Estimating Energy Efficiency and Energy Demand in Households

Dr. Nina Boogen
Centre for Energy Policy and Ecnomics (CEPE), ETH Zürich

Annual Workshop - Economics for Energy & Fundación Ramón Areces
Madrid, 16. February 2018

Outline

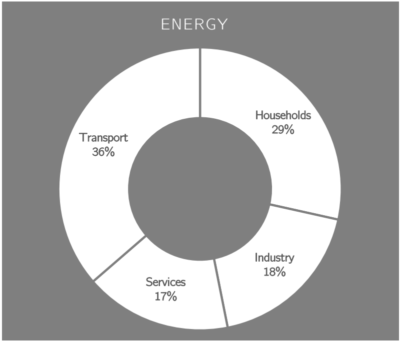
1. Importance of energy efficiency in households
2. Definition of energy efficiency
3. Measurement of energy efficiency potential
4. Policy instruments for energy efficiency: Demand-side management programs

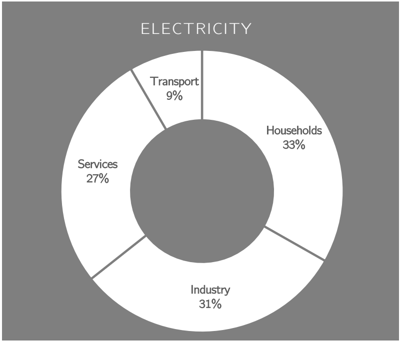
Importance of energy efficiency in households

- Energy efficiency a part of the strategy of many industrialised nations to reduce the emissions of greenhouse gases
- Benefits of energy efficiency:
  - Reduce air pollution from SO_2, NO_x, O_3 and PM.
  - Improve energy security
  - Prevent the need for constructing expensive new power plants
  - Prevent the need for upgrades in the transmission networks
- International Energy Agency (2009) highlights huge potential of CO_2 reductions from increased end-use energy efficiency

Importance of energy efficiency in households

End-use in Switzerland (2016)





Importance of energy efficiency in households

- Following the Fukushima Daiichi nuclear disaster, the Swiss Federal Council decided to gradually phased out the five existing nuclear reactors with no replacements.
- Switzerland is heavily reliant on its nuclear reactors (33% in 2016)
- Therefore reference targets were defined in the Energy Strategy 2050
  - Reduce average energy use per person and year compared to 2000 by 16% (2020) and by 43% (2035)
  - Reduce average electricity use per person and year compared to 2000 by 3% (2020) and by 13% (2035)
- This highlights the need to find policy measures to ensure that the target can be achieved

Outline

1. Importance of energy efficiency in households
2. **Definition of energy efficiency**
3. Measurement of energy efficiency potential
4. Policy instruments for energy efficiency: Demand-side management programs

Definition of energy efficiency

- No consensus on how energy efficiency is actually defined and measured (Filippini and Hunt, 2015)
- Most definitions are based on simple ratio of: $\frac{\text{useful output of a process}}{\text{energy input into a process}}$

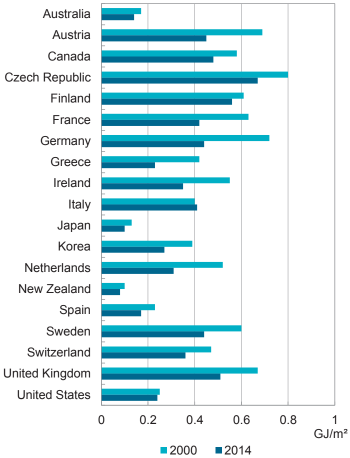
Indicator	**Input unit**	**Output unit**
thermodynamic	thermodynamic	thermodynamic
physical-thermodynamic	thermodynamic	physical
economic	monetary values	monetary values
economic-thermodynamic	thermodynamic	monetary values

- Typical indicator used in policy analysis is *energy intensity*, which is inverse of a economic-thermodynamic indicator (e.g. GJ per Euro)

Definition of energy efficiency

- *Energy intensity* is measured as simple indicator
- State level: ratio of energy consumption to GDP
- Residential level: ratio of energy consumption per square meter
- Energy intensity does not necessarily reflect true energy efficiency

Figure 7. Energy intensity* per floor area of residential space heating by country



Source: IAE, Energy efficiency indicators, 2017

Outline

1. Importance of energy efficiency in households
2. Definition of energy efficiency
3. **Measurement of energy efficiency potential**
4. Policy instruments for energy efficiency: Demand-side management programs

Measuring energy efficiency using...

- ... bottom-up models
- McKinsey & Company (2009) have estimated the potential for energy savings in the US.
  - Economic-engineering approach based on bottom-up models
  - Electricity savings in 2020 in the residential sector is 25%
- Prognos (2011): electricity consumption for households can be reduced by almost 15% by 2035 compared to reference scenario in Switzerland.

  ⇒ In such economic-engineering models the researcher has to make assumptions on the future technology.

Measuring energy efficiency using...

- ... a top-down approach based on microeconomic production theory.
- ... stochastic frontier analysis (SFA).
- Relative technology benchmark, which is given through the sample.
- Estimation of the potential independent of assumptions on future technologies.

Measuring energy efficiency

Microeconomic production theory means...

- Demand for energy is derived from the demand for outputs
- Outputs in residential sector are energy services such as heating, cooling and lighting
- Households use energy, labour and capital to produce outputs

Inefficiency in households may be due to...

- Low adoption of new energy-efficient technology
- Inefficient use of electrical appliances / heating systems

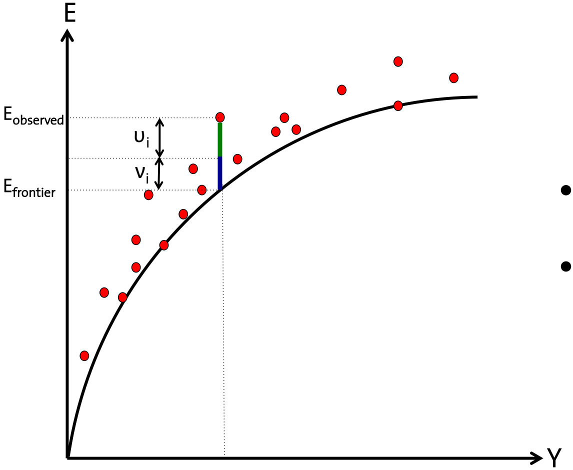
Measuring energy efficiency – Energy demand frontier (Filippini and Hunt, 2011, 2015)

$$E = f(p_E, p_{OG}, Y, ES, ...)$$

$$\ln E = \alpha_0 + \alpha_{p_E} \ln p_E + \alpha_{p_{OG}} \ln p_{OG} + \alpha_Y \ln Y + \alpha_{ES} \ln ES + \varepsilon$$

- The frontier gives the **minimum level of energy necessary** for an household to produce any given level of energy services.
- The **distance from the frontier** measures the level of energy consumption above the baseline demand, e.g. the level of energy inefficiency.

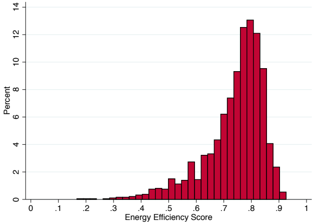
Measuring energy efficiency – Stochastic frontier



- $\varepsilon_i = \nu_i + \upsilon_i$
- $EF_i = \frac{E_{frontier}}{E_{observed}} < 1$

Measuring energy efficiency – Boogen (2017)

- Household survey by Swiss utility association:
  - 962 households in 2005
  - 906 households in 2011
  - Household characteristics
  - Energy services
  - Appliance stock
  - Electricity consumption (provided by utility)
- Cross-sectional approach
- Average inefficiency of around 20 to 25%.



Outline

1. Importance of energy efficiency in households
2. Definition of energy efficiency
3. Measurement of energy efficiency potential
4. **Policy instruments for energy efficiency: Demand-side management programs**

Policy instruments for energy efficiency

Market instruments	Efficiency bonus Rebate systems Energy tax
Non-market instruments	Information campaign Voluntary agreements on targets Appliance standards Labelling

Demand Side Management programs

- Demand Side Management (DSM) is defined as:

  "the planning, implementing, and monitoring activities of electric utilities that are designed to encourage consumers to modify patterns of electricity usage, including the timing and level of electricity demand" (Energy Information Administration, 1999)

- Covers energy efficiency and load shifting
- Empirical literature is concentrated on the US, only two studies outside US
- Thus in Boogen et al. (2017) we studied the effectiveness of DSM in Switzerland

Demand Side Management – In Switzerland

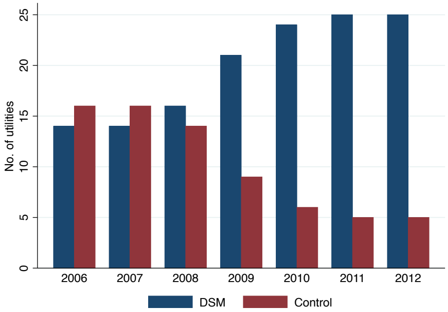
What does DSM include in Switzerland

- Information material (leaflets, magazine, web-page)
- Public relations (Fairs etc.)
- Rental of energy meters
- Personal consulting at home (Energy audits)
- Energy advice centres
- Tariff design (TOU and others)
- Funding for replacement of appliances / electric heating systems

Demand Side Management – Effectiveness

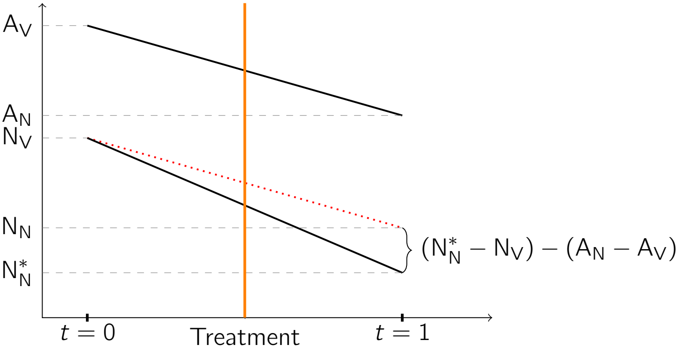
- Do DSM measures in Switzerland actually influence the electricity demand of households?
- If yes, how large is it? And how cost effective is it?
- Panel data utility survey conducted by CEPE
  - 105 utilities, 30 utilities answered
  - 45% of the Swiss residential end use
  - Data between 2006–2012, N=182
  - Questions: Residential consumption, tariffs, number of residential customers, DSM measures and their cost
  - Additional statistics: Heating and cooling degree days, populations, taxable income
- We use a Difference in Differences regression approach

Demand Side Management – Data



Variable	mean	sd	min.	max.
Binary variable (yes/no DSM)	0.66	0.47	0	1
DSM expenditure per customer	2.86	6.13	0	30.83

Demand Side Management – Policy evaluation



	Treated group	**Control group**
Before treatment (t=0)	N_V	A_V
After treatment (t=1)	N_N^*	A_N

Demand Side Management – Estimation

- Difference-in-differences regression:

$$\ln E_{it} = \beta_0 + \beta_1 DSM_{it} + \beta_2 p^E_{it} + \beta_3 Y_{it} + \beta_4 HS_{it} + \beta_5 HDD_{it} + \beta_6 CDD_{it} + \lambda_i + \delta_t + \epsilon_{it},$$

- E_{it}: electricity consumption per customer of utility i in year t,
- DSM_{it}: policy variable,
- p^E_{it}: electricity price,
- Y_{it}: average taxable income,
- HS_{it} average household size
- HDD_{it}, and CDD_{it}: heating and cooling degree days,
- λ_i: utility specific effect
- δ_t: year specific effect

Demand Side Management – Findings

- We find a negative and significant effect of DSM on residential electricity demand:
  - Binary variable: −4.70%
  - Increase of CHF/customer of 10%: −0.14%
- Using a counter-factual approach we can calculate the cost of DSM programs to be 0.04 CHF/kWh.

Conclusions

- Energy efficiency can be measured using a top-down, microeconomic approach
- Using this approach for Swiss households, we find a level of inefficiency in the use of electricity of 20-25%
- Further work: Using a large household survey from EU-Projekt PENNY to estimate the potential for European households
- Utilities might also invest in energy efficiency using DSM
- In Switzerland, DSM expenditure seemed to have a significant and negative effect on residential electricity demand

QUESTIONS?

Thank you for your attention...

nboogen@ethz.ch
@NinaBoogen

Boogen, N. (2017). Estimating the potential for electricity savings in households. Energy Economics, 63:288–300.

Filippini, M. and Hunt, L. (2015). Measurement of Energy Efficiency Based on Economic Foundations. Energy Economics, 52:S5–S16.

Boogen, N., Datta, S., and Filippini, M. (2017). Demand-side management by electric utilities in Switzerland: Analyzing its impact on residential electricity demand. Energy Economics, 64:402–414.

Bibliography

Boogen, N. (2017). Estimating the potential for electricity savings in households. *Energy Economics*, 63:288–300.

Boogen, N., Datta, S., and Filippini, M. (2017). Demand-side management by electric utilities in Switzerland: Analyzing its impact on residential electricity demand. *Energy Economics*, 64:402–414.

Energy Information Administration (1999). Annual Energy Review 1999. http://www.eia.gov/totalenergy/data/annual/archive/038499.pdf, accessed December 2015.

Filippini, M. and Hunt, L. (2015). Measurement of Energy Efficiency Based on Economic Foundations. *Energy Economics*, 52:S5–S16.

Filippini, M. and Hunt, L. C. (2011). Energy demand and energy efficiency in the OECD countries: A stochastic demand frontier approach. *Energy Journal*, 32(2):59–80.

International Energy Agency (2009). World Energy Outlook 2009. *International Energy Agency*.

McKinsey & Company (2009). Unlocking energy efficiency in the US economy. *McKinsey & Company*.

Prognos (2011). Energieszenarien fur die Schweiz bis 2050, Erste Ergebnisse der angepassten Szenarien I und IV aus den Energieperspektiven 2007 – Zwischenbericht im Auftrag des BFE. *Prognos AG*.