Households' Willingness to Curtail Electricity Usage During Winter Shortages

A Field Experiment

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29. January 2025

Introduction

Source: IAE CampaignXchange: https://userstcp.org/case-studies/campaignxchange/

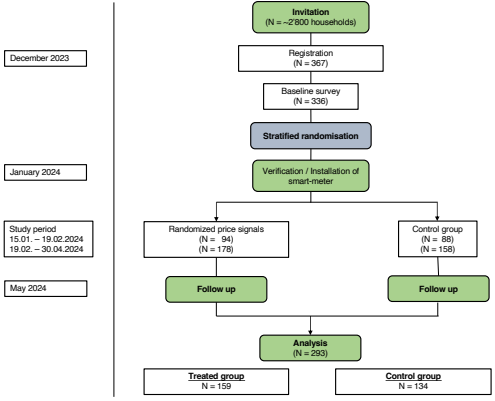
Introduction

- Meta-reviews on demand response show a serious shortcoming: focus on consumer willingness to accept load shifting without any loss of personal comfort (see, e.g., Dutta & Mitra, 2017; Nicolson et al., 2018; Parrish et al., 2020; Yan et al., 2018).
- Seasonal shortages may require load reductions – for large industrial consumers as well as residential customers – resulting in some discomfort for end-users.
- Most studies estimating a value of lost load quantify cost of full black-outs (see, e.g., CEPA & ACER, 2018; Morrissey et al., 2018; Motz, 2021).

Introduction

- Few studies that have assessed the cost of partial load-restrictions or restrictions of individual appliances (see, e.g., Kubli et al., 2018; Winzer et al., 2023) have been based on non-incentivised stated preference elicitation methods.
- In contrast, we investigate households' willingness to make load reductions that:
  - could result in some discomfort
  - in response to a study price signal
  - for a particular device – in our case, the heat pump –
  - in a reliable, incentive-compatible way,
  - based on actual observed choices rather than stated preferences.
- To do this, we conducted a field experiment in cooperation with Primeo Energie – a Swiss energy provider

Experiment Design



- Recruitment/Invitation
- Study registration
- Baseline survey
- Stratified randomisation
- Main intervention period
- Follow-up survey
- Analysis and payout

Experiment Design – Baseline survey

- Information on dwelling characteristics and heat pump
- Socio-economics: Gender, education, household size and type, occupation, income
- Abundance at home
- Energy-related behaviour
- Financial and energy-related investment literacy
- ''Attitudes'': personal norms, social norms, how individuals approach decision situation, political attitude
- Stated preferences (Discrete choice & contingent valuation questions)

Experiment Design – Stratified randomisaton

Variables used for the stratification:

- Gender: female
- Age of respondent: above or below median
- Household size (1-2, 3-4, 5 and more people)
- Income (<5'000, 5'000-10'000, >10'000, no answer)
- Heat pump type: water or air
- Age of the house: older or younger than 2001
- Minergie label (yes/no)
- Main residence (yes/no)
- Floor area: smaller or larger than 200m2
- Smart meter: abundant or need to be installed

Experiment Design – Intervention

- Treated households get a study budget.
- Each week from Jan–April 2024 they receive a price signal which is valid for the following 3 days.
- Households then decide each week whether:
  - to pay the price/consumption → deduction from virtual study budget (price× kWh) or
  - to reduce their consumption by setting the heat pump to a lower indoor temperature → lower deduction (price× kWh).
- ''Observe behaviour'': Smart meter data provided by the utility → compare daily consumption for heating between treated and control group.
- Rest of the virtual study budget → pay out (incentive compatible)

Experiment Design – Intervention

- Text message to the treatment group to inform them on the weekly study electricity price.
- Levels of price signals: 1.00, 2.50, 4.00, 5.50, 7.00 CHF per kWh
- 5 groups with different sequences
- The SMS text includes:
  - Study electricity price
  - Days of validity
  - Estimated savings during 3-day period, when room temperature is reduced by 1° Celsius

Experiment Design – Follow-up survey

- Heating settings changes during study period
- Absence during (and because of) study period
- Energy-related behaviour during study period
- Status quo bias
- Willingness to choose future contract types
- Feedback study design
- Stated preferences (Discrete choice & contingent valuation questions)

Experiment Design – Dataset

Combined data from (inked by customer/meter number):

- baseline survey,
- follow-up survey and
- smart meter data provided by utility

Estimate the treatment effects:

- Dichotomous treatment (between subjects): Difference in outcomes between the treatment and control group
- Continuous treatment (within subjects): Conditional on treatment, exploiting the variation of the price signals

final participant numbers

Results — Summary statistics (respondents characteristics)

Variable	Obs	Mean	Std. Dev.	Min	Max	Swiss statistics
owner	293	0.976	0.1530	0	1	
age	282	55.496	12.3220	0	85	
hhsize	282	2.887	1.1726	1	7	2.644
female	293	0.164	0.3707	0	1	
income (below 3k)	293	0.003	0.0584	0	1	
income (3-5k)	293	0.041	0.1985	0	1	
income (5-6.5k)	293	0.085	0.2798	0	1	
income (6.5-7.5k)	293	0.082	0.2747	0	1	
income (7.5-8.5k)	293	0.075	0.2640	0	1	
income (8.5-9.5k)	293	0.096	0.2945	0	1	
income (9.5-10.5k)	293	0.099	0.2991	0	1	
income (10.5-12k)	293	0.089	0.2849	0	1	
income (12-14k)	293	0.133	0.3403	0	1	
income (14-20k)	293	0.109	0.3124	0	1	
income (above 20k)	293	0.020	0.1419	0	1	
income (NA)	293	0.130	0.3365	0	1	

Sources of Swiss statistics: Federal Statistical Office, 2024a, 2024b.

Results — Summary statistics (dwelling characteristics)

Variable	Obs	Mean	Std. Dev.	Min	Max	Swiss statistics
number of rooms	288	5.486	1.0722	2	7	4.834
sqm (m^2)	284	189.014	52.4227	80	300	120-159[a]
house	293	0.969	0.1728	0	1	
minergie label	287	0.087	0.2825	0	1	
heat pump (water/ground source)	293	0.160	0.3676	0	1	
radiators	288	0.264	0.4415	0	1	
heating only	287	0.401	0.4909	0	1	
second heating system	293	0.437	0.4968	0	1	
built before 1940	293	0.058	0.2342	0	1	
built between 1940-1970	293	0.092	0.2897	0	1	
built between 1971-2000	293	0.000	0.0000	0	0	
built 2001 or later	293	0.427	0.4954	0	1	0.210

Sources of Swiss statistics: Federal Statistical Office, 2024a, 2024b.

Results — Dichotomous treatment effect

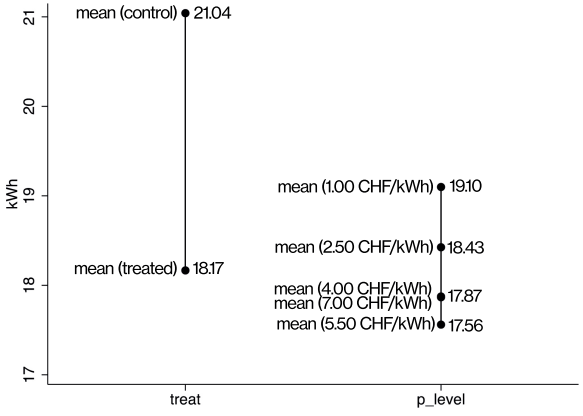
Table 1: OLS regressions of electricity consumption on treatment days (*kWh*) and self-reported changes to heating settings (*heatingsettings*) using household-level clustered standard errors.

	(1) kWh	(2) kWh	(3) heatingsettings	(4) heatingsettings
treated	-2.876*	-2.518*	3.361***	3.399***
	(-1.83)	(-1.83)	(5.94)	(5.88)
control variables	No	Yes	No	Yes
_cons	21.04***	-6.446	2.265***	-0.299
	(16.51)	(-0.43)	(5.59)	(-0.06)
N	11134	10624	287	273
R-sq	0.008	0.304	0.109	0.154

Notes: t statistics in parentheses, * p<0.10, ** p<0.05, *** p<0.01.

control variables

Results — Conditional analysis (effect of intensity of treatment)



	Savings (kWh/day)	Savings (%)
treated	2.88	13.67%
p_level = 1.00	1.94	9.23%
p_level = 2.50	2.62	12.43%
p_level = 4.00	3.18	15.09%
p_level = 5.50	3.48	16.54%
p_level = 7.00	3.17	15.06%

Results — Conditional analysis (effect of intensity of treatment)

Table 2: Conditional OLS regressions of electricity consumption on treatment days (*kWh*) using household-level clustered standard errors

	(1) kWh	(2) kWh
price: 2.50 CHF/kWh	-0.675	-0.895**
	(-1.45)	(-2.19)
price: 4.00 CHF/kWh	-1.234**	-1.582***
	(-1.99)	(-3.20)
price: 5.50 CHF/kWh	-1.539***	-1.360***
	(-2.61)	(-2.83)
price: 7.00 CHF/kWh	-1.227*	-1.346***
	(-1.97)	(-2.76)
control variables	No	Yes
_cons	19.10***	-2.919
	(17.04)	(-0.22)
N	5989	5704
R-sq	0.001	0.349

Notes: t statistics in parentheses, * p<0.10, ** p<0.05, *** p<0.01.

Results — Heterogeneous responses

- Income: not significant as control variable (independent if we use 12 or 3 groups)
- Second heating system → Backup
- Potential of savings: size of the house (m_2) → indicator for heat pump capacity → Backup
- Knowledge of electricity price → Backup

Results — Robustness checks

- Balance check (→ Backup)
- No differences in attrition between treatment and control groups
- Removing outliers (above 80 kWh/day and above 100kWh/day) (→ Backup)
- Regression on non-treated days (→ Backup)
- Panel regressions (→ Backup)

Conclusions

- We have presented experimental evidence on households' revealed willingness to turn down their heat pumps and live with lower room temperatures when facing energy price shocks in response to energy shortages.
- The price-signals we have tested in our study led to an average load reduction of 13.8%.
- Energy savings increased from 9% to 15% as price levels increased from CHF 1.00 to CHF 4.00 per kWh.
- Price levels above CHF 4.00 CHF per kWh appear not to result in significantly greater energy savings.

Policy implications

- Most European countries during the 2022/23 energy crisis relied on voluntary measures and information campaigns.
- Recent experimental studies show that information campaigns can achieve energy savings between 0.4 and 1.5% (Andor et al., 2022; Kirchler et al., 2024).
- We shows, that additional price-based policies using monetary incentives could help achieve higher energy savings of up to 15% during future energy crises.
- Further, currently there is no financial incentive for residential customers to reduce electricity consumption during seasonal energy shortages $\rightarrow$ new tariff designs from 1st of January 2025.
- Lastly, a limitation of this study is that since we have targeted homeowners with heat pumps, which presumably have a greater flexibility capital than households living in rented dwellings with limited financial resources $\rightarrow$ additional research needed.

Thanks for listening

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The field experiment was pre-registered (ID: AEARCTR-0012277)

Download the working paper:

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Back-up slides

Final participant numbers

	TREATED groups							
	1	2	3	4	5	total	CONTROL	TOTAL
Week 01–05	20	17	12	16	17	82	73	155
Without SM	10	13	19	17	18	77	61	138
Week 06–15	30	30	31	33	35	159	134	**293**

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Balance check

	(treated) mean	(control) mean	t-value	p-value
female	0.1761	0.1493	0.617	0.538
age	55.5871	55.3858	0.136	0.892
hhsize	2.8516	2.9291	-0.552	0.582
income (below 3k)	0.0000	0.0075	-1.090	0.277
income (3-5k)	0.0566	0.0224	1.473	0.142
income (5-6.5k)	0.0818	0.0896	-0.237	0.813
income (6.5-7.5k)	0.0692	0.0970	-0.864	0.389
income (7.5-8.5k)	0.0566	0.0970	-1.307	0.192
income (8.5-9.5k)	0.0881	0.1045	-0.475	0.635
income (9.5-10.5k)	0.1321	0.0597	2.075	0.039
income (10.5-12k)	0.0692	0.1119	-1.281	0.201
income (12-14k)	0.1258	0.1418	-0.401	0.689
income (14-20k)	0.1258	0.0896	0.989	0.324
income (above 20k)	0.0252	0.0149	0.614	0.540
income (NA)	0.1447	0.1119	0.829	0.408
heat pump (water/ground source)	0.1698	0.1493	0.476	0.634
built before 1940	0.0629	0.0522	0.387	0.699
built between 1940-1970	0.1132	0.0672	1.357	0.176
built between 1971-2000	0.3774	0.4403	-1.091	0.276
built 2001 or later	0.4340	0.4179	0.276	0.783
minergie label	0.0892	0.0846	0.136	0.892
number of rooms	5.5096	5.4580	0.406	0.685
sqm	187.2258	191.1628	-0.630	0.530
second heating system	0.4277	0.4478	-0.344	0.731
indoor temp setting	21.0581	20.9766	0.644	0.520
political attitude	4.0861	4.1508	-0.433	0.666
env donation	0.3677	0.3307	0.646	0.519

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Control variables

- We control for outside temperature,
- household size,
- income,
- size of the house,
- heat pump type,
- heating type (radiator vs. underfloor heating, heating only, or including warm water),
- abundance of secondary heating systems, and
- baseline indoor temperature.

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Regressions excluding outliers

Column (1) and (2) shows regressions excluding outliers above 100kWh per day, column (3) and (4) shows regressions excluding outliers above 80kWh per day.

Table 3: OLS regressions of electricity consumption on treatment days (*kWh*) using household-level clustered standard errors excluding outliers

	(1) kWh	(2) kWh	(3) kWh	(4) kWh
treated	-2.560* (-1.90)	-2.363* (-1.87)	-2.219* (-1.88)	-2.053* (-1.81)
controlvariables	No	Yes	No	Yes
_cons	20.40*** (19.24)	-0.0695 (-0.01)	19.73*** (21.56)	1.252 (0.13)
N	11080	10570	11003	10494
R-sq	0.007	0.312	0.007	0.321

Notes: t statistics in parentheses, * p<0.10, ** p<0.05, *** p<0.01.

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Regression on non-treated days

Table 4: OLS regressions of electricity consumption on non-treated days (*kWh*) using household-level clustered standard errors

	(1) kWh	(2) kWh
treated	-2.554	-2.132
	(-1.60)	(-1.54)
controlvariables	No	Yes
_cons	21.46***	-9.188
	(16.43)	(-0.61)
N	15431	14724
R-sq	0.007	0.252

Notes: t statistics in parentheses, * p<0.10, ** p<0.05, *** p<0.01.

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Panel regressions – Dichotomous treatment effect

Table 5: Random effects panel regressions of electricity consumption on treatment days (kWh) using household-level clustered standard errors

	(1) kWh	(2) kWh
treated	-2.737*	-2.304*
	(-1.96)	(-1.88)
controlvariables	No	Yes
_cons	20.27***	-5.775
	(17.94)	(-0.44)
N	11134	10624
R-sq (overall)	0.008	0.304

Notes: t statistics in parentheses, * p<0.10, ** p<0.05, *** p<0.01.

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Panel regressions – Conditional analysis

Table 6: Conditional random effects panel regressions of electricity consumption on treatment days (kWh) using household-level clustered standard errors

	(1) kWh	(2) kWh
price: 2.50 CHF/kWh	-0.679	-0.889**
	(-1.46)	(-2.20)
price: 4.00 CHF/kWh	-1.242**	-1.572***
	(-2.00)	(-3.21)
price: 5.50 CHF/kWh	-1.546***	-1.358***
	(-2.62)	(-2.83)
price: 7.00 CHF/kWh	-1.246**	-1.347***
	(-2.00)	(-2.76)
control variables	No	Yes
_cons	18.48***	-6.392
	(18.07)	(-0.54)
N	5989	5704
R-sq	0.001	0.348

Notes: t statistics in parentheses, * p<0.10, ** p<0.05, *** p<0.01.

Heterogenous response – Second heating system

Table 7: Conditional OLS regressions of electricity consumption on treatment days (kWh) using household-level clustered standard errors. Columns (1) and (2) without second heating system, columns (3) and (4) with second heating system.

	(1) kWh	(2) kWh	(3) kWh	(4) kWh
p2	-0.978	-1.061*	-0.255	-0.642
	(-1.49)	(-1.74)	(-0.40)	(-1.33)
p3	-1.762**	-2.153***	-0.5	-0.765
	(-2.00)	(-2.96)	(-0.60)	(-1.27)
p4	-1.498*	-1.578**	-1.603**	-1.031**
	(-1.72)	(-2.05)	(-2.19)	(-2.23)
p5	-2.010**	-2.223***	-0.134	-0.173
	(-2.22)	(-2.90)	(-0.17)	(-0.38)
control variables	No	Yes	No	Yes
_cons	19.84***	6.876	18.06***	-10.52
	-11.95	-0.32	-13.25	(-0.64)
N	3492	3282	2497	2422
R-sq	0.002	0.359	0.002	0.506

Notes: t statistics in parentheses, * $p<0.10$, ** $p<0.05$, *** $p<0.01$.

Heterogenous response – Size of the house

Table 8: OLS regressions of electricity consumption on treatment days (kWh) using household-level clustered standard errors. Columns (1) and (2) show houses $< 200m^2$, columns (3) and (4) show houses $>= 200m^2$.

	(1) kWh	(2) kWh	(3) kWh	(4) kWh
treat	-0.824	-1.716	-4.967**	-3.172*
	(-0.40)	(-0.92)	(-2.14)	(-1.72)
control variables	No	Yes	No	Yes
_cons	19.21***	18.75	22.87***	-11.83
	-12.14	-1.36	-11.58	(-0.49)
N	5862	5727	5272	4987
R-sq	0.001	0.304	0.022	0.343

Notes: t statistics in parentheses, * p<0.10, ** p<0.05, *** p<0.01.

Heterogenous response – Knowledge of electricity price

Table 9: OLS regressions of electricity consumption on treatment days (kWh) using household-level clustered standard errors.

	(1) kWh	(2) kWh
treat	-2.882*	-2.543*
	(-1.84)	(-1.86)
e-price	-2.136	-2.460*
	(-1.40)	(-1.71)
control variables	No	Yes
_cons	22.10***	-6.03
	-13.43	(-0.41)
N	11134	10624
R-sq	0.012	0.31

Notes: t statistics in parentheses, * $p<0.10$, ** $p<0.05$, *** $p<0.01$.