n + Q_n c_n(q_n) + q_n s_n / 2$$

where Q_n is the shipper-to-receiver commodity flow, q_n is the shipment size, c_n is the increasing per ton transport cost, and s_n is the unit storage cost.

In practise, a number of distinct specifications are estimated in this paper. Some specifications are continuous (assuming shipment size can take any value) and some are discrete (assuming shipment size can only take one among a set of predefined value). While a discrete specification can seem to be an unnecessary restriction, it has advantages: it allows more flexibility regarding the structure of transport costs, and it allows taking into account the capacity constraint of vehicles.

2.2 Latent Class Analysis

LCA is a classification method, which assigns observations to latent classes, or segments, based on observed variables [3]. Consider a set of observations; each observation is characterised by a set of nominal variables. LCA classifies the observations into a number of latent classes or segments. Two sets of parameters need to be estimated: the prevalence of each latent class, and the probability of observing a certain combination of observed variables conditional to the membership of each class. These parameters are estimated by maximum likelihood and the application of the Expectation-Maximisation algorithm.

LCA is a relevant approach to model the choice of shipment size: the logistical characteristics of shipments are measured by a large set of categorical variables. There are many of these variables: LCA summarises the information those variables provide into a limited set of dummy variables so that the model is both simple and relevant.

2.3 Data

The data used in this paper comes from the ECHO survey [4]. The ECHO dataset was collected from 2004 to 2005 and describes 10,462 shipments dispatched by about 3,000 shippers. The ECHO survey consists of four distinct parts which focus on: the shipper, the shipment and the shipper-receiver relationship, the transport operation, and the firms involved in the organization and realization of the transport operation (including carriers and freight forwarders). The estimation in the present paper are limited to shipments carried by road and larger than $0.5m^3$, in order to ensure comparability of the results obtained here with the results obtained on German data [1].

3 Results

As explained above, two series of models are estimated in this paper. The first one consists in discrete choice models. The second one consists in continuous model. But before presenting them, the results of the LCA are discussed.

3.1 Identification of the latent classes

The LCA is realised using the following variables:

- Shipper activity (mutually exclusive): the shipper’s main activity is the production (or wholesale) of intermediary products; production (or wholesale) of manufactured products; production (or wholesale) of food products; production (or wholesale) of consumption products; warehousing,
- Conditioning (mutually exclusive): bulk, bags and parcels, pallets
- Other logistical requirements (not mutually exclusive): dangerous, temperature controlled, fragile, voluminous, oversized

Note that 60% of the shipments are conditioned on pallets, and that 70% do not have any other logistical requirements.

When applying LCA, the modeller needs to decide the number of segments. Several values were tested (from 2 to 8), and compared with respect to the adjusted BIC and AIC criteria. Those two criteria are always decreasing, but the improvement becomes much lower above 5 segments. Therefore, the results presented below are for 5 segments. The identified segments are:

- *Standard temperature controlled food products*: shipments from the food sector, on pallets, temperature controlled: 8% of shipments.

- *Special transport*: shipments with a specific constraint except temperature control. 18% of shipments.
- *Bulk cargo*: bulk shipments, production or sale of intermediate products. 17% of shipments.
- *Miscellaneous standard cargo with bags*: shipments in bags or parcels, but without any other specific constraint. 13% of shipments.
- *Miscellaneous standard cargo on pallets:* shipments on pallets without other specific constraints: 44% of shipments.

We observe that in this segmentation, conditioning and handling constraints play a much more important role than the activity of the shipper.

3.2 Transferability of the latent classes

In order to answer the question of transferability raised at the beginning of the paper, the segments presented above are compared to those of [1] who applied the same approach to a similar German shipper survey. They obtained the following four segments:

- *(Temperature controlled) food products,* 10% of shipments;
- *Miscellaneous standard cargo*, mostly standard shipments, 36% of shipments;
- *Special goods,* shipments with specific constraints, 35% of shipments;
- *Unpacked bulk goods*: 19% of shipments.

The results of the previous section are compatible with those: this validates LCA as an approach to introduced useful information to shipment size models, as well as the importance of conditioning and handling variables to explain the choice of shipment size.

3.3 Estimation of the choice of shipment size models.

The first model is the discrete choice one. Shipment sizes fall into three categories: less than 3t, 3t to 12t, and more than 12t. The model's specification is based on the Total Logistics Cost introduced above. As a benchmark, the model is estimated without the latent segments obtained in the previous section. All other things equal, shipment size:

- decreases if the ratio of value density over commodity flow rate increases, as predicted by the EOQ model;
- increases as the density of the shipment increases (this allows to take into account the volume capacity constraint);
- increases with distance;
- decreases when there are transhipments;
- decreases substantially when the receiver is a big client of the shipper (measured as the ratio of commodity flow sent to the receiver over total commodity flow for the shipper);
- increases when the time of delivery is decided half a day or more before the delivery;
- increases when the shipper does not use software applications for the transaction;
- and increases substantially when the destination is abroad.

The introduction of the latent classes into this model improves its explanatory power substantially: the log-likelihood falls to -1,784 from -1,863 for only four additional degrees of freedom; the Mc-Fadden's pseudo R^2 increases to 0.393 from 0.366.

The influence of membership to the latent segments on shipment size is the following (miscellaneous standard cargo on pallets is chosen as the reference):

- *Standard temperature controlled food products*: substantially smaller shipments.
- *Special transport*: slightly larger shipments.
- *Bulk cargo*: slightly larger shipments.
- *Miscellaneous standard cargo with bags*: slightly higher prevalence of intermediate size shipments.

All these results are both intuitive and help better understand the influence of conditioning and handling variables on the choice of shipment size. It would have been much more cumbersome to reach the same simple and meaningful conclusions without the LCA intermediate step.

We will not detail here the results of the estimation of the continuous model; they are qualitatively very close to those of the discrete choice model (to the exception of the influence on shipment size of the weight of the receiver in the shipper's flows, which is not significant in the continuous model). The introduction of the latent classes into the continuous model yields the same effects than with the discrete model, and also increases the explanatory power of the model: the R2 increases to 0.731 from 0.710.

4 Conclusion

The heterogeneity of supply chains is an important challenge for analysing, understanding and modelling freight transport systems. This paper explored a solution based on Latent Class Analysis in order to bring relevant information in shipment size choice models in an efficient way (i.e. without adding too many degrees of freedom). In doing so, the paper showed that handling and conditioning variables are at least if not more important than the activity of shippers to explain shipment size. Latent class segments incorporating this information significantly improve the models' explanatory power. Also, the paper's results, obtained from French data, are qualitatively close to results obtained from a German database. This implies that a segmentation based on conditioning and handling constraint presents good transferability.

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