INTEGRATING LATENT CONCEPTS IN DEMAND MODELS

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Outline

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  - Case study 2: vehicle choice including electric cars
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Introduction & motivation

Context of research: recent progresses in DCM

- Focus on attitudes and perceptions
- Taken into account to model choice behavior

Motivation:

- Choice cannot only be explained by economic indicators (time, price, etc.)
- Important role of attitudes and perceptions in choice behavior

Introduction & motivation

Research questions:

- How to **measure** in most accurate way **attitudes** and **perceptions**?
- How to **integrate** this information into a **discrete choice model**?
- How does this information **impact on forecasting** and helps **predicting demand**?

Introduction & motivation

Issue: latent aspects must be measured from real data

Recently: data from survey with advanced designs developed by social scientists

Current drawback: data not necessarily designed for choice models

Introduction & motivation

DCM with latent constructs capturing attitudes and perceptions:
Hybrid choice model (HCM) (Walker, 2001; Ben-Akiva et al., 2002)

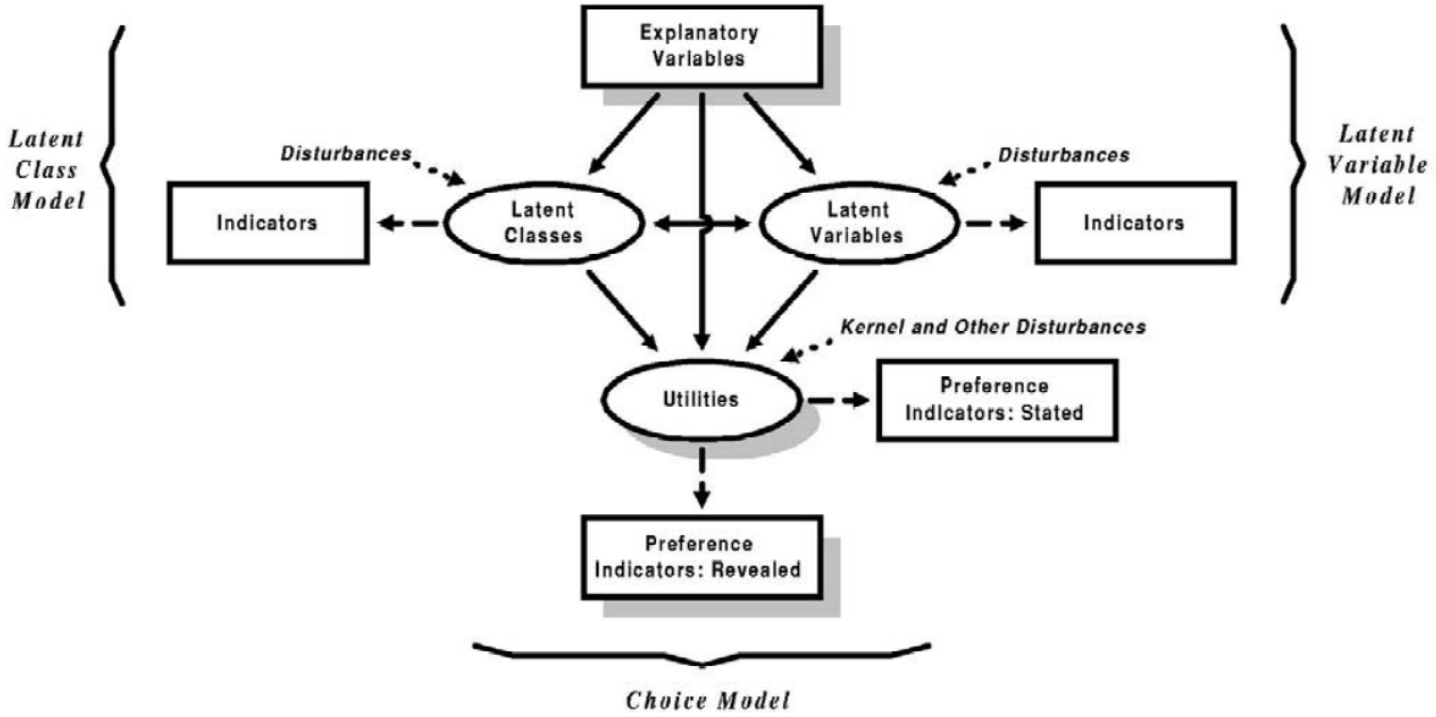


Figure from Walker and Ben-Akiva, 2002.

Data collection

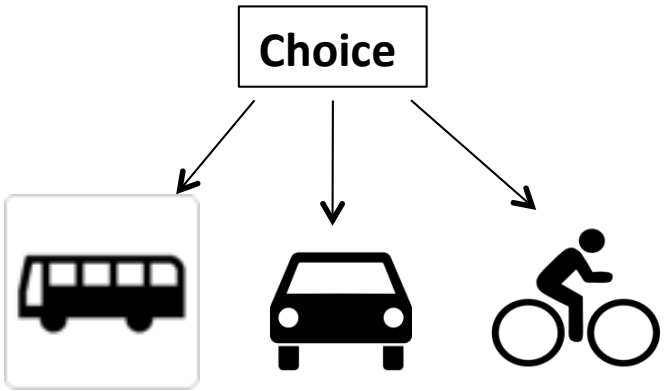
Recent work on two case studies:

Case study 1: mode choice study in low-density areas

Case study 2: vehicle choice including electric vehicles

Data collection

Case study 1: mode choice study in low-density areas of Switzerland



Data collection: mode choice case study

Large-scale survey:

- **Qualitative survey:**
  - Interviews of inhabitants of suburban or rural areas
  - GPS recordings of their trips
  - Trip diaries

- **Quantitative survey:**
  - **Revealed preference (RP) survey** designed on basis of answers to qualitative survey

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Data collection: mode choice case study

RP survey:

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

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

- **57 towns/villages** connected by post busses
- → representative of whole network of PostBus

- Respondents of **16 years and over**

- **1763 valid questionnaires** collected

Data collection: mode choice case study

Structure of RP survey:

- Description of all trips performed in one day
- Mobility habits
- Opinions
- Perception of transport modes
- Personal data & household description

Data collection: mode choice case study

Structure of RP survey:

- Description of all trips performed in one day
- Mobility habits
- Opinions
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- Mode used
- Activity at destination
- Trip duration
- Cost of fuel / public transport ticket

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Data collection: mode choice case study

Structure of RP survey:

- Description of all trips performed in one day
- Mobility habits
- Opinions
- Perception of transport modes
- Personal data & household description

- Transport modes used for particular trips (work, shopping, etc.)
- Transport modes used during childhood

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Data collection: mode choice case study

Structure of RP survey:

- Description of all trips performed in one day:
- Mobility habits
- Opinions
- Perception of transport modes
- Personal data & household description

Statements about environmental concern, mobility, lifestyle, etc.

Taking the bus helps making a town more comfortable and welcoming. [Mobility]

Agreement rated on 5-point Likert scale

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Data collection: mode choice case study

Structure of RP survey:

- Description of all trips performed in one day
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Free report of three adjectives describing best one transport mode:

- Car
- Train
- Bus/metro/tram
- Post bus
- Bike
- Walk

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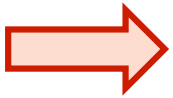

- Classical socio-economic variables: age, gender, etc.
- Household characteristics: family status, number of persons, etc.

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Data collection: mode choice case study

Four themes in statements of opinion:

- Environment
- Mobility
- Residential choice
- Lifestyle

The price of gasoline should be increased in order to reduce traffic congestion and air pollution.

Taking the bus helps making a town more comfortable and welcoming.

Accessibility and mobility conditions are important in the choice of an accommodation.

I always plan my activities a long time in advance.

Respondents rate agreement on 5-point Likert scale:
Total disagreement (1) $\Longrightarrow$ Total agreement (5)

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Data collection: mode choice case study

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**

Data collection: mode choice case study

Adjective data for perception of transport modes:

Data processing:

1. Classification into themes:

- Perception of cost
- Perception of time
- Difficulty of access
- Flexibility
- Comfort, etc.

2. For each theme: attribution of scale from -2 to +2

Comfort	Scale
hardly full	1
packed	-1
bumpy	-2
comfortable	1
hard	-1
irritating	-2
tiring	-1
unsuitable with bags	-1
uncomfortable	-1
bad air	-2

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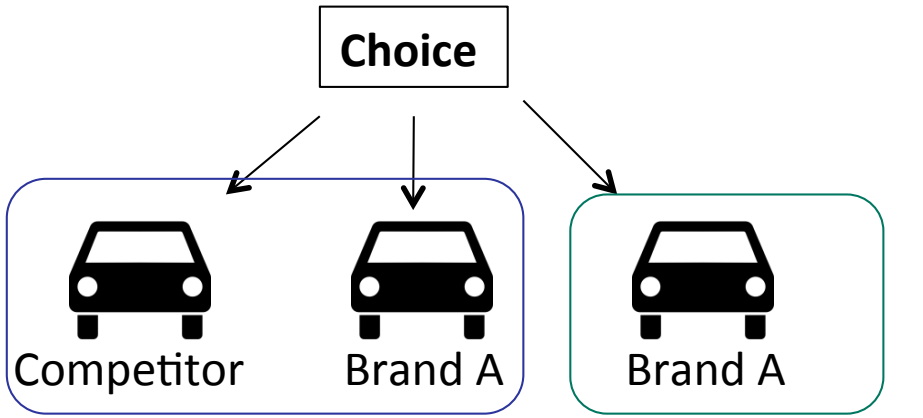
Data collection: vehicle choice case study

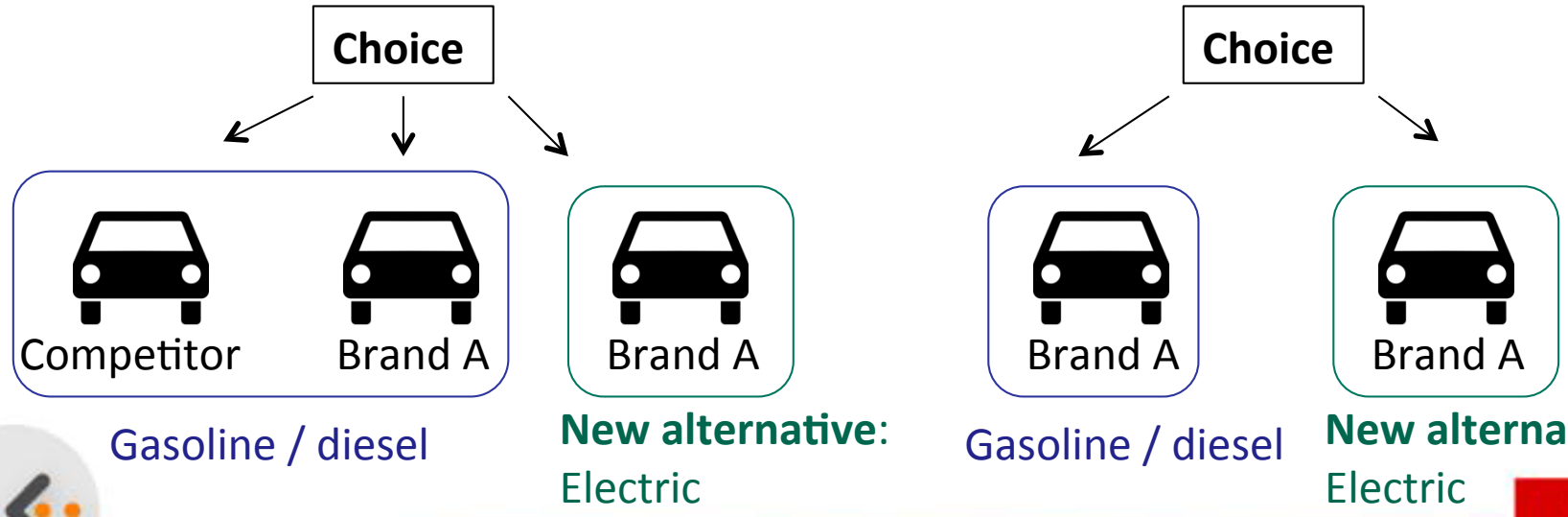
Case study 2: vehicle choice including electric vehicles



Data collection: vehicle choice case study

Type of survey: **stated preference (SP)** survey

- **Within same car segment: hypothetical** choices between
  - Respondents' own car (Brand A or competitors)
  - Brand A – gasoline
  - Brand A – electric



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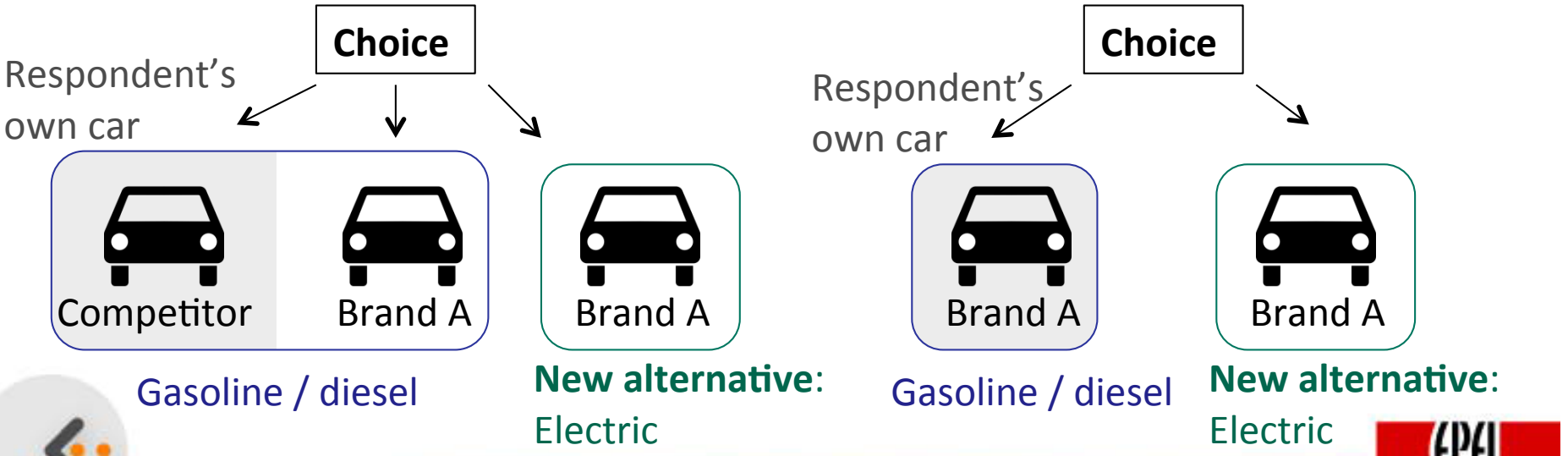

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Data collection: vehicle choice case study

5 types of respondents sampled in Switzerland:

- Recent buyers
- Prospective buyers
- Current customers
- Pre-orders
- Newsletter

Sampling protocol → representativity from:

- 3 language regions of Switzerland (German, French, Italian)
- Gender
- Age category (18-35 years, 36-55 years, 56-74 years)

Data collection: vehicle choice case study

5 types of respondents sampled in Switzerland:

- Recent buyers
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- Pre-orders
- Newsletter

Sampling protocol

All available

Sampling protocol → representativity from:

- 3 language regions of Switzerland (German, French, Italian)
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Data collection: vehicle choice case study

Structure of the survey: 2 phases

- **Phase I:**
  - Characteristics of respondent's car(s)
  - Socio-economic information
  - Mobility habits

→ **Creation of choice situations**

- **Phase II:**
  - Opinions on topics related to EV
  - Perceptions of four categories of EV
  - Choice situations

Data collection: vehicle choice case study

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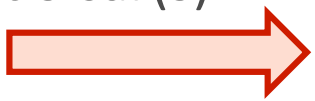

Segmentation, identification of potential users

- **Phase II:**
  - Opinions on topics related to EV
  - Perceptions of four categories of EV
  - Choice situations

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Characterization of mobility of potential users:

•Total distance performed on each weekday

• Total distance performed in the weekend

• Average duration of weekday trips

• Number of cars in the household, etc.

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Data collection: vehicle choice case study

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  - Mobility habits

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  - Opinions on topics related to EV
  - Perceptions of four categories of EV
  - Choice situations

Evaluation of effect of attitudes on choice:

- Environmental concern
- Attitude towards new technologies
- Perception of reliability of EV
- Importance of design
- Perception of leasing

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  - Socio-economic information
  - Mobility habits
- **Phase II:**
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  - Perceptions of four categories of EV
  - Choice situations

Evaluation of effect of perceptions on choice:

- Vehicles with combustion engine
- Hybrid vehicles
- Electric vehicles
- Brand A vehicles

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Data collection: vehicle choice case study

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- **Core of SP survey**
- **5 choice experiments per individual**

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Data collection: vehicle choice case study

An example of choice experiment

Reported by respondent

Characteristics	Your vehicle	Vehicle with combustion engine from brand A	Electric vehicle from brand A
Make	Brand C	Brand A	Brand A
Model	Model X	Model Y	Model Z
Fuel	Gasoline	Gasoline	Electricity
Purchase price (in CHF)	42′400	37′200	56′880
Incentive (in CHF)	0	0	−1′000
Total purchase price (in CHF)	42′400	37′200	55′880
OR: Monthly leasing price (in CHF)	477	399	693
Maintenance costs (in CHF for 30′000 km)	850	850	425
Cost in fuel / electricity for 100 km (in CHF)	11.70	13.55	3.55
Battery lease (in CHF per month)	0	0	125
	☐	☐	☐

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Data collection: vehicle choice case study

An example of choice experiment

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Deduced from segment of owned car

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Obtained from data base of cars currently sold on market

Data collection: vehicle choice case study

An example of choice experiment

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Fixed attributes

Data collection: vehicle choice case study

An example of choice experiment

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	☐	☐	☐

Design variables

Data collection: vehicle choice case study

Experimental design: Fractional factorial design

Design variables:

EV variable	Level 1	Level 2	Level 3	Level 4
Purchase price	(P_{own} + 5'000) * 0.8	(P_{own}+ 5'000) * 1	(P_{own} + 5'000) * 1.2	-
Governmental incentive	- 0 CHF	- 500 CHF	- 1'000 CHF	- 5'000 CHF
Cost of fuel/electricity for 100 km	1.70 CHF	3.55 CHF	5.40 CHF	-
Battery lease	85 CHF	105 CHF	125 CHF	-

Model specification

Different specifications of discrete choice models (DCM) for two case studies:

- **Hybrid choice models** with opinion indicators:
  - Model 1: impact of anti-public transport attitude on mode choice
  - Model 2: impact of anti-public transport and pro-environmental attitudes on mode choice
- **Hybrid choice model** with word indicators:
  - Model 3: impact of perception of comfort in public transport on mode choice
- **Logit model** with multiple alternatives
  - Model 4: identification of factors affecting vehicle choice & choice of electric cars in particular

Model specification: models 1 and 2

Hybrid choice model (continuous form)

Structural equations:

Choice model:

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

Latent variable model:

$$X_n^* = h(X_{in}; \lambda) + \omega_{in} \quad \text{with} \quad \omega_{in} \sim N(0, \sigma_\omega)$$

Measurement equations:

$$I_{kn} = \alpha_{kn} + \theta_{kn} X^*_n + \nu_{kn}, \text{ with } \nu_{kn} \sim N(0, \sigma_{kn})$$

Model specification: model 1

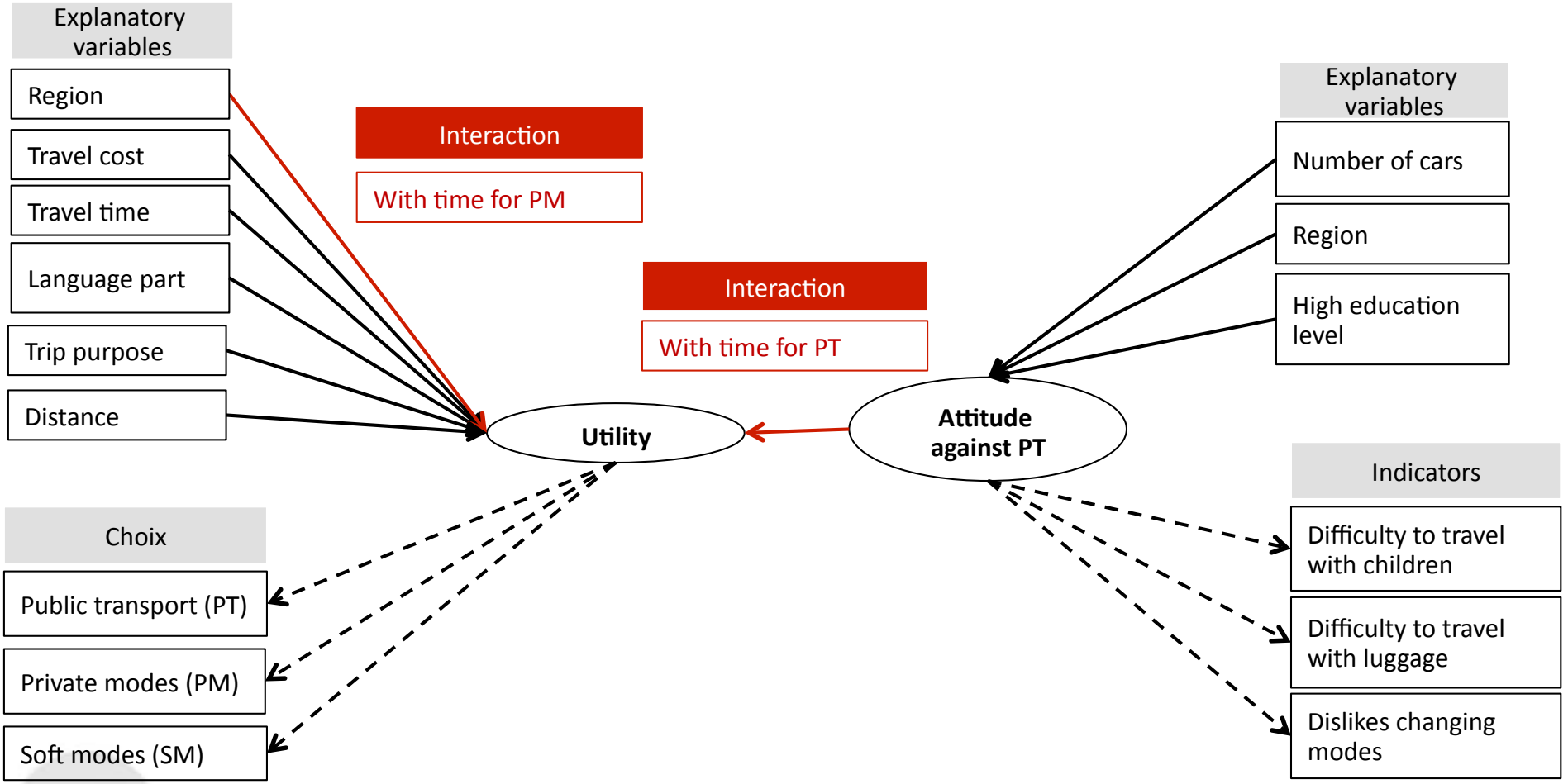

Figure based on Walker and Ben-Akiva, 2002.

Model specification: model 2

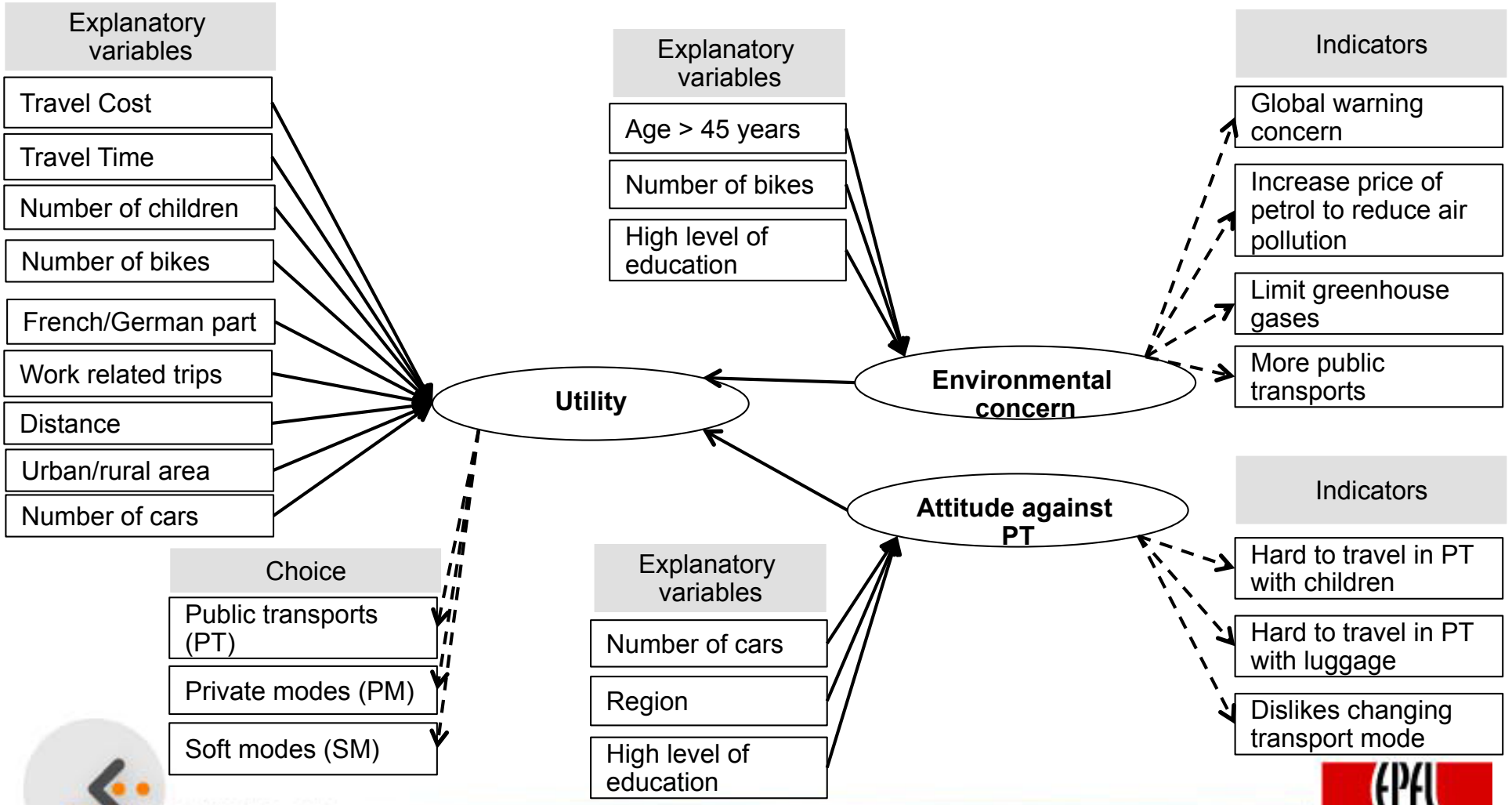

Figure based on Walker and Ben-Akiva, 2002.

Model specification: model 3

Hybrid choice model (discrete form)

Structural equations:

Choice model:

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

Latent variable model:

$$X_n^* = h(X_{in}; \lambda) + \omega_{in} \quad \text{with} \quad \omega_{in} \sim N(0, \sigma_\omega)$$

Measurement equations:

$$I_n = m(X_n^*; \alpha) + \upsilon_n$$

with $\upsilon_n \sim Logistic(0,1)$

$$I_n = \begin{cases} -2 \text{ if } -\infty < X_n^* \le \tau_1 \\ -1 \text{ if } \tau_1 < X_n^* \le \tau_2 \\ 0 \text{ if } \tau_2 < X_n^* \le \tau_3 \\ 1 \text{ if } \tau_3 < X_n^* \le \tau_4 \\ 2 \text{ if } \tau_4 < X_n^* \le +\infty \end{cases}$$

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Model specification: model 3

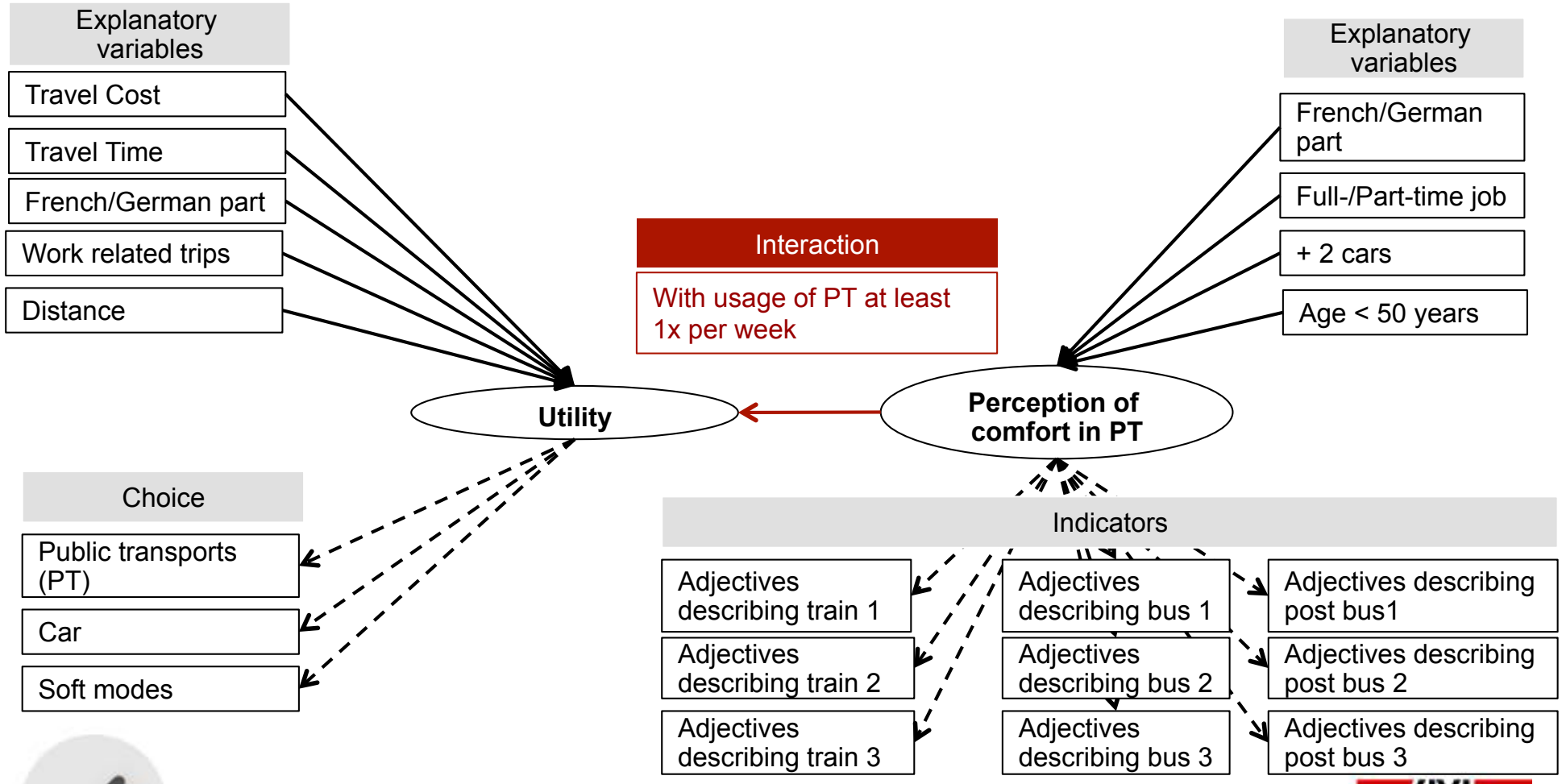


Figure based on Walker and Ben-Akiva, 2002.

Model specification: model 4

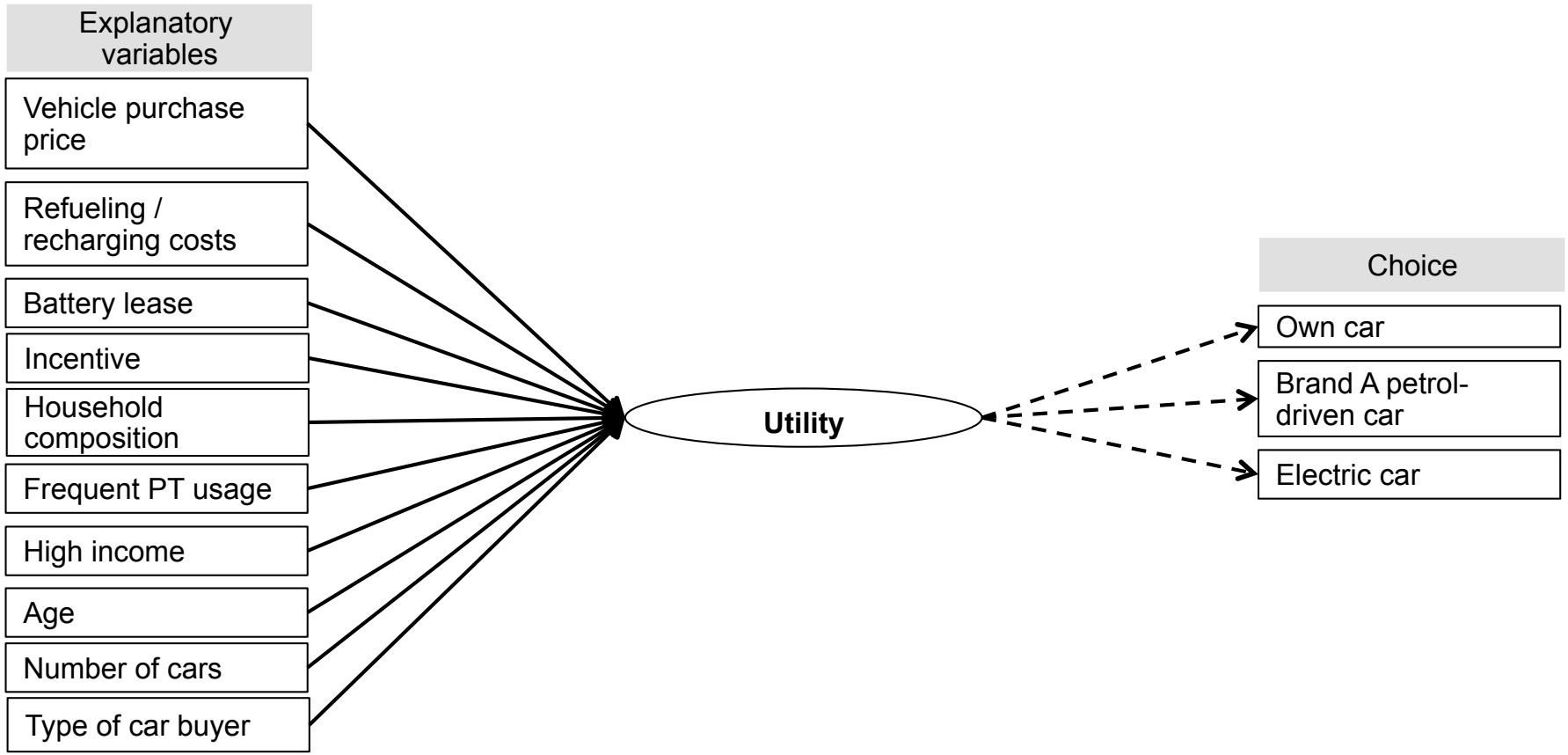
Logit model with multiple alternatives

Structural equation:

Choice model:

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

Model specification: model 4



Estimation results

- **For HCM: likelihood function** given by:

$$L = \prod_{n=1}^{N} f(y_{in}, I_n \mid X_{in}; \alpha, \beta, \lambda, \sigma_\omega) \quad \text{with}$$

$$f(y_{in}, I_n \mid X_{in}; \alpha, \beta, \lambda, \sigma_\omega) = \int_{X_n^*} P(y_{in} \mid X_{in}, X_n^*; \beta) \cdot f(I_n \mid X_{in}, X_n^*; \alpha) \cdot f(X_n^* \mid X_n; \lambda, \sigma_\omega) dX_n^*$$

$$y_{in} = \begin{cases} 1 \text{ if } U_{in} = \max_j U_{jn} \\ 0 \text{ otherwise} \end{cases}$$

- Estimation by **maximum likelihood**
- Use of software **BIOGEME** (Bierlaire, 2003; Bierlaire and Fetiarison, 2009)

Estimation results: model 1

Choice model

- Cost and distance negatively impact on choice.
- Impact of time in PM differs across regions.
- Individuals with strong anti-PT attitude very sensitive to changes in time in PT.
- PT preferred for work-related trips.
- Individuals in French-speaking regions prefer PM.

Utilities	Private modes	Public transport modes	Soft modes
0.483	-	1	-
0.175	-	-	1
-0.0421	Time PM	-	-
0.0142	-	Time PT	-
-0.92	-	Time PT · Anti-PT / 100	-
0.00735	Time PM · Valais	-	-
0.018	Time PM · Bern	-	-
0.0156	Time PM · Bâle	-	-
0.0147	Time PM · Est CH	-	-
0.0133	Time PM · Grisons	-	-
-0.0709	Cost PM	Cost PT	-
-0.231	-	-	Distance
-0.465	Work trips	-	-
1.35	French	-	-

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Estimation results: model 1

Latent variable model

- PT well perceived in German-speaking regions
- Individuals with several cars in household dislike PT.
- High education level drives positive attitude towards PT.

Anti-PT attitude	Variable
2.95	1
-0.224	Basel
-0.27	Grisons
-0.205	East CH
-0.198	Valais
-0.34	Bern
0.123	Number of cars
-0.159	High education

Estimation results: model 2

Choice model

- Expected negative coefficients for time, cost and distance.
- Anti-PT attitude negatively impacts on choice of PT.
- Pro-environmental attitude favors choice of PT.

Utilities	Private modes	Public transport modes	Soft modes
-0.599	1	-	-
-0.772	-	-	1
-0.0294	Time PM	-	-
-0.0119	-	Time PT	-
-0.0559	Cost PM	Cost PT	-
-0.224	-	-	Distance
-0.574	-	Anti-PT	-
0.393	-	Pro-environment	-

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Estimation results: model 2

Choice model

- Several cars, children in the household favors the use of PM.
- PT and SM preferred for work-related trips.
- PM preferred in French-speaking regions.
- PT preferred in urban areas.
- Students prefer PT.
- Households with several bikes prefer SM.

Utilities	Private modes	Public transport modes	Soft modes
0.970	Number of cars	-	-
0.215	Number of children	-	-
--0.583	Work trips	-	-
1.06	French	-	-
0.283	-	Urban	-
3.26	-	Student	-
0.385	-	-	Number of bikes

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Estimation results: model 2

Latent variable models

Anti-PT

- Several cars in the household, low education are factors driving anti-PT attitude.
- Individuals in German-speaking regions show pro-PT attitude.

Pro-environment

- High education, several bikes in household, increasing age explain a pro-environmental attitude.

Attitudes	Anti-PT	Pro-environment
3.02	1	-
3.23	-	1
0.104	Number of cars	-
0.235	- High education	High education
0.0845	-	Number of bikes
0.00445	-	Age > 45
-0.223	Valais	
-0.361	Bern	-
-0.256	Basel	-
-0.228	East CH	-
-0.303	Grisons	-

Estimation results: model 3

Choice model

- Expected negative coefficients for time, cost and distance.
- PT and soft modes preferred for work-related trips.
- PM preferred over PT in French-speaking regions.
- Good image of comfort in PT encourages its choice.

Utilities	Private modes	Public transport modes	Soft modes
0.425	1	-	-
-1.78	-	1	-
-0.0214	Time PM	-	-
-0.00857	-	Time PT	-
-0.0223	Cost PM	Cost PT	-
-0.209	-	-	Distance
-0.553	Work trips	-	-
-0.114	-	Work trips	-
0.966	French	-	-
0.411	-	French	-
0.394	-	Image comfort PT	-

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Estimation results: model 3

Latent variable model

- Good perception of comfort in German-speaking regions.
- Young people perceive comfort in PT negatively.
- Full-/Part-time workers have negative image of comfort in PT.
- Individuals with more than 2 cars have a negative image of comfort in PT.

Image of comfort in PT	Variable
7.43	1
0.143	German
-0.277	Age < 50
-0.286	Full-/Part-time job
-0.193	Number of cars > 1

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Estimation results: model 4

Choice model

- Price affects mostly choice EV.
- Heterogeneity in perception of price in population of future buyers.

Utilities	Competitor – Gasoline	Brand A – Gasoline	Brand A – Electric
-0.0212**	Price CG	-	-
-0.211	-	Price AG · TG1245	-
-0.598	-	Price AG · TG3	-
-0.404	-	-	Price AE · TG12
-1.00	-	-	Price AE · TG3
-0.628	-	-	Price AE · TG45
-0.049**	Operating cost gasoline	Operating cost gasoline	-

** <90% significance

Estimation results: model 4

Choice model

- Impact of operating costs differ across EV models.
- Operating cost only affect choice of 1 of the 2 EV models.
- Important impact of high governmental incentive.

Utilities	Competitor – Gasoline	Brand A – Gasoline	Brand A – Electric
-0.252	-	-	High operating cost · Model1
-0.778	-	-	High operating cost · Model2
-0.447	-	-	Medium operating cost · Model2
-0.205*	-	-	High battery lease
-0.0539**	-	-	Medium battery lease
0.73	-	-	High incentive
0.0803**	-	-	Medium incentive
-0.00224**	-	-	Low incentive

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Estimation results: model 4

Choice model

- PT users in favor of EV.
- Families with children: potential adopters.
- High income impacts choice of EV.
- Taste heterogeneity across population of future buyers.

Utilities	Competitor – Gasoline	Brand A – Gasoline	Brand A – Electric
-0.279	PT · TG1245	-	-
-0.552	-	PT · TG1245	-
-1.85	PT · TG3	-	-
-1.07	-	PT · TG3	-
-0.217	Family with children	-	-
0.0454**	-	Family with children	-
-0.25	Income	-	-
-0.297	-	Income	-

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Estimation results: model 4

Choice model

- EV adopters already own several cars.
- EV more appreciated in Swiss-German and Swiss-Italian regions.
- Age has an impact on car choice.

Utilities	Competitor – Gasoline	Brand A – Gasoline	Brand A – Electric
-0.172	Nb cars · TG1245	-	-
-0.157	-	Nb cars · TG1245	-
-0.384**	Nb cars · TG3	-	-
-0.729	-	Nb cars · TG3	-
0.335	French	-	-
0.0876**	-	French	-
0.0124	Age	-	-
-0.00187**	-	Age	-

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Estimation results: model 4

Choice model

- Heterogeneity of taste across different segments of future car buyers.

Utilities	Competitor – Gasoline	Brand A – Gasoline	Brand A – Electric
1.97	TG12	-	-
1.04	-	TG12	-
-0.635	TG3	-	-
2.45	-	TG3	-
-2.12	1	-	-
-1.67	-	1	-

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Estimation results: model 4

Correction of the constants

Use:

- Market data of current alternatives
- SP survey data

} To estimate possible share for new alternative

Estimation results: model 4

Correction of the constants (ctd)

Evaluation of potential market share (MS) for EV

Acceptance rate EV in the questionnaire for CG owners (weighted)

Acceptance rate EV in the questionnaire for AG owners (weighted)

$$MS(\text{AE}) = \%(\text{Choice AE} \mid \text{Owns CG}) \cdot 95\% + \%(\text{Choice AE} \mid \text{Owns AG}) \cdot 5\%$$

Market share of competitors

Market share of brand A

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Validation & forecasting

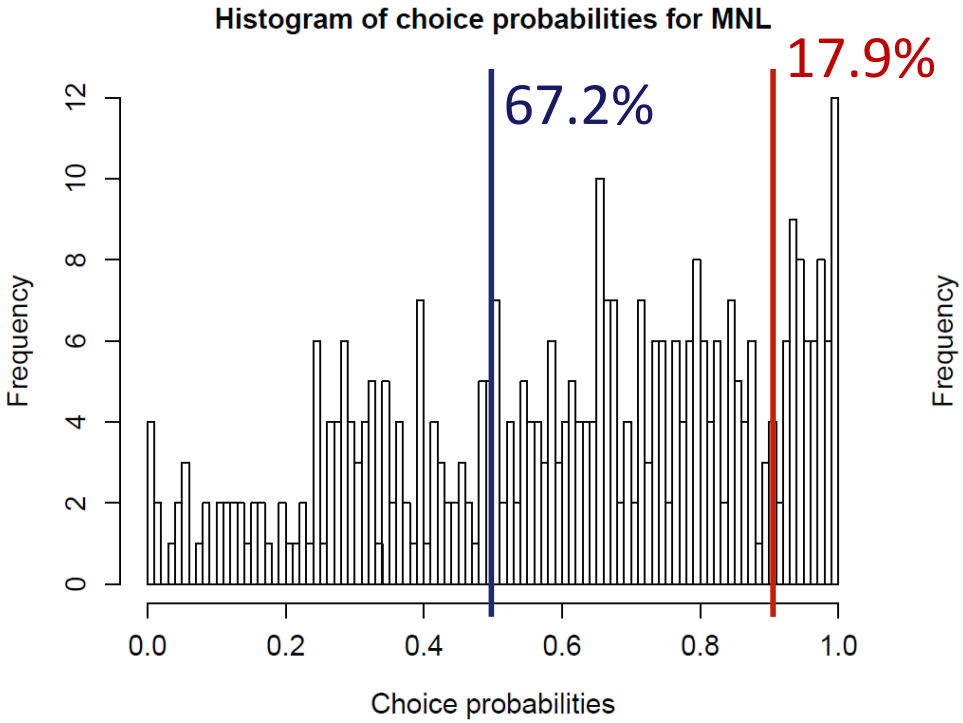
Evidence of improvement of prediction power of choice models by including latent variables

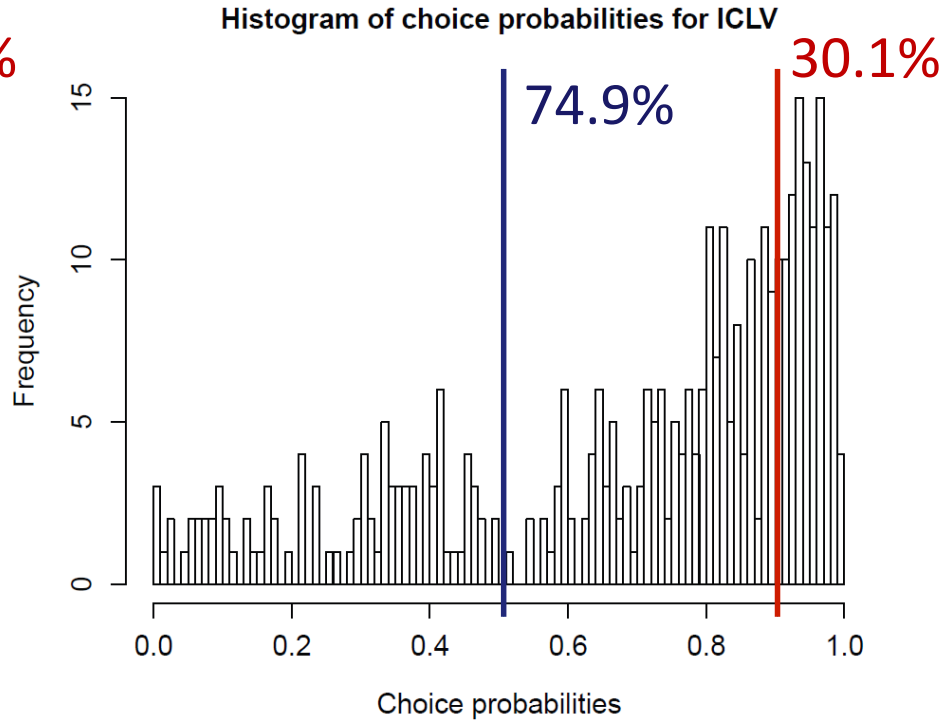
$\Longrightarrow$ Histogram of choice probabilities

$\Longrightarrow$ Example for model 3 (mode choice case study)

Validation & forecasting: model 3

Histogram of choice probabilities predicted by MNL and ICLV (80%/20%)





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Validation & forecasting

Issues in validation & forecasting of HCM:

1. Analysis of demand indicators built on latent variables

2. Inclusion of aggregate market data for forecasting

Validation & forecasting

1. Analysis of demand indicators built on latent variables

Computation of demand indicators depending on value of latent variable:

$\Longrightarrow$ Capture heterogeneity of value of time (VOT) in population (Abou-Zeid et al., 2010)

Validation & forecasting: model 1

Value of time PT:

$$VOT_{PT,n} = \frac{\beta_{timePT} - \beta_{attPT} \cdot attPT_n}{\beta_{cost}}$$

Result:

- Individuals with more negative attitude against PT
  $\Longrightarrow$ Increase in TT will **decrease** probability to choose PT
  Individuals with more a positive attitude towards PT.
  $\Longrightarrow$ Increase in TT will **increase** probability to choose PT
- Impacts on VOT

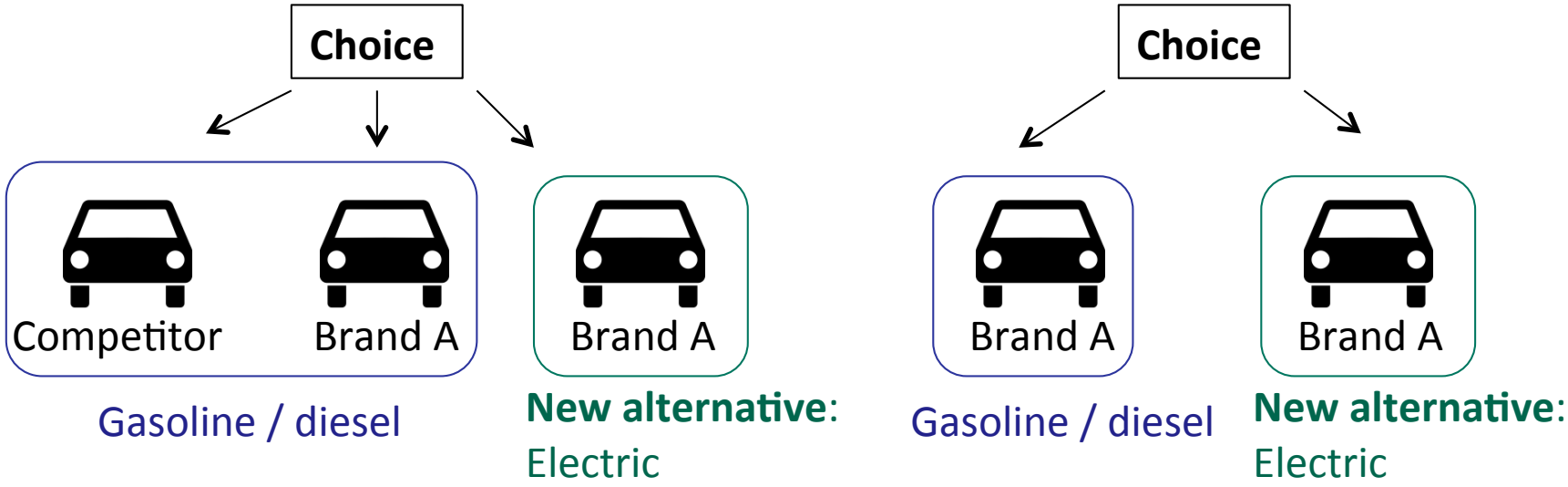
Validation & forecasting

2. Inclusion of aggregate market data for forecasting

Inclusion of aggregate alternatives in SP survey to deal with missing information

Validation & forecasting: model 4

Two types of choice in a choice situation context



Issue:

- Choice is supposed to represent all possible alternatives for decision maker
- Not the case for owners of cars of brand A

Solution:

- Impute aggregate alternative of gasoline – competitors for these individuals

Validation & forecasting: model 4

Aggregate alternative imputed for Competitor – Gasoline (CG):

$$V_{CG} = \log \sum_{l \in L} \exp V_{ln}$$

$$V_{\ln} = ASC_{CG} + \sum_{s \in S_n} \beta_s \cdot x_s + \beta_{price_{CG}} \cdot price_l + \beta_{UseCostGasoline} \cdot Cost100_l \cdot (Cost100_l \leq 12)$$

Create **aggregate alternative** from **prices** & **operating costs** of new cars on market
(matching segment of 2 other alternatives in choice situation)

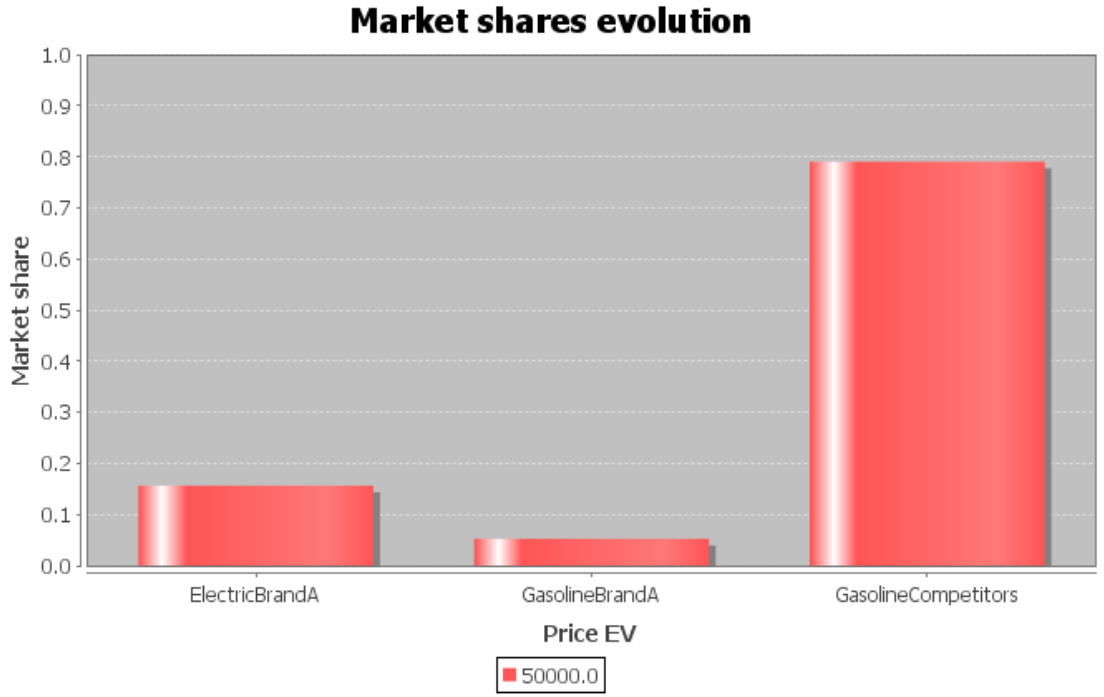
Validation & forecasting

Market shares evolution

Models can be used to forecast effect of change in one variable (or more) on market shares of all alternatives.

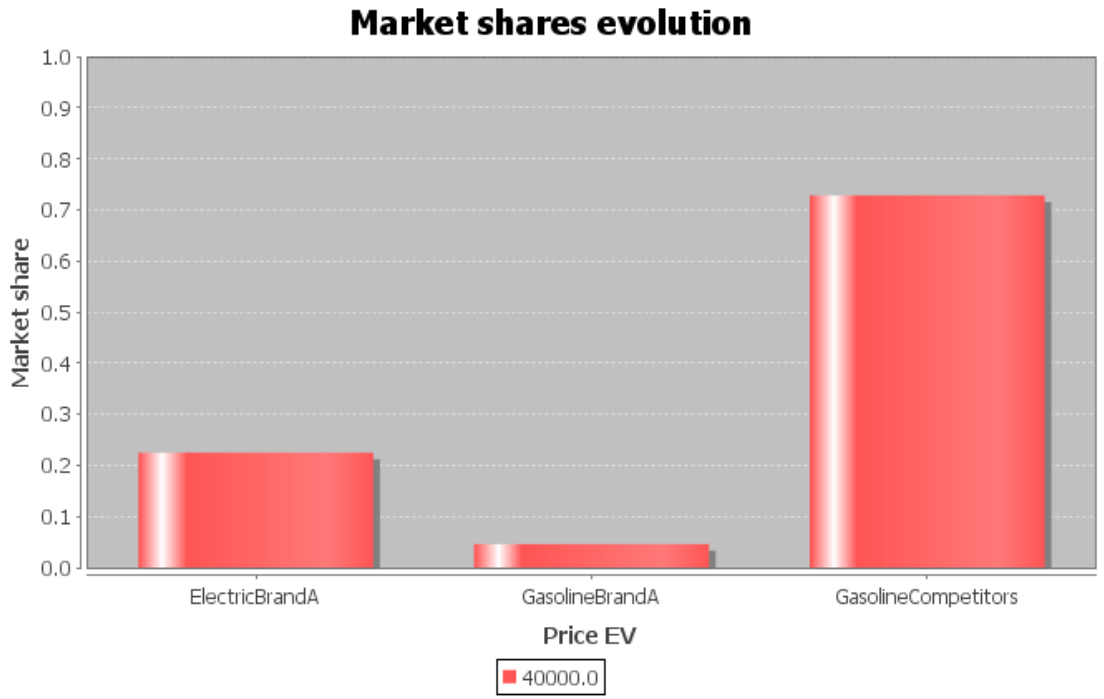
Example (model 4): what is the effect of the decrease in the price of an EV on the car market?

Validation & forecasting: model 4



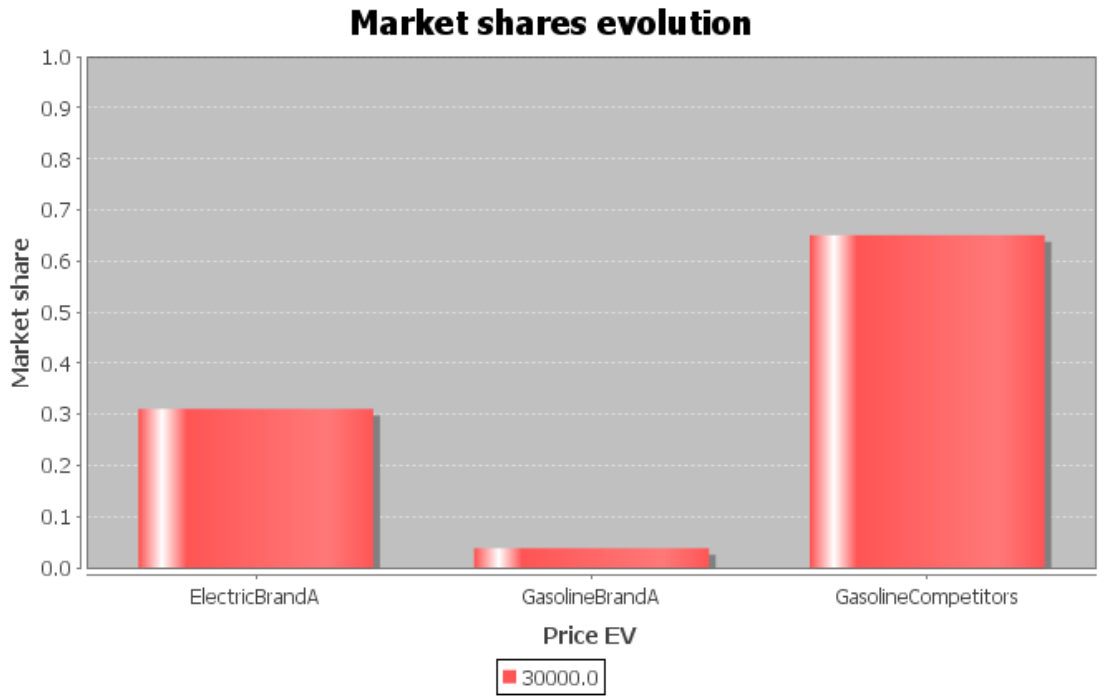
Market shares when price EV = 50'000 CHF

Validation & forecasting: model 4



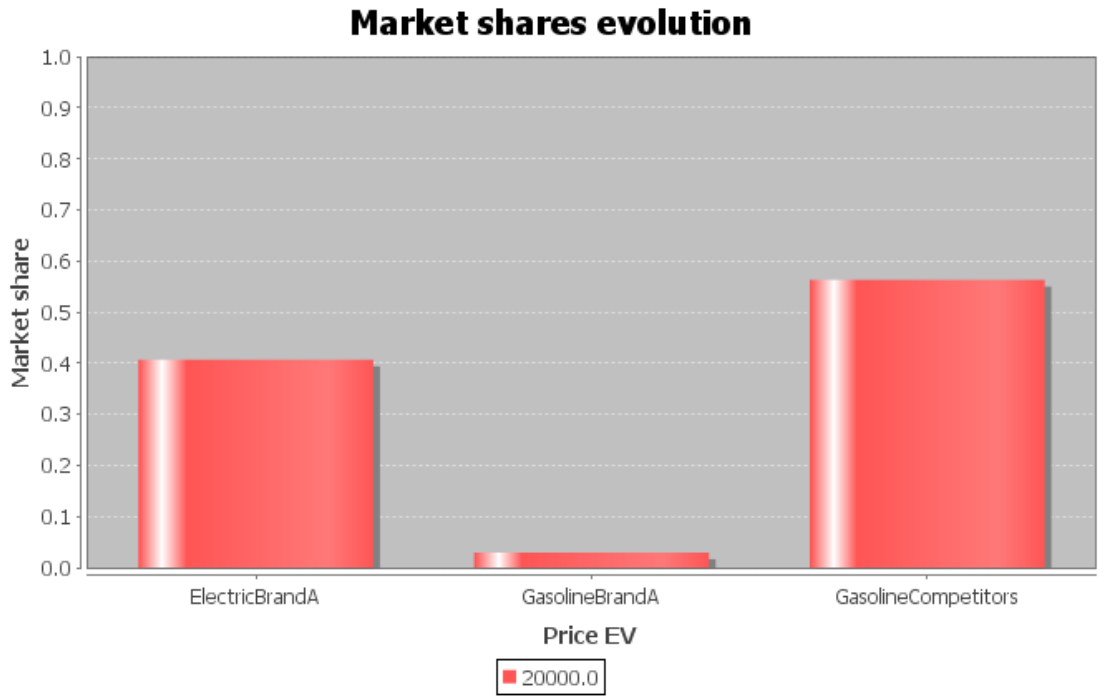
Market shares when price EV = 40'000 CHF

Validation & forecasting: model 4



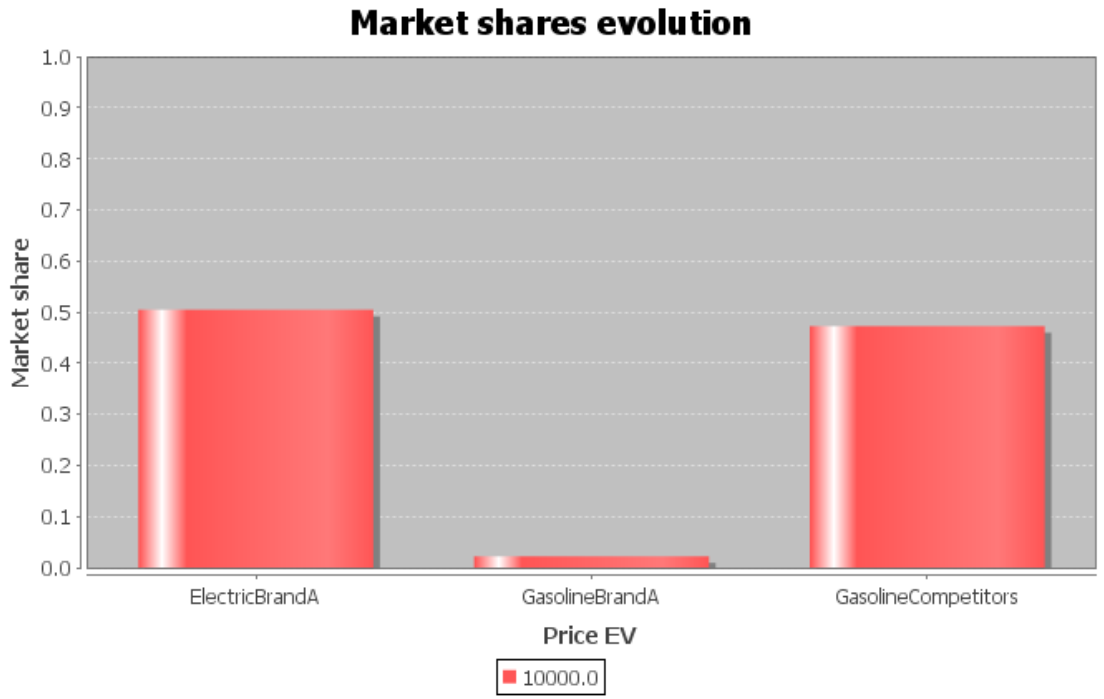
Market shares when price EV = 30'000 CHF

Validation & forecasting: model 4



Market shares when price EV = 20'000 CHF

Validation & forecasting: model 4



Market shares when price EV = 10’000 CHF

Conclusion

Recent developments in DCM: integration of attitudes/ perceptions into choice model

- Significant impact of attitude/perception variables on choice
- Improvement of prediction power of logit models
- Improvements in computation of indicators of demand
- Several issues in forecasting need to be taken into account (e.g. missing data, real market situation)

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Thank you!