Residential Energy Demand and Underlying Efficiency in Switzerland

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Outline

- Introduction
- Efficiency concepts
- The Household Survey
- Econometric estimation
- Preliminary results
- Outlook
- Discussion
Motivation

- Residential sector consumes about 25% to 30% of the total end-use energy consumption in Switzerland

- About 58% of it is based on fossil fuels

Source: BFE: 2015, Schweizerische Gesamtenergiestatistik 2014
Motivation

- Improving energy efficiency using energy policy instruments is one of the most cost-effective ways of
  - Reducing CO₂ emissions and air pollution
  - Increasing security of energy supply

- One of the **main pillars** of the Swiss “Energy Strategy 2050”
  - Targets for Energy Efficiency: Reductions in average energy consumption per person (base year 2000)
    - 16% in 2020
    - 43% in 2035

Source: BFE: 2016, Energiestrategie 2050: Stand nach der zweitberatung im Nationalrat, Abteilung Medien und Politik
Motivation

- Fostering the adoption of energy-efficient appliances (heating, lighting etc.) is an important strategy to enhance residential energy-efficiency

- Empirical evidence for presence of inefficiency in the use of energy

- Inefficient use of energy (waste of energy) due to:
  - Low adoption of energy-efficient technologies
  - Inefficient use of electrical appliances / heating systems
  - Inefficient combination of inputs in production of energy services
Barriers to adoption of energy-efficient appliances

- Lack of information → Market failure
  - Energy-related product information often not salient enough

- Inability to use the available information → Behavioural failure
  - Appliance choice involves inter-temporal optimization
  - Difficulties in identifying appliance with lowest lifetime cost → people use decision heuristic
  - Status-quo bias
  - Bounded rationality: processing of information is cognitively burdensome
Research questions

- Measuring the level of energy efficiency of Swiss households in terms of electricity and/or gas consumption
- Identifying the differences in the level of EE between Swiss households and what drives them
  - role of behavioral factors
  - role of policy measures
- Estimating the potential for energy savings in the Swiss residential sector
- Examining the role of technological change for the reduction of energy consumption in Swiss households
Efficiency Analysis
What is energy efficiency?

- No consensus on definition and measurement
  - A typical indicator used is **Energy Intensity** (i.e. Energy Consumption / GDP)
  - Inappropriate to use it as a proxy for energy efficiency since it is a function of
    - Structure of the economy, level of production, climate,
    - Level of efficiency in the use of resources, technical change

- Measurement based on bottom-up approach
  - e.g. on-site efficiency analysis of buildings
  - Behavioural aspects in energy use are unaccounted for

- We focus on definitions based on the microeconomic theory of production

Household Production Theory

- Household’s energy demand is actually a *derived* demand for energy services
  - Inputs: Energy, Capital and Labour
  - Output: Energy Services
  - Underlying production function → Minimize the production costs!
- Reductions in energy consumptions for production of energy services can be achieved by
  - improving efficiency in the use of inputs
  - adopting new energy-saving technology

→ Total reductions is a result of the interplay of technological change and household’s behaviour
Household Production Theory

- A household maximizes utility from consumption of energy services ($S$) and other goods ($X$) while taking into account the individual budget constraint and the production function.

- Optimization Process:

$$L = U(S, X) + \lambda_1 \cdot (I - P_E E - P_K K - P_X X) + \lambda_2 \cdot (S - F(E, K))$$

- $U(S, X)$ = utility function
- $F(E, K)$ = production technology
- $\lambda_1$ = shadow value of income (~marginal utility of income)
- $\lambda_2$ = marginal utility of an additional unit of output $S$
Input specific inefficiency

- Situation 1: Household A is using the inputs in an inefficient way
  - Behaviour:
    - Optimize the amount of time that windows are opened during the day
    - Optimize use of a heating/cooling system
    - Turning off lights
  - Substitution of energy with capital:
    - Installing a device on an heating system
    - Substitution of the windows
    - Improving insulation of the building
Radial measures (Farrell, 1957)

Technical Efficiency ($TE = \theta$) = $\frac{O\theta x_1}{Ox_1}$

Allocative Efficiency ($AE$) = $\frac{O\alpha x_1}{O\theta x_1}$

Productive Efficiency ($PE = \alpha$) = $\frac{O\alpha x_1}{Ox_1}$

Situation 2: Household is using an old technology
  → inefficient use of input(s)
  → energy efficiency gap

Adoption of a new technology
  ▪ new building technology
  ▪ more efficient appliances
Persistent and Transient Inefficiency

- Persistent: Time invariant
  - Structural issues in production of energy services
    - old appliance stock
    - poor insulation
  - Systematic behavioural failures
    - leaving the windows open during winters
    - not switching off lights/appliances after use

- Transient: Inefficiencies that could be solved in the short-run
  - Non-structural issues
    - Few days of harsh hot/cold weather
  - Unsystematic shortcomings
    - temporary use of an old freezer
Methodology

Econometric estimation
Empirical Estimation

- Frontier functions are used to estimate the level of input specific efficiency

- Empirical studies are generally based on the estimation of three functions:
  - an input requirement function (Boyd, 2008);
  - a stochastic frontier energy demand function (Filippini and Hunt, 2011).
  - a sub-vector distance function (Zhou et al., 2012);
Empirical Estimation

- Parametric approaches
  - Allow for unobserved heterogeneity among different economic agents
  - A pre-specified (but flexible) functional form
  - Separates inefficiency from noise
  - Commonly known as Stochastic Frontier Analysis (SFA) approach

- Non-parametric approaches
  - No specific functional form is imposed
  - Assumes a unique deterministic frontier for all units
  - e.g., Data Envelopment Analysis (DEA)
## Applications with SFA

<table>
<thead>
<tr>
<th>Source</th>
<th>Model</th>
<th>Topic</th>
</tr>
</thead>
<tbody>
<tr>
<td>Boyd (2008)</td>
<td>Input requirement function</td>
<td>Energy use in corn milling plants in the US</td>
</tr>
<tr>
<td>Khayyat &amp; Heshmati (2014)</td>
<td>Input requirement function</td>
<td>Energy use in Korean industry</td>
</tr>
<tr>
<td>Zhou et al. (2012b)</td>
<td>Sub-vector distance function</td>
<td>Energy use in OECD countries</td>
</tr>
<tr>
<td>Lin &amp; Du (2013)</td>
<td>Sub-vector distance function</td>
<td>Energy use in China</td>
</tr>
<tr>
<td>Buck &amp; Young (2007)</td>
<td>Input demand function</td>
<td>Energy use in commercial buildings</td>
</tr>
<tr>
<td>Filippini &amp; Hunt (2011)</td>
<td>Input demand function</td>
<td>Energy use in OECD countries</td>
</tr>
<tr>
<td>Filippini &amp; Hunt (2012)</td>
<td>Input demand function</td>
<td>Energy use in the US</td>
</tr>
<tr>
<td>Filippini et al. (2014)</td>
<td>Input demand function</td>
<td>Energy use in the EU</td>
</tr>
<tr>
<td>Orea et al. (2015)</td>
<td>Input demand function</td>
<td>Energy use and rebound in the US</td>
</tr>
<tr>
<td>Weyman-Jones et al. (2015)</td>
<td>Input demand function</td>
<td>Electricity in Portuguese households</td>
</tr>
</tbody>
</table>

Survey
The Household Survey

- 9 Swiss Electric and Gas utilities that operate in (sub)urban regions: AMB, AIL, SiL, ESB, EWL, Stadtwerk Winterthur, IBAarau, IWB and EWB

Survey organisation
- Online survey, invitation sent with bill/separately
- To all customers or to a randomly chosen subsample
- Response rates between 3.2 and 7.6%, depending on the mode of invitation
- Lottery based incentive → 30 Smartboxes “Happy Day” per utility
- Consumption data linked to survey data via customer number (only if customer agreed)
Questionnaire

- House/apartment characteristics
- Socio-demographics of the respondent and household members
- Appliance stock and energy services
- Energy-related behaviour
- Attitudes towards environment
- Energy related knowledge (energy-literacy)
- Energy consumption (collected from the utilities)

Test link: www.research.net/r/srvy_en
Energy literacy index constructed accounting for several dimensions:
- average price of 1 kWh in Switzerland
- knowledge of usage cost of household appliances (2 questions)
- knowledge of electricity consumption of household appliances (3 questions)
- compound interest calculation → investment literacy

Energy saving behaviour index
- completely switching off electronic appliances after use (no standby)
- running washing machine only on full load
- washing clothes on a lower water temperature (less than 30°C)
- dishwasher cycle based on level of dirtiness

Index score in 0 – 4
Sample Characteristics

- represent the population in the three urban areas to a large extent → all gender, age and income groups sufficiently covered
- In tendency, the samples are slightly biased towards
  - male and older respondents
  - respondents from couple households as compared to single households
  - more educated respondents
  - respondents with lower income
- Share of respondents who donated money to an environmental organization largely in line with Swiss average → limited self-selection of pro-environmental households
Dataset used here

- 3 utilities: Aarau, Winterthur and Lugano
- ~1245 households
- Data from 2010 to 2014 (~ 5600 samples)

- Households with electric space heating are not considered (for now)
Preliminary Results
**GTREM: Stochastic Frontier Analysis (SFA)**

Model:  
\[ y_{it} = \alpha + \beta' x_{it} + \varepsilon_{it} \]

\[ \varepsilon_{it} = w_i + h_i + u_{it} + \nu_{it} \]

\[ u_{it} \sim N^+[0, \sigma_u^2] \]

**Full random error** \( \varepsilon_{it} : \)

\[ h_i \sim N^+[0, \sigma_h^2] \]

\[ \nu_{it} \sim N[0, \sigma_{\nu}^2] \]

\[ w_{i} \sim N[0, \sigma_{w}^2] \]

**Household specific effects:**  
\( N(\alpha, \sigma_w^2) \)

**Persistent inefficiency estimator:**  
\( E(h_i | y_i) \)

**Transient inefficiency estimator:**  
\( E(u_{it} | y_i) \)

- \( w_i \rightarrow \) unobserved time-invariant heterogeneity
- \( h_i \rightarrow \) time-persistent inefficiency
- \( u_{it} \rightarrow \) time-transient inefficiency
- \( \nu_{it} \rightarrow \) a symmetric disturbance capturing the effect of noise

**Level of efficiency:**  
\[ EF_{it} = \frac{E_{it}^F}{E_{it}} \]
Empirical results and Conclusions

- Estimation of an indicator of the level of energy efficiency for each household
  - Measure of efficiencies (median values)
    - Persistent: 0.76
    - Transient: 0.85

- Higher persistent inefficiency
  - structural problems faced by household
  - systematic behavioural shortcomings

- Positive role of energy related literacy and energy saving behaviour
  - Electricity consumption is lower in households exhibiting energy saving behaviours
  - Higher level of energy literacy is associated with lower electricity consumption
Next Steps / Synergies

- Extending analysis to all 9 utilities
  - Ongoing survey + data collection

- Including Gas demand

- Policy evaluation and potential for energy saving and CO$_2$ reductions

Synergies:

- SCCER-CREST
  - Energy Literacy
  - Behaviour/Attitude

- H2020 Project (PENNY)
Application of efficiency analysis methods in other fields

- Use of efficiency analysis in related fields
  - Transport and mobility
  - Industry
  - Manufacturing
  - Productive efficiency in Hydropower Plants

- Other non-standard applications:
  - Mark-up calculation:
    - Mark-up = \( \frac{\text{Price} - \text{MC}}{\text{MC}} \)
    - In a competitive market, \text{mark-up} = 0
  - Presence of market power
  - Useful for regulating agencies

- Reporting error:
  - Reported crime \( \leq \) Actual crime

Questions/Discussion
References

- BFE: 2016, Energiestrategie 2050: Stand nach der zweitberatung im Nationalrat, Abteilung Medien und Politik
- Blasch, J., Boogen N., Filippini M. and Kumar, N. (2016). Transient and Persistent efficiency in residential electricity consumption in Switzerland and the role of energy literacy and energy saving behavior, *Work In Progress*