ENERGY EFFICIENCY

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The Impact of Building Energy Codes on the Energy Efficiency of Residential Space Heating in European countries - A Stochastic Frontier Approach

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How to measure energy efficiency?

- **Energy intensity**
  - Energy per GDP
  - Easy to calculate, with widely available data
  - Encompasses more than just energy efficiency
- **Decomposition analysis**
  - Distinguish improvements in energy efficiency from changes in the structure of a country's economy
- **Stochastic Frontier Analysis**

What is Stochastic Frontier Analysis?

- Aigner, Lovell, & Schmidt (1977)
  - Objective: measure the technical efficiency of firms
- SFA can estimate the efficiency of a production process
- SFA can also estimate how efficiently an input is used in a production process
- By considering energy as an input to the economy, SFA can be used to estimate energy efficiency
  - Filippini & Hunt (2011)

What is Stochastic Frontier Analysis? (2)

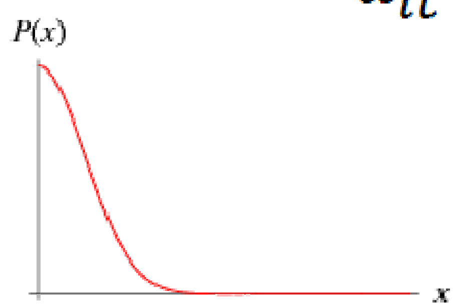
- **To estimate country-wide energy efficiency, we consider a panel of countries over a period of time**
  - **Energy consumption**
  - **Explanatory variables for this energy consumption**
- **SFA provides an econometric methodology to determine what energy consumption would have been in each country and each year, holding explanatory variables constant, if there was no energy inefficiency**
- **This hypothetic "perfectly efficient" consumption is the *frontier consumption***
- **The *distance* between the frontier consumption and actual consumption is energy inefficiency**
- **The *ratio* between the frontier consumption and actual consumption is an estimate of energy efficiency**

How does Stochastic Frontier Analysis work?

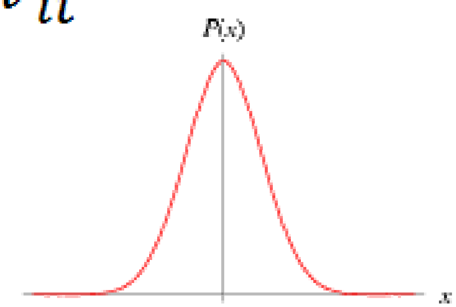
- **Let's consider that energy consumption E in country i and year t is determined by a vector of explanatory variable Y (log-linearized form):**

$$E_{it} = aY_{it} + \varepsilon_{it}$$

$$u_{it} + v_{it}$$



$N^{+}(0, \sigma_u)$



$N(0, \sigma_v)$

How does Stochastic Frontier Analysis work? (2)

- Residuals are split into two components:
  - Random error variables v_{it} with a normal distribution
  - Non-negative half-normal random variables u_{it}
- The u_{it} term represents energy inefficiency
- To calculate energy efficiency estimates:

$$EF_{it} = \frac{E_{it}^{F}}{E_{it}} = \exp\left(-\hat{u}_{it}\right)$$

- To specify the model, we need to choose explanatory variables that determines space heating energy consumption

Explanatory variables that determine space heating energy consumption

- Final energy consumption for space heating
- Household income
- Price of energy used for space heating
- Total number of permanently occupied dwellings
- Average floor area per dwellings, in square meter
- Share of multi-family dwellings in the total buildings stock
- Number of heating degree days

- To estimate the model, we need hypotheses on the functional form of the inefficiency term, u_{it}

Functional form of the inefficiency term

- **Estimate the trend in energy efficiency: Time varying efficiencies (Battese & Coelli, 1992)**

$$u_{it} = u_i \exp\left[-\eta(t - t_0)\right]$$

- **Estimate the impact of building energy codes: Efficiency effects frontier (Battese & Coelli, 1995)**

$$u_{it} = \beta_0 + \beta_C C_{it} + \varepsilon_{it}$$

where C_{it} is is a variable representing the number of years elapsed since buildings energy codes were established in country i in year t

Estimation data

- **Panel of 7 European countries, observed from 1990 to 2008**
  - **Austria, Denmark, Finland, France, Germany, Poland and the UK**

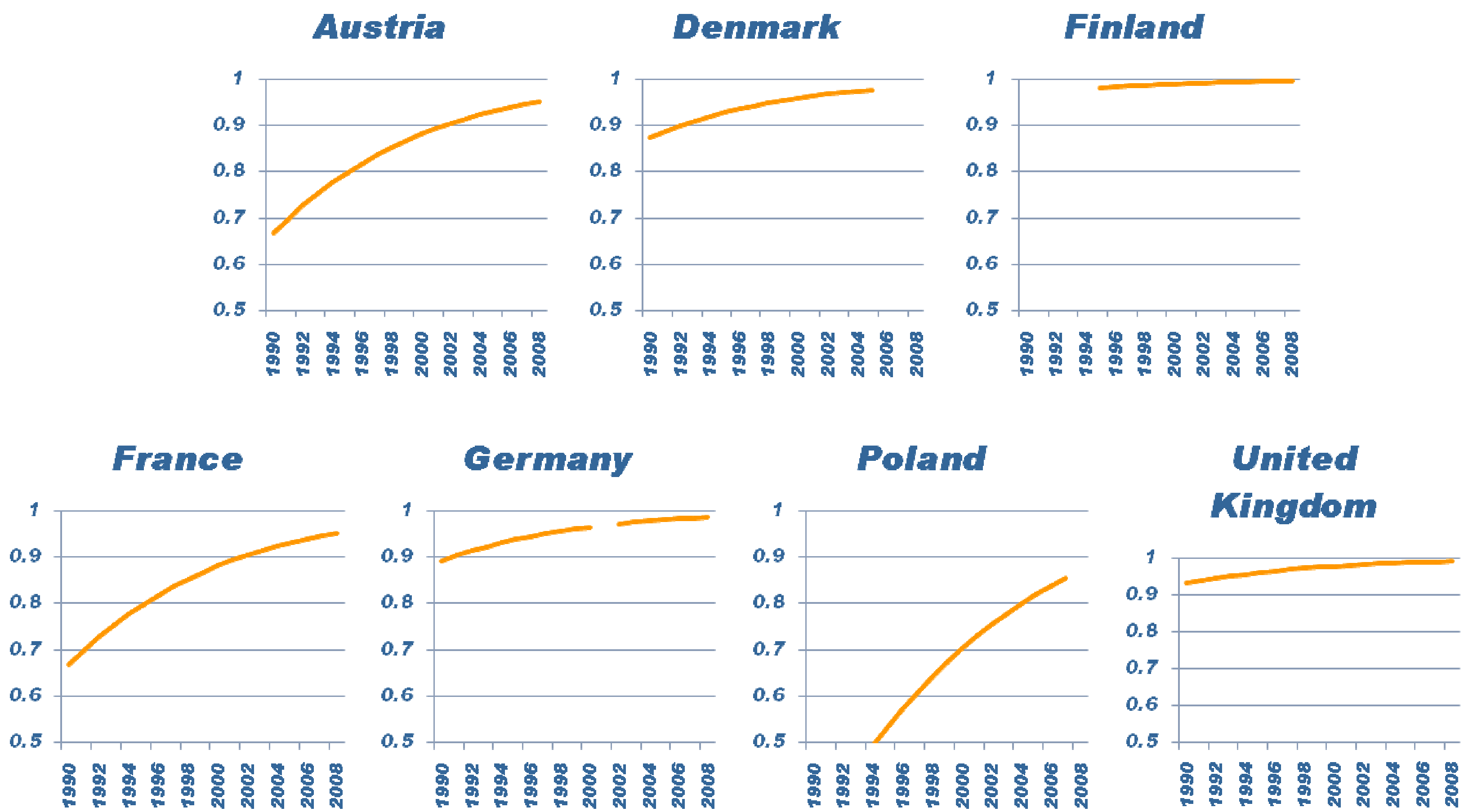
	Name	Unit	Mean	Std. dev.
Space heating final energy consumption	**E**	Mtoe	19.7	16.0
Household income	**Y**	EUR	16,328	5,468
Space heating energy price	**P**	1990 = 100	128.0	51.4
Permanently occupied dwellings	**DW**	thousands	15,633	12,507
Average dwelling floor area	**A**	sqm	11.4	109.9
Share of multi-family dwellings	**SM**	%	44.8	14.2
Heating degree days	**HDD**		3,405	903

Model results: Estimated parameters

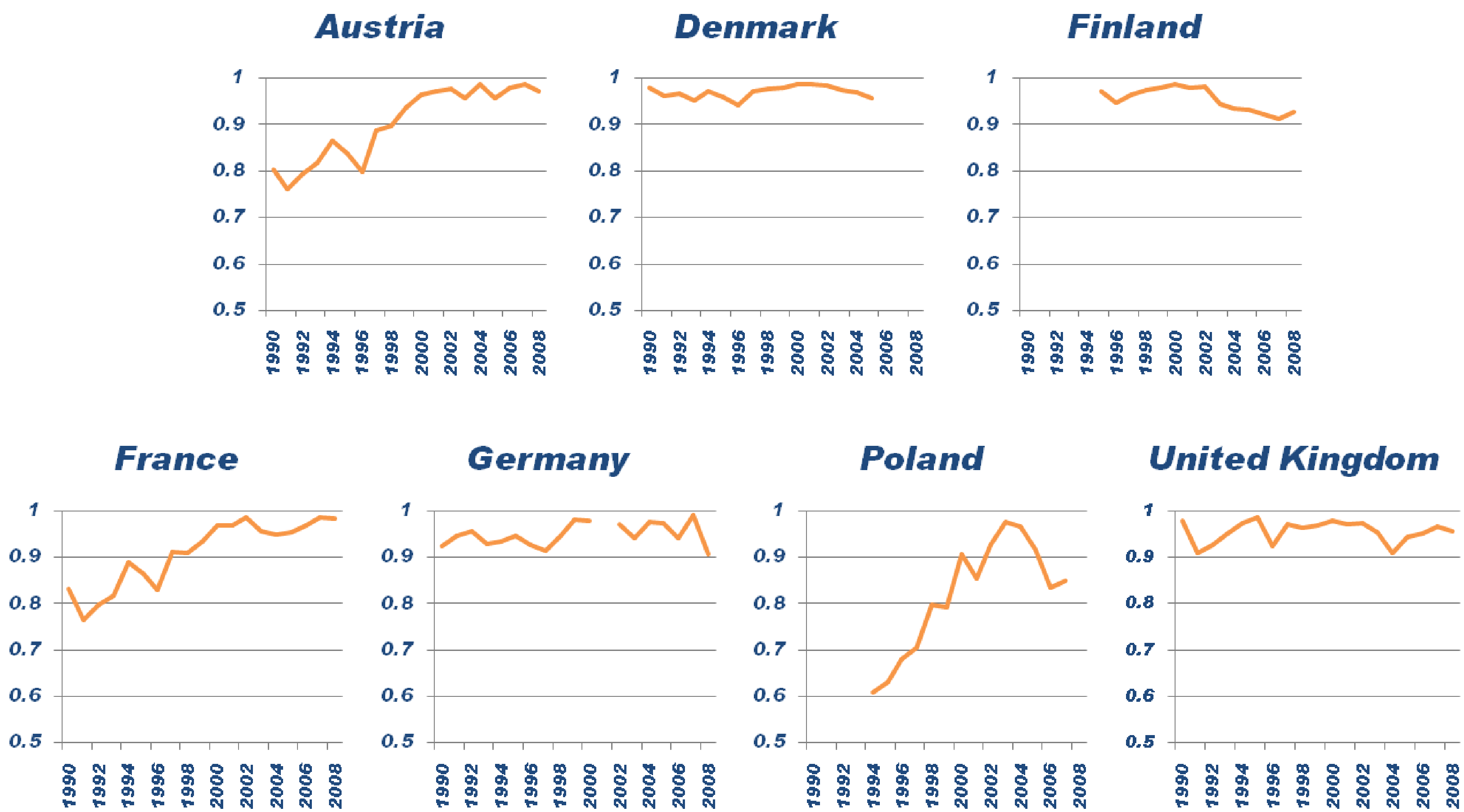
	Random error components specification	Efficiency effects frontier specification
Income	0.10 ** *(0.03)*	0.03 *(0.02)*
Price	-0.16 *** *(0.01)*	-0.21 *** *(0.02)*
Number of dwellings	1.07 *** *(0.01)*	1.03 *** *(0.01)*
Average floor area per dwelling	1.09 *** *(0.11)*	0.97 *** *(0.11)*
Share of multi-family dwellings	0.27 *** *(0.06)*	0.41 *** *(0.04)*
Heating degree days	0.66 *** *(0.06)*	0.41 *** *(0.05)*
Time effect (η)	0.12 *** *(0.01)*	–
Buildings energy codes effect (β_C)	–	-0.02 * *(0.01)*
Log-likelihood	198.55	129.99
Number of observations (N)	119	119

$*** : p < 0.001; ** : p < 0.01; * : p < 0.05$

Model results: Estimated efficiencies (Time varying efficiencies)



Model results: Estimated efficiencies (Efficiency effects frontier)



Conclusion and future work

- **Conclusions**
  - **Space heating energy efficiency has been improving in the 7 countries considered over the past 20 years**
  - **Under the hypotheses considered, there is a statistically significant, positive impact of building energy codes on space heating energy efficiency**
- **Future work**
  - **Improve the representation of the building energy codes**
  - **Grow the panel beyond European countries**
  - **Use country-wise heteroskedastic distributions of the inefficiency terms**
  - **Use fixed effects panel model to alleviate unobserved**

Thank you for your attention

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