Residential Energy Demand and Underlying Efficiency in Switzerland

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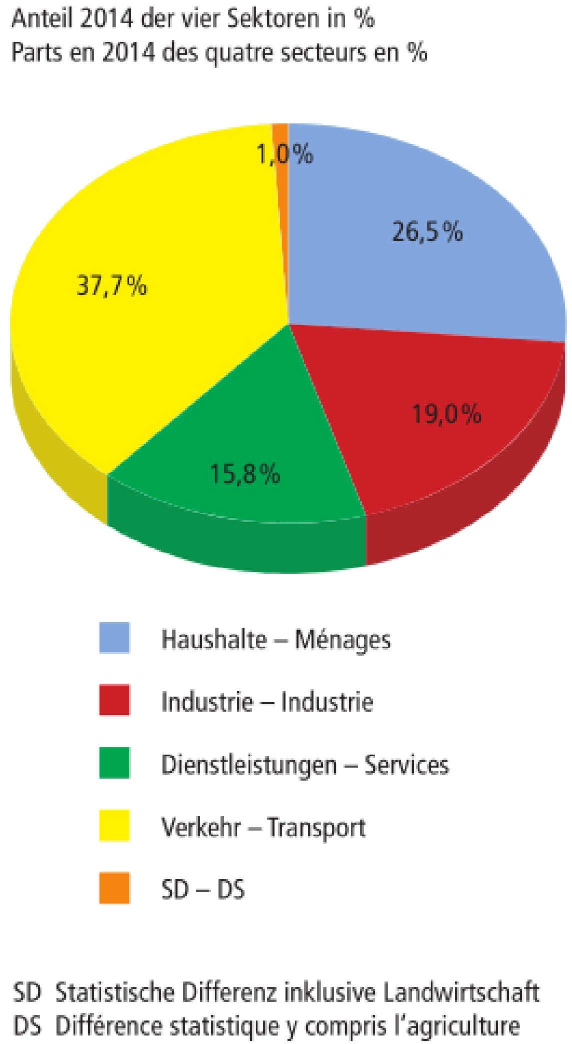
Outline

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

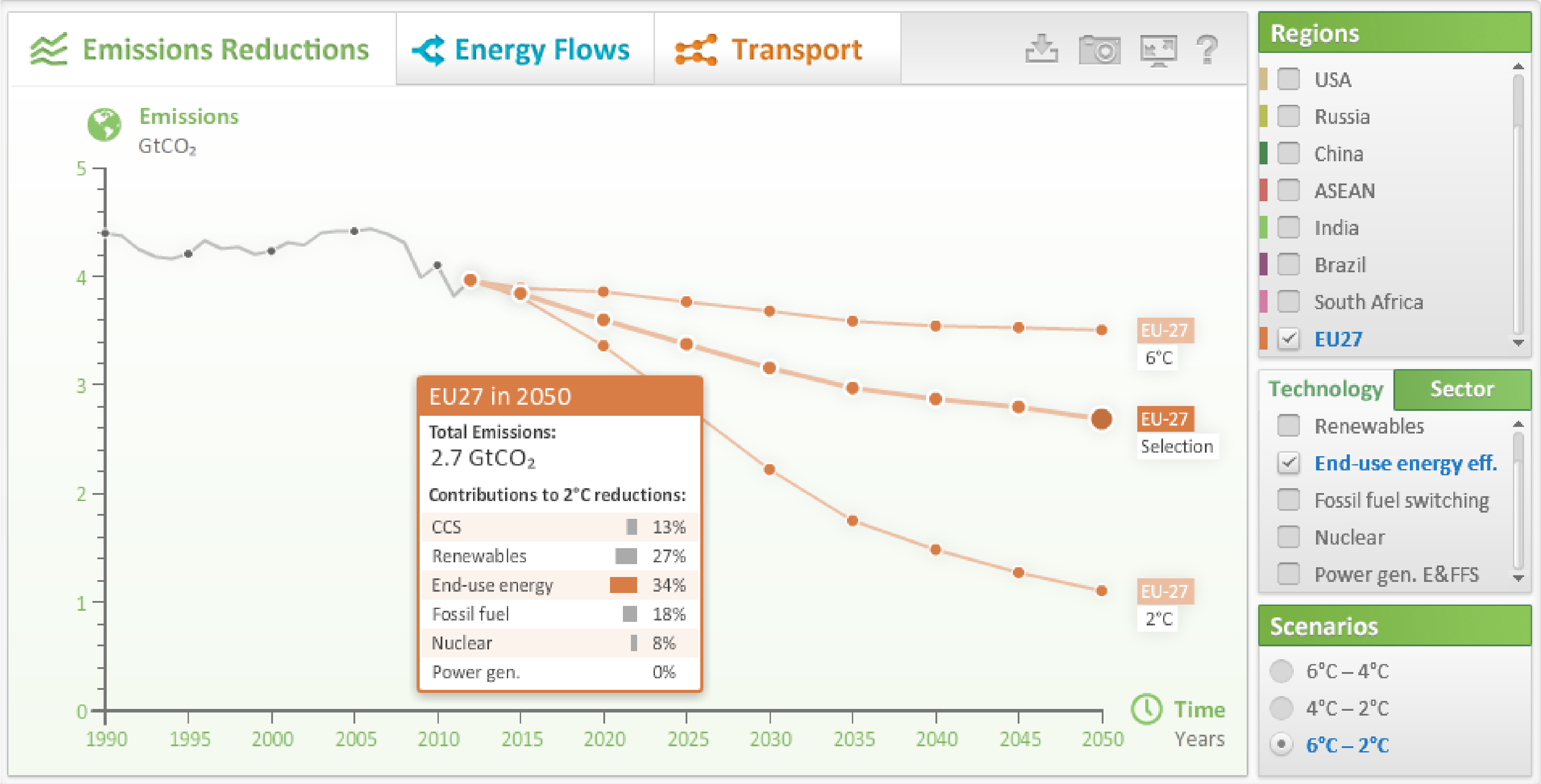
Motivation

- 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

IEA Projections



Source: IEA: 2016, Energy Technology Perspectives : ETP 2015 Data Visualization, web: http://www.iea.org/etp/explore/

Motivation

- Improving energy efficiency using energy policy instruments is one of the most cost-effective ways of
  - Reducing CO_2 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

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Theory

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 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

Source: Filippini, M. and Hunt, L. C. (2015). Measurement of Energy Efficiency Based on Economic Foundations. Energy Economics

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

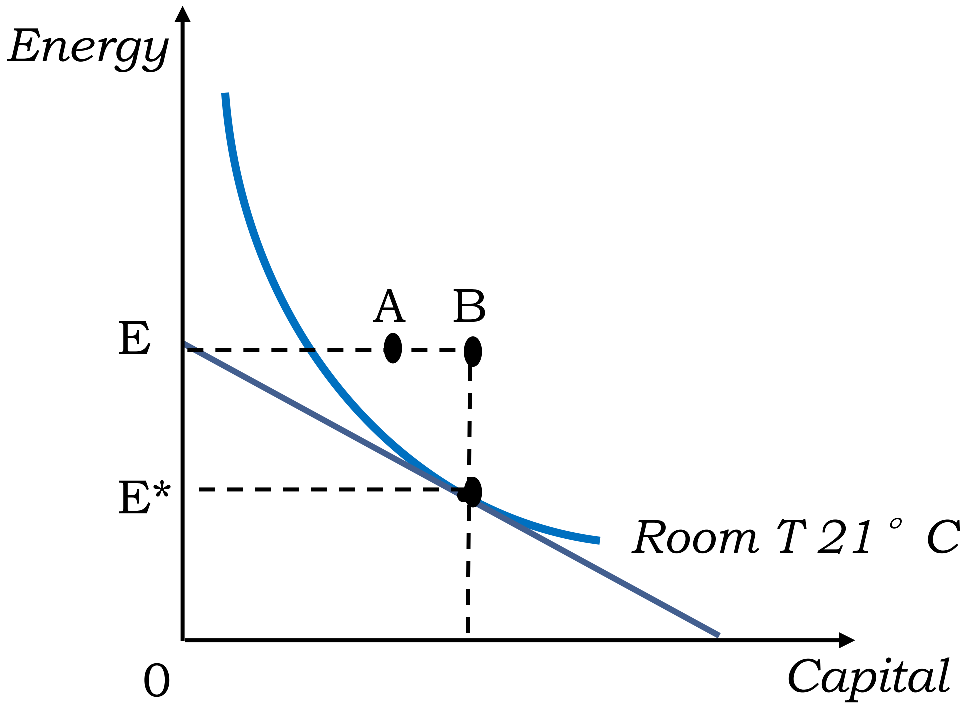
- A household maximizes utility from consumption of energy services (S) and other goods (X) while taking into account the individual budget constraint and the production function
- Optimization Process:

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

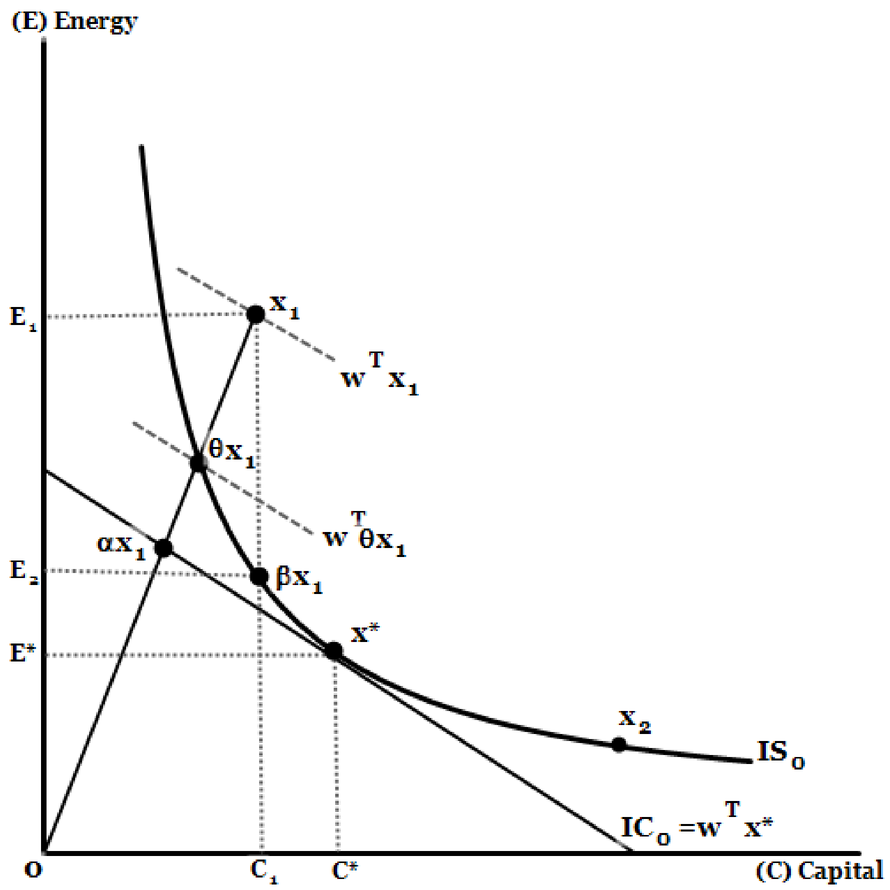
  - $U(S, X)$ = utility function
  - $F(E, K)$ = production technology
  - λ_1 = shadow value of income ($\sim$ marginal utility of income)
  - λ_2 = marginal utility of an additional unit of output S

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



Productive, Technical and Allocative efficiency



Radial measures (Farrell, 1957)

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

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

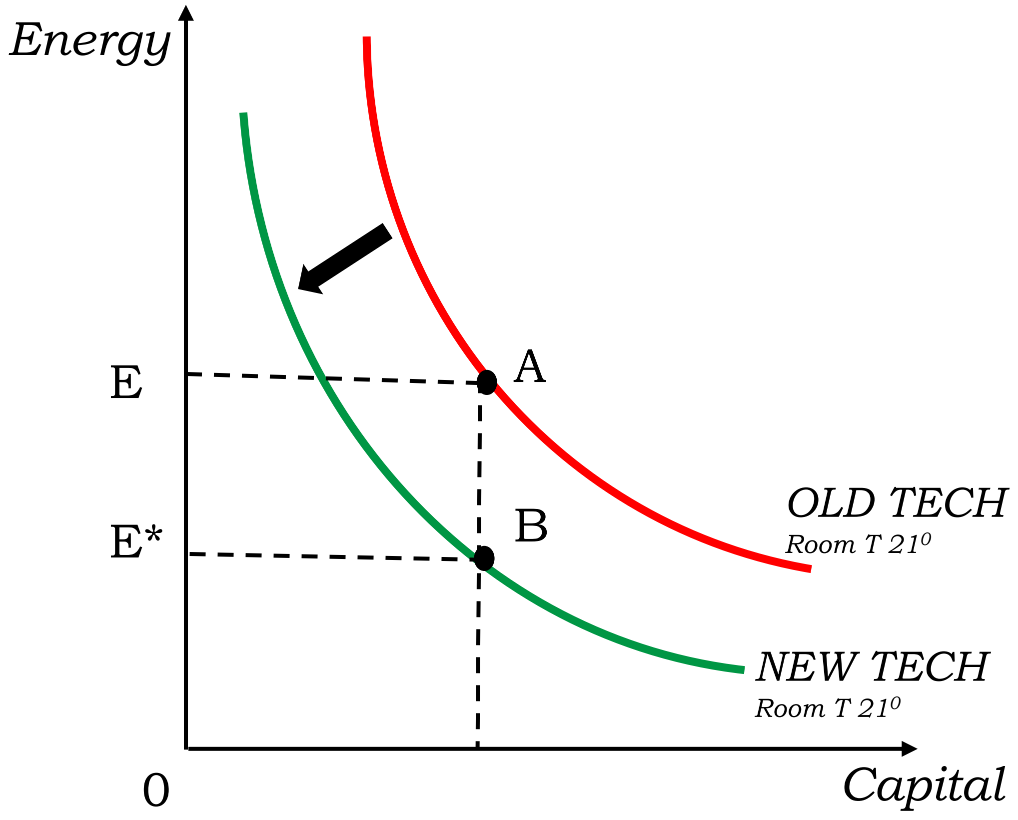
$$\text{Productive Efficiency } (PE = \alpha) = \frac{O\alpha x_1}{O x_1}$$

→ Prod. Inefficiency = Tech. Ineff. + Alloc. Ineff.

Technical Progress and the Energy Efficiency Gap

- 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

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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

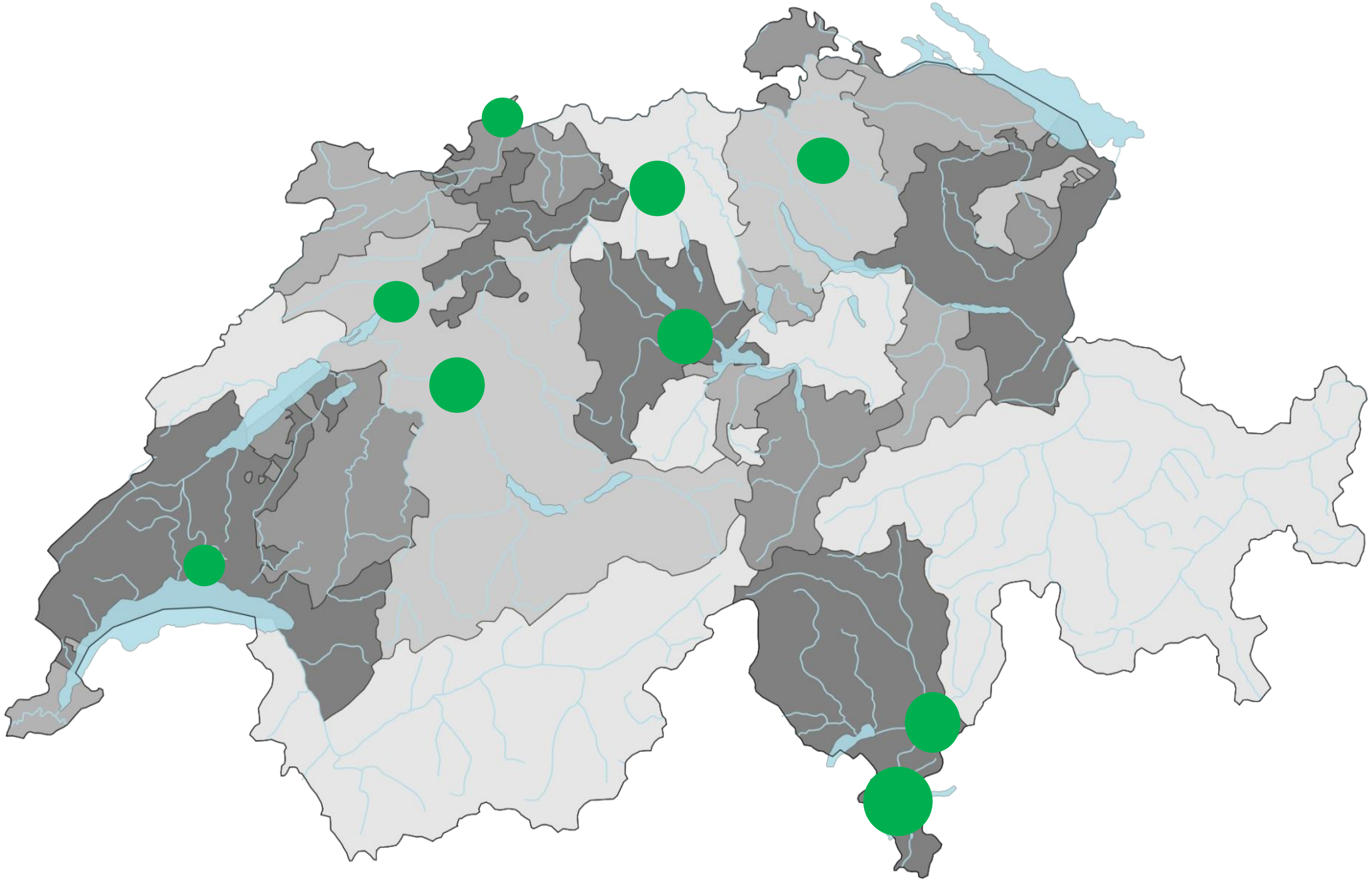
- Parametric approaches
  - Allow for unobserved heterogeneity among different economic agents
  - A pre-specified (but flexible) functional form
  - Separates inefficiency from noise
  - Commonly known as Stochastic Frontier Analysis (SFA) approach
- Non-parametric approaches
  - No specific functional form is imposed
  - Assumes a unique deterministic frontier for all units
  - e.g., Data Envelopment Analysis (DEA)

Applications with SFA

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

Source: Boogen, N. (2016). Essays on energy economics and policy: Price elasticity, policy evaluation and potential savings. *PhD thesis*, ETH Zurich, Table 3.1 on page 103

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 and Energy Saving Behaviour

- 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 literacy score in 0 –14

- 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)

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Preliminary Results

GTREM: Stochastic Frontier Analysis (SFA)

Model:	$y_{it} = \alpha + \boldsymbol{\beta}'\mathbf{x}_{it} + \varepsilon_{it}$
Full random error ε_{it}:	$\varepsilon_{it} = w_i + h_i + u_{it} + \nu_{it}$ $u_{it} \sim N^+[0, \sigma_u^2]$ $h_i \sim N^+[0, \sigma_h^2]$ $\nu_{it} \sim N[0, \sigma_\nu^2]$ $w_i \sim N[0, \sigma_w^2]$
Household specific effects:	$N(\alpha, \sigma_w^2)$
Persistent inefficiency estimator:	$\mathrm{E}(h_i \vert \mathbf{y}_i)$
Transient inefficiency estimator:	$\mathrm{E}(u_{it} \vert \mathbf{y}_i)$

- w_i → unobserved time-invariant heterogeneity
- h_i → time-persistent inefficiency

- u_{it} → time-transient inefficiency
- v_{it} → a symmetric disturbance capturing the effect of noise

- Level of efficiency: $EF_{it} = \frac{E_{it}^F}{E_{it}}$

Source: 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

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 = $\frac{Price - MC}{MC}$
  - In a competitive market, **mark-up = 0**
  - Presence of market power
  - Useful for regulating agencies

- Reporting error:
  - Reported crime $\leq$ Actual crime

Source: Kumbhakar, S. C. and Lovell, C. K. (2000). Stochastic Frontier Analysis. Cambridge University Press.

Questions/Discussion

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