A discrete shipment size choice model with latent classes of shipments’ attributes

World Conference on Transport Research - WCTR 2016
Shanghai. 10-15 July 2016

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Agenda

- Introduction
- Discrete shipment size choice model
- Latent classes of shipment‘s attributes
- Data and estimation results
- Summary and prospects
Introduction

- Why shipment size choice modeling?
  - High relevance for subsequent decisions (mode choice, transport chains)
  - Proxy for logistical decisions
  - Displays reactions of various stakeholders on policy measures (behaviorally-sensitive)

→ Important aspect in the modeling of freight transport demand
Introduction - Challenges

- Huge variety of deciding subjects

- Enormous diversity of corresponding objects (transported commodities)

- (Disaggregate) data availability is strongly limited

- Simulation-related analysis is problematic (adequate level of abstraction)
Introduction - Approach

- Two questions arise:
  1. How can the shipment size choice be modelled behaviorally-sensitive?
  2. How can the heterogeneity be addressed in a manageable way?

- Approaches:
  1. Discrete shipment size choice model
     - Total logistics cost as rational core
     - Shipment sizes show up empirical dependency on given vehicle and bundle sizes
     - Operationalization in large-scale freight transport model systems
  2. Latent Classes of shipments attributes
     - Similar behavior (similar logistical characteristics)
     - Less data requirements
Discrete shipment size choice model – Total logistics cost

- Total logistics cost (TLC) per year for decision maker $n$:

$$c_n(q_n) = \frac{Q_n}{q_n} F_n + Q_n c_n(q_n) + \frac{q_n}{2} (w_n + r v_n)$$

- $Q_n$: Constant and continuous flow of goods regarding individual $n$ per period (ton/year)
- $q_n$: Shipment size per transport of individual $n$ to satisfy $Q_n$ (ton/shipment)
- $F_n$: Fixed transport costs per shipment for individual $n$ (cost/shipment).
- $c_n(q_n)$: Variable transport costs for individual $n$ dependent on shipment size $q_n$ (€/ton)
- $w_n$: Warehousing costs per unit of commodity per year for individual $n$ (€/ton)
- $r$: Interest rate valuing the bounded capital in form of inventory holding costs
- $v_n$: Value density of the transported commodities (€/ton)
Discrete shipment size choice model

- A discrete shipment size choice model requires shipment size categories \( q_i, i = 1, 2, ..., I \):

\[
C_n(q_i) = \frac{F_n}{q_i} Q_n + c_n(q_i) Q_n + \frac{q_i}{2} (w_n + r v_n)
\]

- Warehousing cost \( w_n \) mainly depend on handling and space consumption
  - \( w_n \) constant regarding each shipment size category

- Restriction to road transports - assumptions:
  - Fixed transport cost constant for all decision makers \( n \)
  - Variable transport cost only varying between shipment size categories
    - Approximation by piecewise linear function: transport cost \( t_{q_i} \) (per tkm) times the haulage distance \( d_n \)

\[
C_n(q_i) = \frac{q_i w_{q_i}}{2} + \frac{F_{q_i}}{q_i} Q_n + t_{q_i} d_n Q_n + \frac{q_i r}{2} v_n
\]
Latent classes of shipment’s attributes – Motivation

\[ C_n(q_i) = \frac{q_i w_{qi}}{2} + \frac{F_{qi}}{q_i} Q_n + t_{qi} d_n Q_n + \frac{q_i r}{2} v_n \]

- Cost components are affected by logistical attributes of the transport e.g.
  - Fix cost \( F_{qi} \): loading, unloading, processing of the commodities
  - Value of time \( v_n \): importance of the good in the supply chain (JIT/JIS (time critical) production vs. lubricants and consumables)

- Segmentation approach: Latent Class Analysis
  - Exogenous segmentation
  - Externally visible segments
  - Segments of transports by similar response patterns on the basis of categorical items (logistical attributes)
Latent classes of shipment’s attributes – Approaches of integration

- Piendl, Liedtke and Matteis (2015) : TLC approach with supplement and deductions to utility function

(1) Food products (temperature-controlled)
(2) Miscellaneous standard cargo
(3) Special goods
(4) Unpacked bulk goods

- Reasonable order of coefficients’ magnitudes: (1) < (2) < (3) < (4)

- Now: One discrete choice model per estimated segment \( s = 1, \ldots, S \), \( \varepsilon_{q_i,n|s} \)
distributed i.i.d. extreme value type I

\[
-U_{q_i,n|s} = C_{n|s}(q_i) + \varepsilon_{q_i,n|s}
\]

\[
-U_{q_i,n|s} = \alpha_{q_i|s} + \beta_{q_i,1|s} \cdot Q_n + \beta_{q_i,2|s} \cdot Q_n d_n + \beta_{q_i,3|s} \cdot v_n + \varepsilon_{q_i,n|s}
\]
Data and estimation results

- Survey conducted within the scope of the German federal infrastructure planning 2015 (BVWP)

- Computer Assisted Personal Interviews: 487 usable road transport observations due to calculation of variables, revealed preference (RP) data

- Detailed information about the transport were sampled:
  - Type, weight, value and characteristics of the transported commodity
  - Frequency of the transport
  - Position in the supply chain
  - Duration, costs and distance of the transport

- Classification of shipment sizes
  - Up to 3t: Piece goods
  - 3t – 12t: Partial truck loads
  - > 12t: (multiple) Full truck loads
Data and estimation results – Latent Class Analysis

- Four latent classes show best segmentation result

<table>
<thead>
<tr>
<th>No. classes</th>
<th>Log-Likelihood</th>
<th>BIC</th>
</tr>
</thead>
<tbody>
<tr>
<td>2</td>
<td>-2608.16</td>
<td>5371.02</td>
</tr>
<tr>
<td>3</td>
<td>-2541.76</td>
<td>5318.68</td>
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<td>4</td>
<td>-2496.73</td>
<td>5309.06</td>
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<td>5</td>
<td>-2470.68</td>
<td>5337.41</td>
</tr>
<tr>
<td>6</td>
<td>-2452.43</td>
<td>5381.36</td>
</tr>
</tbody>
</table>

- Characterization of classes:
  1. Miscellaneous Goods (time-sensitive)
  2. Special Goods
  3. Food products (temperature-controlled)
  4. Bulk Goods (time-insensitive)
# Data and estimation results – Latent Class Analysis

<table>
<thead>
<tr>
<th>Class</th>
<th>Class 1</th>
<th>Class 2</th>
<th>Class 3</th>
<th>Class 4</th>
</tr>
</thead>
<tbody>
<tr>
<td>$\gamma_s$</td>
<td>0.3330</td>
<td>0.2060</td>
<td>0.0918</td>
<td>0.3692</td>
</tr>
</tbody>
</table>

Conditional probability of answering “Yes”

<table>
<thead>
<tr>
<th>Property</th>
<th>Class 1</th>
<th>Class 2</th>
<th>Class 3</th>
<th>Class 4</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fragile</td>
<td>0.0862</td>
<td><strong>0.5284</strong></td>
<td>0.2014</td>
<td><strong>0.0000</strong></td>
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<tr>
<td>Valuable</td>
<td>0.2619</td>
<td><strong>0.8194</strong></td>
<td>0.2320</td>
<td>0.2222</td>
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<tr>
<td>Bulky</td>
<td>0.3494</td>
<td><strong>0.4746</strong></td>
<td><strong>0.0000</strong></td>
<td>0.2543</td>
</tr>
<tr>
<td>Temperature</td>
<td>0.0549</td>
<td>0.0000</td>
<td><strong>0.7284</strong></td>
<td>0.0364</td>
</tr>
<tr>
<td>Food</td>
<td>0.0000</td>
<td>0.0000</td>
<td><strong>1.0000</strong></td>
<td>0.0740</td>
</tr>
<tr>
<td>Dangerous</td>
<td><strong>0.1947</strong></td>
<td>0.0187</td>
<td>0.0000</td>
<td>0.1588</td>
</tr>
<tr>
<td>Bulk Cargo</td>
<td>0.0173</td>
<td>0.0000</td>
<td>0.0458</td>
<td><strong>0.1677</strong></td>
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<tr>
<td>Liquid</td>
<td><strong>0.0000</strong></td>
<td>0.0000</td>
<td>0.0549</td>
<td>0.0142</td>
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<tr>
<td>Standard</td>
<td><strong>0.6500</strong></td>
<td>0.2512</td>
<td>0.6094</td>
<td>0.3068</td>
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<tr>
<td>Custom</td>
<td>0.1536</td>
<td><strong>0.4032</strong></td>
<td><strong>0.0446</strong></td>
<td><strong>0.0925</strong></td>
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<tr>
<td>Accumulation</td>
<td><strong>0.6669</strong></td>
<td>0.3674</td>
<td>0.5594</td>
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<tr>
<td>Processing</td>
<td><strong>0.7278</strong></td>
<td>0.2551</td>
<td>0.4597</td>
<td><strong>0.1214</strong></td>
</tr>
</tbody>
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Observations: 487
Parameter estimated: 51
## Data and estimation results – Logit-Model

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Constant</td>
<td>$q_{2}: 3t - 12t$</td>
<td>-5.6010</td>
<td>2.8028</td>
<td>-4.2494</td>
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<tr>
<td></td>
<td>$q_{2}: 3t - 12t$</td>
<td>(3.2884)</td>
<td>(8.7964)</td>
<td>(3.9363)</td>
</tr>
<tr>
<td></td>
<td>$q_{3}: &gt; 12t$</td>
<td>-13.0818 **</td>
<td>0.1431</td>
<td>-9.2072 *</td>
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<td>$q_{3}: &gt; 12t$</td>
<td>(4.5164)</td>
<td>(12.5992)</td>
<td>(4.6503)</td>
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<tr>
<td>$Q_{n}$</td>
<td>$q_{2}: 3t - 12t$</td>
<td>0.0020 .</td>
<td>0.0031</td>
<td>0.0017</td>
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<tr>
<td></td>
<td>$q_{2}: 3t - 12t$</td>
<td>(0.0011)</td>
<td>(0.0030)</td>
<td>(0.0011)</td>
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<tr>
<td></td>
<td>$q_{3}: &gt; 12t$</td>
<td>0.0025 *</td>
<td>0.0038</td>
<td>0.0019 .</td>
</tr>
<tr>
<td></td>
<td>$q_{3}: &gt; 12t$</td>
<td>(0.0011)</td>
<td>(0.0031)</td>
<td>(0.0011)</td>
</tr>
<tr>
<td>$\ln(d_{n} \cdot Q_{n})$</td>
<td>$q_{2}: 3t - 12t$</td>
<td>0.6224 *</td>
<td>0.4620</td>
<td>0.4449</td>
</tr>
<tr>
<td></td>
<td>$q_{2}: 3t - 12t$</td>
<td>(0.2915)</td>
<td>(0.8456)</td>
<td>(0.3535)</td>
</tr>
<tr>
<td></td>
<td>$q_{3}: &gt; 12t$</td>
<td>1.3248 ***</td>
<td>1.1608</td>
<td>1.3862 **</td>
</tr>
<tr>
<td></td>
<td>$q_{3}: &gt; 12t$</td>
<td>(0.3927)</td>
<td>(1.2355)</td>
<td>(0.4310)</td>
</tr>
<tr>
<td>$\ln v_{n}$</td>
<td>$q_{2}: 3t - 12t$</td>
<td>-0.2261</td>
<td>-1.2991 .</td>
<td>-0.1407</td>
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<tr>
<td></td>
<td>$q_{2}: 3t - 12t$</td>
<td>(0.2168)</td>
<td>(0.7410)</td>
<td>(0.1813)</td>
</tr>
<tr>
<td></td>
<td>$q_{3}: &gt; 12t$</td>
<td>-0.5247*</td>
<td>-2.3739 *</td>
<td>-1.0163 **</td>
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<tr>
<td></td>
<td>$q_{3}: &gt; 12t$</td>
<td>(0.2565)</td>
<td>(1.007)</td>
<td>(0.2831)</td>
</tr>
</tbody>
</table>

Number of observations: 162 92 42 191
McFadden $R^2$ ($\rho^2$): 0.3557 0.3228 0.4784 0.4400
Adj. McFadden $R^*$ ($\bar{\rho}^2$): 0.3093 0.2421 0.3050 0.3959
Likelihood ratio test: $\chi^2 = 122.74$ $\chi^2 = 64.00$ $\chi^2 = 44.15$ $\chi^2 = 159.6$

Significance levels: . p<0.1; * p<0.05; ** p<0.01; *** p<0.001
Summary and prospects

- Discrete shipment size choice models for interregional road transports have been developed.

- Exogeneously derived latent segments of shipments’ attributes account for omnipresent heterogeneity exceeding TLC variables.

- Estimated models have reasonable signs and orders of the coefficients’ magnitude.

- Problematic: low amount of observations in some of the estimated segments.

- Incorporation of latent segments into a freight transport model framework needs to be investigated further:
  - Sample biased
  - Adequate statistical mapping technique (NST 2007 to estimated segments).
Thank you for your attention!