FORECASTING THE DEMAND FOR ELECTRIC VEHICLES

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EDC seminar, University of Leeds
12th November 2013

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OUTLINE

Introduction & motivation

Data collection

Methodology

Model
- SP model
- Choice model for forecasting

Forecasting analysis

Conclusion

INTRODUCTION & MOTIVATION

Aim

- Develop a **comprehensive methodology** to forecast demand for a new technology: **electric vehicles**

Context

- Current situation:
  - Alternative fuel vehicles (LPG, CNG, etc.) on the car market
  - Electric vehicles (EV) being released
- Collaborative project EPFL-Renault Suisse:
  - Renault has launched Zero Emission (Z.E.) product line in 2011-2013
  - **Aim**: analyze demand for two EV models for **private use**

Zoé

Fluence Z.E.

INTRODUCTION & MOTIVATION

Literature

- SP survey design:
  - Personalized choice situations (Bunch et al., 1993, Achtnicht et al., 2008, etc.)
  - Fractional factorial designs (Brownstone et al., 1996, Ewing and Sarigöllü, 2000, Horne et al., 2005)

- Choice models for demand for EVs or alternative-fuel vehicles:
  - Widely applied (Brownstone and Train, 1999, Dagsvik et al., 2002, Mueller and de Haan, 2009, etc.)
  - Integrated choice and latent variable (ICLV) models for environmental concern (Alvarez-Daziano and Bolduc, 2009)

- Model application:
  - Models developed on SP data need adjustments before application (Brownstone et al., 1996)
  - Joint RP-SP estimations (e.g. Brownstone et al., 2000)
  - Lack of examples of applications of models designed to evaluate demand for new alternatives (Daly and Rohr, 1998)

INTRODUCTION & MOTIVATION

Main features of this research

- Customized choice situations using iterative proportional fitting (IPF)
- Include attitudinal dimensions
- Specify model for the whole market, from a model based on SP data

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COMPREHENSIVE FRAMEWORK

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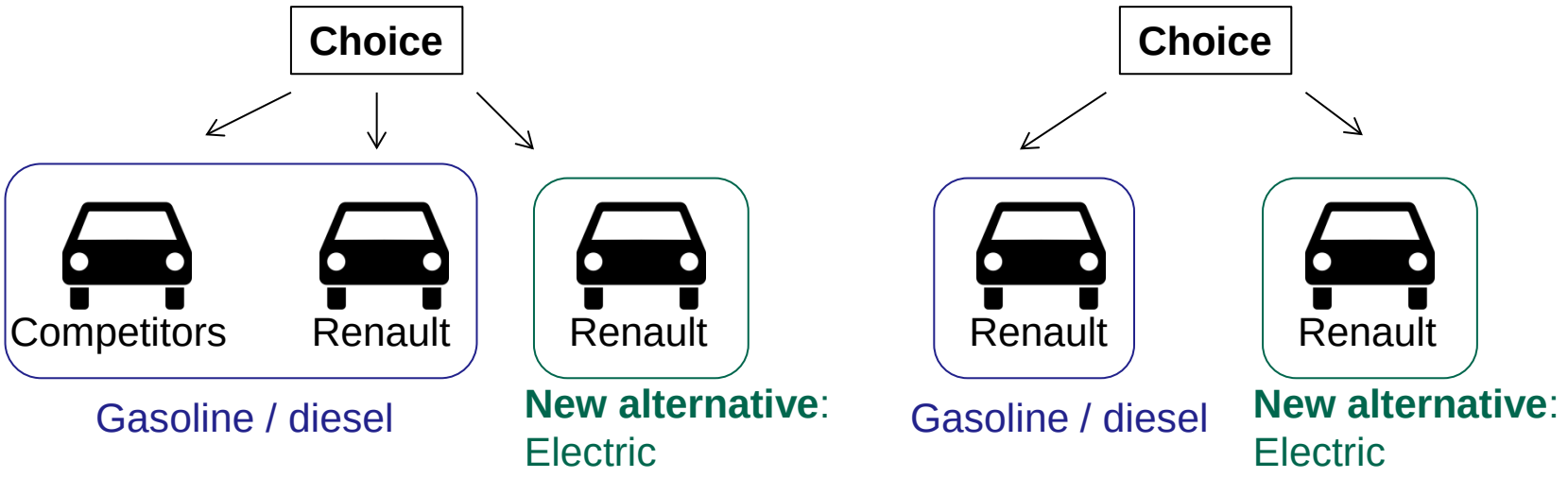
DATA COLLECTION

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

Within same car segment: **hypothetical** choices between

- Own car
- Renault – gasoline (if own car is not Renault)
- Renault – electric



DATA COLLECTION

STRUCTURE OF THE SURVEY

2 phases:

Phase I:

- Characteristics of respondent's car(s)
- Socio-economic information
- Mobility habits

Phase II:

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

DATA COLLECTION

STRUCTURE OF THE SURVEY

2 phases:

Phase I:

- Characteristics of respondent's car(s)
- Socio-economic information
- Mobility habits

…used to design…

Phase II:

- Choice situations
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DATA COLLECTION

STRUCTURE OF THE SURVEY

Opinions on themes related to electric vehicles

- Environmental concern (5 statements)
  Example: An electric car is a 100% ecological solution.
- Attitude towards new technologies (5 statements)
  Example: A control screen is essential in my use of a car.
- Perception of the reliability of an electric vehicle (5 statements)
  Example: Electric cars are not as secure as gasoline cars.
- Perception of leasing (5 statements)
  Example: Leasing is an optimal contract which allows me to change car frequently.
- Attitude towards design (5 statements)
  Example: Design is a secondary element when purchasing a car, which is above all a practical transport mode.

Ratings

- Total disagreement (1)
- Disagreement (2)
- Neutral opinion (3)
- Agreement (4)
- Total agreement (5)
- I don't know (6)

DATA COLLECTION

SAMPLE

5 types of respondents sampled in Switzerland:

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

DATA COLLECTION

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Sampling protocol

All available

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

GfK
Ask GfK

0% 25% 50% 75% 100%

Situation de choix 4 de 5

Vous avez ici la description de votre véhicule actuel ainsi que celle de véhicules similaires, thermique et électrique, de la marque Renault. Compte tenu des caractéristiques de chacun de ceux-ci, laquelle des trois solutions choisiriez-vous, si vous deviez changer de voiture aujourd'hui ?

Les valeurs indicatives de leasing sont calculées sur la base d'un apport initial de 20%, d'un kilométrage annuel de 10'000 km et d'une durée de financement de 48 mois.

Caractéristiques	Votre véhicule	Véhicule thermique Renault	Véhicule électrique Renault
Marque	SEAT	RENAULT	RENAULT
Modèle	LEON	MEGANE	FLUENCE
Carburant	Diesel	Diesel	Electricité
Prix d'achat (en CHF)	37510	42739	34008
Prime du gouvernement (en CHF)	0	0	0
Prix total à l'achat (en CHF)	**37510**	**42739**	**34008**
OU : Prix mensuel du leasing (en CHF)	402	435	404
Coûts d'entretien (en CHF par 30'000 km)	850	850	425
Coût en carburant/électricité par 100 km (en CHF)	9.65	10.8	3.55
Leasing de la batterie (en CHF par mois)	0	0	105
	○	○	○

précédent suivant

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DATA COLLECTION

EXPERIMENTAL DESIGN

An example of choice experiment

Characteristics	**Your vehicle**	**Renault vehicle with combustion engine**	**Renault electric vehicle**
Make	Audi	Renault	Renault
Model	A4	Laguna	Fluence
Fuel	Petrol	Petrol	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

An example of choice experiment

Reported by respondent

Characteristics	Your vehicle	Renault vehicle with combustion engine	Renault electric vehicle
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Deduced from segment of owned car

DATA COLLECTION

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Obtained from data base of cars currently sold on market

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Fixed attributes

DATA COLLECTION

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Design variables

DATA COLLECTION

EXPERIMENTAL 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	-

DATA COLLECTION

Fractional factorial design with sampling weights

Fractional factorial design

- Orthogonal
- Size = 64 (full factorial design has size 108)

Sampling weights:

- Correct for **oversampling** of some levels
- Weights computed with **iterative proportional fitting (IPF)**

EXPERIMENTAL DESIGN

	Incentive	Price	Fuel cost of 100 km	Battery lease
1	0	0.80	1.70	85
2	0	1.00	3.55	125
3	0	1.00	5.40	105
4	0	1.20	3.55	105
5	-500	0.80	1.70	125
6	-500	1.00	3.55	85
7	-500	1.00	5.40	105
8	-500	1.20	3.55	105
9	-1000	0.80	3.55	105
10	-1000	1.00	5.40	105
11	-1000	1.00	3.55	85
12	-1000	1.20	1.70	125
13	-5000	0.80	3.55	105
14	-5000	1.00	5.40	105
15	-5000	1.00	3.55	125
16	-5000	1.20	1.70	85

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METHODOLOGY

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

Allows to capture e.g. attitudes et perceptions

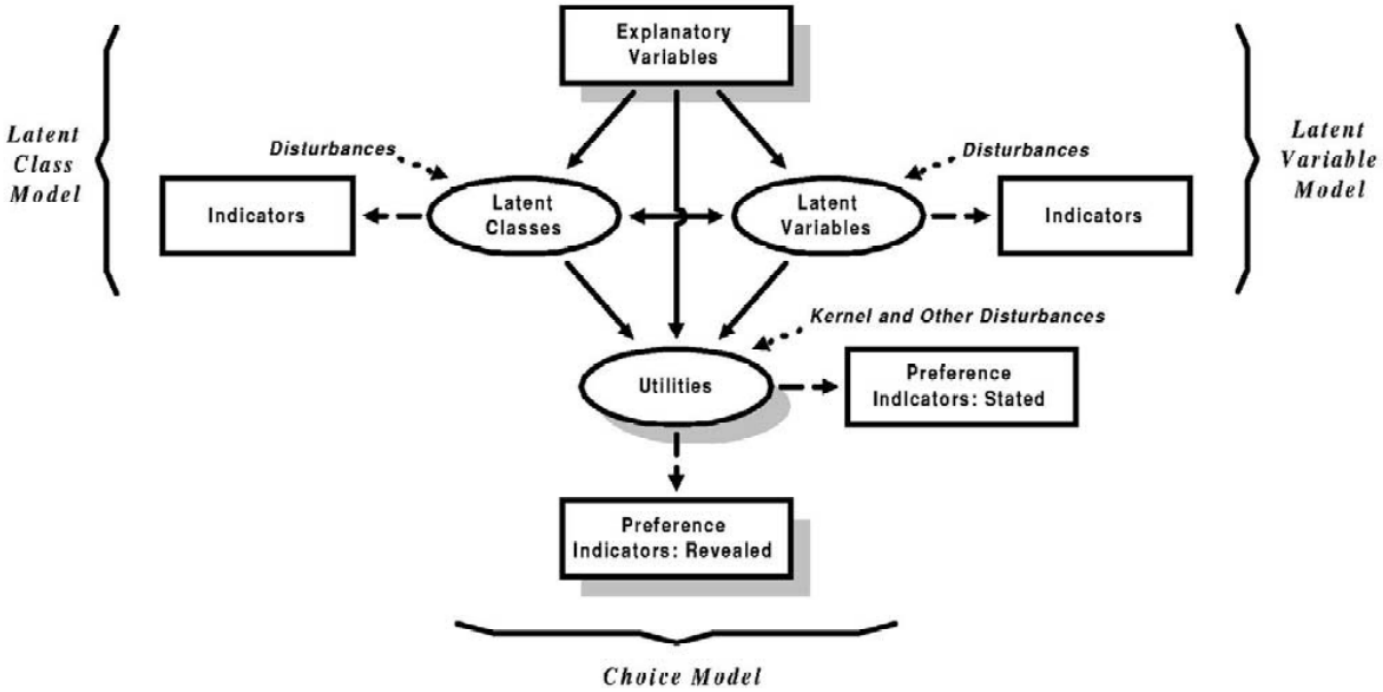
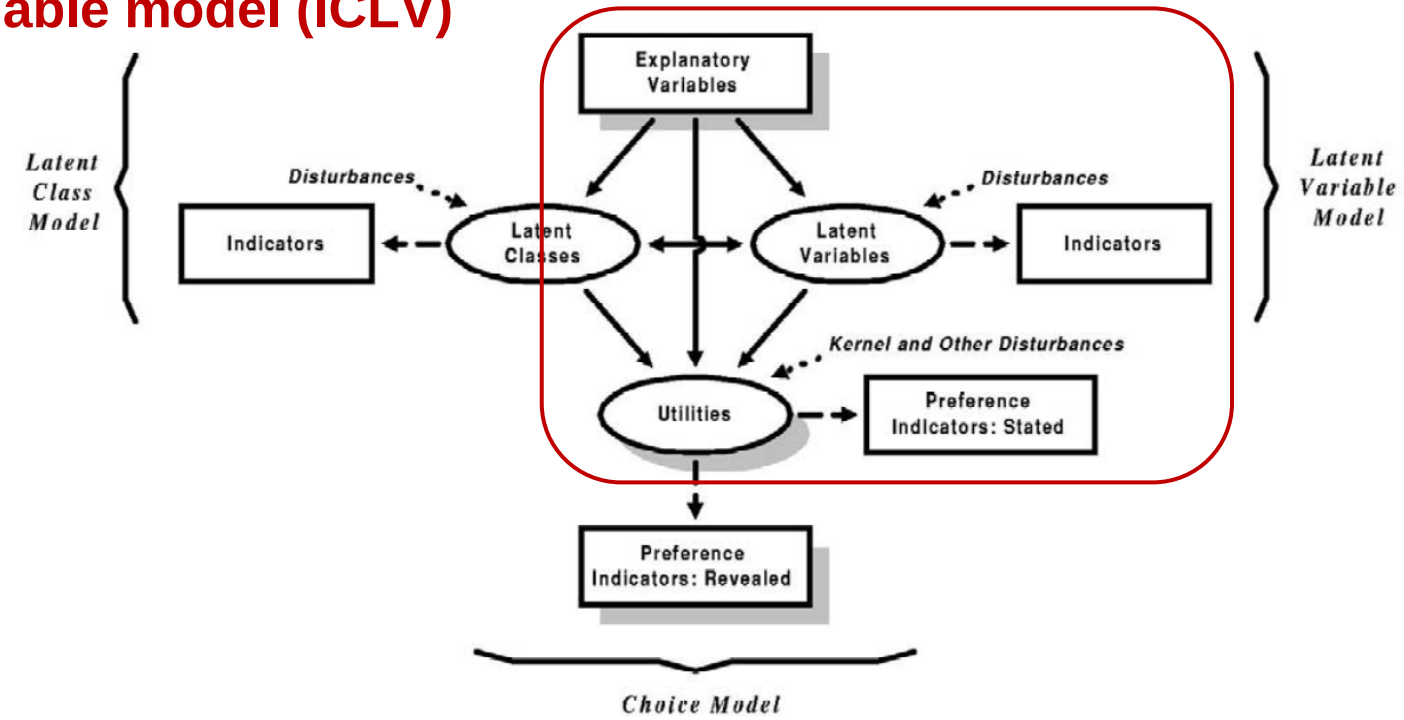


Figure extracted from Walker and Ben-Akiva, 2002.

METHODOLOGY

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

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



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METHODOLOGY

Hybrid choice model specification

Structural equations:

Choice model:

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

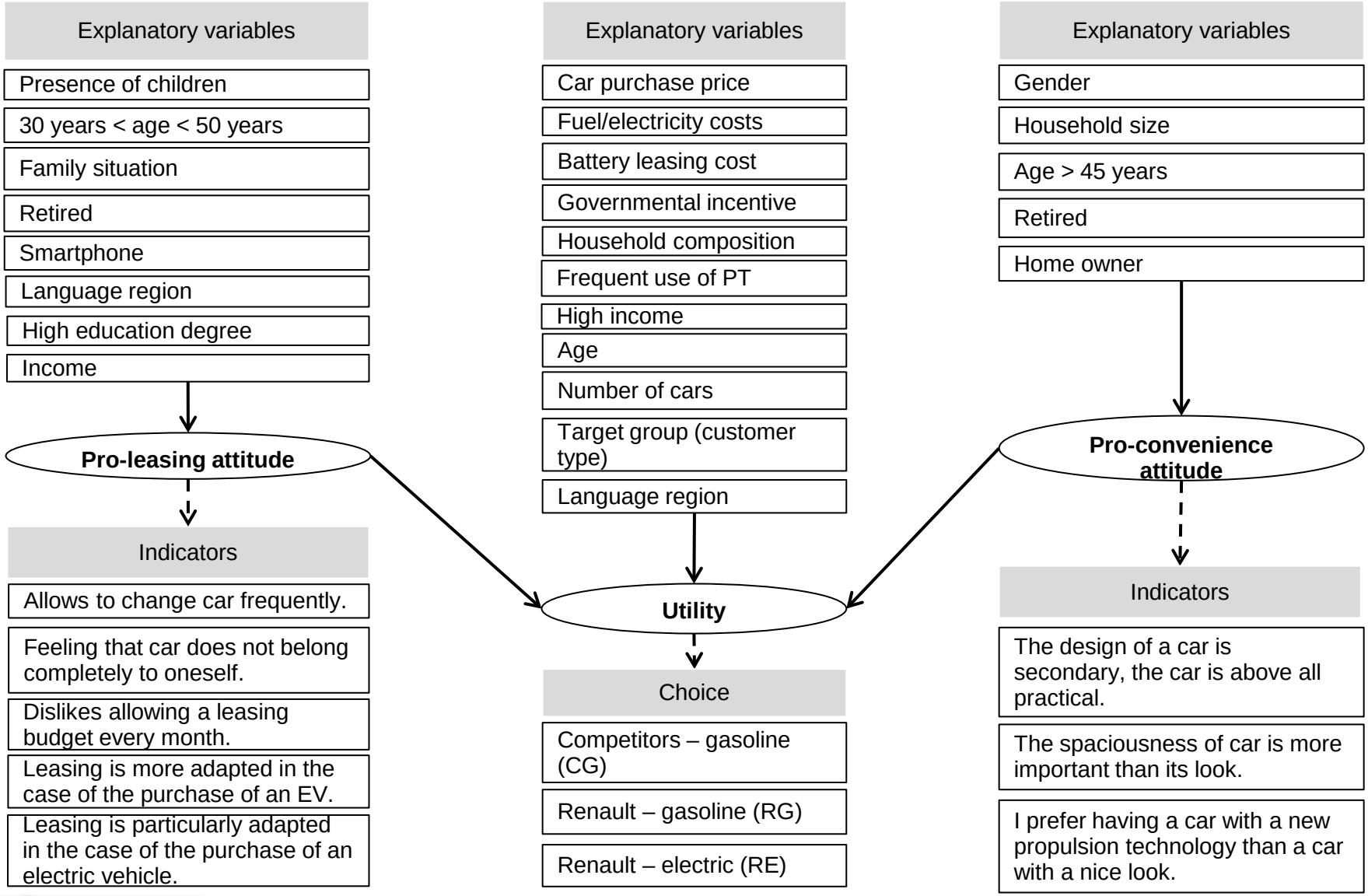
Latent variable model:

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

Measurement equations (continuous):

$I_n^* = m(X_n^*; \alpha) + \nu_n$ with $\nu_n \sim N(0, \sigma_\nu)$

SP MODEL



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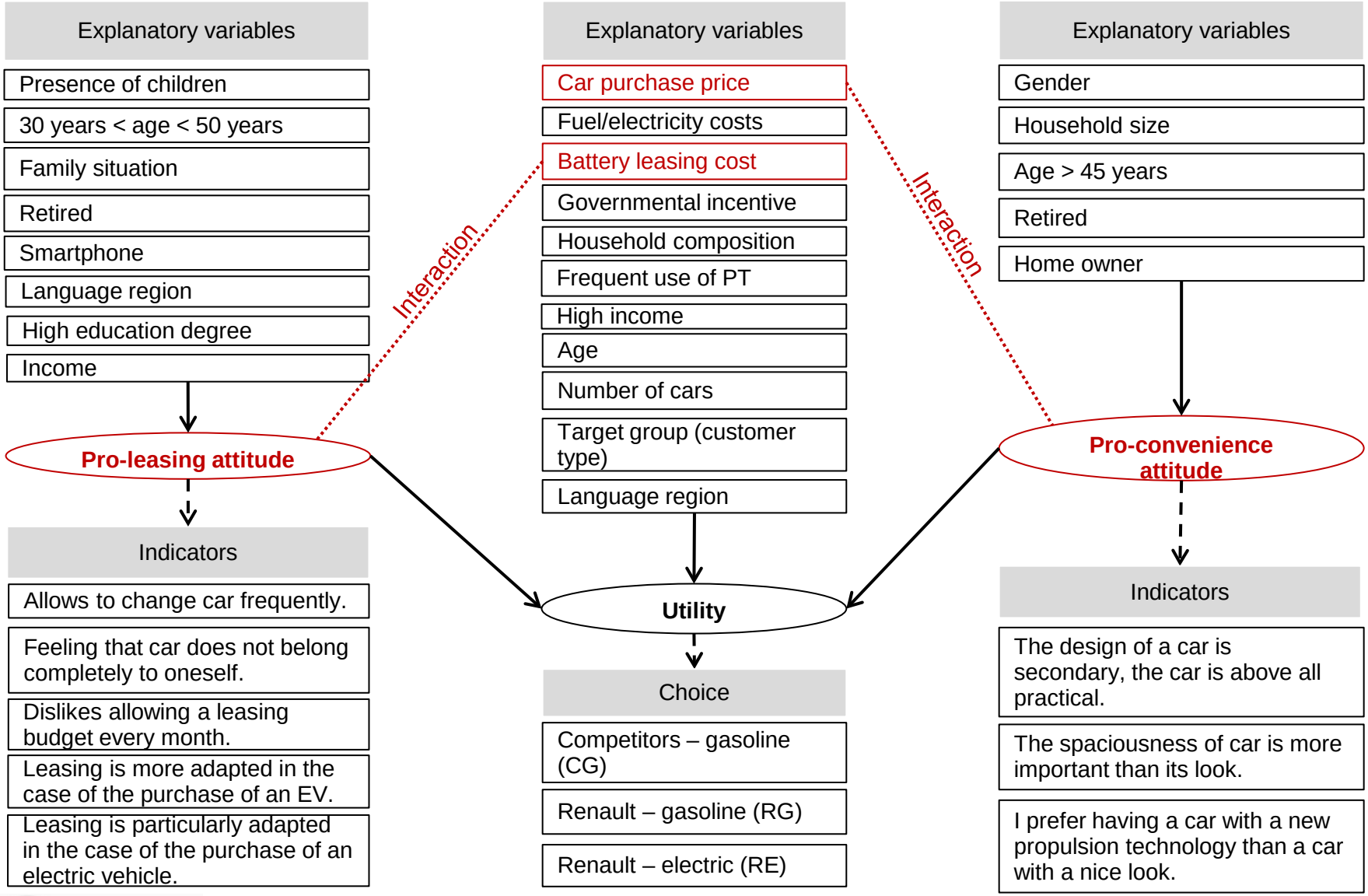
SP MODEL



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SP MODEL

SPECIFICATION

Structural equations:

Choice model:

$$U_{CG} = -\exp\left(\beta_{price_{CG}} + \beta_{AttC} AttC\right) price_{CG} + \sum_k \beta_k X_k + \varepsilon_{CG,n}$$

$$U_{RG} = -\exp\left(\beta_{price_{RG,TG1245}} TG1245 + \beta_{price_{RG,TG3}} TG3 + \beta_{AttC} AttC\right) price_{RG} + \sum_i \beta_i X_i + \varepsilon_{RG,n}$$

$$U_{RE} = -\exp\left(\beta_{price_{RE,TG12}} TG12 + \beta_{price_{RE,TG3}} TG3 + \beta_{price_{RE,TG45}} TG45 + \beta_{AttC} AttC\right) price_{RE} - \exp\left(\beta_{Battery} + \beta_{AttL} AttL\right) Battery + \sum_m \beta_m X_m + \varepsilon_{RE,n} \text{ with } \varepsilon_{in} \sim EV(0,1)$$

Latent variable model:

$$AttL = \beta_{Mean1} + \sum_i \beta_{1,i} \cdot X_{1,i} + \exp(\nu_1) \cdot \Omega_1 \text{ with } \Omega_1 \sim N(0,1)$$

$$AttC = \beta_{Mean2} + \sum_i \beta_{2,i} \cdot X_{2,i} + \exp(\nu_2) \cdot \Omega_2 \text{ with } \Omega_2 \sim N(0,1)$$

Measurement equations (continuous):

$$I_{1,k} = \alpha_{1,k} + \lambda_{1,k} \cdot AttL + \exp\left(\sigma_{1,k}\right) \Omega_{1,k} \text{ with } \Omega_{1,k} \sim N(0,1), \text{ for } k = 1, \dots, 5$$

$$I_{2,k} = \alpha_{2,k} + \lambda_{2,k} \cdot AttC + \exp\left(\sigma_{2,k}\right) \Omega_{2,k} \text{ with } \Omega_{2,k} \sim N(0,1), \text{ for } k = 1,2,3$$

SP MODEL

ESTIMATION RESULTS

Name	Value	t-test	Name	Value	t-test
Parameters in linear terms			*Parameters in linear terms (ctd)*		
ASC_{CG}	-2.71	-4.77	$\beta_{Income_{CG}}$	-0.223*	-1.92
ASC_{RG}	-2.17	-3.63	$\beta_{Income_{RG}}$	-0.259	-2.25
$\beta_{UseCostGasoline}$	-0.0469**	-1.41	$\beta_{French_{CG}}$	0.373	2.94
$\beta_{UseCostElecHigh_{Fluence}}$	-0.264	-2.20	$\beta_{French_{RG}}$	0.0254**	0.19
$\beta_{UseCostElecHigh_{Zoé}}$	-0.802	-4.82	$\beta_{Age_{CG}}$	0.0172	3.65
$\beta_{UseCostElecMed_{Zoé}}$	-0.514	-3.21	$\beta_{Age_{RG}}$	-0.00210**	-0.43
$\beta_{IncentiveHigh}$	0.799	6.21	$\beta_{TG12_{CG}}$	1.60	4.57
$\beta_{IncentiveMed}$	0.0538**	0.40	$\beta_{TG12_{RG}}$	0.664*	1.89
$\beta_{IncentiveLow}$	0.0164**	0.12	$\beta_{TG3_{CG}}$	0.104**	0.11
$\beta_{PT_{CG,TG1245}}$	-0.259	-1.96	$\beta_{TG3_{RG}}$	2.63	5.18
$\beta_{PT_{RG,TG1245}}$	-0.577	-3.67	*Parameters in non-linear terms*		
$\beta_{PT_{CG,TG3}}$	-2.64	-3.85	$\beta_{price_{CG}}$	-3.60	-4.77
$\beta_{PT_{RG,TG3}}$	-1.17	-4.40	$\beta_{price_{RG,TG1245}}$	-1.39	-4.33
$\beta_{FamSit_{CG}}$	-0.157**	-1.37	$\beta_{price_{RG,TG3}}$	-0.290**	-1.06
$\beta_{FamSit_{RG}}$	0.183**	1.56	$\beta_{price_{RE,TG12}}$	-0.365	-2.57
$\beta_{NbCars_{CG,TG1245}}$	-0.207	-2.75	$\beta_{price_{RE,TG3}}$	0.342	2.10
$\beta_{NbCars_{RG,TG1245}}$	-0.193	-2.32	$\beta_{price_{RE,TG45}}$	-0.152**	-1.33
$\beta_{NbCars_{CG,TG3}}$	-0.664*	-1.88	β_{AttC}	-0.142	-4.93
$\beta_{NbCars_{RG,TG3}}$	-0.945	-6.24	$\beta_{Battery}$	2.17	5.87
			β_{AttL}	-0.193*	-1.74

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- $\beta_{AttC} < 0$ and significant: pro-convenience individuals less price-sensitive

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- $\beta_{AttC} < 0$ and significant: pro-convenience individuals less price-sensitive
- $\beta_{AttL} < 0$ and significant: pro-leasing individuals less affected by changes in battery leasing price

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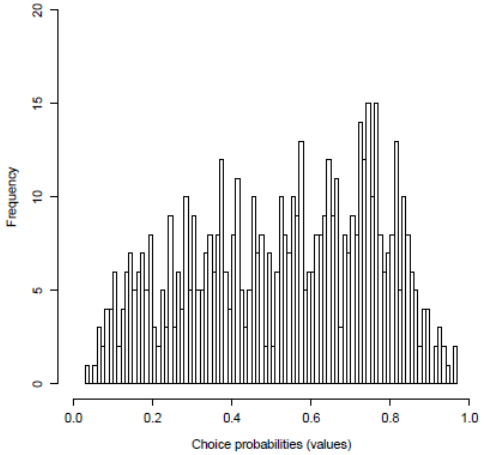
SP MODEL

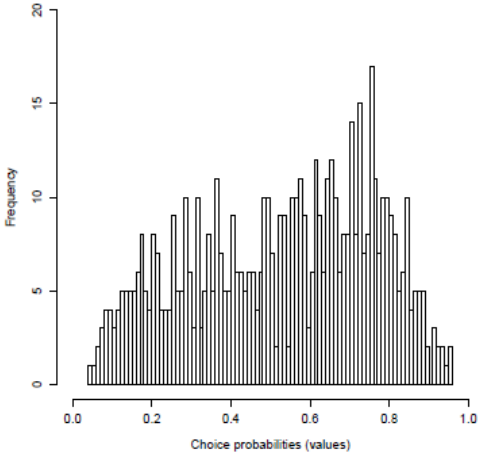
VALIDATION

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

ICLV



MNL



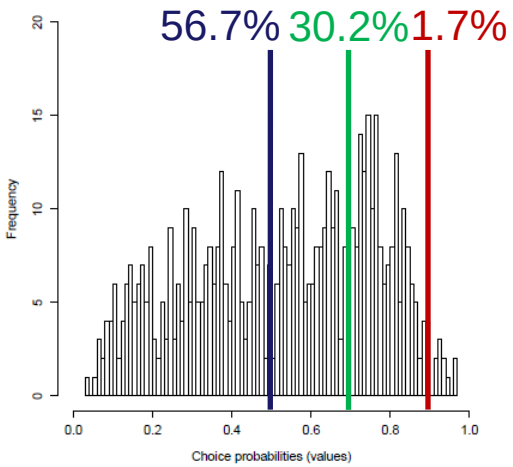
Value

SP MODEL

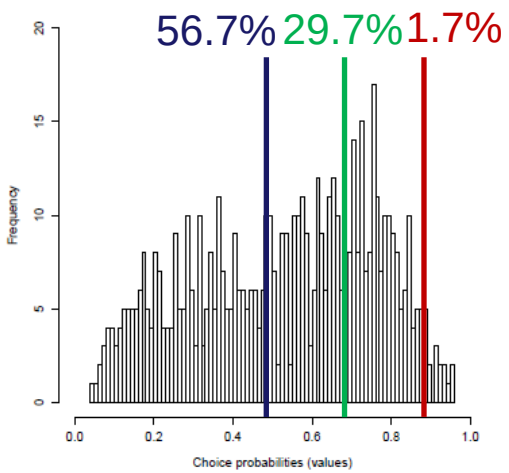
VALIDATION

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

ICLV



MNL



Value

TRANSP-OR

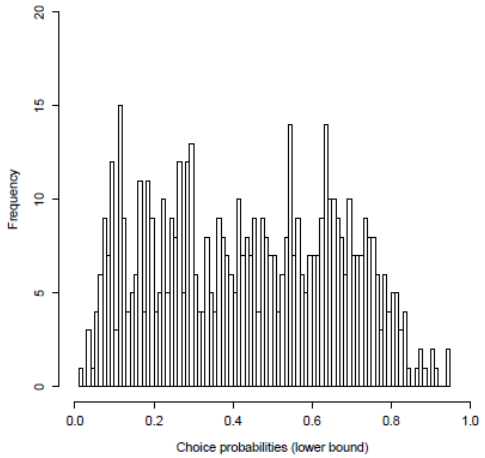
ÉCOLE POLYTECHNIQUE FÉDÉRALE DE LAUSANNE

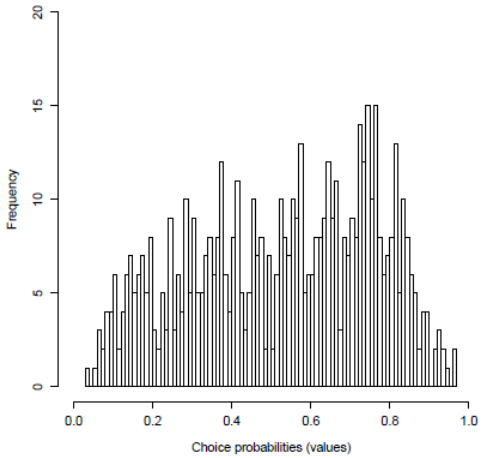
SP MODEL

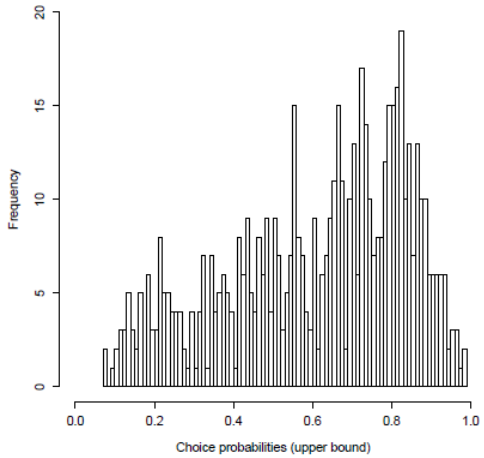
VALIDATION

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

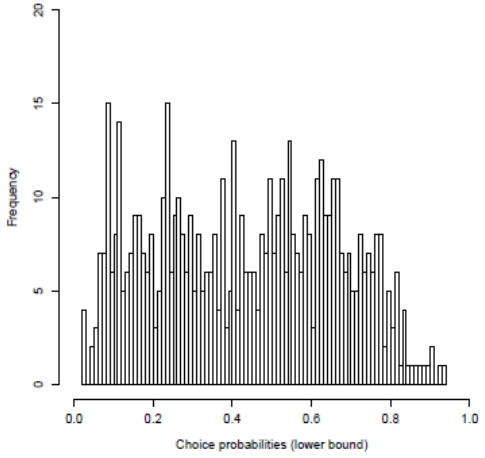
ICLV

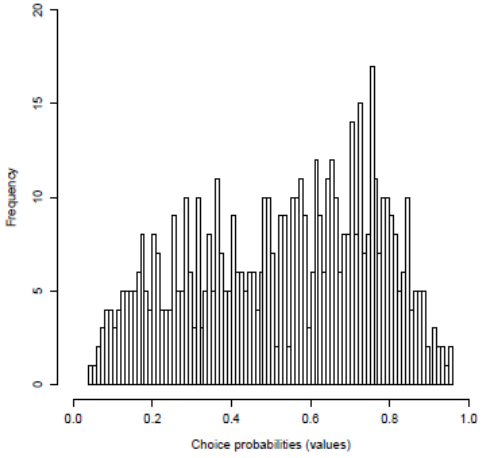


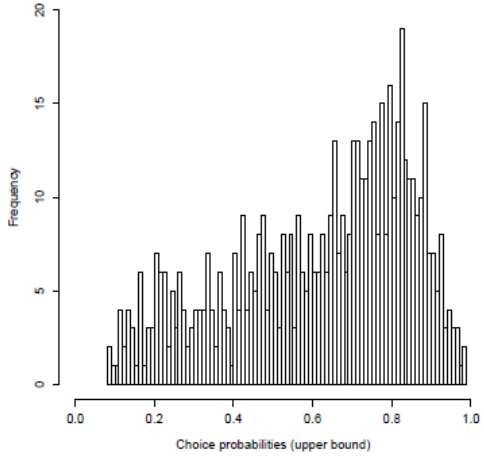




MNL







Lower bound

Value

Upper bound

TRANSP-OR

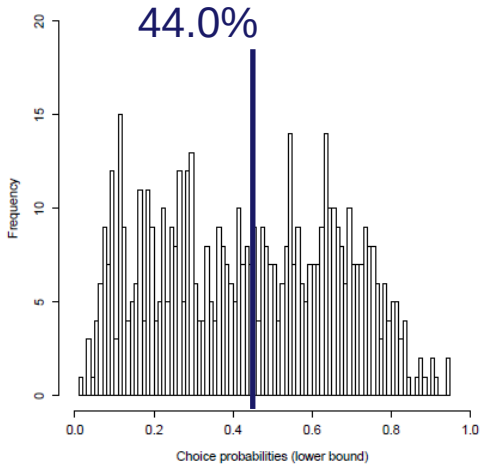
ÉCOLE POLYTECHNIQUE FÉDÉRALE DE LAUSANNE

SP MODEL

VALIDATION

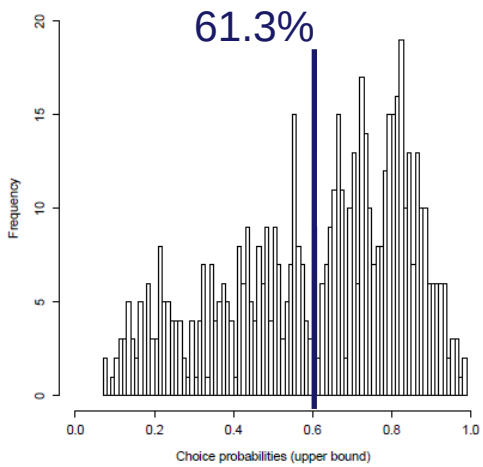
Histogram of **choice probabilities** predicted by MNL and ICLV (80%/20%)

ICLV

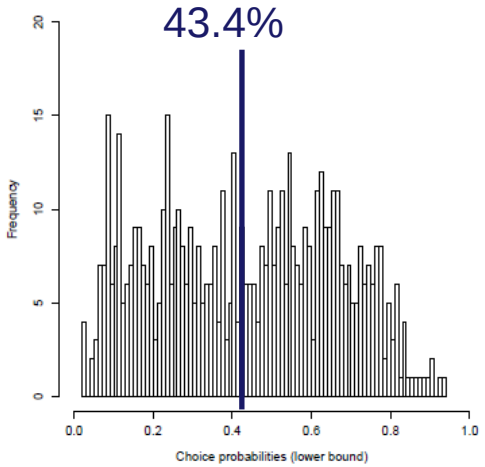


Difference between average confidence bounds

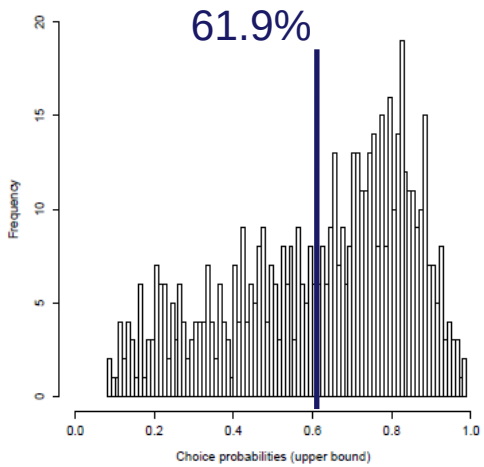
17.3%



MNL



18.5%



Lower bound

Upper bound

TRANSP-OR

ÉCOLE POLYTECHNIQUE FÉDÉRALE DE LAUSANNE

CHOICE MODEL FOR FORECASTING

Several corrections to the SP model are needed before the model can be applied for scenario forecasting:

1. **Introduction of an aggregate alternative** for car models from competitors (using logsum)

2. **Correction of constants**:

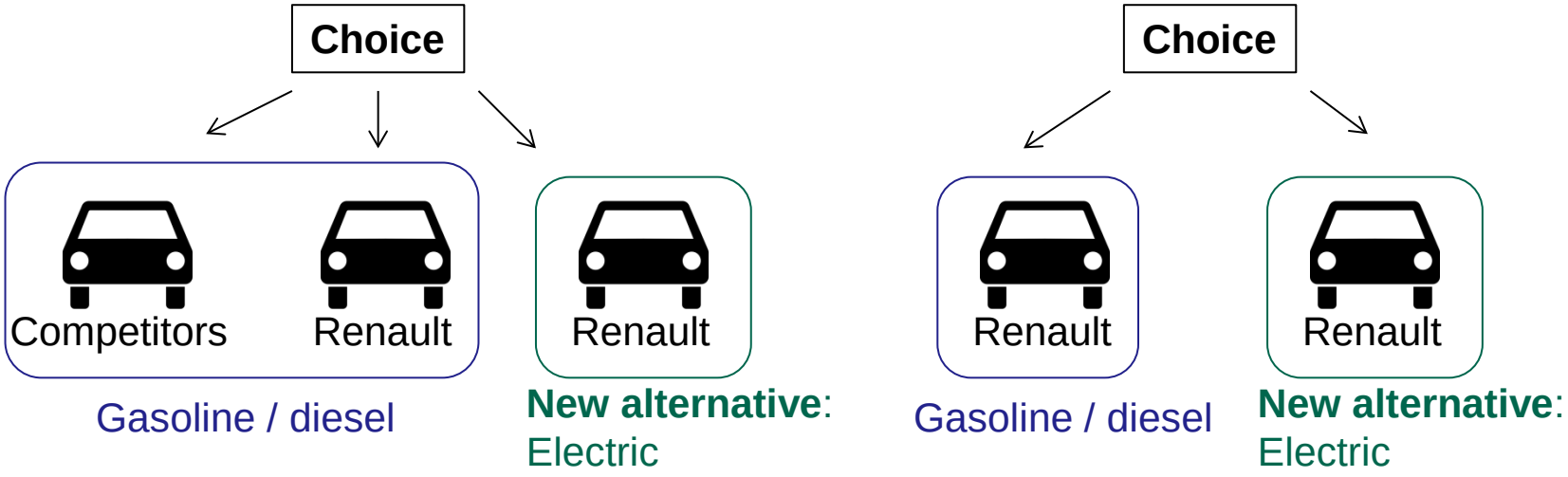
   - Current ratio of market shares between Renault and competitors is preserved.

   - Estimate potential market share of EV using acceptance rate and Swiss market data.

CHOICE MODEL FOR FORECASTING

1. AGGREGATE ALTERNATIVE

Two possible choice situations



Issue:

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

Solution:

- Impute aggregate alternative of gasoline – competitors for these individuals

CHOICE MODEL FOR FORECASTING

1. AGGREGATE ALTERNATIVE

Aggregate alternative imputed for Competitors – Gasoline (CG)

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

$$U_{\ln} = ASC_{CG} + \sum_{s \in S_n} \beta_s \cdot x_s - \exp(\beta_{price_{CG}} + \beta_{AttC} \cdot AttC_n) \cdot price_l + \beta_{UseCostGasoline} \cdot Cost100_l \cdot (Cost100_l \leq 12) + \varepsilon_{\ln}$$

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

CHOICE MODEL FOR FORECASTING

2. CORRECTIONS OF CONSTANTS

Idea:

Use:

- Market data of current alternatives
- SP survey data

} To estimate possible share for new alternative

CHOICE MODEL FOR FORECASTING

2. CORRECTIONS OF CONSTANTS

Idea:

Use:

- Market data of current alternatives
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} To estimate possible share for new alternative

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 RG owners (weighted)

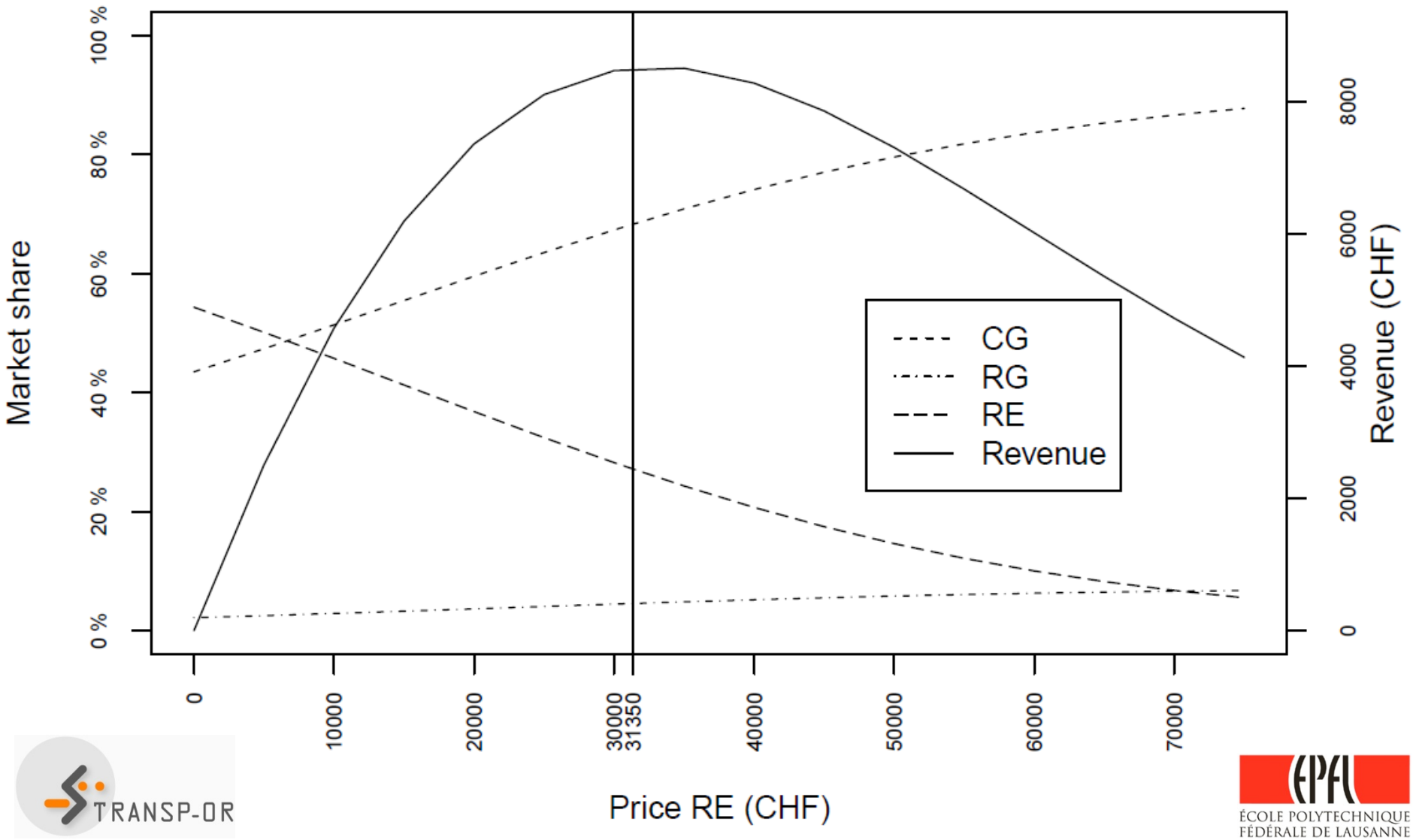
$$MS(\text{RE}) = \%(\text{Choice RE} \mid \text{Owns CG}) \cdot 94\% + \%(\text{Choice RE} \mid \text{Owns RG}) \cdot 6\%$$
$$= 27\%$$

Market share of competitors

Market share of Renault

FORECASTING ANALYSIS

Example of scenario



CONCLUSION

Conclusions

- Operational model obtained by the presented procedure: from data collection to model application
- Important to include market data when forecast for a new alternative

Future analyses

- Analyzed the demand for EV for private use, but alternative uses exist (e.g. car sharing)
- Now that EVs are more present on the market, revealed preferences (RP) data can be collected and the model can integrate both.

Thank you!