Freight transport demand modeling: Recent developments and directions for future research

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Concepción Román
Institute of Tourism and Sustainable Economic Development. University of Las Palmas G.C., Spain

Tides
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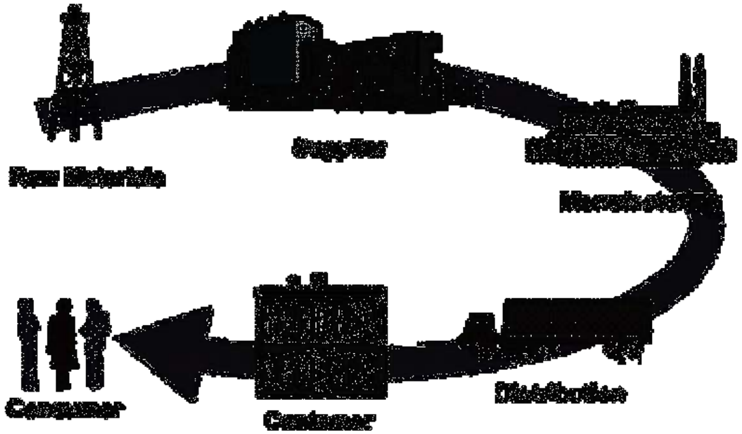
Importance of freight transport

- The competitiveness of nations is largely grounded on the existence of efficient transport systems.
- Transport is considered an input more of the entire production process (*derived demand*).



Comparative advantages of countries and regions are now evaluated within a global context.

The intensification globalization processes has increased the importance of freight transport

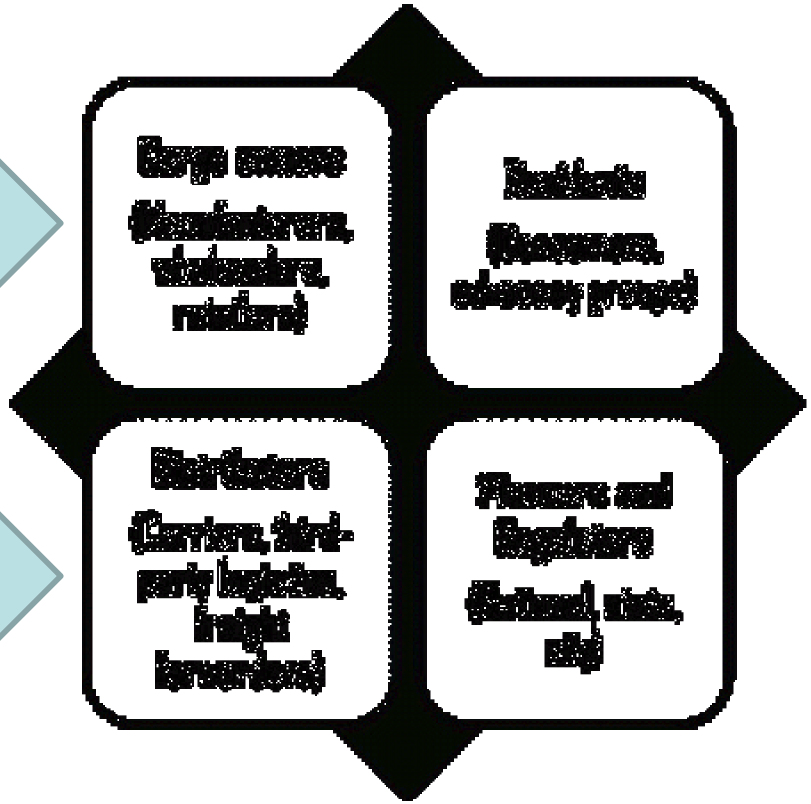
Freight stakeholders

"Those who are affected by the movement of goods"

Products arrive at the destination:
- As scheduled
- As ordered
- Damage-free
- Convenient cost

MOTOR CARRIERS:
- Potential routes

LOG. OPERATORS:
- Lowest cost
- Fastest time,
- etc,



A huge list of agents:
- ✓Different motivations
- ✓Different interests
- ✓Making different decisions

Building a demand freight model is not a simple thing

Freight transport demand

Why is freight transport demand modeling important?

- **A detailed knowledge about the transport demand behavior is paramount in making decisions about what should be the optimal planning for the transport system.**
- **The ability to make investment decisions however will depend on the degree of knowledge of the transport demand as well as on the accuracy with which benefits and costs associated to different actions are quantified.**

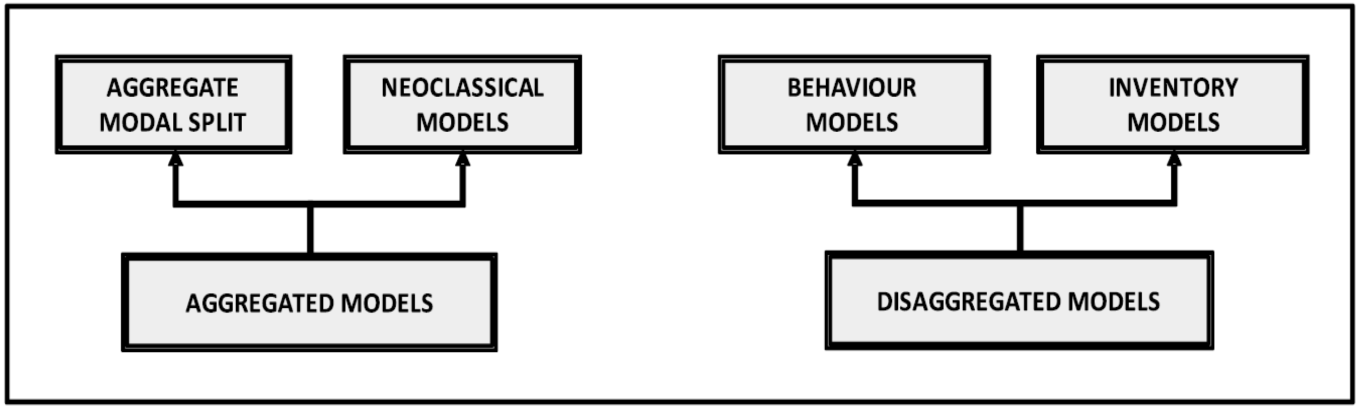
The modeling of freight transport demand has evolved significantly over the past decades, from the use of aggregate models based on global data of shippers and shipments, to the use of more sophisticated disaggregated models based on individual data.

Interesting reviews of the state-of-the-art literature regarding freight transport modeling:

Tavasszy and de Jong (2014)
Ben-Akiva et al. (2013)
Nuzzolo et al. (2013)
Chow et al. (2010)

Freight transport demand

Winston (1983). makes the following classification of demand modeling approach



Source: Feo et al (2011)

The basic unit of observation is an aggregate variable:
e.g. the aggregate share of a particular mode of transport in an O/D pair.

The basic unit of observation is the decision made by a particular decision maker:
e.g. the choice of mode of transport for a particular shipment.

Main advantages:

- ✓ **Useful in the context of large scale analyses. National or regional models**

Main advantages:

- ✓ **They are grounded in microeconomic theories that reflect the process of decision-making.**
- ✓ **Allow a much richer specification, capturing important characteristics of the decision-maker.**
- ✓ **Provide more accurate estimates of important figures used in economic analysis: WTP and Elasticity values**

Theory of choice

Choice can be represented by a sequential process

1. Definition of the choice problem

2. Generation of the choice set

3. Evaluation of the alternatives in the choice set

4. Making a choice

1. Who is the **decision-maker**
2. What are the **characteristics** of the **decision-maker**
3. What are the **alternatives available** for the choice
4. What are the **attributes** or characteristics **of the alternatives**
5. What is the **decision rule** to make a choice

a person,
a household,
a family,

Income, gender, age, size of the firm, type of

Route 1: Motorway
Route 2: conventional road not available for

Continuous/discrete
Generic/specific
Measured/perceived

Behavioural assumtion:
- Utility maximization (Rational decision-maker)
- Other rules

Theoretical framework for disaggregate demand modeling

Discrete Choice Theory: McFadden (1981)

The individual consumes continuous (or divisible) goods

The individual chooses among a set of discrete alternatives (non divisible goods) mutually exclusive.

Discrete alternatives are represented by a vector Q_j of characteristics (Lancaster, 1966)

$$\underset{X,j}{Max} \quad U(X,Q_j) = \underset{j}{Max}\,[\underset{X}{Max} \quad U(X,Q_j)]$$

$$s.a. \quad \sum_i p_i x_i + c_j \le I \qquad j \in M$$

$$x_i \ge 0 \quad i = 1,\ldots,n$$

p_i, x_i are price/amount of good i

c_j is the cost of the alternative j

I is individual's income

$Q_j = (q_{1j}, q_{2j}, \ldots, q_{kj})$ characteristics of alternative j

➢ **Conditional indirect utility of alternative *j*:** $V_j = V(P, I - c_j, Q_j)$

➢ **Willingness to pay for improving attribute k:**

$$WTP_k^j = -\frac{dc_j}{dq_{kj}} = \frac{\dfrac{\partial V_j}{\partial q_{kj}}}{\dfrac{\partial V_j}{\partial c_j}}$$

DECISION RULE:

The decision-maker selects the alternative with the highest utility

$$V^* = \underset{j}{Max}\left\{V_j(P, I - c_j, Q_j)\right\}$$

$$V^* = \underset{j}{Max}\left\{V_{jq}(P_q, I_q - c_{jq}, Q_{jq}, \theta_q)\right\}$$

Theoretical framework for disaggregate demand modeling

Some simplifications

1) We cannot estimate a set of parameters for each individual *q*, thus population level parameters are interacted with socioeconomic characteristics of the decision-maker S_q
2) Prices of the continuous goods are neglected as do not intervene in the choice of alternative.
3) Income can be considered as another characteristic and merged into S_q
4) The cost of the alternative c_{jq} is considered as another attribute and merged into the vector of characteristics that is renamed $x_{jq}=\{c_{jq}, Q_{jq}\}$

$$V^* = \underset{j}{Max}\left\{V_{jq}(x_{jq}, S_q, \theta)\right\}$$

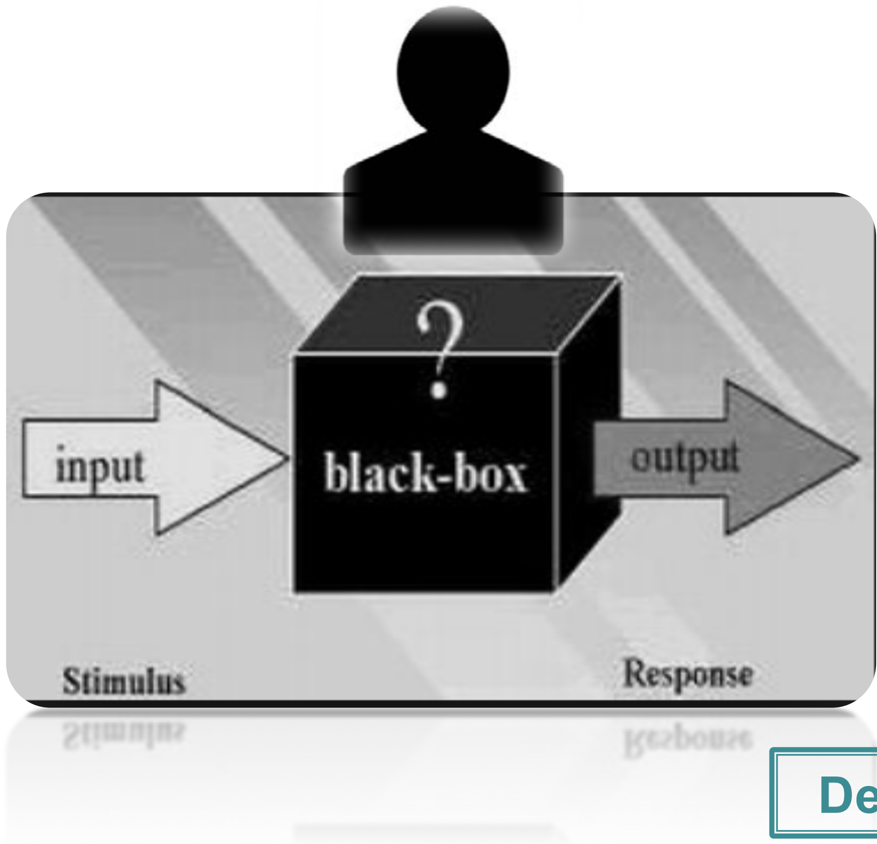
Theoretical framework for disaggregate demand modeling

Experience

Soc. characteristics

Attributes

Constraints



Deterministic outcome

Probabilistic choice mechanism

Theoretical framework for disaggregate demand modeling

Probabilistic Choice Theory: Random Utility Theory (Domencich and McFadden,1975)

The utility of alternative j for an individual has two components: a systematic or deterministic part (measurable) and a random component.

$$U_{jq} = V_{jq} + \varepsilon_{jq}$$

The systematic component depends on the attributes of the alternative, the socioeconomic characteristics and unknown parameters

$$V_{jq} = F(\vec{x}_{jq}, \vec{S}_q, \vec{\theta}_j)$$

The random part accounts for unobserved elements.

$$\varepsilon_{jq}$$

$$U_{iq} \geq U_{jq} \quad \forall\ j \neq i$$

$$V_{iq} + \varepsilon_{iq} \geq V_{jq} + \varepsilon_{jq} \quad \Leftrightarrow \quad \underbrace{V_{iq} - V_{jq}}_{\text{measurable}} \geq \underbrace{\varepsilon_{jq} - \varepsilon_{iq}}_{\text{random}}$$

Choice Probability

$$P_{iq} = P(\varepsilon_{jq} \leq V_{iq} - V_{jq} + \varepsilon_{iq}\ \forall\ j \neq i)$$

Demand response

Demand elasticities

Theoretical framework for disaggregate demand modeling

Different assumptions about the distribution of the random term yield different discrete choice models (RUM models):

- ✓ Multinomial Logit
- ✓ Nested Logit
- ✓ Multinomial Probit
- ✓ Mixed Logit
  - – Random parameter
  - – Error components
- ✓ Hybrid Choice Models

SOFTWARE

- ➢ Biogeme
  - Bison Biogeme
  - Python Biogeme
- ➢ Nlogit
- ➢ R
- ➢ Matlab

❖ Train, K. (2009). Discrete Choice Methods with Simulation, 2nd edition, Cambridge University Press, Cambridge.

❖ Hensher, D.A., Rose, J.M, and Greene, W.H. (2015). Applied choice analysis. 2nd edition. Cambridge University Press, Cambridge.

❖ Ortúzar, J. de D. and Willumsen, L.G. (2011). Modelling Transport. 4th edition, John Wiley & Sons, Chichester.

Data required to estimate a DCM

Minimum content of a discrete choice data set

- **Alternatives and their availability**
  Not all the alternatives are available to all the individuals
- **Alternative chosen by the individual**
  (Dependent variable)
- **Attributes of the chosen/non-chosen alternatives**
  Some socioeconomic characteristics
  (Explanatory variables)

Main data sources

Market data and experimental data

Market data or Revealed Preferences

- •Represent **real market situations** in which the decision-maker face the choice among a finite set of alternatives.
- •Provide information about consumers current behavior in the market place

Disadvantages of RP data

- •Low variability in explanatory variables
- •Correlation among explanatory variables
- •Difficulty to measure the effect of latent variables
- •Inability to analyze demand for new alternatives

Measurement errors

- •Error in the measurement of explanatory variables
- •Accuracy in the measurement of the dependent variable (choice)

Experimental data or Stated Preferences

- •Represent **hypothetical market situations** created by the researcher in a **experimental design**
- •Experimental designs define a set of hypothetical scenarios, similar to real market situations in order to define an appropriate context
- •The decision-maker express his preferences in these hypothetical situations:
  - •- Choice (DCE)- Raking- Rating-B-W scales

Information needed to create an experimental design

- •The set of relevant attributes or explanatory variables
- •The levels of the attributes (possible values)
- •Specialized software to create de experimental design that creates scenarios considering combinations of the different levels of the different attributes (NGENE)
  - •Efficient designs

Measurement errors

- •Error in the measurement of the dependent variable
- •Accuracy in the measurement of explanatory variables

Critical issues in freight demand modeling

(Feo et al. 2011) Building a freight demand model is not trivial

1. **Identification of the decision-maker**
   - ✓Data collection
   - ✓Information for model building
2. **Heterogeneity in transport flows**
   - ✓Shipping distance
   - ✓Shipment size
   - ✓Origin/destination
   - ✓Value of freight
   - ✓Type of good (finished, raw material, bulk, etc)
3. **Explanatory variables**
   - ✓Top variables
     - −Cost
     - −Transit time, speed
     - −Frequency
     - −Reliability
     - −Flexibility
4. **Representation of preferences: Specification of the utility**
5. **Behavioral assumptions about the decision rule**

Dealing with heterogeneity

$$V_{jq} = \alpha_j + \sum_k \theta_k X_{jkq} + \varepsilon_{jq}, \text{ with } \theta_k \quad \text{fixed in the population}$$

$$\frac{\partial V_{jq}}{\partial X_{jkq}} = \theta_k \text{ Marginal utility constant accross individuals}$$

Homogeneous population

How can we deal with heterogeneous preferences?

Systematic heterogeneity

$$V_{jq} = \alpha_j + \sum_k \left(\theta_k + \sum_r \theta_{rk} S_{rq} \right) X_{jkq} + \varepsilon_{jq}$$

$$\frac{\partial V_{jq}}{\partial X_{jkq}} = \theta_k + \sum_r \theta_{rk} S_{rq} \text{ varies with } S_{rq}$$

How to start specifying interactions?

Random heterogeneity

$$V_{jq} = \alpha_j + \sum_k \beta_{kq} X_{jkq} + \varepsilon_{jq} \qquad \beta \to f_{\mu\,\Sigma}(\beta)$$

$$\frac{\partial V_{jq}}{\partial X_{jkq}} = \beta_k \text{ random variable}$$

$$\beta_k \to N(\mu_k, \sigma_k)$$

$$\beta_k = \mu_k + \sigma_k \eta_k \qquad \eta_k \to N(0,1)$$

Which parameters are random?
Which distribution?

Heterogeneity in mean

$$\beta_k = \left[\mu_k + \left(\sum_r \mu_{rk.} S_{rq} \right) \right] + \sigma_k \eta_k \qquad \eta_k \to N(0,1)$$

Dealing with heterogeneity

- Heterogeneity in the WTP is one of the main motivations for building models accounting for heterogeneous preferences
- Problems faced when computing WTP figures:

$$WTP_k^j = -\frac{dc_j}{dq_{kj}} = \frac{\boxed{\dfrac{\partial V_j}{\partial q_{kj}}}}{\boxed{\dfrac{\partial V_j}{\partial c_j}}} \qquad \frac{\text{Random}}{\text{Random}}$$

Unknown distribution

  - Systematic heterogeneity:
    - No major problems (preferences are homogeneous within socioeconomic group)
  - Random heterogeneity
    - WTP is a random variable that could follow an unknown distribution. Simulation is required to obtain WTP.
      - The distribution of the denominator may contain zeros
      - The distributions may contain inconsistent values (wrong sign)

      Specifying a distribution taking positive or negative values can help
      - Which figure should be used as a representative WTP?
        » Mean
        » Median

Dealing with heterogeneity

- Other models to analyze preference heterogeneity:
  - Latent Class Models (LCM).
    - Semi-parametric variant of the MNL that resembles the ML model by approximating the underlying continuous distribution by a discrete one.
    - It does not require specific assumptions about the parameters distributions *(Greene and Hensher, 2003).*
    - The model assumes that the population consists of a number Q of latent classes that is exogenously determined and <u>unobserved heterogeneity is captured by these classes</u> through the estimation of a parameter vector for each class
    - The derivation of the choice probability for the LCM is based on:
      - i) The (conditional on class membership) choice probability of the different alternatives
      - ii) The class membership probability for the different classes
    - Thus, the unconditional choice probability is obtained by taking the expectation over all the Q classes
    - Bayesian estimation can be used to obtain posterior estimates of the individual-specific parameters
  - Advance software packages (NLOGIT6) permit the estimation Latent Class Models (LCM) considering more flexible specifications for the underlying behavioral choice model (random coefficients and error components) (Greene and Hensher, 2013)

Representation of preferences

$$V_{jq} = \alpha_j + \sum_k \theta_k X_{jkq} + \varepsilon_{jq}$$

Behavioral assumptions

- ✓**Symmetry in preferences**
- ✓**Compensatory behavior**
- ✓**Risk neutrality**

Asymmetric preferences

Prospect Theory
(Kahneman and Tversky, 1979)

- ✓Reference dependence
- ✓Loss aversion
- ✓Diminishing sensitivity

These properties characterize the utility function in a decision under risk framework

The decision making process involve:

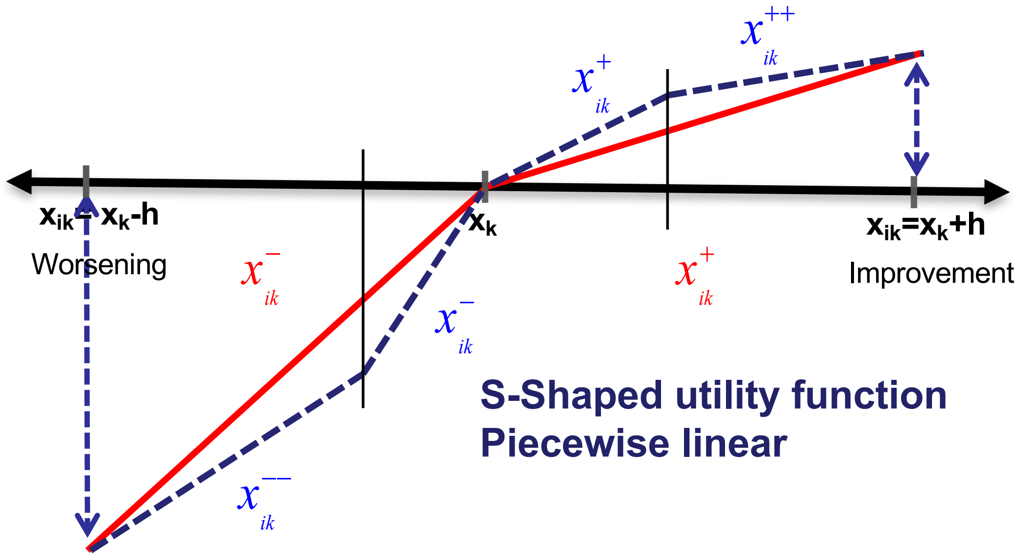
i. The evaluation of gains and losses defined in relation to a reference point **(reference dependence)**

ii. A higher evaluation for losses than gains **(loss aversion)**

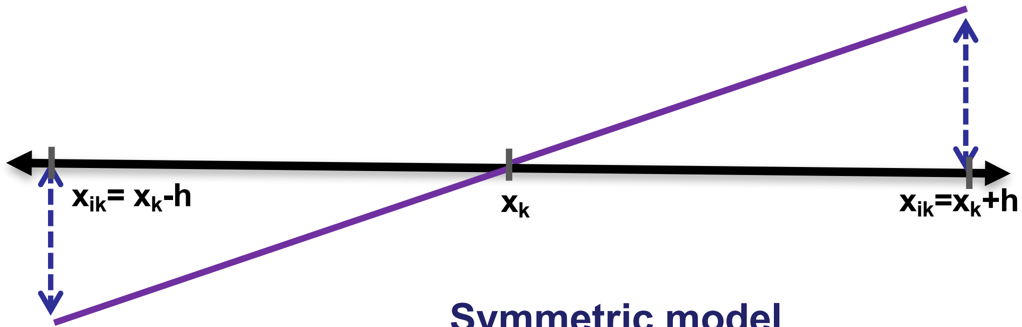
iii. Decreasing marginal values in both positive and negative domains **(diminishing sensitivity)**

(Hess, Rose and Hensher, 2008)
(Massiero and Hensher, 2010)

Representation of preferences



S-Shaped utility function
Piecewise linear



Symmetric model
Linear utility function

WTP / WTA Measures

Desirable attributes: $WTP = \frac{-\theta_y^+}{\theta_c^+}$; $WTA = \frac{\theta_y^-}{-\theta_c^-}$

Undesirable attributes: $WTP = \frac{-\theta_x^-}{\theta_c^+}$; $WTA = \frac{\theta_x^+}{-\theta_c^-}$

✓Reference dependence

Utility must be defined in terms of deviations with respect to the reference point. Data about reference alternative are required. Pivot designs

✓Loss aversion

The impact of a loss (-) is higher than the impact of a gain of the same magnitude (+)

✓Diminishing sensitivity

The further we move from the reference the impact diminishes

$$V_i = \sum_k \left(\theta_{x_k}^+ x_{ik}^+ + \theta_{x_k}^- x_{ik}^- \right)$$

$$x_{ik}^+ = \max\left(x_{ik} - x_k, 0\right) \qquad x_{ik}^- = \max\left(x_k - x_{ik}, 0\right)$$

$$H_0 : \quad \theta_{x_k}^+ + \theta_{x_k}^- < 0$$

$$V_i = \sum_k \left(\theta_{x_k}^+ x_{ik}^+ + \theta_{x_k}^{++} x_{ik}^{++} + \theta_{x_k}^- x_{ik}^- + \theta_{x_k}^{--} x_{ik}^{--} \right)$$

$$H_0 : \quad \theta_{x_k}^+ > \theta_{x_k}^{++} \; ; \; \theta_{x_k}^- < \theta_{x_k}^{--}$$

Representation of preferences

Non-compensatory behavior

Traditional approach to analyze choice behavior assumes that DM use all the information in a compensatory, utility maximization framework

- There exist evidence that individuals use non-compensatory decision strategies

(Ford et al, 1989)

- Incorporation of cutoff-based heuristics

Instruments used by decision makers to simplify the task of making a decision

Cutoff information can be collected easily

Hard cutoffs: cannot be violated

- Elimination by aspects (Tversky, 1972)
- Conjunctive (Dawes, 1964)

Sometimes, self-imposed cutoffs are violated during the elicitation of preferences

Each attribute “reflects a decision maker behavioral intent”, but when all attributes are jointly analyzed, “decision makers may be willing to either change or violate cut-offs”.

(Swait, 2001)

Swait (2001) proposes an extension to the traditional compensatory utility maximization framework where:

i) cut-offs are incorporated exogenously

ii) it is possible for the consumer to treat these constraints as “soft” by permitting their violation at a certain cost

Representation of preferences

The standard utility incorporates a penalization term that depends on the magnitude of the cutoff violation

$$V_{jq} = \boxed{\alpha_j + \sum_k \theta_k Y_{jkq} + \sum_r \theta_r X_{jrq}} + \underbrace{\sum_k \theta_{CoY_k} \max\left\{0, CoY_{kq} - Y_{jkq}\right\} + \sum_r \theta_{CoX_r} \max\left\{0, X_{jrq} - CoX_{rq}\right\}}_{\text{PENALIZED UTILITY}} + \varepsilon_{jq}$$

Marginal effects:

DESIRABLE ATTRIBUTES

$$\frac{\partial U_j}{\partial Y_j} = \begin{cases} \beta_Y - \beta_{CO\_Y} & \text{if } \; Y_j < CoY \\ \beta_Y & \text{if } \; Y_j > CoY \end{cases}$$

UNDESIRABLE ATTRIBUTES

$$\frac{\partial U_j}{\partial X_j} = \begin{cases} \beta_X & \text{if } \; X_j < CoX \\ \beta_X + \beta_{CO\_X} & \text{if } \; X_j > CoX \end{cases}$$

Recent contributions

Marcucci and Scaccia, (2004)
Danielis and Marcucci (2007)
Feo-Valero el al. (2016)
Román et al. (2017)

Representation of preferences

Other interesting topics

- **Incorporation of risk attitudes in attribute processing** *(Li and Hensher, 2012)*
  ✓The linear model assumes risk-neutral attitudes under the RUM framework
  ✓The attitude towards risk is crucial to decision making, especially within a risky context (e.g. travel time uncertainty).
  ✓Risk attitudes towards the perception of an attribute are related to the shape of the Utility (concave/convex)

Constant Relative Risk Aversion Model

$$V_{jq} = \alpha_j + \sum_k \theta_k \left(\frac{X_{jkq}^{1-\alpha_k}}{1-\alpha_k} \right) + \varepsilon_{jq}$$

Risk taking if $1-\alpha_k < 1$

Risk averse if $1-\alpha_k > 1$

Risk neutral if $1-\alpha_k = 1$

Representation of preferences

Other interesting topics

•**Other behavioral rules can be used instead of RUM**

•**Random regret minimization (RRM) behavioral rule** *(Chorus, 2012)*

✓A variety of empirically well-established behavioral phenomena are not captured by conventional RUM-models

✓Many of these phenomena readily emerge from the RRM model structure

✓Chorus (2012) propose a regret-based DCM-approach on the following basis:

"When making choices, people aim to minimize regret rather than maximize utility"

✓Regret arises when one or more non-chosen alternatives perform better than the chosen one in terms of one or more attributes.

Random regret associated with a considered alternative i

$$RR_i = R_i + \varepsilon_i = \sum_{j \neq i} \sum_m \ln(1 + \exp\left[\beta_m \cdot \left(x_{jm} - x_{im}\right)\right] + \varepsilon_i$$

$$P_i = P(RR_i < RR_j) = P(-RR_i > -RR_j) = \frac{\exp(-R_i)}{\sum_j \exp(-R_j)}$$

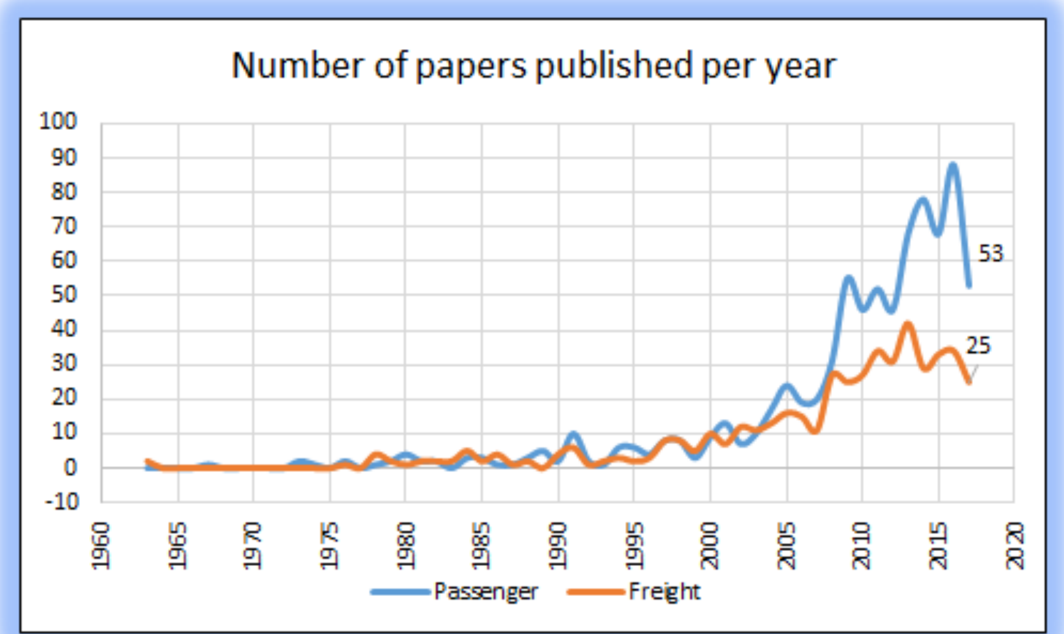
Directions for future research

- Discrete choice methods represent a powerful tool to analyze consumer preferences in the field of transport.
- Now, very sophisticated models can be built, relaxing the strong modeling hypotheses that have accompanied much of the research done up until now.
- These more recent models can provide measures that permit an accurate evaluation of the different policies, especially those aligned with the objectives of EU.
- But, in the area of freight transport, more research is still needed

Representation of preferences

Search in Scopus (1960-2017)
Key search in abstrat, title and key words

"choice, freight, transport" → 474 papers
"choice, passenger, transport" → 788 papers



Directions for future research

- **EC Strategy of Transport for 2050 includes an ambitious plan to increase mobility and reduce emissions**

  GOALS (60% cut in transport emissions by 2050):

  - Urban travel:
    - Achieve essentially **CO_2-free movement of goods in major urban centers** by **2030**.
  - Intercity travel:
    - **By 2030, 30%** of road freight over 300 km should shift to other modes such as rail or waterborne transport, and more **than 50% by 2050**.
    - Ensure **connections of seaports to the rail freight** and inland waterway system.
    - Framework for a **European multimodal transport information**
    - **Internalization of externalities**

Directions for future research

More research is needed to help policy makers to define:

- Which policies are more appropriate to favor the diversion of traffic from road to more sustainable modes of transport. Favor rail and maritime transport or penalize road?
- Which mechanisms should be adopted to internalize road externalities?
- What are the preferences for intermodal options?
- Which policies would encourage the use of EV for urban freight distribution?

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Thank You!!