A generalized multinomial logit model for the preferences of Swiss households towards the risk of an electricity blackout

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Overview

Preliminary analysis, feedbacks more than welcome!

1. Background & Goals
2. Choice experiment
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The Swiss nuclear phase-out and long-term energy policy

In the aftermath of the Fukushima nuclear accident (2011), Switzerland decided to gradually withdraw from the use of nuclear energy (16% of electricity generation capacity, 35%-40% of net electricity generation)

In order to phase-out nuclear without endangering the security, sustainability, and affordability of electricity supplies, the Swiss electric system needs to be restructured:

- Generation capacity
- Transmission and distribution grids

New challenges and new approaches to SOS

The spreading of distributed and/or intermittent renewable-based plants (wind, solar pv, ...) and the decommissioning of large, programmable generation plants (nuclear) could hinder the functioning of distribution and transmission grids, and threaten the security of electricity supplies (SOS) to end consumers.

SOS was traditionally regarded as a technical problem for the vertically integrated monopolist (supply side) and as a public good that to which all consumers were entitled (demand side).

In recent years the development of smart technologies, that make selective interructions possible, has paved the way for demand response. Demand response may be used to efficiently manage demand/supply imbalances (supply side), by efficiently rationing supplies to those consumers that place a lower value on the SOS (demand side).

Research question

- What is the optimal amount of resources that should be invested in grid upgradings to preserve/improve current SOS levels?
- What discount would consumers ask in order to provide demand response?

We would like to measure:

1. The willingness-to-pay (WTP) of Swiss households for SOS, as measured by the frequency and duration of:
   - Long blackouts (4 hours)
   - Short blackouts (5 minutes)
2. While accounting for the preferences of Swiss households toward selected generation technologies:
   - Nuclear, wind, hydro, solar, and an unspecified generation mix with an increasing share of unspecified renewables

Methodological background

We opted for a discrete choice experiment:

- Extensively used in research related to energy provision/consumption and environmental preservation
- Useful when the good is not traded on a market
- Suitable to investigate discrepancies between WTP and willingness-to-accept (WTA)

The survey

The choice experiment was administered via a web-based survey, collecting additional information on demographic, behavioural and attitudinal variables.

Before starting the choice experiment, a short text described the share of each primary energy source used for generation in Switzerland, as well as the current electricity prices for households and the average probability of experiencing long (4 hours) and short (5 minutes) blackouts.

The survey was administered to a stratified sample of $\sim$2700 respondents, of which 1006 validly completed the task.

The discrete choice experiment (1)

What electricity contract would you be ready to sign for your own dwelling?

- 5 labelled alternatives
- 4 attributes
- Attribute levels: see table (red circle ⇒ current levels):

		Alternatives				
		Nuclear	Mix	Hydroelectric	Sun	Wind
Attributes	Price (CHF cent/kWh)	14.5, 18, 21, 24, 27.5, 50	14.5, 18, 21, 24, 27.5, 50	18, 21, 24, 27.5, 50	21, 24 ,27.5, 50	18, 21, 24, 27.5, 50
	Nr of 5-minute-long blackouts per year	0, 0.25, 1, 4				
	Nr of 4-hours-long blackouts per year	0, 0.25, 1, 4				
	% of electricity from renewable energy sources		40, 60, 80, 100			

The discrete choice experiment (2)

- The choice tasks were defined through efficient design with blocking
- The design was obtained as an average of a random parameter and an error component specification
- The design was corrected with the preliminary estimates resulting from a pilot on 10% of the final sample

Econometric framework

Following Fiebig (2010), we estimated three models, starting from the general framework:

$$U_{ijt} = ASC_j + \beta'_{ij} x_{jt} + \frac{\epsilon_{ijt}}{\sigma_i}$$

(i → respondents, j → alternatives, t → choice tasks)
and gradually relaxing some of the assumptions:

1. A multiniomial logit (MNL) model: $\beta_{ij} = \beta_j$; ϵ_{ijt} type 1 E.V. with $E[\epsilon_{ijt}] = 0$ and $VAR[\epsilon_{ijt}] = \frac{\pi^2}{6}$; $\sigma_i = 1$
2. A random parameter (RP) multinomial logit model: MNL with taste heterogeneity through $\beta_j = \beta_j + \eta_j$, $\eta_j \sim N(0, \Sigma_{\eta_j})$
3. A generalized multinomial logit (GMNL) model: $U_{ijt} = \sigma_i ASC_j + [\sigma_i \beta_j + \gamma \eta_{ij} + (1-\gamma)\sigma_i \eta_{ij}]' x_{jt} + \epsilon_{ijt}$, with: $\eta_j \sim N(0; \Sigma_{\eta_j})$; $\gamma \in [0; 1]$; $\sigma_i = exp(\bar{\sigma} + \tau \varepsilon_{0,i})$; $\varepsilon_{0,i} \sim i.i.d.\ N(0; 1)$; $\bar{\sigma} = -\frac{\tau^2}{2} \Rightarrow E[\sigma_i] = 1$ to help identification

The GMNL model

In the GMNL model:

$$U_{ijt} = \sigma_i ASC_j + [\sigma_i \beta_j + \gamma \eta_{ij} + (1-\gamma)\sigma_i \eta_{ij}]' x_{jt} + \epsilon_{ijt}$$

- $\sigma_i = exp(\bar{\sigma} + \tau \varepsilon_{0,i})$ stands for scale heterogeneity: if $\tau \neq 0$, the model detects significant scale heterogeneity
- η_{ij} stands for taste heterogeneity

The parameter γ governs "*how the variance of residual taste heterogeneity varies with scale in a model that includes both*":

- $\gamma \to 0$ implies that the β_js have proportionally different means and standard deviations
- $\gamma \to 1$ implies that the β_js have different means, but equal standard deviations

Model specification (1)

The variables we included in the analysis are the alternatives' attributes:

- ASC_{source}, with $ASC_{mix} = 0$
- Prices enter in a linear form, with alternative-specific price coefficients: β_{price_source}
- The (short and long, more frequent or less frequent) blackout attributes are included linearly, as percentage variations with respect to the current level (0.25, i.e. 1 short/long blackout every 4 years): e.g.

$$sb = -\frac{nr.\ short\ blackouts\ -\ 0.25}{0.25}$$

Model specification (2)

- Increases and decreases in the frequency of short and long blackouts are included as separate variables, so that we can estimate the WTA for avoiding an increase in the frequency of blackouts, and the WTP for reducing the frequency of blackouts wrt. current levels
- Hence, for each kind of blackout we have two variables:
  - Decreased frequency of short/long blackouts, ranging from 0 (base level) to 1 (0 short/long blackouts per year)
  - Increased frequency of short/long blackouts, ranging from -15 (4 short/long blackouts per year) 0 (base level)
- Long and short blackouts have alternative-specific coefficients: e.g. $\beta_{long\ blackouts\_more\ frequent\_source}$
- Long and short blackouts coefficients are randomized in the RP and GMNL specifications

ASCs, price coefficients, τ (1)

The results of our estimates are mostly consistent across the three specifications, and of the expected sign and magnitude.

- The ASCs show that consumers prefer, ceteris paribus, renewable energy sources over nuclear and mix
- The price coefficients partially counterbalance this ordering
- The coefficient for the percentage of renewable-based supply in the mix alternative is positive and significant, confirming the preferences for renewables even if the kind of primary source is not specified

ASCs, price coefficients, τ (2)

Both the RP and the GMNL models detect significant heterogeneity in consumers' preferences:

- RP model: the standard deviations of the long and short blackouts coefficients are mostly significant
- GMNL model:
  - The τ scale parameter is significant
  - As the γ parameter resulted very close to 1, we decided to fix its value: $\gamma = 1$
  - Hence, the GMNL model detects significant scale heterogeneity, and suggests that this heterogeneity mostly affects the βs' averages

ASCs, price coefficients, τ (3)

	MNL	RP	GMNL, gamma = 1
ASC_hydro	0.881**	0.784**	0.555**
ASC_mix	0 (fixed)	0 (fixed)	0 (fixed)
ASC_nuclear	-0.591*	0.306	0.130
ASC_sun	0.486**	0.996**	1.134**
ASC_wind	1.03**	1.21**	1.606**
Beta_price_hydro	-0.058**	-0.066**	-0.078**
Beta_price_mix	-0.059**	-0.091**	-0.121**
Beta_price_nuclear	-0.088**	-0.133**	-0.186**
Beta_price_sun	-0.048**	-0.071**	-0.092**
Beta_price_wind	-0.076**	-0.101**	-0.118**
Beta_res_mix	0.937**	1.47**	1.718**
Tau			0.73**
Gamma			1 (fixed)

* $p < 0.05$, ** $p < 0.01$

Short and long blackouts (1)

We present the results concerning the coefficients for short and long blackouts in WTP/WTA terms, in order to compare their magnitude with electricity prices and with similar studies.

According to our estimates:

- The WTA for avoiding an increase in the number of blackouts is always negative, as expected: consumers strongly object any worsening wrt. current SOS levels
- The WTP for further increasing the SOS shows mixed signs. Swiss consumers already enjoy very high levels of SOS, and the marginal value of security improvements is decreasing for increasing levels of security
- Different energy sources are associated with different WTA and WTP values in all models. Renewables are usually associated with higher WTA values

Short and long blackouts (2)

The average "value of security" we estimate is around 3% of 2014 electricity prices for short blackouts, and 12% for long blackouts. These values are in line with comparable estimates.

	MNL		RP				GMNL, gamma = 1			
	WTP	WTA	WTP		WTA		WTP		WTA	
	Mean	Mean	Mean	Std.Dev.	Mean	Std.Dev.	Mean	Std.Dev.	Mean	Std.Dev.
Short interruption										
Hydro	3.39**	-0.75**	0.39	6.19	-0.86**	0.43	-1.22	4.96**	-0.60**	1.02**
Mix	-4.29**	-0.16*	-1.97	11.73**	-0.34**	1.22**	-2.45**	8.57**	-0.39**	1.25**
Nuclear	-0.41	-0.43**	16.92**	21.65**	-0.86**	0.95**	4.71**	10.85**	-0.19**	0.28**
Sun	3.78**	-0.93**	7.31**	17.09**	-1.03**	1.20**	1.53	10.27**	-0.69**	1.02**
Wind	-5.71**	-0.36**	3.97**	4.04	-0.75**	0.73**	-1.21	3.65**	-0.73**	0.51**
Long interruption										
Hydro	0.38	-2.02**	4.37**	3.79	-4.08**	2.50**	-0.85	0.90	-2.55*	0.47**
Mix	1.13	-1.31**	3.96**	13.1**	-1.88**	2.12**	2.57**	10.09**	-1.52**	1.12**
Nuclear	-4.21**	-0.54**	3.24	4.78**	-5.05**	3.43**	0.24**	3.35**	-2.01**	1.04**
Sun	-5.91**	-2.03**	2.98	12.54**	-5.04**	3.71**	0.92	9.20**	-3.49**	1.92**
Wind	2.37**	-2.26**	3.80*	11.68**	-2.51**	0.94	1.59	6.87**	-2.06**	0.19

* $p < 0.05$, ** $p < 0.01$

As price coefficients all have ** significance levels, the significance level for WTP and WTA values correspond to those of the estimated *sb* and *lb* coefficients and their standard deviations. WTP and WTA values are computed as ratios between the interruption coefficient and the price coefficient for the same alternative.

Measures of fit

	MNL	RP	GMNL, gamma = 1
Loglikelihood	-8813.9	-7968.7	-8032.4
Adj. R squared	0.220	0.292	0.287
AIC	17687.8	16037.5	16166.7
BIC	17835.2	16283.2	16417.3
Nr of estim. Param.	30	50	51

The RP and GMNL models yield similar performance indicators. We opt for the latter as our preferred model, as it produces more stable results as regards the WTP/WTA for short and long blackouts.

Posterior distributions of the GMNL random coefficients (1)

As suggested by Hess (2007), we computed the posterior distributions of the GMNL random coefficients.

The posterior coefficients for each respondent i are computed by means of R individual-specific draws from the estimated random distributions $f(\beta|\Omega)$, conditioned on the observed sequence of choices for each respondent (Y_i):

$$\hat{\beta}_i = \frac{\sum_{r=1}^{R} [L(Y_i|\beta_r)\beta_r]}{\sum_{r=1}^{R} L(Y_i|\beta_r)}$$

This procedure should help obtaining more stable results.

Posterior estimates for blackouts coefficients (2)

GMNL, gamma = 1, posterior WTP and WTA				
	WTP		WTA	
	Mean	Std.Dev.	Mean	Std.Dev.
Short interruption				
Hydro	-1.29	2.59	-0.60	0.65
Mix	-2.66	5.46	-0.39	0.98
Nuclear	4.42	5.69	-0.18	0.14
Sun	2.14	6.63	-0.76	0.73
Wind	-1.27	2.09	-0.74	0.44
Long interruption				
Hydro	-0.83	0.67	-2.51	1.27
Mix	2.60	7.10	-1.54	1.22
Nuclear	0.32	1.59	-1.79	1.05
Sun	1.22	6.10	-3.80	2.40
Wind	1.52	4.32	-2.07	1.01

Probabilities of obtaining WTP/WTA values with "desirable" sign

- WTP or WTA $< 0 \Rightarrow$ Coherent with expectations: consumers want a higher security and are willing to pay for that
- WTP or WTA $> 0 \Rightarrow$ A measure of demand response?
- Which is the estimate I can trust more?

% of values below 0								
	MNL		RP		GMNL, gamma = 1		GMNL, gamma = 1, posterior betas	
	WTP	WTA	WTP	WTA	WTP	WTA	WTP	WTA
Short interruption								
Hydro	0%	100%	n.s.	91%	50%	72%	79%	77%
Mix	100%	100%	50%	62%	80%	64%	87%	65%
Nuclear	n.s.	100%	0%	81%	8%	64%	3%	68%
Sun	0%	100%	4%	83%	50%	75%	20%	81%
Wind	100%	100%	2%	81%	50%	85%	81%	87%
Long interruption								
Hydro	n.s.	100%	0%	100%	n.s.	100%	84%	99%
Mix	n.s.	100%	14%	90%	21%	92%	16%	92%
Nuclear	100%	100%	50%	100%	45%	98%	40%	96%
Sun	100%	100%	50%	100%	50%	99%	31%	99%
Wind	0%	100%	13%	100%	50%	100%	23%	98%

n.s. if neither the avg., nor the std.dev. are significant at a 10% level

More on posterior estimates for blackouts coefficients

As an exploratory assessment of the sources of heterogeneity in the estimated WTP/WTA values, we computed the correlations across the individual posterior WTP/WTA resulting from the GMNL model and the available demographic and attitudinal variables:

- WTA values for long and short blackouts tend to be positively correlated (∼45%) across energy sources
- No clear correlation pattern was instead detected between WTP/WTA values and demographic or attitudinal variables

Comments

- All estimates suggest that consumers are willing to pay to avoid an increased risk of blackouts (WTA < 0) $\Rightarrow$ The marginal value of SOS is a useful piece of information for deciding investments in grid upgradings
- All estimates suggest that consumers are less interested in paying for further security improvements (WTP values with mixed sign)
- There is sizeable heterogeneity among consumers, suggesting a sizeable potential for demand response
- There seems to be a positive correlation between aversion wrt. blackouts and appreciation for renewable energy sources

Open issues

- The policy maker has to decide the optimal level of security. Does it make sense to provide information regarding the marginal value of security and the observed heterogeneity for the population as a whole, irrespective of the sources of this heterogeneity?
- Do we really learn much from the posterior distributions of the βs?
- Next steps: investigate the sources of this heterogeneity by including demographic variables and latent classes/variables