AN ENHANCED MEASUREMENT MODEL OF PERCEPTION OF COMFORT IN PUBLIC TRANSPORTATION

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OUTLINE

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

INTRODUCTION & MOTIVATION

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)

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INTRODUCTION & MOTIVATION

Hybrid choice model (HCM): DCM with latent constructs.

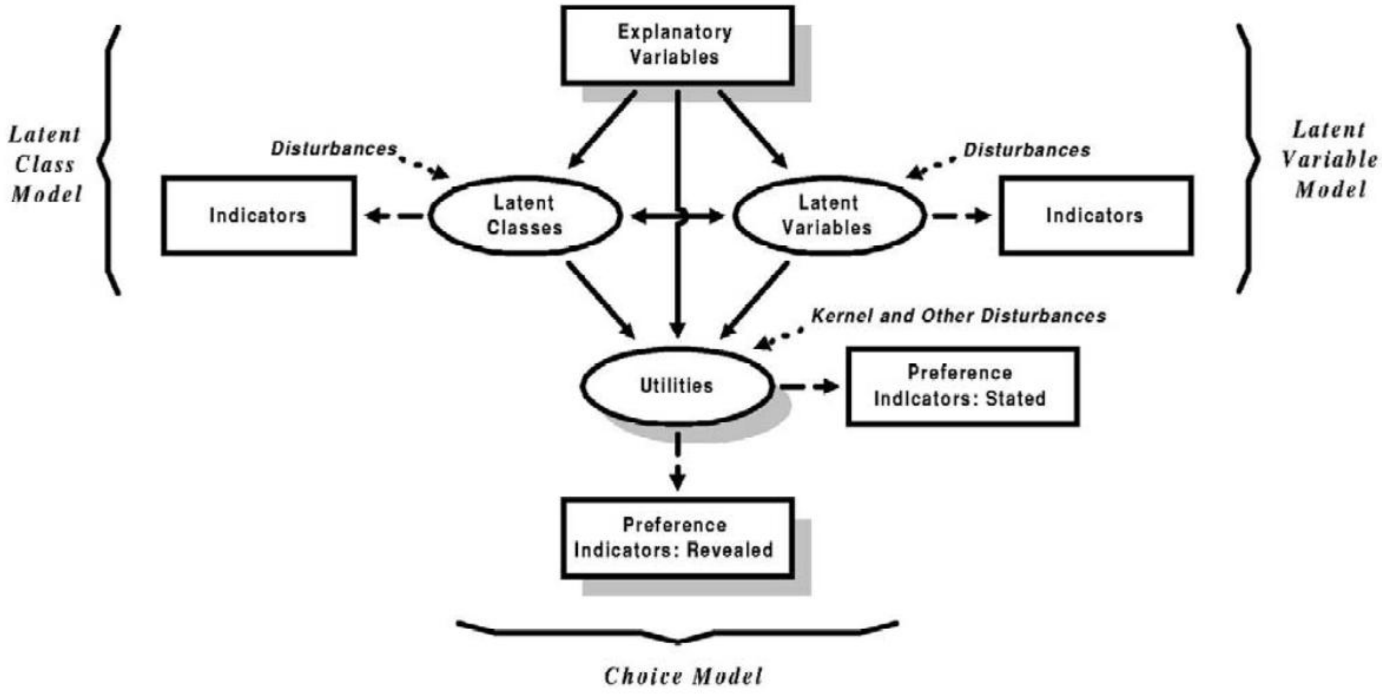

Figure extracted from Walker and Ben-Akiva, 2002.

INTRODUCTION & MOTIVATION

Hybrid choice model (HCM): DCM with latent constructs.

In this research: focus on the **integration of choice model and latent variable model**

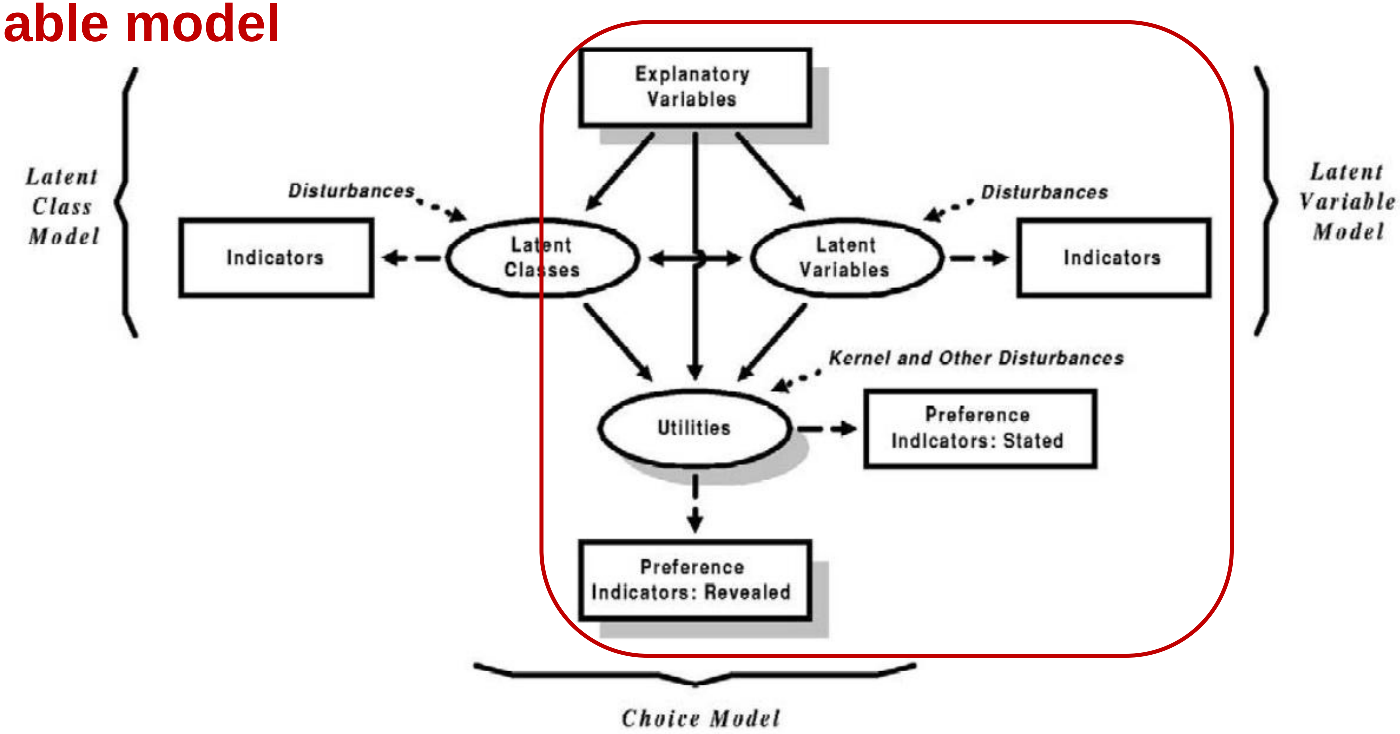

Figure extracted from Walker and Ben-Akiva, 2002.

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INTRODUCTION & MOTIVATION

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?

INTRODUCTION & MOTIVATION

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)

INTRODUCTION & MOTIVATION

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

INTRODUCTION & MOTIVATION

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

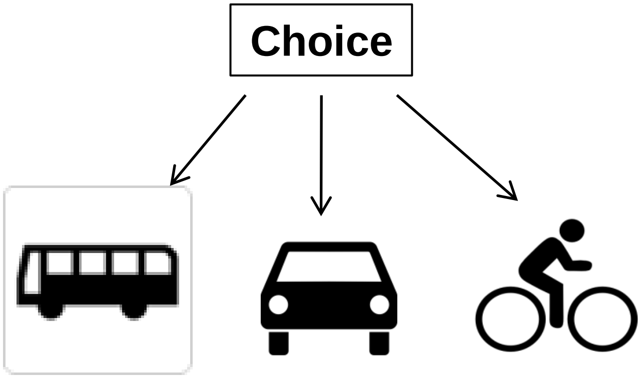
THE DATA

Two surveys:

- Revealed preferences (RP) survey
- Survey with evaluators (adjective quantification survey)

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



THE DATA

RP SURVEY

Adjective data for perception of transport modes:

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

		Adjective 1	Adjective 2	Adjective 3
1	The car is:			
2	The train is:			
3	The bus, the metro and the tram are:			
4	The post bus is:			
5	The bicycle is:			
6	The walk is:			

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THE DATA

RP SURVEY

Adjective data for perception of transport modes:

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

		Adjective 1	Adjective 2	Adjective 3
1	The car is:	**convenient**	**comfortable**	**expensive**
2	The train is:	**relaxing**	**punctual**	**restful**
3	The bus, the metro and the tram are:	**fast**	**frequent**	**cheap**
4	The post bus is:	**punctual**	**comfortable**	**cheap**
5	The bicycle is:	**stimulating**	**convenient**	**cheap**
6	The walk is:	**healthy**	**relaxing**	**independent**

THE DATA

RP SURVEY

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)

Comfort
hardly full
packed
bumpy
comfortable
hard
irritating
tiring
unsuitable with bags
uncomfortable
bad air
…

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THE DATA

RP SURVEY

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⇨ **LATENT VARIABLE WE STUDY**

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…

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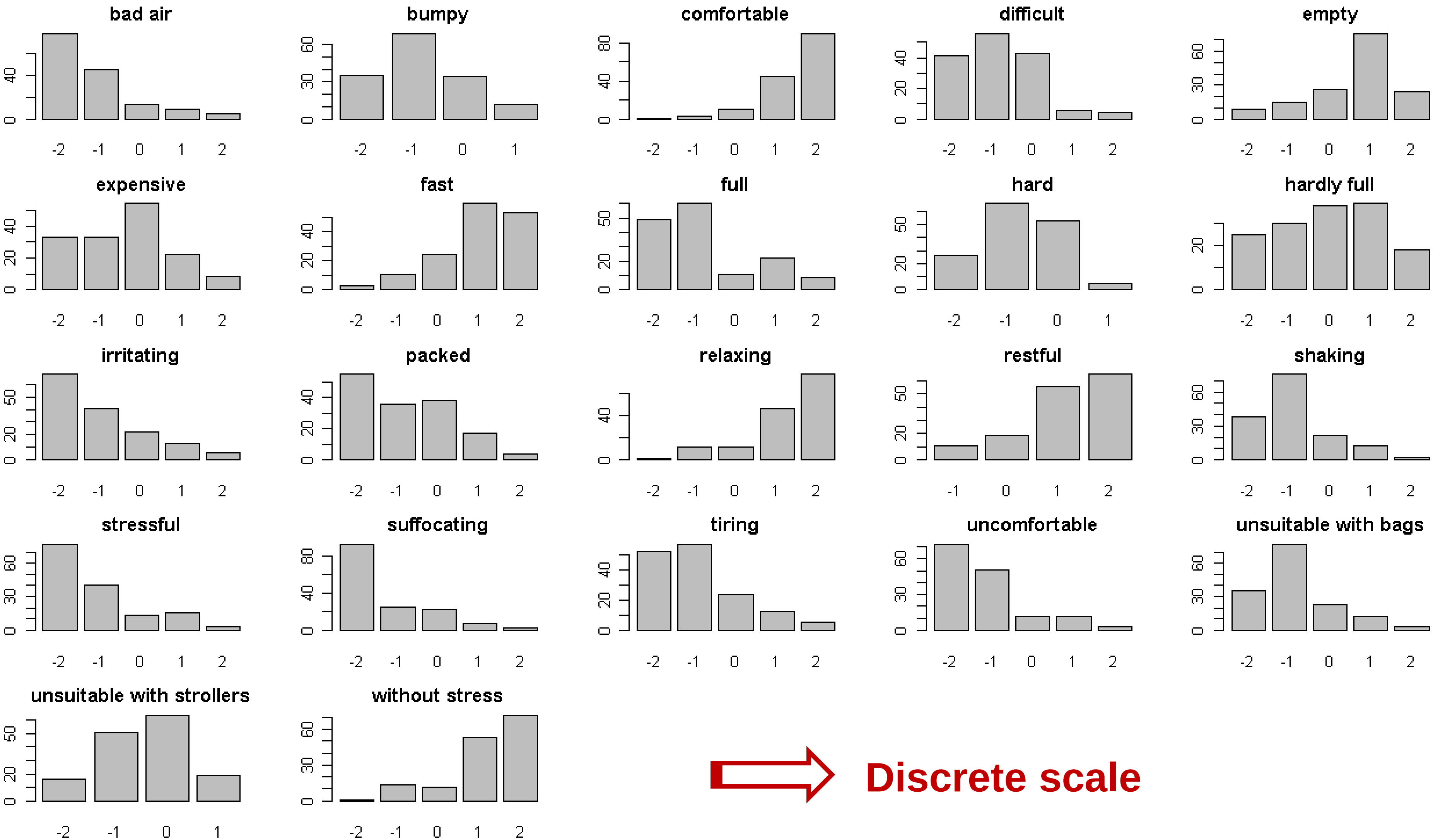
Adjective quantification survey

- 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

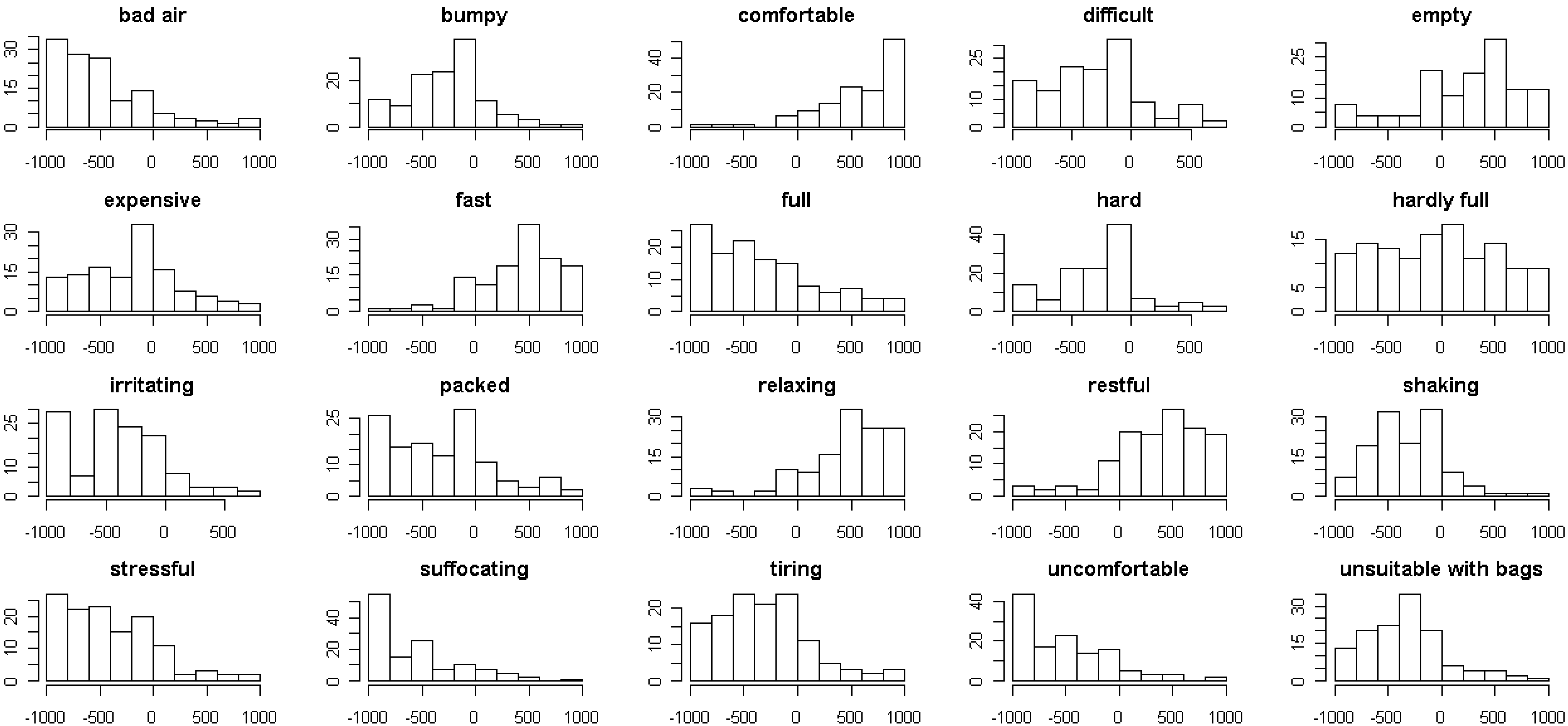
ADJECTIVE QUANTIFICATION SURVEY

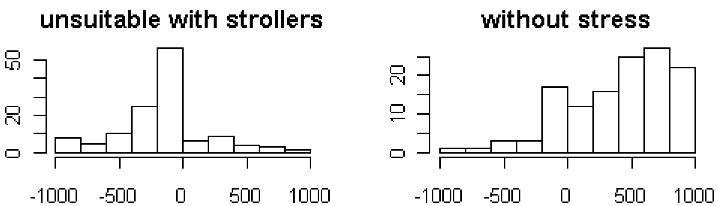


Discrete scale

THE DATA

ADJECTIVE QUANTIFICATION SURVEY





⇒ **Continuous scale**

THE INTEGRATED MODEL FRAMEWORK

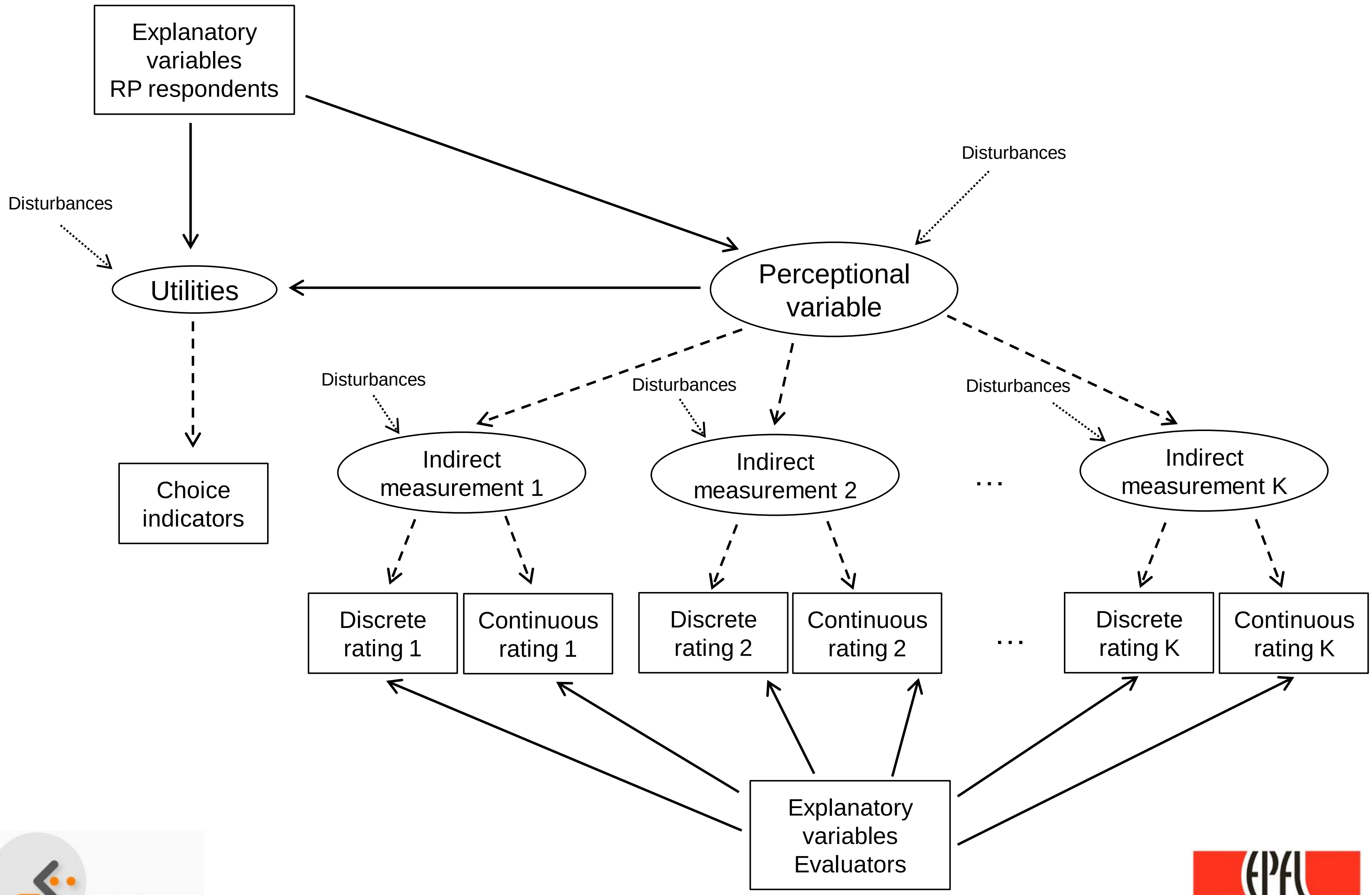
Purpose of the developed HCM:

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

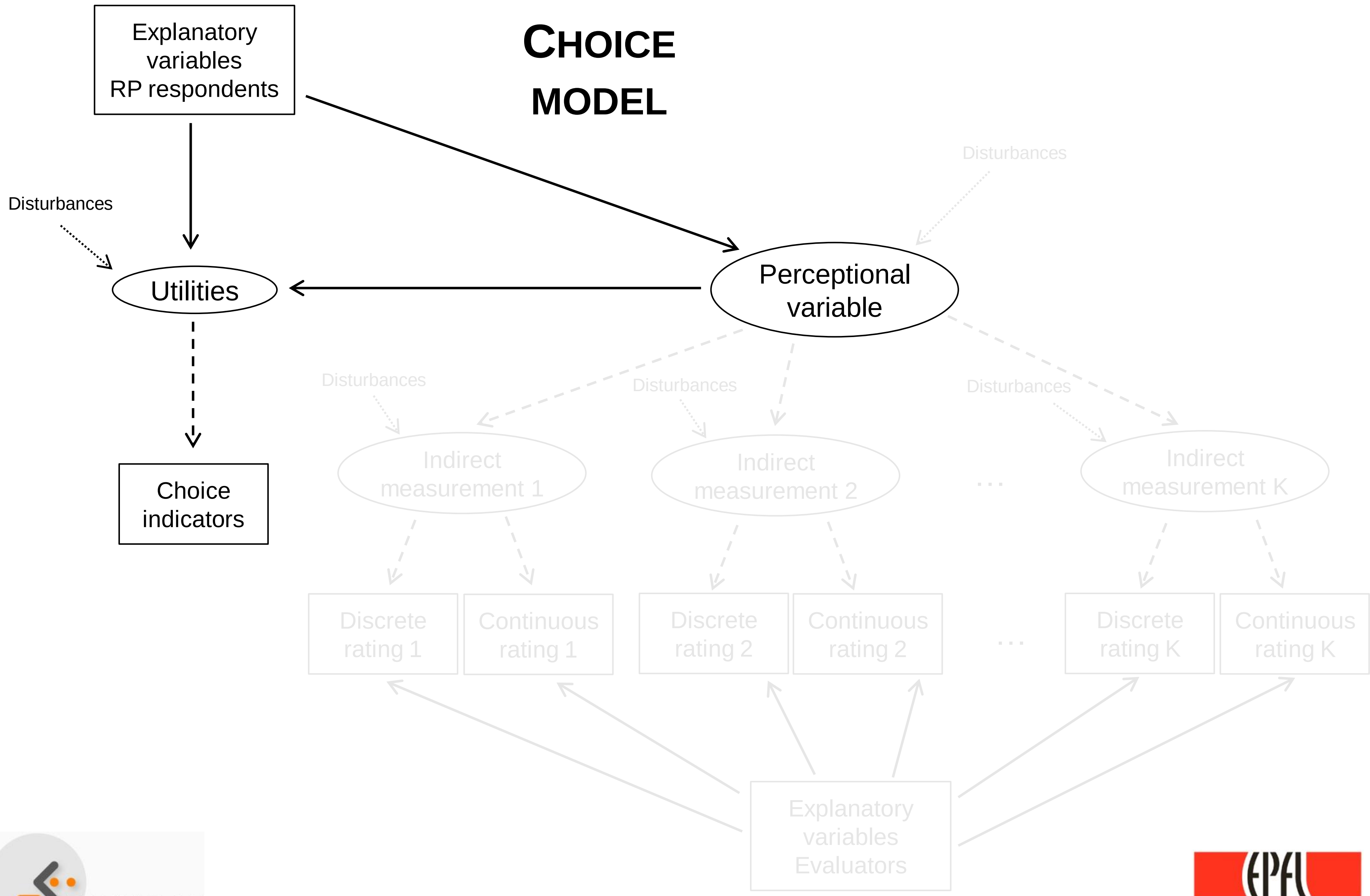
Framework involves three components:

- Discrete choice model
- Latent variable model for the perception
- Quantification model for the indicators of the latent variable

THE INTEGRATED MODEL FRAMEWORK



THE INTEGRATED MODEL FRAMEWORK



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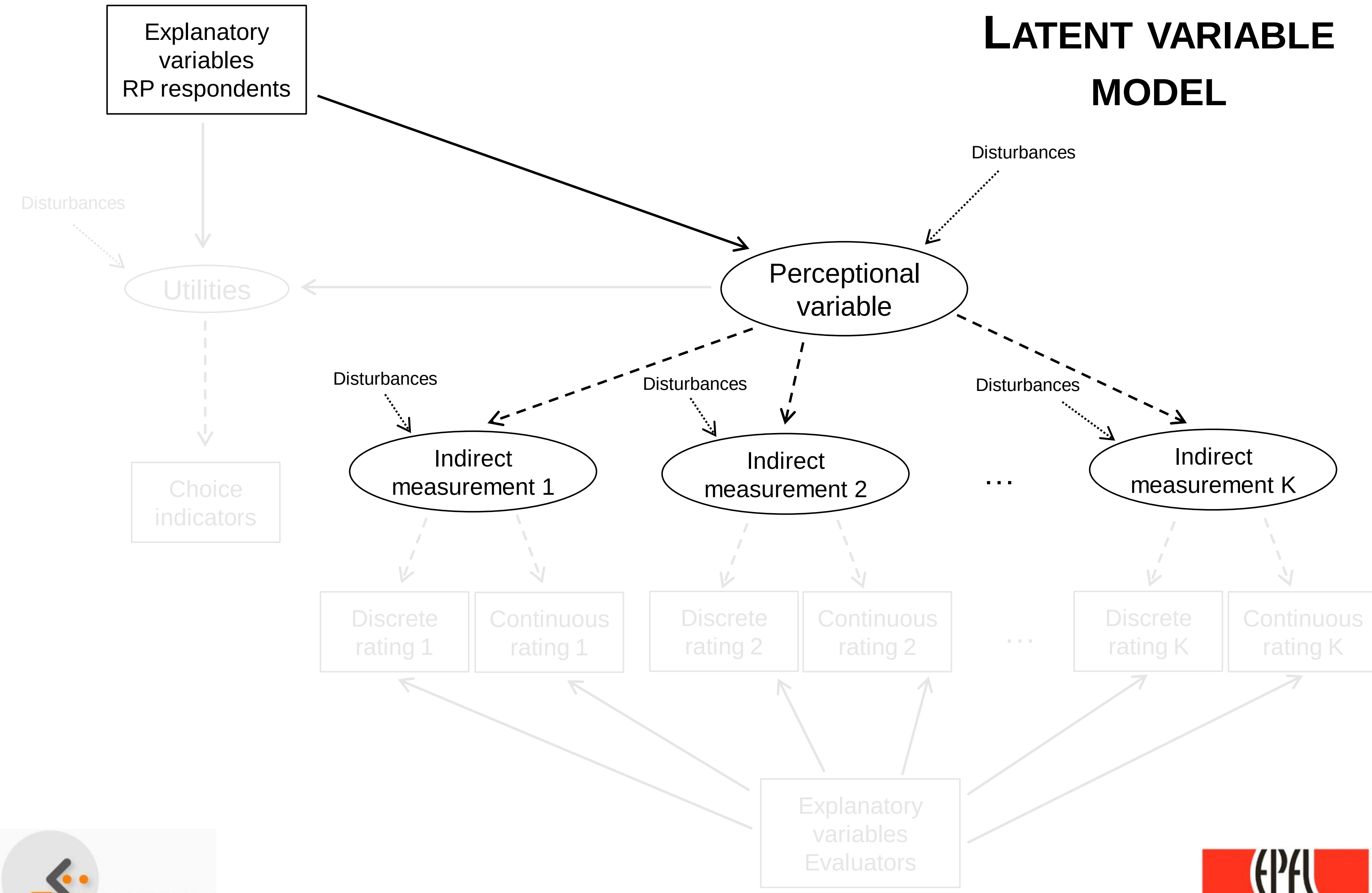
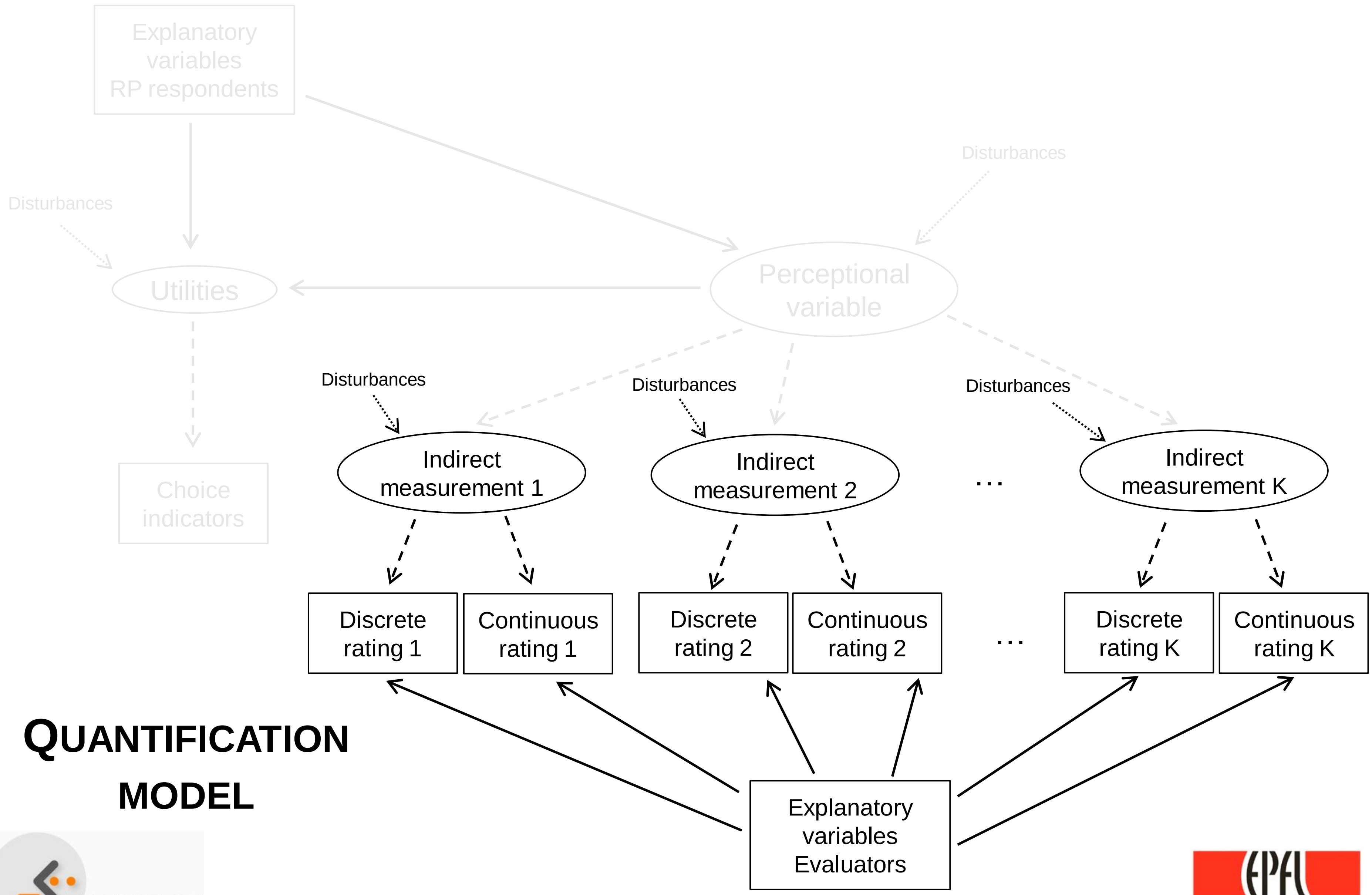
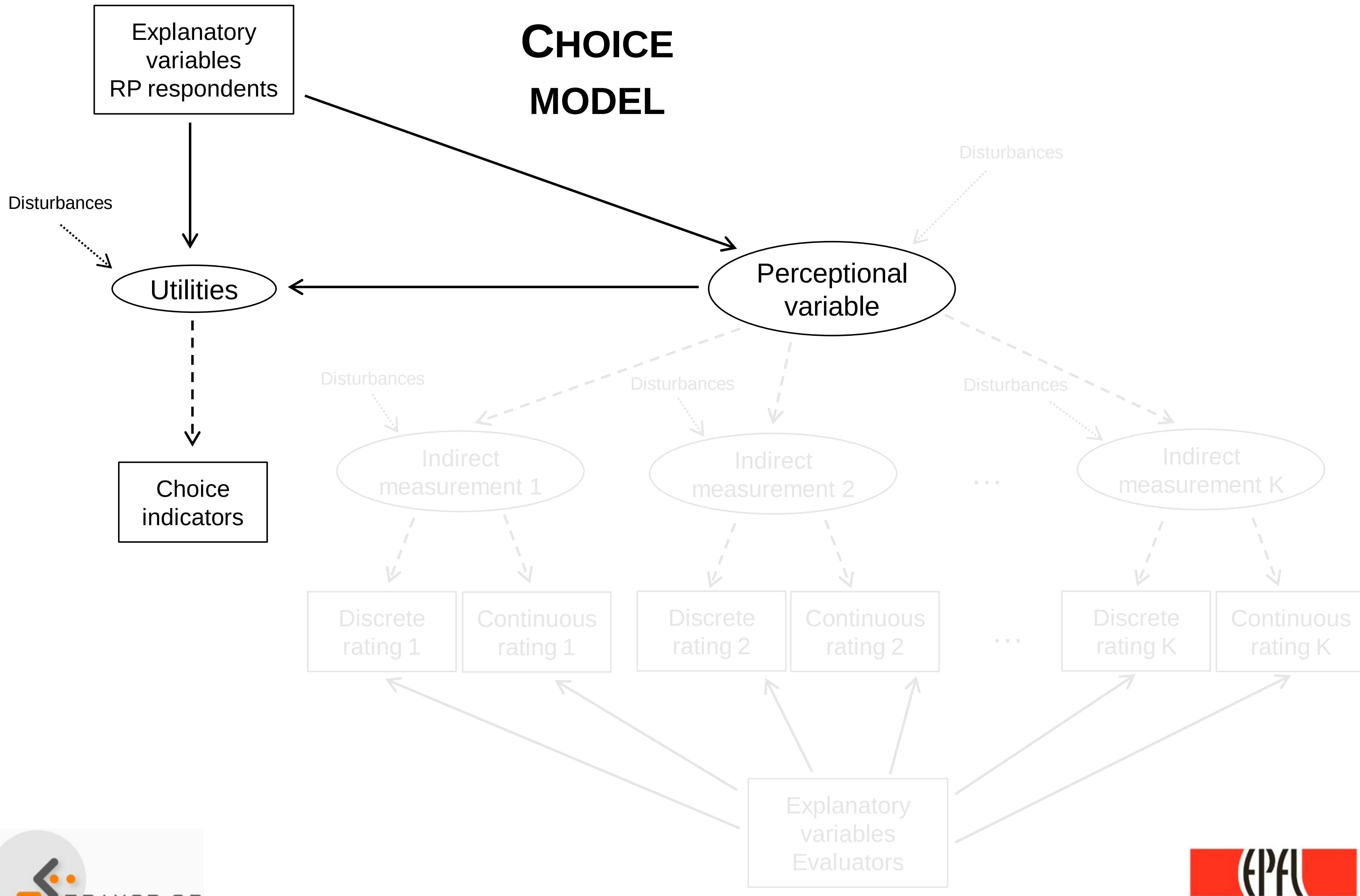


THE INTEGRATED MODEL FRAMEWORK



QUANTIFICATION MODEL

THE INTEGRATED MODEL FRAMEWORK



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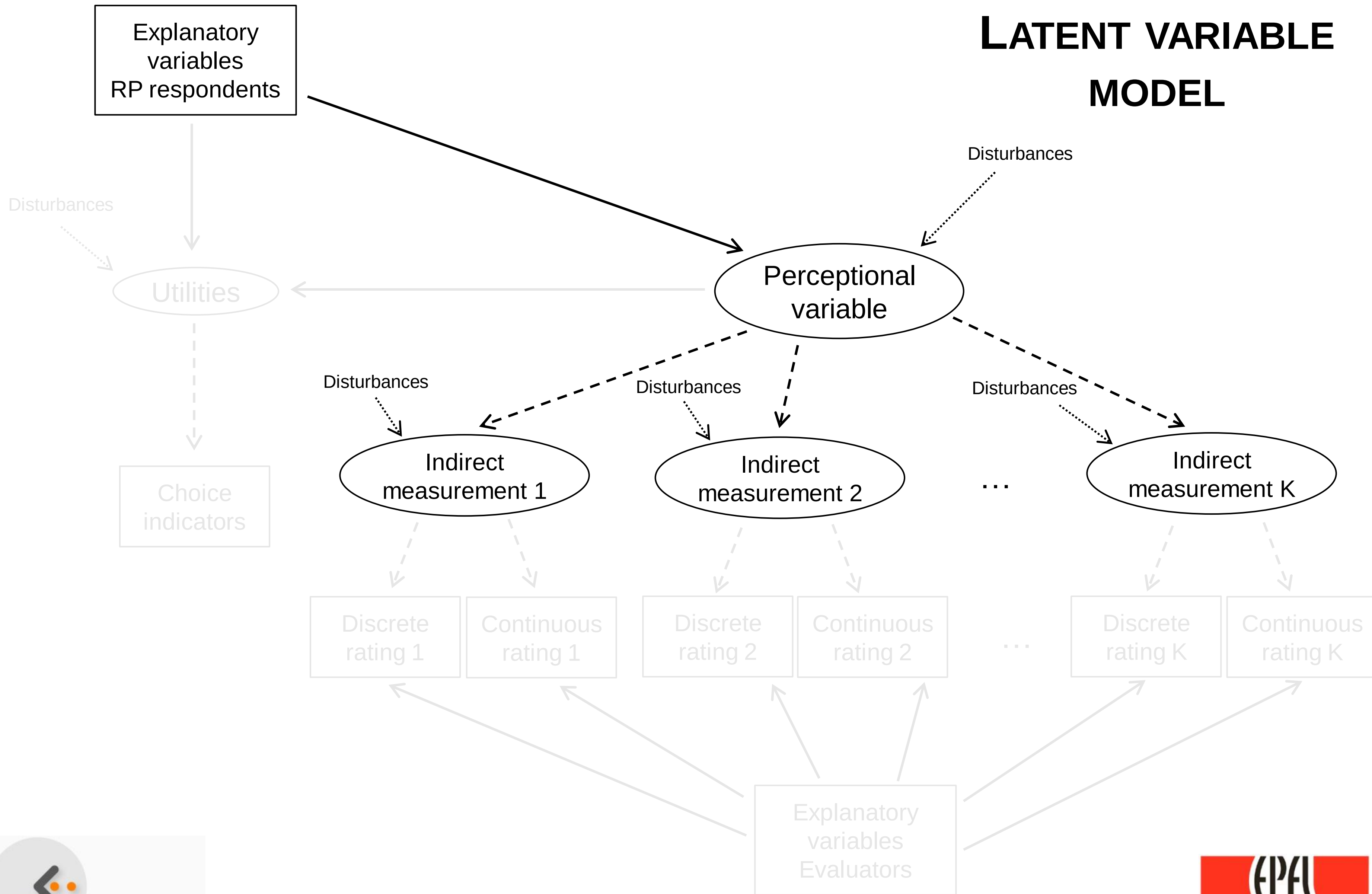
Discrete choice model is standard:

$$U_{in} = V(X_{in}, X_n^*; \beta) + \varepsilon_{in} \qquad \text{with } \varepsilon_{in} \sim EV(0,1)$$

THE INTEGRATED MODEL FRAMEWORK

LATENT VARIABLE MODEL



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THE INTEGRATED MODEL FRAMEWORK

Latent variable model of perception (SEM):

Structural equation:

$$X_n^* = h(X_n; \mu) + \omega_n, \qquad \text{with } \omega_n \sim \mathcal{N}(0, \sigma_\omega)$$

Measurement equation:

$$I_{kn}^* = r_k(X_n^*; \eta_k) + \upsilon_{kn}, \qquad \text{with } \upsilon_{kn} \sim \mathcal{N}(0, \sigma_k)$$

THE INTEGRATED MODEL FRAMEWORK

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Measurement equation:

$$\boxed{I_{kn}^*} = r_k(X_n^*; \eta_k) + \upsilon_{kn}, \qquad \text{with } \upsilon_{kn} \sim \mathcal{N}(0, \sigma_k)$$

Unobservable score of indicator *k* for individual *n* ⇒ **Indirect measurement** of perception X_n^*, which is treated as a latent variable

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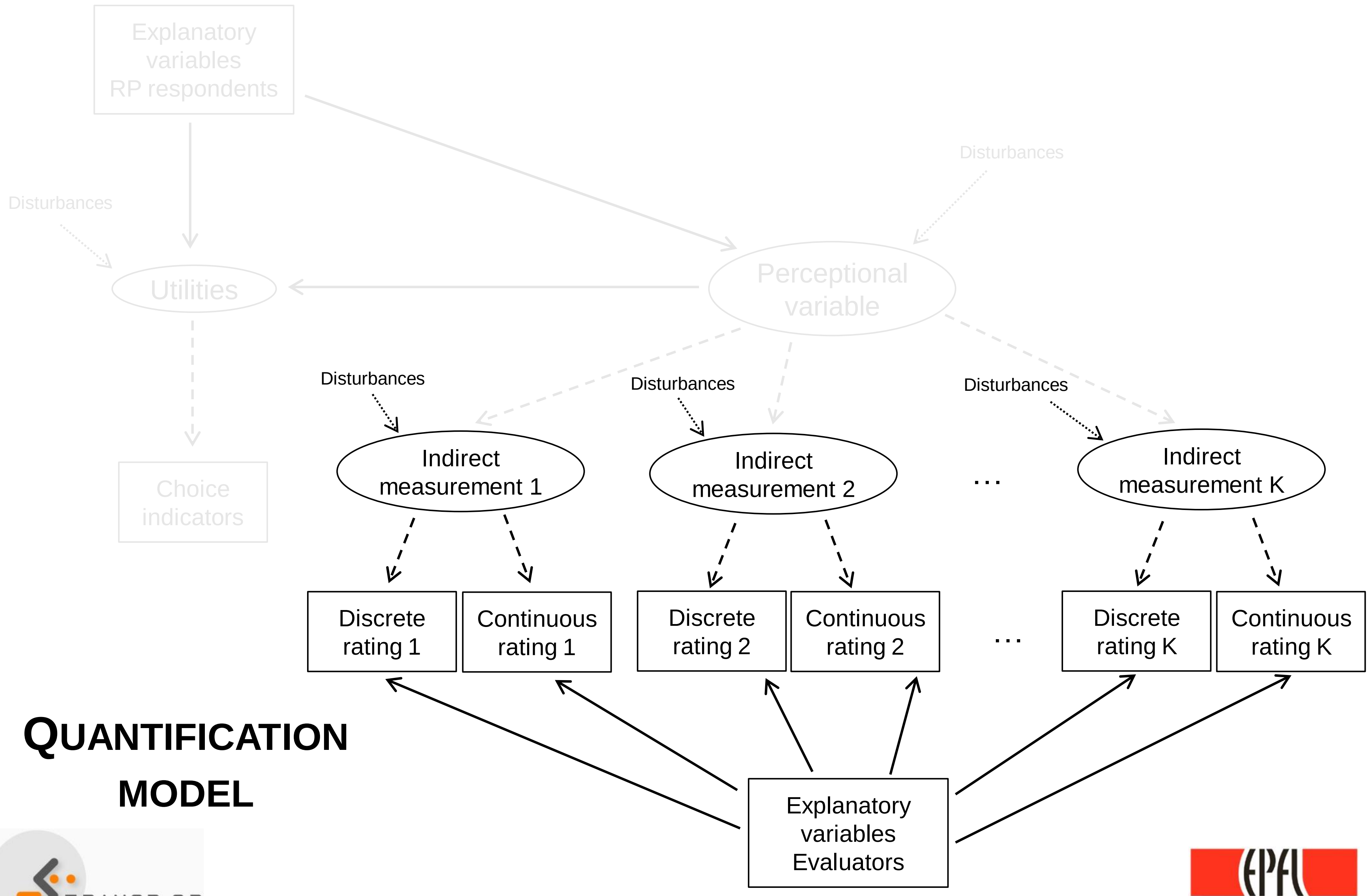
THE INTEGRATED MODEL FRAMEWORK



QUANTIFICATION MODEL

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THE INTEGRATED MODEL FRAMEWORK

Quantification model (SEM):

Structural equation:

Score of adjective *l* by individual *m*

$$\boxed{J^*_{lm}} = c_l + \delta_\gamma, \qquad \text{with } \delta_\gamma \sim \mathcal{N}(0, \sigma_\gamma)$$

Measurement equation:

Discrete:

$$\tilde{J}^D_{lm} = \lambda_D \cdot J^*_{lm} + \beta^D_{Xl} \cdot X_m + \delta_D, \text{ with } \delta_D \sim \text{Logistic}(0,1)$$

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

Continuous:

$$J^C_{lm} = \alpha_C + \lambda_C \cdot J^*_{lm} + \beta^C_{Xl} \cdot X_m + \delta_C, \text{ with } \delta_C \sim \mathcal{N}(0, \sigma_C)$$

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Quantification model (SEM):

Structural equation:

Adjective-specific constant to be estimated

$$J^*_{lm} = \boxed{c_l} + \delta_\gamma, \qquad \text{with } \delta_\gamma \sim \mathcal{N}(0, \sigma_\gamma)$$

Measurement equation:

Discrete:

$$\tilde{J}^D_{lm} = \lambda_D \cdot J^*_{lm} + \beta^D_{Xl} \cdot X_m + \delta_D, \text{ with } \delta_D \sim \text{Logistic}(0,1)$$

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Quantification model (SEM):

Structural equation:

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Measurement equation:

Discrete:

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- Socio-economic information of the evaluator is introduced into measurement equation.
- Heterogeneity in response behavior is handled.

THE INTEGRATED MODEL FRAMEWORK

QUANTIFICATION MODEL

Estimation of the quantification model alone:

- Likelihood for an adjective *l*:

$$\mathcal{L}_l = \prod_{m=1}^{M} \int_{J^*_{lm}} f(J^C_{lm} | J^*_{lm}, X_m; \alpha_C, \lambda_C, \beta^C_X, \sigma_C) f(J^D_{lm} | J^*_{lm}, X_m; \lambda_D, \beta^D_X, \tau_1, \tau_2, \tau_3, \tau_4) f(J^*_{lm} | c_l, \sigma_\gamma) dJ^*_{lm}$$

- Score of adjective *l* by individual *m* is inferred.

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

- The obtained scores are then introduced as measurements of the perceptional variable.

THE INTEGRATED MODEL FRAMEWORK

Integration of the 3 model components:

- Simultaneous estimation of the DCM and LVM of perception

- Likelihood

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

APPLICATION EXAMPLE

Specification

Structural equation:

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

Measurement equations:

Discrete $$\tilde{J}^D_{lm} = \lambda_D \cdot J^*_{lm} + \boxed{\beta^D_{\text{Educ},l} \cdot \text{Educ}_m} + \delta_D, \text{ with } \delta_D \sim \text{Logistic}(0, 1)$$

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

Observation from exploratory analysis:

Evaluators with higher education level give higher scores.

Continuous $$J^C_{lm} = \alpha_C + \lambda_C \cdot J^*_{lm} + \boxed{\beta^C_{\text{Educ},l} \cdot \text{Educ}_m} + \delta_C, \text{ with } \delta_C \sim \mathcal{N}(0, \sigma_C)$$

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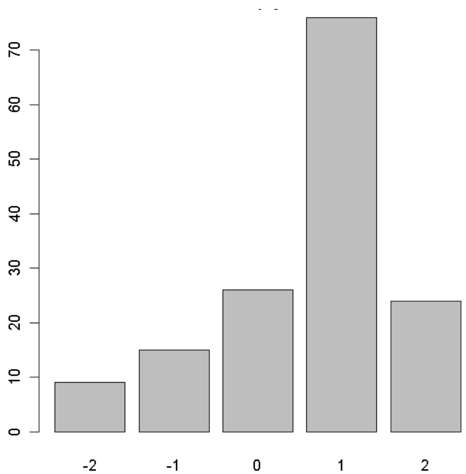
APPLICATION EXAMPLE

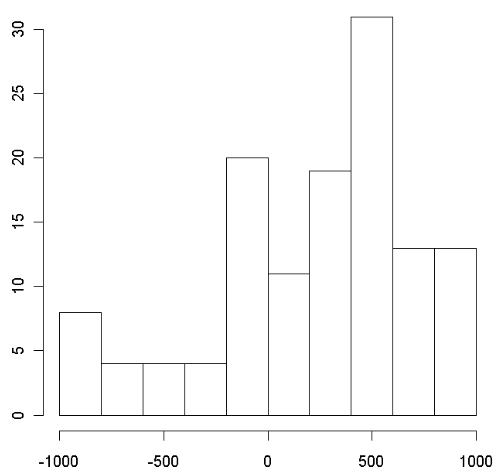
QUANTIFICATION MODEL

Model estimated for all 22 adjectives:

- Separate estimation for each adjective
- Results consistent with expectations

Example: empty





Name	Value	*t*-test
c_{empty}	0.348	29.52
$\beta^{C}_{\text{Educ, empty}}$	0.245	24.29
$\beta^{D}_{\text{Educ, empty}}$	0.372	2.08
$\sigma^{C}_{\text{empty}}$	-2.74	-29.32
$\tau_{1,\text{ empty}}$	-2.72	-7.3
$\delta_{1,\text{ empty}}$	1.23	3.99
$\delta_{2,\text{ empty}}$	1.16	5.49
$\delta_{3,\text{ empty}}$	2.85	10.21

Loglikelihood: - 373

- 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.

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APPLICATION EXAMPLE

QUANTIFICATION MODEL

Model estimated for all 22 adjectives:

- Separate estimation for each adjective
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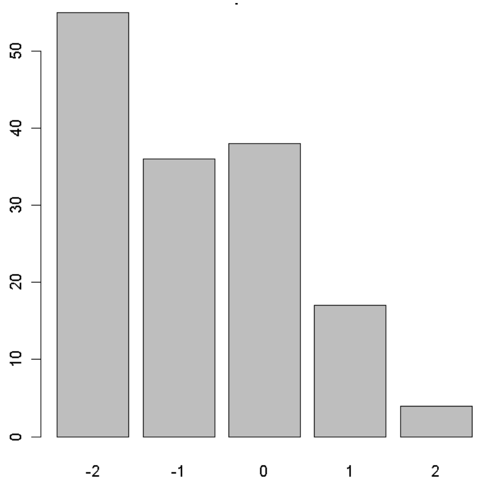
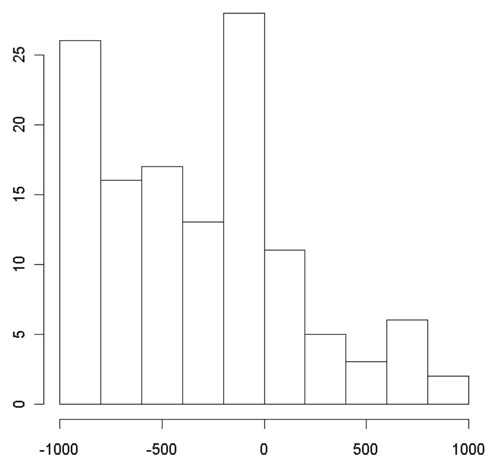
Example: packed





Name	Value	*t*-test
c_{packed}	-0.547	-25.46
$\beta^{C}_{\text{Educ, packed}}$	-0.237	-18.34
$\beta^{D}_{\text{Educ, packed}}$	-0.447	-2.54
$\sigma^{C}_{\text{packed}}$	-2.62	-24.2
$\tau_{1,\text{ packed}}$	-1.43	-6.36
$\delta_{1,\text{ packed}}$	1.23	6.64
$\delta_{2,\text{ packed}}$	1.68	6.77
$\delta_{3,\text{ packed}}$	1.93	3.99

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.

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APPLICATION EXAMPLE

INTEGRATED MODEL

Estimation results for the DCM and LVM of perception

Discrete choice model

Name	Value	*t*-test
ASC_{PT}	-0.161	-0.8
ASC_{PMM}	0.42	2.28
β_{Cost}	-0.0653	-8.1
β_{TimePT}	-0.0208	-7.15
$\beta_{TimeCar}$	-0.0323	-9.45
$\beta_{Distance}$	-0.235	-11.44
$\beta_{Work, PT}$	-0.0441	-0.19
$\beta_{Work, PMM}$	-0.575	-2.6
$\beta_{Language, PT}$	-0.0507	-0.17
$\beta_{Language, PMM}$	0.964	3.55
$\beta_{PerceptionComfortPT}$	1.32	4.4

Latent variable model of perception (structural equation)

Name	Value	*t*-test
$b_{meanImageConfortTP}$	7.59	10.41
$b_{regionLanguage}$	-0.726	-2.51
$b_{age<50}$	-1.15	-5.06
b_{actif}	-1.15	-4.72
$b_{voiture}$	-0.727	-3.2

Loglikelihood of the HCM: - 4355

APPLICATION EXAMPLE

Estimation results for the DCM and LVM of perception

Discrete choice model

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ASC_{PT}	-0.161	-0.8
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$\beta_{Language, PT}$	-0.0507	-0.17
$\beta_{Language, PMM}$	0.964	3.55
$\beta_{PerceptionComfortPT}$	1.32	4.4

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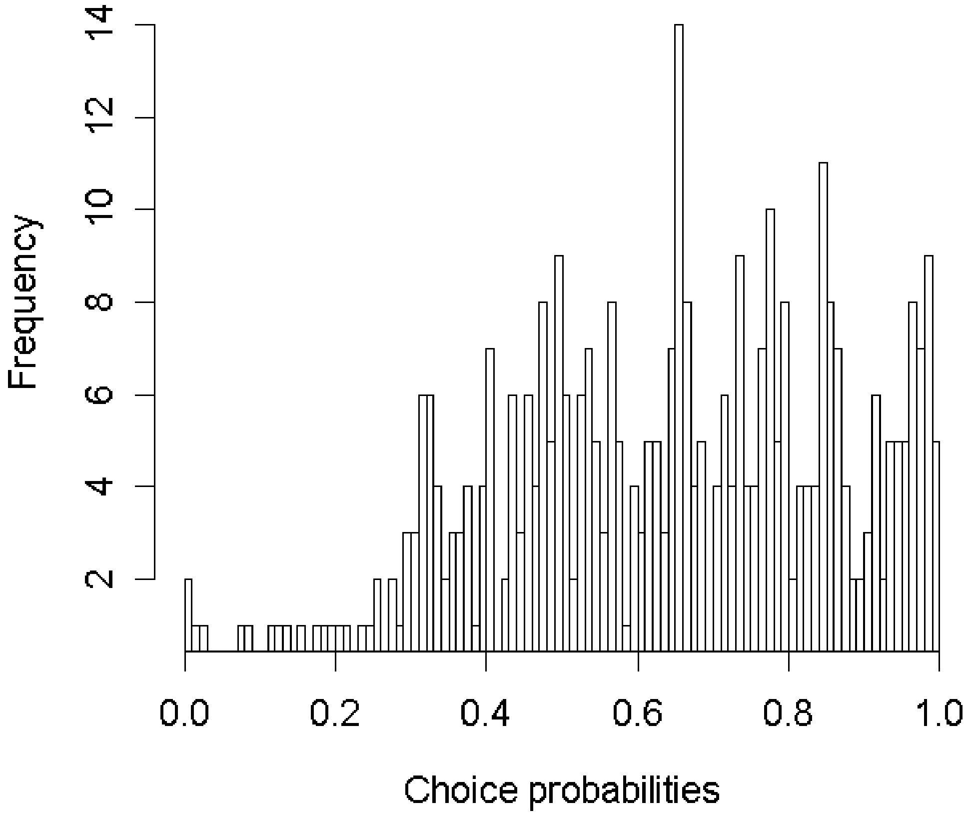
Loglikelihood of the HCM: - 4355

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.

CONCLUSION

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.

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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!