# 3rd International Workshop on Empirical Methods in Energy Economics (EMEE2010)

**Surrey Energy Economics Centre (SEEC)**

**University of Surrey, UK**

**24th – 25th June 2010**

***NOTE:***

**The following Presentation represents *Work in Progress* for discussion at the EMEE2010 workshop. It therefore must not be referred to without the consent of the author(s).**

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# The Value of Continuous Power Supply for Flemish Households*

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* Part of the research project '*Embedded generation: a global approach to energy balance and grid power quality and security*'. Funded by the Agency for Innovation by Science and Technology (IWT).

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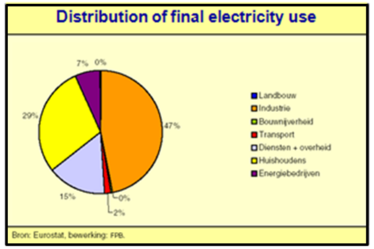
# Outline

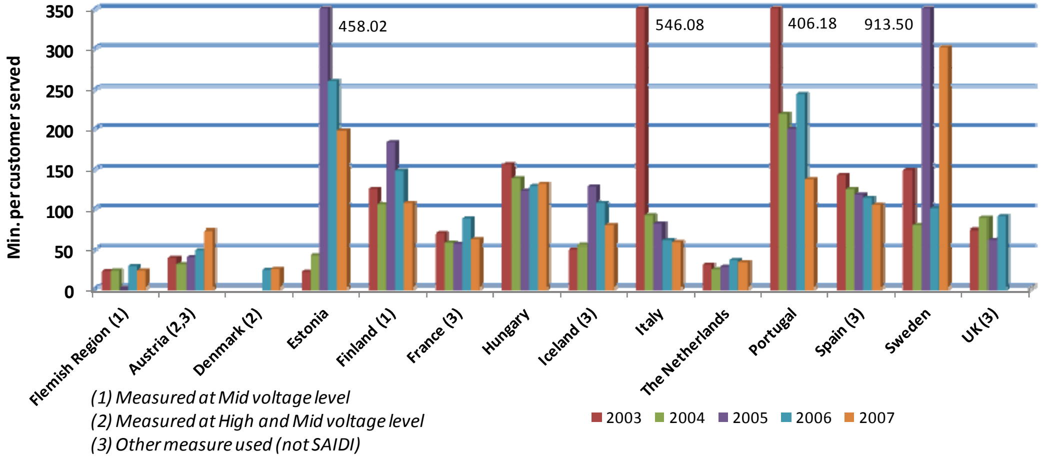
- Research question
- Literature & estimation methods
- The data: survey & choice experiment
- Model specifications
  - Conditional Logit vs. Random Parameters Logit
- WTP estimates
  - Marginal WTP
  - Offering power outage profiles as a private good
- Conclusions

# Research Question

- What is the value of continuous power supply for Flemish Households?
  - How does it depend on power outage characteristics and/or household characteristics?
- Motivation
  - Increased attention for the consequences of (large scale) PO
    - Belgium has good track record → Too good?
  - Are we willing to accept lower reliability levels?
    - Smart grids would allow individualized approach
      - Offer a menu of power outage profiles and let users decide
- Why Flemish households?
  - Household mkt share in electricity consumption: ±30%
  - Flemish Project + cost considerations



# Power System Reliability in Flanders

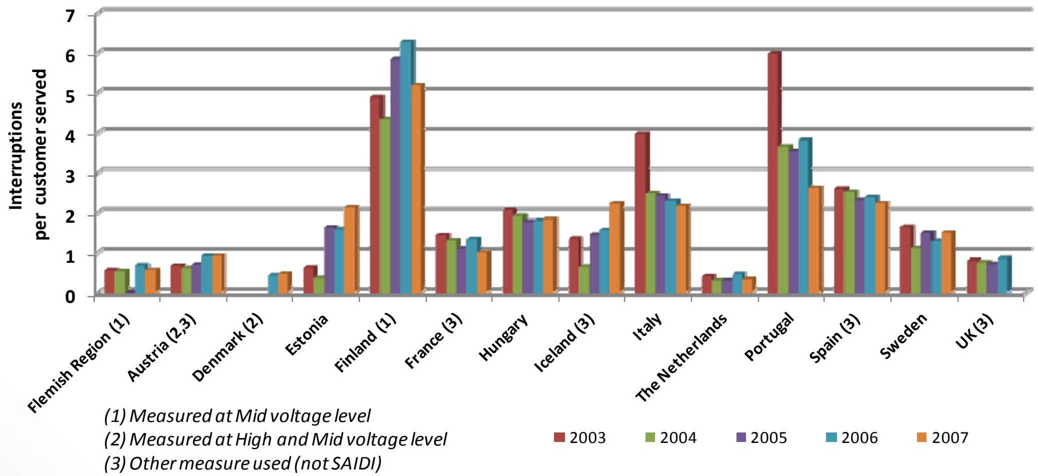



$$SAIDI = \frac{\sum r_i N_i}{N_T}$$

$r_i$ = the duration of interruption *i*

$N_i$ = Number of customers hit by interruption *i*

$N_T$ = Total number of customers served




$$SAIFI = \frac{\sum N_i}{N_T}$$

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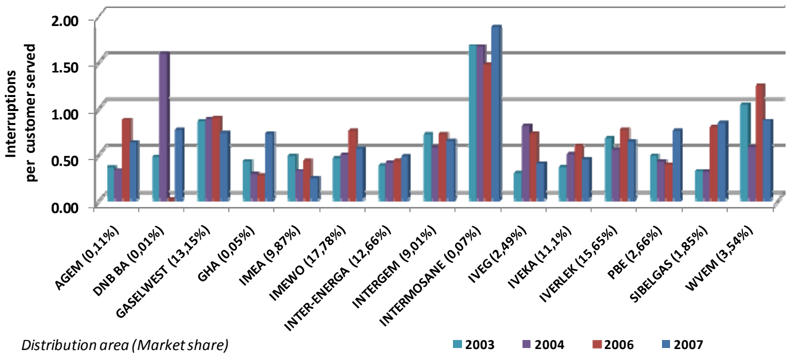
# Power System Reliability in Flanders

- Variability of the SAIFI within Flemish distribution areas is relatively small
  - Data only reflect PO occurring at the mid voltage level
    - LV and HV <u>not</u> included!




| System Average Interruption Duration Index (SAIDI – minutes per customer served) (Sum of all customer interruption durations/total number of customers served) | | | | | | |
|---|---|---|---|---|---|---|
| | **2003** | **2004** | **2005** | **2006** | **2007** | **Average** |
| **Min** | 6,85 | 8,63 | - | 0,00 | 9,08 | 9,60 |
| **Weighted average** | 21,78 | 22,22 | - | 28,22 | 22,19 | 18,88 |
| **Max** | 86,92 | 88,53 | - | 71,00 | 98,65 | 84,15 |
| **Wtd St. Dev.** | 6,87 | 8,64 | - | 11,11 | 8,21 | 8,04 |

| System Average Interruption Frequency Index (SAIFI – interruptions per customer served) (total number of customer interruptions/total number of customers served) | | | | | | |
|---|---|---|---|---|---|---|
| | **2003** | **2004** | **2005** | **2006** | **2007** | **Average** |
| **Min** | 0,280 | 0,271 | - | 0,000 | 0,225 | 0,354 |
| **Weighted average** | 0,555 | 0,527 | - | 0,679 | 0,556 | 0,579 |
| **Max** | 1,655 | 1,646 | - | 1,459 | 1,870 | 1,658 |
| **Wtd St. Dev.** | 0,195 | 0,166 | - | 0,194 | 0,160 | 0,157 |

The data refer to the mid-voltage level. Interruptions at the transmission level and at the low voltage level are not included VREG (2008).

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# Literature & Estimation Methods

- Two basic approaches to estimate value of continuous power supply
  - Within each approach → different methods
    - Use macro data
      - Average kWh tariff, GDP per kWh, wage rate, input-output tables
    - Use micro data
      - Revealed Preferences (RP) → Observe customer behaviour
        - Consumer surplus method
        - Backup power method
        - Subscription load method
      - Stated preferences (SP) → Ask for customer's response under hypothetical scenarios
        - Cost decomposition method
        - Contingent valuation method
        - Choice experiments

# Literature & Estimation Methods

- Empirical literature
  - Older literature mostly applied to non-European countries
    - Usually following a macro or micro-revealed-preferences approach
  - A recent revival
    - The Netherlands
      - Baarsma et al (2004)
        - Micro-SP (Choice experiment)
    - Sweden
      - Carlsson & Martinsson (2008a,2008b)
        - Micro- SP (Choice experiment)
    - Only one estimate found for Belgium
      - Devogelaer and Gusbin (2004), Belgian Planning Bureau
        - Macro (Wage rate approach)
    - ...

# The Data

## The Survey

- Sample of 1488 Flemish households
  - Taken from an 'access panel' (DIMARSO)
- Survey content (41 questions)
  - PO Attitude, PO Perception, PO Experience
  - Valuation questions
    - Contingent valuation, Rating questions
    - Choice experiment questions
  - Socio-demographic information
- Data collection: Nov 2004 – Jan 2005

# The Data

## Choice Experiment

- Describe PO scenario (a profile) in terms of attributes and attribute levels
  - Attributes: Annual frequency of PO , Avg. duration of PO, Season, Timing, Announcement, Bill impact
  - Levels: Different values that an attribute can take
- 216 PO profiles = full factorial design

  ($3^3 \times 2^3 = 216$ PO profiles)
  - Impossible to present all at once → use fractional factorial design
    - All main (9) and two-way interaction effects (33) can be estimated

| | Frequency per year | Avg. Duration per outage | Season | Timing | Announced / Not Announced | Effect on Annual Bill |
|---|---|---|---|---|---|---|
| Attributes → | | | | | | |
| Levels → | 1 | 15 min | Winter | Off-peak | Not Ann. | -10% |
| | 2 | 30 min | Summer | Peak | Announced | No effect |
| | 4 | 4 hours | | | | +10% |
| | 3 | 3 | 2 | 2 | 2 | 3 |

# The Data

## Choice Experiment

- Story told to respondents
  - Electricity firm proposes a set of 4 contracts (= choice set)
    - Each choice set contains 3 contract proposals and a ‘status quo’
    - Each contract proposal contains a description of a PO profile
- Each respondent is faced with 12 choice sets (= 1 Block)
  - Indicates best alternative in each choice set
- 24 different blocks → 24 versions of the survey
  - Each version was answered by 62 respondents
    - 24 x 62 = 1488 respondents
    - 1488 x 12 = 17856 choice sets were evaluated by respondents

# The Data

## Choice Experiment

| Choice Set | Scenario | Freq. | Duration | Season | Peak Off-P. | Announced. | Effect on Bill |
|---|---|---|---|---|---|---|---|
| 1 | 1 | 1 | 15 min. | Summer | Off-P. | No | No change |
| | 2 | 2 | 15 min. | Summer | Off-P. | No | 10% reduction |
| | 3 | 1 | 4 hr. | Winter | Peak | No | 10% increase |
| | 4 | | | | | | You prefer the status quo |
| 2 | 1 | 4 | 15 min. | Winter | Peak | No | 10% reduction |
| | 2 | 2 | 15 min. | Summer | Peak | Yes | 10% reduction |
| | 3 | 4 | 4 hr. | Winter | Off-P. | Yes | No change |
| | 4 | | | | | | You prefer the status quo |
| 3 | 1 | 2 | 30 min. | Summer | Peak | No | 10% reduction |
| | 2 | 4 | 15 min. | Summer | Peak | Yes | 10% increase |
| | 3 | 1 | 15 min. | Summer | Peak | No | 10% reduction |
| | 4 | | | | | | You prefer the status quo |
| 4 | 1 | 4 | 30 min. | Winter | Peak | No | 10% increase |
| | 2 | 1 | 30 min. | Summer | Off-P. | Yes | 10% increase |
| | 3 | 2 | 15 min. | Winter | Off-P. | No | No change |
| | 4 | | | | | | You prefer the status quo |
| 5 | 1 | 1 | 4 hr. | Winter | Peak | Yes | No change |
| | 2 | 2 | 30 min. | Winter | Off-P. | Yes | No change |
| | 3 | 1 | 4 hr. | Winter | Off-P. | No | 10% reduction |
| | 4 | | | | | | You prefer the status quo |

# Model Specifications

- Random utility model $U_{njt} = V_{njt} + \varepsilon_{njt}$
  - At time ***t***, household ***n*** derives utility ***U*** from profile ***j***
    - Partially observed (V), partially unobserved (ε)
      $\Rightarrow$ Only probabilistic statements can be made
- Conditional logit model $P(j|C) = P(U_{njt} > U_{nit},\ \forall i \neq j \in C)$
  - Assumes
    - Homogenous household preferences
    - IIA
    - ε is i.i.d. type I extreme value

$$P_{njt} = \frac{e^{V_{njt}}}{\sum_{i \in C} e^{V_{nit}}}$$

Usually, $V_{njt} = \beta x_{njt}$

- Random parameters logit model
  - Relaxes $V_{njt} = \beta_n x_{njt} = (\beta + \eta_n) x_{njt}$
    - Homogenous preferences to heterogenous preferences
      - Normal distribution for all random parameters $\eta_n \sim N(0, \Sigma_\eta)$
    - IIA
  - Simulation is required to estimate

$$P_{nj} = \int \prod_{t=1}^{T} \frac{e^{\beta x_{nj_t t}}}{\sum_{i \in C} e^{\beta x_{ni_t t}}} f(\eta | 0, \Sigma_\eta) d\eta$$

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# Model Specifications

| *Model* | *Description* |
|---|---|
| **CL Main** | Conditional logit model including alternative specific constants and main effects for all PO attributes. |
| **CL Main & IA** | CL Main **and attribute interactions with attitude, perception, experience and demographic covariates**. |
| **RPL Main & IA** | **Random parameter logit model** including alternative specific constants, main and interaction effects for all PO attributes and attribute interactions with attitude, perception, experience and demographic covariates. |
| **Correlated RPL Main & IA** | **Random parameter logit model** with **correlated random effects** including alternative specific constants, main and interaction effects for all PO attributes and attribute interactions with attitude, perception, experience and demographic covariates. |

$$
\begin{aligned}
U_{it} = {} & \beta_i^C ASC_i \\
& + \left( \beta_0^N + \lambda^{NL} X_{it}^L + \lambda^{NP} X_{it}^P + \lambda^{NS} X_{it}^S + \lambda^{NA} X_{it}^A + \mathbf{A}^N + \mathbf{P}^N + \mathbf{E}^N + \mathbf{D}^N + \eta^N \right) X_{it}^N \\
& + \left( \beta_0^L + \lambda^{LP} X_{it}^P + \lambda^{LS} X_{it}^S + \lambda^{LA} X_{it}^A + \mathbf{A}^L + \mathbf{P}^L + \mathbf{E}^L + \mathbf{D}^L + \eta^L \right) X_{it}^L \\
& + \left( \beta_0^A + \lambda^{AP} X_{it}^P + \lambda^{AS} X_{it}^S + \eta^A \right) X_{it}^A \\
& + \left( \beta_0^P + \lambda^{PS} X_{it}^S + \eta^P \right) X_{it}^P \\
& + \left( \beta_0^S + \eta^S \right) X_{it}^S \\
& + \left( \beta_0^B + \mathbf{A}^B + \mathbf{P}^B + \mathbf{M}^B \right) X_{it}^B \\
& + \varepsilon_{it}
\end{aligned}
$$

$$\eta_n \sim N\left(0, \Sigma_\eta\right)$$

$$
\begin{aligned}
&\mathbf{A}^q = \alpha_1^q A_1^{WTP} + \alpha_2^q A_2^{WTP} + \alpha_3^q A_1^{WTA} + \alpha_4^q A_2^{WTA} && (q = N, L, B) \\
&\mathbf{P}^m = \pi_1^m P_1^{\Pr PO} + \pi_2^m P_3^{\Pr PO} + \pi_3^m P_1^{Expen} + \pi_4^m P_2^{Expen} && (m = N, L, B) \\
&\mathbf{E}^k = \varepsilon_1^k E^{PO} && (k = N, L) \\
&\mathbf{D}^r = \delta_1^r D^{ElHeat} + \delta_2^r D^{Urban} + \delta_3^r D^{60+} + \delta_4^r D^{Home} && (r = N, L) \\
&\mathbf{M}^s = \mu_1^s M^{Lo} + \mu_1^s M^{Mi} + \mu_1^s M^{Hi} && (s = B)
\end{aligned}
$$

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# Model Specifications

| *Variable* | *Description* | *Coding* |
|---|---|---|
| | **Attitudes** | |
| $A_1^{WTP}$ | WTP more if prob. of a power outage would be reduced? | 1=Yes, -1=Don't know, 0=No |
| $A_2^{WTP}$ | WTP more if prob. of a power outage would be reduced? | 1=No, -1=Don't know, 0=Yes |
| $A_1^{WTA}$ | WTA more power outages if electricity bill would decrease? | 1=Yes, -1=Don't know, 0=No |
| $A_2^{WTA}$ | WTA more power outages if electricity bill would decrease? | 1=No, -1=Don't know, 0=Yes |
| | **Perception** | |
| $P_1^{Pr\,PO}$ | In your opinion, would you expect future probability of PO to… | 1= Decrease, -1= No change, 0=Increase |
| $P_3^{Pr\,PO}$ | In your opinion, would you expect future probability of PO to… | 1= Increase, -1= No change, 0=Decrease |
| $P_1^{Expen}$ | Perceived level of the current electricity bill | 1=Very low to avg., -1=No opinion, 0=High to very high |
| $P_2^{Expen}$ | Perceived level of the current electricity bill | 1=High to very high, -1=No opinion, 0=Very low to avg. |
| | **Experience** | |
| $E^{PO}$ | Did you experience power outages over the past 2 years? | 1=Yes, -1= No |
| | **Socio - demographics** | |
| $D^{60+}$ | Respondent is older than 60 | 1= $60^+$, -1=younger than 60 |
| $D^{ElHeat}$ | Household mainly uses electric heating | 1=Electr. heating, -1=No electr. heating |
| $D^{Urban}$ | Household lives in urban area | 1=Urban, -1=Rural |
| $D^{Home}$ | Respondent spends at lot of time at home | 1= Usually at home, -1=Usually not at home |
| | **Income** | |
| $M^{Lo}$ | Household reports low income | 1 = Inc. in 1st Q., -1= Unknown, 0=Inc. not in 1st Q. |
| $M^{Mi}$ | Household reports medium income | 1 = Inc. in 2nd or 3rd Q., -1= Unknown, 0=Inc. not in 2nd or 3rd Q. |
| $M^{Hi}$ | Household reports high income | 1 = Inc. in 4th Q., -1= Unknown, 0 = Inc. not in 4th Q. |

# Estimation Results

## Attribute Main Effects

| | CL - Main effects | | RPL - Main & IA | | Corr. RPL - Main & IA | |
|---|---|---|---|---|---|---|
| Variable | Coefficient | SE | Coefficient | SE | Coefficient | SE |
| **ASC1** | -1,419296*** | 0,086609 | -0,628605*** | 0,119857 | -1,042827*** | 0,116705 |
| **ASC2** | -1,422683*** | 0,084281 | -0,652804*** | 0,119347 | -1,074515*** | 0,116868 |
| **ASC3** | -1,518399*** | 0,085904 | -0,740571*** | 0,118857 | -1,143159*** | 0,116114 |
| **Frequency** | -0,269694*** | 0,022368 | -2,841582*** | 0,303992 | -1,372221*** | 0,200373 |
| ***St. Dev.*** | | | 2,559336*** | 0,164455 | | |
| **Duration** | -0,006207*** | 0,000388 | -0,018071*** | 0,003070 | -0,022796*** | 0,003403 |
| ***St. Dev.*** | | | 0,007634*** | 0,000665 | | |
| **Pop (Peak=1)** | -0,154258*** | 0,022827 | -0,178304*** | 0,063510 | -0,408935*** | 0,076412 |
| ***St. Dev.*** | | | 0,413317*** | 0,044500 | | |
| **Sea (Summer=1)** | 0,212124*** | 0,024574 | 0,126111* | 0,066132 | -0,052745 | 0,076181 |
| ***St. Dev.*** | | | -0,533442*** | 0,043185 | | |
| **Ann (Ann=1)** | 0,118537*** | 0,022926 | 0,053013 | 0,064149 | -0,137118* | 0,073546 |
| ***St. Dev.*** | | | 0,439379*** | 0,045168 | | |
| **Bill** | -0,015293*** | 0,001210 | -0,026868*** | 0,003193 | -0,028001*** | 0,003359 |

*, **, *** significant at 90%, 95% and 99% confidence. level respectively.

| | | | |
|---|---|---|---|
| **Df** | 9 | 61 | 71 |
| **N** | 32408 | 32408 | 32408 |
| **Wald chi2** | 1130,19*** | | |
| **LR chi2** | | 2642,05 | 3.025,526 |
| **Pseudo LL** | -6847,92 | -5251,02 | -5.059,279 |
| **AIC** | 13713,85 | 10624,03 | 10260,56 |
| **BIC** | 13789,32 | 11135,59 | 10855,98 |

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# Estimation Results

## Attribute Interaction Effects

| | *CL - Main effects* | | *RPL - Main & IA* | | *Corr. RPL - Main & IA* | |
|---|---|---|---|---|---|---|
| **Variable** | **Coefficient** | **SE** | **Coefficient** | **SE** | **Coefficient** | **SE** |
| **Freq x Pop** | | | -0,011984 | 0,025077 | -0,044793* | 0,025895 |
| **Freq x Sea** | | | 0,024097 | 0,025252 | -0,030522 | 0,025009 |
| **Freq x Ann** | | | 0,041186* | 0,024577 | -0,009883 | 0,024739 |
| **Freq x Dur** | | | -0,000181 | 0,000312 | -0,000649** | 0,000321 |
| **Dur x Pop** | | | -0,001295*** | 0,000364 | -0,001627*** | 0,000377 |
| **Dur x Sea** | | | 0,000798** | 0,000366 | 0,000542 | 0,000387 |
| **Dur x Ann** | | | 0,000019 | 0,000354 | -0,000207 | 0,000366 |
| **Ann x Sea** | | | 0,016145 | 0,028911 | -0,030903 | 0,029154 |
| **Ann x Pop** | | | -0,004051 | 0,028076 | -0,056279*** | 0,028269 |
| **Pop x Sea** | | | -0,007949 | 0,028874 | -0,033419 | 0,029012 |

*, **, *** significant at 90%, 95% and 99% confidence. level respectively.

| | **Freq** | **Dur** | **Pop** | **Sea** | **Ann** |
|---|---|---|---|---|---|
| **Freq** | -0,621512***<br>*0,071583* | | | | |
| **Dur** | -0,004439***<br>*0,000826* | 0,005559***<br>*0,000899* | | | |
| **Pop** | 0,866326***<br>*0,089446* | 0,007140***<br>*0,001336* | 0,627036***<br>*0,060118* | | |
| **Sea** | 0,296505***<br>*0,079529* | 0,001386<br>*0,000929* | 0,509056***<br>*0,067407* | 0,519938***<br>*0,059378* | |
| **Ann** | 0,083398<br>*0,063374* | -0,002420**<br>*0,000940* | 0,553716***<br>*0,060799* | 0,115884*<br>*0,062248* | 0,234631***<br>*0,061421* |

**Choleski matrix *(corr. RPL – Main & IA)***

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# Estimation Results

## Interactions With Attitude and Perception Covariates

| | *CL - Main effects* | | *RPL - Main & IA* | | *Corr. RPL - Main & IA* | |
|---|---|---|---|---|---|---|
| **Variable** | **Coefficient** | **SE** | **Coefficient** | **SE** | **Coefficient** | **SE** |
| **AWTP_Yes x Freq** | | | 0,040615 | 0,132427 | 0,054951 | 0,121048 |
| **AWTP_No x Freq** | | | 0,042377 | 0,095865 | 0,179286** | 0,090953 |
| **AWTP_Yes x Dur** | | | -0,001715 | 0,001365 | -0,002866* | 0,001692 |
| **AWTP_No x Dur** | | | -0,000030 | 0,000910 | 0,002028 | 0,001274 |
| **AWTP_Yes x Bill** | | | 0,004574*** | 0,001670 | 0,004982*** | 0,001706 |
| **AWTP_No x Bill** | | | -0,003086*** | 0,001160 | -0,003260*** | 0,001211 |
| **AWTA_Yes x Freq** | | | 1,043679*** | 0,140701 | 0,226552*** | 0,079009 |
| **AWTA_No x Freq** | | | -0,585541*** | 0,096204 | -0,149094** | 0,070428 |
| **AWTA_Yes x Dur** | | | 0,002110** | 0,000945 | 0,002162** | 0,000994 |
| **AWTA_No x Dur** | | | -0,000932 | 0,000778 | -0,000464 | 0,000926 |
| **AWTA_Yes x Bill** | | | -0,005581*** | 0,001299 | -0,006519*** | 0,001345 |
| **AWTA_No x Bill** | | | -0,000536 | 0,001013 | 0,000209 | 0,001058 |
| **PPrPO_Dec x Freq** | | | -0,378081*** | 0,138458 | -0,065729 | 0,115956 |
| **PPrPO_Inc x Freq** | | | 0,324712** | 0,135552 | 0,023272 | 0,087224 |
| **PPrPO_Dec x Dur** | | | -0,000432 | 0,001223 | -0,001172 | 0,001408 |
| **PPrPO_Inc x Dur** | | | 0,000306 | 0,001023 | 0,001262 | 0,001164 |
| **PPrPO_Dec x Bill** | | | 0,006395*** | 0,001541 | 0,005644*** | 0,001559 |
| **PPrPO_Inc x Bill** | | | -0,004591*** | 0,001385 | -0,003774*** | 0,001416 |
| **PExpEn_Lo x Freq** | | | -0,474790** | 0,228002 | -0,078680 | 0,157635 |
| **PExpEn_Hi x Freq** | | | -0,554279** | 0,227802 | -0,103014 | 0,157789 |
| **PExpEn_Lo x Dur** | | | 0,004392 | 0,002850 | 0,004964 | 0,003035 |
| **PExpEn_Hi x Dur** | | | 0,005836** | 0,002849 | 0,005782* | 0,003033 |
| **PExpEn_Lo x Bill** | | | 0,002364 | 0,002891 | 0,002574 | 0,003047 |
| **PExpEn_Hi x Bill** | | | 0,004559 | 0,002898 | 0,005271* | 0,003046 |

*, **, *** significant at 90%, 95% and 99% confidence. level respectively.

# Estimation Results

## Interactions With Experience and Socio-Demographic Covariates

| | *CL - Main effects* | | *RPL - Main & IA* | | *Corr. RPL - Main & IA* | |
|---|---|---|---|---|---|---|
| **Variable** | **Coefficient** | **SE** | **Coefficient** | **SE** | **Coefficient** | **SE** |
| **ExperPO x Freq** | | | 0,881406*** | 0,088353 | 0,039156 | 0,065798 |
| **ExperPO x Dur** | | | -0,000589 | 0,000735 | -0,000638 | 0,000937 |
| **DAge x Freq** | | | -0,657868*** | 0,104584 | -0,034492 | 0,081315 |
| **DAge x Dur** | | | 0,000640 | 0,000779 | 0,002406** | 0,001029 |
| **DElecHeat x Freq** | | | -0,294690*** | 0,075717 | -0,146351* | 0,076959 |
| **DElecHeat x Dur** | | | -0,002329*** | 0,000740 | -0,001745* | 0,000908 |
| **Durban x Freq** | | | -0,167396*** | 0,060594 | -0,011949 | 0,055837 |
| **Durban x Dur** | | | -0,000249 | 0,000537 | -0,000903 | 0,000666 |
| **D@Home x Freq** | | | -0,317318*** | 0,101996 | 0,018082 | 0,060223 |
| **D@Home x Dur** | | | -0,000058 | 0,000708 | -0,001043 | 0,000823 |
| **MIncLo x Bill** | | | -0,007300*** | 0,001676 | -0,007884*** | 0,001740 |
| **MIncMi x Bill** | | | -0,001977 | 0,001275 | -0,001863 | 0,001318 |
| **MIncHi x Bill** | | | 0,003894*** | 0,001379 | 0,004593*** | 0,001429 |

*, **, *** significant at 90%, 95% and 99% confidence. level respectively.

# WTP Estimates

- Marginal WTP for an attribute change

$$WTP_q = -\frac{\partial U / \partial X^q}{\partial U / \partial X^B} \Rightarrow \begin{cases} WTP_q = -\dfrac{\left(\beta_0^q + \eta^q\right) + \left(\sum\limits_{\substack{m \in \{N,L,A,P,S\} \\ m \neq q}} \lambda^{qm} X^m\right) + \mathbf{A}^q + \mathbf{P}^q + \mathbf{E}^q + \mathbf{D}^q}{\beta_0^B + \mathbf{A}^B + \mathbf{P}^B + \mathbf{M}^B} & (q = N, L) \\ WTP_q = -2 \times \left\{ \dfrac{\left(\beta_0^q + \eta^q\right) + \sum\limits_{\substack{m \in \{N,L,A,P,S\} \\ m \neq q}} \lambda^{qm} X^m}{\beta_0^B + \mathbf{A}^B + \mathbf{P}^B + \mathbf{M}^B} \right\} & (q = A, P, S) \end{cases}$$

- Change in consumer surplus (McFadden (1973))
  - To compare 2 or more profiles

$$\Delta E\left(CS_n\right) = \frac{1}{\beta_0^B + \mathbf{A}^B + \mathbf{P}^B + \mathbf{M}^B} \left\{ \ln\left(\sum_{j \in C_{After}} e^{V_{nj}^{After}}\right) - \ln\left(\sum_{j \in C_{Before}} e^{V_{nj}^{Before}}\right) \right\}$$

$$\Delta E\left(CS_n\right) = \frac{1}{\beta_0^B + \mathbf{A}^B + \mathbf{P}^B + \mathbf{M}^B} \left\{ V_{nj}^{After} - V_{ni}^{Before} \right\}$$

(comparing 2 profiles *i* and *j*)

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# WTP Estimates

- Reference Household

| Attitudes, Perception, Experience & Socio-economic variables | Reference |
|---|---|
| Is the respondent WTP for reduced probabilities of POs? | No |
| Is the respondent WTA more POs in return for a lower bill | No |
| Does the respondent expect a change in the future probability of a PO? | No change |
| How does the respondent evaluate the level of his/her electricity bill? | Very low to average |
| Did the respondent experience at least one PO within the past two years? | Yes |
| Does the respondent use electric heating to heat the house? | No |
| Does the respondent live in a rural or an urban area? | Urban |
| Is the respondent older or younger than 61? | 60- |
| Does the respondent spend most of his/her time at home? | No |
| What is the respondent's income level? | High income |
| **Attribute** | |
| Annual number of power outages | 0,5 per year |
| Average duration of a power outage | 20 minutes |
| Peak / Off-peak | -1 (off-peak) |
| Season | -1 (winter) |
| Announced / Unannounced | -1 (unannounced) |
| Annual Bill (euro) | €600 per year |

# WTP Estimates

## Marginal WTP values

| Reference CL – Main effects | | | | | |
|---|---|---|---|---|---|
| | **Off-peak → Peak** | **Winter → Summer** | **Not Ann. → Ann.** | **Add. outage** | **1 extra minute** |
| *Point estimate* | -20,17 | 27,74 | 15,50 | -17,64 | -0,41 |
| **Reference correlated RPL** | | | | | |
| | **Off-peak → Peak** | **Winter → Summer** | **Not Ann. → Ann.** | **Add. outage** | **1 extra minute** |
| *Mean* | -29,03 | 0,98 | -4,58 | -43,44 | -0,65 |
| *90% Conf, Interval* | (-110,62 up to 51,33) | (-93,43 up to 94,98) | (-84,9 up to 75,31) | (-116,84 up to 28,67) | (-1,36 up to 0,04) |
| *% positive* | 27,6% | 50,8% | 46,3% | 16,0% | 6,2% |
| **Medium Income** | | | | | |
| | **Off-peak → Peak** | **Winter → Summer** | **Not Ann. → Ann.** | **Add. outage** | **1 extra minute** |
| *Mean* | -23,16 | 0,78 | -3,66 | -34,67 | -0,52 |
| *90% Conf, Interval* | (-88,12 up to 40,98) | (-74,45 up to 75,8) | (-67,72 up to 60,07) | (-92,93 up to 22,93) | (-1,08 up to 0,03) |
| *% positive* | 27,6% | 50,8% | 46,3% | 16,0% | 6,2% |
| **Low Income** | | | | | |
| | **Off-peak → Peak** | **Winter → Summer** | **Not Ann. → Ann.** | **Add. outage** | **1 extra minute** |
| *Mean* | -19,57 | 0,65 | -3,09 | -29,30 | -0,44 |
| *90% Conf, Interval* | (-74,44 up to 34,63) | (-62,98 up to 64,01) | (-57,24 up to 50,7) | (-78,59 up to 19,34) | (-0,91 up to 0,03) |
| *% positive* | 27,6% | 50,8% | 46,3% | 16,0% | 6,2% |
| **Households claiming to be WTP for a reduction of PO probability** | | | | | |
| | **Off-peak → Peak** | **Winter → Summer** | **Not Ann. → Ann.** | **Add. outage** | **1 extra minute** |
| *Mean* | -43,50 | 1,52 | -6,91 | -72,74 | -1,25 |
| *90% Conf, Interval* | (-168,3 up to 76,75) | (-140,55 up to 143,28) | (-128,41 up to 113,22) | (-188,1 up to 35,96) | (-2,43 up to -0,19) |
| *% positive* | 27,6% | 50,8% | 46,3% | 13,6% | 2,6% |
| **Households is WTA more power outages in return for a lower bill** | | | | | |
| | **Off-peak → Peak** | **Winter → Summer** | **Not Ann. → Ann.** | **Add. outage** | **1 extra minute** |
| *Mean* | -23,01 | 0,76 | -3,64 | -22,83 | -0,43 |
| *90% Conf, Interval* | (-87,68 up to 40,68) | (-74,12 up to 75,28) | (-67,39 up to 59,63) | (-80,98 up to 34,6) | (-1 up to 0,12) |
| *% positive* | 27,6% | 50,8% | 46,3% | 25,6% | 9,8% |
| **An decrease in the PO probability is expected** | | | | | |
| | **Off-peak → Peak** | **Winter → Summer** | **Not Ann. → Ann.** | **Add. outage** | **1 extra minute** |
| *Mean* | -41,93 | 1,35 | -6,65 | -68,64 | -0,99 |
| *90% Conf, Interval* | (-162,35 up to 73,63) | (-135,52 up to 137,7) | (-123,46 up to 108,78) | (-178,74 up to 35,72) | (-2,09 up to 0,01) |
| *% positive* | 27,6% | 50,8% | 46,3% | 14,0% | 5,2% |
| **An increase in the PO probability is expected** | | | | | |
| | **Off-peak → Peak** | **Winter → Summer** | **Not Ann. → Ann.** | **Add. outage** | **1 extra minute** |
| *Mean* | -27,16 | 0,92 | -4,30 | -41,48 | -0,56 |
| *90% Conf, Interval* | (-103,72 up to 48,04) | (-87,43 up to 88,94) | (-79,5 up to 70,35) | (-110,43 up to 26,05) | (-1,23 up to 0,09) |
| *% positive* | 27,6% | 50,8% | 46,3% | 15,6% | 7,9% |

Confidence intervals are produced using the Krinsky Robb method with 1000 random draws (See Hensher and Greene (2003) and Hole (2007)).

# WTP Estimates

## Offering a Menu of Power Outage Profiles

| Contract | Frequency of outages per year | Average duration of one outage | Peak/off-peak | Season | Announcement | Bill |
|---|---|---|---|---|---|---|
| **C1 (Status Quo)** | 0.50 | 20 min | Off-peak | Winter | Not ann. | 600 |
| **C2** | 1.00 | 20 min | Off-peak | Winter | Not ann. | 570 |
| **C3** | 2.00 | 20 min | Off-peak | Winter | Not ann. | 540 |
| **C4** | 0.25 | 20 min | Off-peak | Winter | Not ann. | 630 |
| **C5** | 0.25 | 40 min | Off-peak | Winter | Not ann. | 600 |
| **C6** | 0.50 | 10 min | Off-peak | Winter | Not ann. | 630 |
| **C7** | 0.50 | 40 min | Off-peak | Winter | Not ann. | 570 |
| **C8** | 0.50 | 60 min | Off-peak | Winter | Not ann. | 540 |
| **C9** | 0.25 | 10 min | Off-peak | Winter | Not ann. | 660 |
| **C10** | 1.00 | 40 min | Off-peak | Winter | Not ann. | 540 |

| | | C1 | C2 | C3 | C4 | C5 | C6 | C7 | C8 | C9 | c10 | ΔCS | %ΔRef |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | ***Bill*** | ***600*** | ***570*** | ***540*** | ***630*** | ***600*** | ***630*** | ***570*** | ***540*** | ***660*** | ***540*** | | |
| **Ref. household (CLM Main)** | Avg | 27,9 | 9,0 | 10,9 | 4,4 | 6,1 | 4,4 | 9,1 | 12,7 | 3,0 | 12,6 | -66,97 | |
| | (Lo /Up ) | - | - | - | - | - | - | - | - | - | - | - | |
| **Ref. household** | Avg | 21,0 | 8,4 | 11,6 | 4,9 | 7,0 | 4,0 | 10,5 | 16,4 | 2,8 | 13,5 | -26,0 | - |
| | (Lo /Up ) | (8,3/31,1) | (4,7/11,1) | (0,5/40,9) | (1,1/9,9) | (2,2/11,6) | (1,3/6,8) | (5,8/13) | (9,7/23,1) | (0,5/6,4) | (5,6/19,5) | (-45,4/7) | |
| **Medium Income class** | Avg | 17,8 | 8,4 | 13,2 | 3,4 | 5,9 | 2,8 | 10,7 | 20,0 | 1,7 | 16,1 | -14,9 | 42,9% |
| | (Lo /Up ) | (4,5/25,6) | (5,2/10,5) | (0,9/46,9) | (0,4/5,7) | (1,2/9,5) | (0,5/3,9) | (4,6/14,1) | (12,8/32,3) | (0,1/2,6) | (9,7/23,9) | (-25,2/20,8) | |
| **Low Income class** | Avg | 14,8 | 8,1 | 14,6 | 2,4 | 5,0 | 2,0 | 10,5 | 23,3 | 1,0 | 18,4 | -7,1 | 72,8% |
| | (Lo /Up ) | (4,5/25,6) | (5,2/10,5) | (0,9/46,9) | (0,4/5,7) | (1,2/9,5) | (0,5/3,9) | (4,6/14,1) | (12,8/32,3) | (0,1/2,6) | (9,7/23,9) | (-25,2/20,8) | |
| **WTP for red. prob. PO** | Avg | 25,8 | 8,0 | 8,7 | 7,7 | 8,0 | 6,6 | 9,4 | 10,6 | 6,0 | 9,3 | -53,3 | -104,7% |
| | (Lo /Up ) | (13,3/33,7) | (3,6/11,5) | (0,3/33,6) | (2,3/13,9) | (3,3/11,9) | (2,8/9,9) | (6,3/11,5) | (5,7/16,1) | (1,4/12,3) | (3,0/15,8) | (-81,0/-15,7) | |
| **WTA more PO for lower Bill** | Avg | 15,5 | 8,6 | 18,1 | 2,8 | 5,0 | 2,4 | 9,8 | 19,3 | 1,3 | 17,3 | -9,5 | 63,6% |
| | (Lo /Up ) | (4,2/27,1) | (5,3/10,9) | (1,2/55,1) | (0,4/6,5) | (1,1/9,7) | (0,5/4,8) | (3,8/13,5) | (9,5/27,9) | (0,2/3,4) | (9,1/22,3) | (-31,3/26,4) | |
| **Likel. of decr. in prob. PO** | Avg | 24,7 | 7,9 | 8,7 | 7,2 | 8,2 | 5,9 | 9,8 | 12,2 | 5,3 | 10,0 | -48,4 | 86,0% |
| | (Lo /Up ) | (12,4/32,8) | (3,7/11,1) | (0,3/33,6) | (2,1/13,2) | (3,3/12,4) | (2,4/9,1) | (6,6/12) | (6,7/18,3) | (1,2/11,1) | (3,3/16,6) | (-75,2/-11,3) | |

# Conclusions

- Estimate results are in line with expectations
- Heterogeneous preferences
  - Are important in explaining WTP for continuous power supply
    - The RPL dominates the conditional logit model
  - Distribution of means depend on observable characteristics
- Estimates are higher than reported in other studies
  - Why?
  - Non-negligible share of the population is willing to accept more or longer PO in return for relatively small compensation
- Topic for future research
  - Validation of results (e.g. contingent valuation information)
  - Using log-normal distributions for Frequency and Duration