AN ENHANCED MEASUREMENT MODEL OF PERCEPTION OF COMFORT IN PUBLIC TRANSPORTATION

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Introduction & motivation

The data
- RP survey
- Adjective quantification survey

The integrated model framework
- Discrete choice model
- Latent variable model
- Quantification model

Application example
- Quantification model
- Integrated model
- Validation of the integrated model

Conclusion
Recent developments in discrete choice modeling (DCM)

- Choice cannot only be explained by economic indicators (travel duration, price of a trip, etc.)

- **Psychological constructs (attitudes, perceptions, etc.) play important role in choice behavior:** need to be integrated in an appropriate way into DCMs.

- Framework handling this issue: **hybrid choice model (HCM)** framework (Walker, 2001; Ben-Akiva et al., 2002)
Hybrid choice model (HCM): DCM with latent constructs.
Hybrid choice model (HCM): DCM with latent constructs.

In this research: focus on the integration of choice model and latent variable model.
Issues related to the integration of latent variables into choice models:

1. **Measurement of latent variable**
   
   How to obtain the most realistic and accurate measure of a perception?

2. **Integration of the measurement into the choice model**

   How to incorporate this information in the choice modeling framework?
1. **Measurement of latent variable:**

   - **Use of opinion statements**
     - Five-point Likert scale
   
   Usual way in literature
   (Likert, 1932; Bearden and Netemeyer, 1999)

   - **Recent technique** developed in **social sciences:**

     Respondents report **adjectives** characterizing a variable of interest
     (Kaufmann et al., 2001; Kaufmann et al., 2010)

     Reflects **spontaneous** perceptions of individuals
     (≠ survey designer’s conception of the perception)
2. Integration of the measurement into the choice model:

- **Structural equation model (SEM)** framework used to characterize latent variable and relate it to its measurement indicators (e.g. Bollen, 1989).

- Latent variable model embedded into DCM \(\rightarrow\) HCM framework

- Integration of measurements into HCM framework:
  - Easy for models with opinion statements
  - Needs an **additional modeling step** for model with adjectives
Purpose of the research:

Develop an HCM that uses adjectives as measurements of latent construct

Steps:

1. Collection of choice data & psychometric data in the form of adjectives

2. Quantification of adjectives:
   1. Survey to obtain ratings of adjectives
   2. Quantification model
   3. Integration of the quantification model into the HCM framework
THE DATA

Two surveys:

• Revealed preferences (RP) survey

• Survey with evaluators (adjective quantification survey)
THE DATA

RP survey

- **Mode choice study**

- Conducted between 2009-2010 in low-density areas of Switzerland

- Conducted with PostBus (major bus company in Switzerland, operates in low-density areas)

- Info on **all trips performed by inhabitants in one day**:
  - Transport mode
  - Trip duration
  - Cost of trip
  - Activity at destination
  - Etc.

- **1763 valid questionnaires** collected
Adjective data for perception of transport modes:

*For each of the following transport modes, give three adjectives that describe them best according to you.*

<table>
<thead>
<tr>
<th></th>
<th>Adjective 1</th>
<th>Adjective 2</th>
<th>Adjective 3</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>The car is:</td>
<td></td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>The train is:</td>
<td></td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>The bus, the metro and the tram are:</td>
<td></td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>The post bus is:</td>
<td></td>
<td></td>
</tr>
<tr>
<td>5</td>
<td>The bicycle is:</td>
<td></td>
<td></td>
</tr>
<tr>
<td>6</td>
<td>The walk is:</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
### Adjective data for perception of transport modes:

For each of the following transport modes, give three adjectives that describe them best according to you.

<table>
<thead>
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<th>Adjective 1</th>
<th>Adjective 2</th>
<th>Adjective 3</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>The car is:</td>
<td>convenient</td>
<td>comfortable</td>
</tr>
<tr>
<td>2</td>
<td>The train is:</td>
<td>relaxing</td>
<td>punctual</td>
</tr>
<tr>
<td>3</td>
<td>The bus, the metro and the tram are:</td>
<td>fast</td>
<td>frequent</td>
</tr>
<tr>
<td>4</td>
<td>The post bus is:</td>
<td>punctual</td>
<td>comfortable</td>
</tr>
<tr>
<td>5</td>
<td>The bicycle is:</td>
<td>stimulating</td>
<td>convenient</td>
</tr>
<tr>
<td>6</td>
<td>The walk is:</td>
<td>healthy</td>
<td>relaxing</td>
</tr>
</tbody>
</table>
Extraction of information on perceptions

1. Classification into themes:
   - Perception of cost
   - Perception of time
   - Difficulty of access
   - Flexibility
   - Comfort, etc.

2. Focused on adjectives related to one theme only and one mode only:

**Comfort in public transportation (PT)**

<table>
<thead>
<tr>
<th>Comfort</th>
</tr>
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<tbody>
<tr>
<td>hardly full</td>
</tr>
<tr>
<td>packed</td>
</tr>
<tr>
<td>bumpy</td>
</tr>
<tr>
<td>comfortable</td>
</tr>
<tr>
<td>hard</td>
</tr>
<tr>
<td>irritating</td>
</tr>
<tr>
<td>tiring</td>
</tr>
<tr>
<td>unsuitable with bags</td>
</tr>
<tr>
<td>uncomfortable</td>
</tr>
<tr>
<td>bad air</td>
</tr>
<tr>
<td>…</td>
</tr>
</tbody>
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- Perception of time
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**Comfort in public transportation (PT)**

\[
\begin{align*}
\text{Comfort} & : \\
\text{hardly full} & , \\
\text{packed} & , \\
\text{bumpy} & , \\
\text{comfortable} & , \\
\text{hard} & , \\
\text{irritating} & , \\
\text{tiring} & , \\
\text{unsuitable with bags} & , \\
\text{uncomfortable} & , \\
\text{bad air} & .
\end{align*}
\]
Adjective quantification survey

• Asked external evaluators to rate the adjectives on scale of comfort.

• Two scales:
  • Discrete scale: ratings from -2 to 2.
  • Continuous scale: ratings from -1000 to 1000.

• Number of evaluators: 277
THE DATA

ADJECTIVE QUANTIFICATION SURVEY

Discrete scale
THE DATA

ADJECTIVE QUANTIFICATION SURVEY

Continuous scale
Purpose of the developed HCM:

Assess impact of perception on choice. Using adjective data need following integrated framework.

Framework involves three components:

• Discrete choice model

• Latent variable model for the perception

• Quantification model for the indicators of the latent variable
THE INTEGRATED MODEL FRAMEWORK

Explanatory variables
RP respondents

Utilities

Perceptional variable

Choice indicators

Indirect measurement 1
Discrete rating 1 Continuous rating 1

Indirect measurement 2
Discrete rating 2 Continuous rating 2

Indirect measurement K
Discrete rating K Continuous rating K

Explanatory variables
Evaluators

Disturbances
THE INTEGRATED MODEL FRAMEWORK

Explanatory variables
RP respondents

Utilities

Choice indicators

Perceptional variable

Indirect measurement 1
Indirect measurement 2
Indirect measurement K

Discrete rating 1
Continuous rating 1
Discrete rating 2
Continuous rating 2
Discrete rating K
Continuous rating K

Disturbances

Utilities

Choice indicators

Indirect measurement 1
Indirect measurement 2
Indirect measurement K

Discrete rating 1
Continuous rating 1
Discrete rating 2
Continuous rating 2
Discrete rating K
Continuous rating K

Disturbances

Explanatory variables
Evaluators

Utilities

Choice indicators
THE INTEGRATED MODEL FRAMEWORK

LATENT VARIABLE MODEL

Explanatory variables
RP respondents

Utilities

Choice indicators

Disturbances

Perceptual variable

Indirect measurement 1
Discrete rating 1
Continuous rating 1

Indirect measurement 2
Discrete rating 2
Continuous rating 2

Indirect measurement K
Discrete rating K
Continuous rating K

Explanatory variables
Evaluators

Disturbances
THE INTEGRATED MODEL FRAMEWORK

Utilities

Choice indicators

Explanatory variables
RP respondents

Perceptional variable

Indirect measurement 1
- Discrete rating 1
- Continuous rating 1

Indirect measurement 2
- Discrete rating 2
- Continuous rating 2

Indirect measurement K
- Discrete rating K
- Continuous rating K

Disturbances

Utilities

Explanatory
variables
Evaluators

Quantification Model
THE INTEGRATED MODEL FRAMEWORK

Explanatory variables
RP respondents

Utilities

Choice indicators

Perceptual variable

Choice model

Indirect measurement 1
Indirect measurement 2
... Indirect measurement K

Discrete rating 1
Continuous rating 1
Discrete rating 2
Continuous rating 2
... Discrete rating K
Continuous rating K

Explanatory variables
Evaluators

Disturbances
Discrete choice model is standard:

$$U_{in} = V(X_{in}, X^*_n; \beta) + \varepsilon_{in} \quad \text{with} \quad \varepsilon_{in} \sim EV(0, 1)$$
The Integrated Model Framework

Explanatory variables
RP respondents

Utilities

Choice indicators

Perceptual variable

Indirect measurement 1
Indirect measurement 2
...
Indirect measurement K

Discrete rating 1
Continuous rating 1
Discrete rating 2
Continuous rating 2
...
Discrete rating K
Continuous rating K

Explanatory variables
Evaluators

Disturbances

Latent Variable Model
Latent variable model of perception (SEM):

**Structural equation:**

\[ X^*_n = h(X_n; \mu) + \omega_n, \quad \text{with} \quad \omega_n \sim \mathcal{N}(0, \sigma_\omega) \]

**Measurement equation:**

\[ I^*_{kn} = r_k(X^*_n; \eta_k) + \nu_{kn}, \quad \text{with} \quad \nu_{kn} \sim \mathcal{N}(0, \sigma_k) \]
Latent variable model of perception (SEM):

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Unobservable score of indicator \( k \) for individual \( n \)  \quad \text{Indirect measurement of perception} \( X^*_n \), which is treated as a latent variable
THE INTEGRATED MODEL FRAMEWORK

Utilities

Choice indicators

Explanatory variables
RP respondents

Perceptional variable

Utilities

Explanatory variables
Evaluators

Disturbances

Indirect measurement 1
Discrete rating 1
Continuous rating 1

Indirect measurement 2
Discrete rating 2
Continuous rating 2

Indirect measurement K
Discrete rating K
Continuous rating K

Quantification model

Explanatory variables
Evaluators

RAW TEXT END
THE INTEGRATED MODEL FRAMEWORK

QUANTIFICATION MODEL

Quantification model (SEM):

Structural equation:

Score of adjective $l$ by individual $m$

$$J_{lm}^* = c_l + \delta_{\gamma}, \quad \text{with } \delta_{\gamma} \sim \mathcal{N}(0, \sigma_{\gamma})$$

Measurement equation:

Discrete:

$$J_{lm}^D = \lambda_D \cdot J_{lm}^* + \beta_{XL}^D \cdot X_m + \delta_D, \quad \text{with } \delta_D \sim \text{Logistic}(0,1)$$

$$J_{lm}^D = \begin{cases} 
-2 & \text{if } -\infty < J_{lm}^* \leq \tau_{1l} \\
-1 & \text{if } \tau_{1l} < J_{lm}^* \leq \tau_{2l} \\
0 & \text{if } \tau_{2l} < J_{lm}^* \leq \tau_{3l} \\
1 & \text{if } \tau_{3l} < J_{lm}^* \leq \tau_{4l} \\
2 & \text{if } \tau_{4l} < J_{lm}^* \leq +\infty 
\end{cases}$$

Continuous:

$$J_{lm}^C = \alpha_C + \lambda_C \cdot J_{lm}^* + \beta_{XL}^C \cdot X_m + \delta_C, \quad \text{with } \delta_C \sim \mathcal{N}(0, \sigma_{C})$$
Quantification model (SEM):

**Structural equation:**

\[ J_{lm}^* = c_l + \delta_\gamma, \quad \text{with } \delta_\gamma \sim \mathcal{N}(0, \sigma_\gamma) \]

**Measurement equation:**

Discrete:

\[ J_{lm}^D = \lambda_D \cdot J_{lm}^* + \beta_{xl}^D \cdot X_m + \delta_D, \quad \text{with } \delta_D \sim \text{Logistic}(0, 1) \]

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\end{cases} \]

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Quantification model (SEM):

**Structural equation:**

\[ J_{lm}^* = c_l + \delta_\gamma, \quad \text{with } \delta_\gamma \sim \mathcal{N}(0, \sigma_\gamma) \]

**Measurement equation:**

Discrete:

\[ \tilde{J}_{lm}^D = \lambda_D \cdot J_{lm}^* + \beta_D^{X_l} \cdot X_m + \delta_D, \quad \text{with } \delta_D \sim \text{Logistic}(0, 1) \]

\[ J_{lm}^D = \begin{cases} 
-2 & \text{if } -\infty < \tilde{J}_{lm}^* \leq \tau_{1l} \\
-1 & \text{if } \tau_{1l} < \tilde{J}_{lm}^* \leq \tau_{2l} \\
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\end{cases} \]

Continuous:

\[ J_{lm}^C = \alpha_C + \lambda_C \cdot J_{lm}^* + \beta_C^{X_l} \cdot X_m + \delta_C, \quad \text{with } \delta_C \sim \mathcal{N}(0, \sigma_C) \]

- Socio-economic information of the evaluator is introduced into measurement equation.
- Heterogeneity in response behavior is handled.
Estimation of the quantification model alone:

• Likelihood for an adjective $l$:

$$
\mathcal{L}_l = \prod_{m=1}^{M} \int_{J_{lm}^*} f(J_{lm}^C|J_{lm}^*, X_m; \alpha_C, \lambda_C, \beta_C, \sigma_C) f(J_{lm}^D|J_{lm}^*, X_m; \lambda_D, \beta_D, \tau_1, \tau_2, \tau_3, \tau_4) f(J_{lm}^*|c_l, \sigma_\gamma) dJ_{lm}^*
$$

• Score of adjective $l$ by individual $m$ is inferred.

$$\hat{J}_{lm}^* = c_l, \forall m$$

• The obtained scores are then introduced as measurements of the perceptual variable.
Integration of the 3 model components:

- Simultaneous estimation of the DCM and LVM of perception

- Likelihood

\[
\mathcal{L} = \prod_{n=1}^{N} \int_{X_n^*} \prod_{i=1}^{I} P(y_{in} | X_{in}, X_n^*; \beta)^{y_{in}} \cdot f(X_n^* | X_n; \mu, \sigma_\omega) \cdot \prod_{k=1}^{K} f(I_{kn}^* | X_n^*, \eta_k; \sigma_k) dX_n^*
\]
**Specification**

**Structural equation:**
\[
J_{lm}^* = c_l + \delta_{\gamma}, \quad \text{with } \delta_{\gamma} \sim \mathcal{N}(0, \sigma_{\gamma})
\]

**Measurement equations:**

**Discrete**
\[
\tilde{J}_{lm}^D = \lambda_D \cdot J_{lm}^* + \beta_{\text{Educ},l}^D \cdot \text{Educ}_m + \delta_D, \quad \text{with } \delta_D \sim \text{Logistic}(0, 1)
\]

\[
J_{lm}^D = \begin{cases} 
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\end{cases}
\]

**Continuous**
\[
J_{lm}^C = \alpha_C + \lambda_C \cdot J_{lm}^* + \beta_{\text{Educ},l}^C \cdot \text{Educ}_m + \delta_C, \quad \text{with } \delta_C \sim \mathcal{N}(0, \sigma_C)
\]

Observation from exploratory analysis:

Evaluator with higher education level give higher scores.
Model estimated for all 22 adjectives:

- Separate estimation for each adjective
- Results consistent with expectations

Example: empty

- Constants have expected signs: adjectives related to comfort have + signs.
- Results from exploratory analysis confirmed: the higher the level of education, the higher the scores in absolute value.

<table>
<thead>
<tr>
<th>Name</th>
<th>Value</th>
<th>t-test</th>
</tr>
</thead>
<tbody>
<tr>
<td>$c_{\text{empty}}$</td>
<td>0.348</td>
<td>29.52</td>
</tr>
<tr>
<td>$\beta_{\text{Educ}, \text{empty}}^C$</td>
<td>0.245</td>
<td>24.29</td>
</tr>
<tr>
<td>$\beta_{\text{Educ}, \text{empty}}^D$</td>
<td>0.372</td>
<td>2.08</td>
</tr>
<tr>
<td>$\sigma_{\text{empty}}^C$</td>
<td>-2.74</td>
<td>-29.32</td>
</tr>
<tr>
<td>$\tau_{1, \text{empty}}$</td>
<td>-2.72</td>
<td>-7.3</td>
</tr>
<tr>
<td>$\delta_{1, \text{empty}}$</td>
<td>1.23</td>
<td>3.99</td>
</tr>
<tr>
<td>$\delta_{2, \text{empty}}$</td>
<td>1.16</td>
<td>5.49</td>
</tr>
<tr>
<td>$\delta_{3, \text{empty}}$</td>
<td>2.85</td>
<td>10.21</td>
</tr>
</tbody>
</table>

Loglikelihood: -373
APPLICATION EXAMPLE

Model estimated for all 22 adjectives:

- Separate estimation for each adjective
- Results consistent with expectations

Example: packed

<table>
<thead>
<tr>
<th>Name</th>
<th>Value</th>
<th>t-test</th>
</tr>
</thead>
<tbody>
<tr>
<td>$c_{\text{packed}}$</td>
<td>-0.547</td>
<td>-25.46</td>
</tr>
<tr>
<td>$\beta_{C, \text{Educ, packed}}$</td>
<td>-0.237</td>
<td>-18.34</td>
</tr>
<tr>
<td>$\beta_{D, \text{Educ, packed}}$</td>
<td>-0.447</td>
<td>-2.54</td>
</tr>
<tr>
<td>$\sigma_{C, \text{packed}}$</td>
<td>-2.62</td>
<td>-24.2</td>
</tr>
<tr>
<td>$\tau_{1, \text{packed}}$</td>
<td>-1.43</td>
<td>-6.36</td>
</tr>
<tr>
<td>$\delta_{1, \text{packed}}$</td>
<td>1.23</td>
<td>6.64</td>
</tr>
<tr>
<td>$\delta_{2, \text{packed}}$</td>
<td>1.68</td>
<td>6.77</td>
</tr>
<tr>
<td>$\delta_{3, \text{packed}}$</td>
<td>1.93</td>
<td>3.99</td>
</tr>
</tbody>
</table>

Loglikelihood: -380

- Constants have expected signs: adjectives related to discomfort have - signs.
- Results from exploratory analysis confirmed: the higher the level of education, the higher the scores in absolute value.
Estimation results for the DCM and LVM of perception

### Discrete choice model

<table>
<thead>
<tr>
<th>Name</th>
<th>Value</th>
<th>t-test</th>
</tr>
</thead>
<tbody>
<tr>
<td>ASC(_{PT})</td>
<td>-0.161</td>
<td>-0.8</td>
</tr>
<tr>
<td>ASC(_{PMM})</td>
<td>0.42</td>
<td>2.28</td>
</tr>
<tr>
<td>(\beta_{\text{Cost}})</td>
<td>-0.0653</td>
<td>-8.1</td>
</tr>
<tr>
<td>(\beta_{\text{TimePT}})</td>
<td>-0.0208</td>
<td>-7.15</td>
</tr>
<tr>
<td>(\beta_{\text{TimeCar}})</td>
<td>-0.0323</td>
<td>-9.45</td>
</tr>
<tr>
<td>(\beta_{\text{Distance}})</td>
<td>-0.235</td>
<td>-11.44</td>
</tr>
<tr>
<td>(\beta_{\text{Work, PT}})</td>
<td>-0.0441</td>
<td>-0.19</td>
</tr>
<tr>
<td>(\beta_{\text{Work, PMM}})</td>
<td>-0.575</td>
<td>-2.6</td>
</tr>
<tr>
<td>(\beta_{\text{Language, PT}})</td>
<td>-0.0507</td>
<td>-0.17</td>
</tr>
<tr>
<td>(\beta_{\text{Language, PMM}})</td>
<td>0.964</td>
<td>3.55</td>
</tr>
<tr>
<td>(\beta_{\text{PerceptionComfortPT}})</td>
<td>1.32</td>
<td>4.4</td>
</tr>
</tbody>
</table>

### Latent variable model of perception (structural equation)

<table>
<thead>
<tr>
<th>Name</th>
<th>Value</th>
<th>t-test</th>
</tr>
</thead>
<tbody>
<tr>
<td>(b_{\text{meanImageComfortPT}})</td>
<td>7.59</td>
<td>10.41</td>
</tr>
<tr>
<td>(b_{\text{regionLanguage}})</td>
<td>-0.726</td>
<td>-2.51</td>
</tr>
<tr>
<td>(b_{\text{age&lt;50}})</td>
<td>-1.15</td>
<td>-5.06</td>
</tr>
<tr>
<td>(b_{\text{actif}})</td>
<td>-1.15</td>
<td>-4.72</td>
</tr>
<tr>
<td>(b_{\text{voiture}})</td>
<td>-0.727</td>
<td>-3.2</td>
</tr>
</tbody>
</table>

Loglikelihood of the HCM: - 4355
Estimation results for the DCM and LVM of perception

**Discrete choice model**

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<tr>
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<tbody>
<tr>
<td>ASC&lt;sub&gt;PT&lt;/sub&gt;</td>
<td>-0.161</td>
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<tr>
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<tr>
<td>β&lt;sub&gt;Cost&lt;/sub&gt;</td>
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<td>-8.1</td>
</tr>
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<td>β&lt;sub&gt;TimePT&lt;/sub&gt;</td>
<td>-0.0208</td>
<td>-7.15</td>
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<tr>
<td>β&lt;sub&gt;TimeCar&lt;/sub&gt;</td>
<td>-0.0323</td>
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<td>-11.44</td>
</tr>
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<td>-0.19</td>
</tr>
<tr>
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<td>-0.17</td>
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<tr>
<td>β&lt;sub&gt;PerceptionComfortPT&lt;/sub&gt;</td>
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<td>4.4</td>
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**Latent variable model of perception (structural equation)**

<table>
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<th>Name</th>
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Loglikelihood of the HCM: -4355

For individuals with a better perception of comfort in PT, the impact of an increase in travel time is less strong.
APPLICATION EXAMPLE

VALIDATION OF THE INTEGRATED MODEL

Model estimation on 80% data and application on 20% data.

Choice probabilities generally well predicted.
Main findings:

• *Alternative approach* to measure perceptions

• *Main advantage* over classical opinion statements: *spontaneity* of respondents captured.

• Difficulty: code and integrate these measurements in choice model.

The proposed *model*:

1. Quantifies adjectives
2. *Accounts for subjectivity* inherent to quantification method:
   • Uses a fairly large sample of evaluators
   • Account for bias linked to different education levels

• Importance of including individual-level information in measurement component of an LVM in HCM.
CONCLUSION

Next steps:

- Further validation: comparison of the prediction power of the presented HCM with HCMs including ratings of individual evaluators.
- Estimate the quantification model parts relative to each adjective simultaneously.
Thanks!