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# Economics of innovation In Energy-Efficient Fossil-Fuel Technologies: Empirical Evidence


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FEEM

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# Outline

Database of patents in energy-efficient fossil-fuel electricity technologies

- EPO/OECD PATSTAT
- Technology selection process
- A few graphs

Preliminary study of energy-effiency in fossil-fuel electricity production

- Background and modelling choices
- Knowledge stocks using patent
- Results, Comments and Next Steps

# 1. Database: description of the project

Building a database of patens in energy-efficient technologies stating from PATSTAT

- Focus on electricity production, but potential to be enlarged to include also other sectors
- Ovrcome the lack of data regarding investments in R&D in the energy sector (>80 granting authorities worldwide)

Use for econometric analysis

- International and intersectoral spillovers
- construction of knowledge stocks
- estimation of elasticities between knowledge and other physical inputs

Application of results to climate-economy models



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# 1. Database: Patents and how they look like

**Fluidized bed reactor having a furnace strip-air system and method for reducing heat content and increasing combustion efficiency of drained furnace solids**

Bibliographic data | Description | Claims | Mosaics | Original document | INPADOC LEGAL status

| | |
|---|---|
| **Patent number:** | US5390612 (A) |
| **Publication date:** | 1995-02-21 |
| **Inventor(s):** | TOTH STEPHEN J [US] |
| **Applicant(s):** | FOSTER WHEELER ENERGY CORP [US] |
| **Classification:** | |
| **- international:** | *F23C10/00; F23C10/24; F23C10/00;* (IPC1-7): F23G7/00 |
| **- european:** | F23C10/00D; F23C10/24 |
| **Application number:** | US19930024041 19930301 |
| **Priority number(s):** | US19930024041 19930301 |

**View INPADOC patent family**
**View list of citing documents**

**Also published as:**

- EP0614043 (A1)
- JP7004615 (A)
- PT614043 (T)
- ES2137321 (T3)
- CA2116283 (A1)

more >>

**Cited documents:**

- US3662719 (A)
- US4227488 (A)
- US4335661 (A)
- US4349969 (A)
- US4397102 (A)

more >>

Report a data error here

Abstract of **US 5390612 (A)**

A fluidized bed reactor having a furnace strip-air system and method for reducing heat content and increasing combustion efficiency of drained furnace solids in which a bed of particulate material is

# 1. Database: the technologies

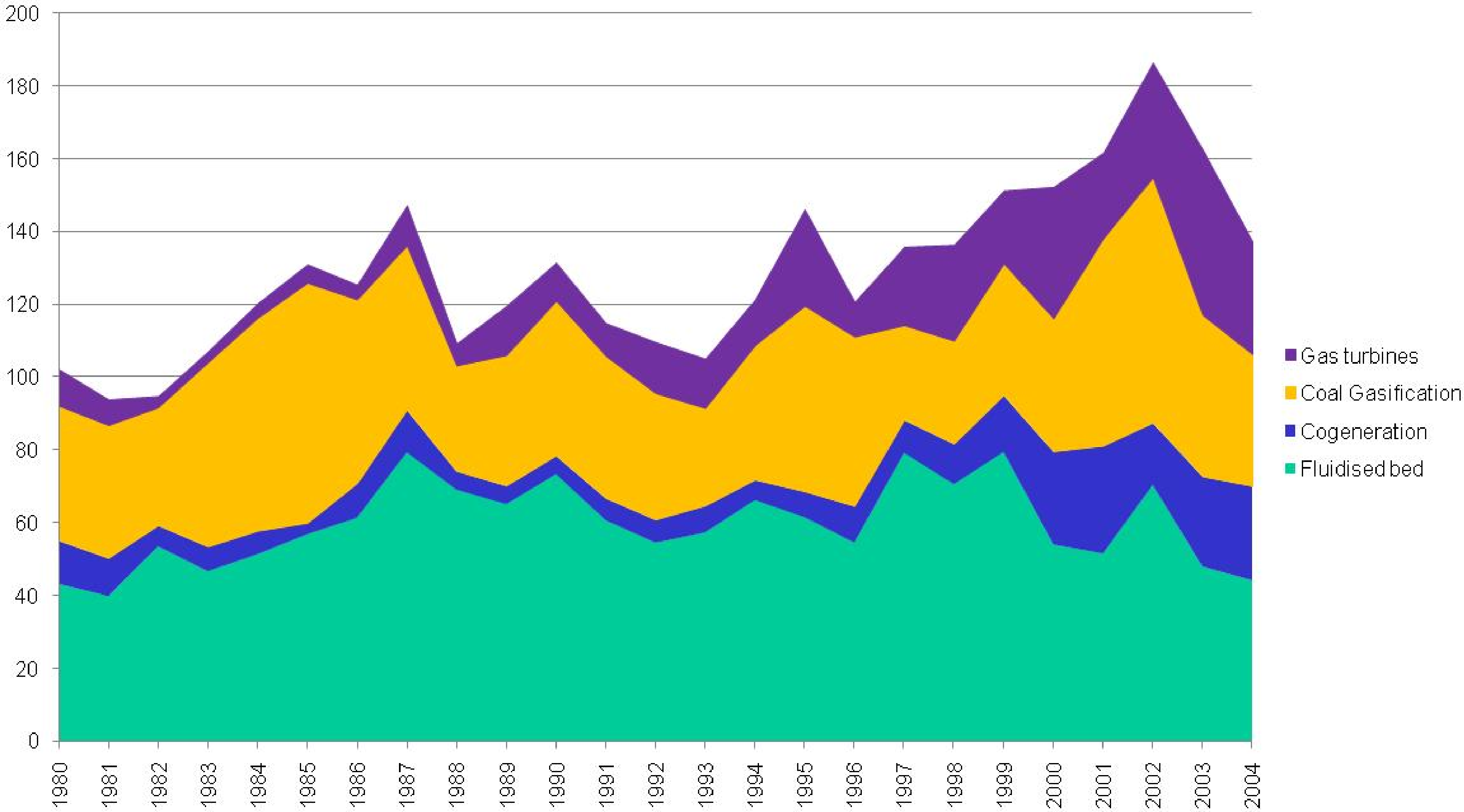
Sources of Electricity:

- Fossil Fuels (Oil, Gas, Coal), Renewables (Solar, Wing, Geothermal, Ocean, Hydro), Nuclear

Focus up to now on Fossil Fuels

- Coal Gasification
- Fluidised-bed combustion
- Integrated gasification combined cycle
- Process heaters and super-heaters
- Compressed ignition engines
- Energy-efficiency improving gas turbines
- Co-generation
- Combined cycle combustion
- Fuel cells

# Database: the technologies



# The Determinants of Energy-Efficiency in Fossil-Fuel Electricity Production

Elena Verdolini



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# 2. Fossil Fuels, Energy Demand and Electricity

- WEC 2007: growth of energy demand forecast at an annual average rate of 1.6% between 2004 and 2030. Over 70% of growth coming from developing countries, with China accounting for some 30% of increased energy demand.
- WEO 2008: electricity demand projected to increase by 3.8% per year in non-OECD countries, 1.1% per year on average in OECD countries between 2006 and 2030 . Globally, industrial demand grows faster than demand by households and services

Fossil fuels remain the main input for power generation

- WEO 2008: Coal share projected to increase from 41% to 44%, while gas and oil shares decrease due to rising prices

Big differences in power plant efficiency across countries

- WOE 2008: Overall efficiency of coal-fired generation is projected to increase: 34% in 2006, 36% in 2015 and 38% in 2030



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# 2. Fossil Fuels, Electricity and $CO_2$ emissions

Power-sector: a main contributor of $CO_2$ emissions

- Sector emitted 36% of global $CO_2$ emissions in 1990, 39% in 2000 and 41% in 2006, will be responsible for over half the increase in energy-related $CO_2$ emissions to 2030

Nearly all of the increase in $CO_2$ emissions is projected to be from non-OECD countries

World average emissions per MWh of electricity generated falls (slightly) due to increase in the thermal efficiency and greater use of renewables

However, savings do not outweigh the increase in electricity demand

## 2. Research Questions

***What are the determinants of energy efficiency in fossil-fuel electricity generation?***

***In particular, how does innovation contribute to increasing efficiency and lowering $CO_2$ emissions?***

*Answer these questions using data on the electricity sector (fossil-fuels) for 23 OECD countries and patent statistics as a proxy for innovation*



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# 2. Empirical Specification: Energy Efficiency

Phylipsen et al. (1998) and Graus et al. (2007) define energy efficiency is defined as:

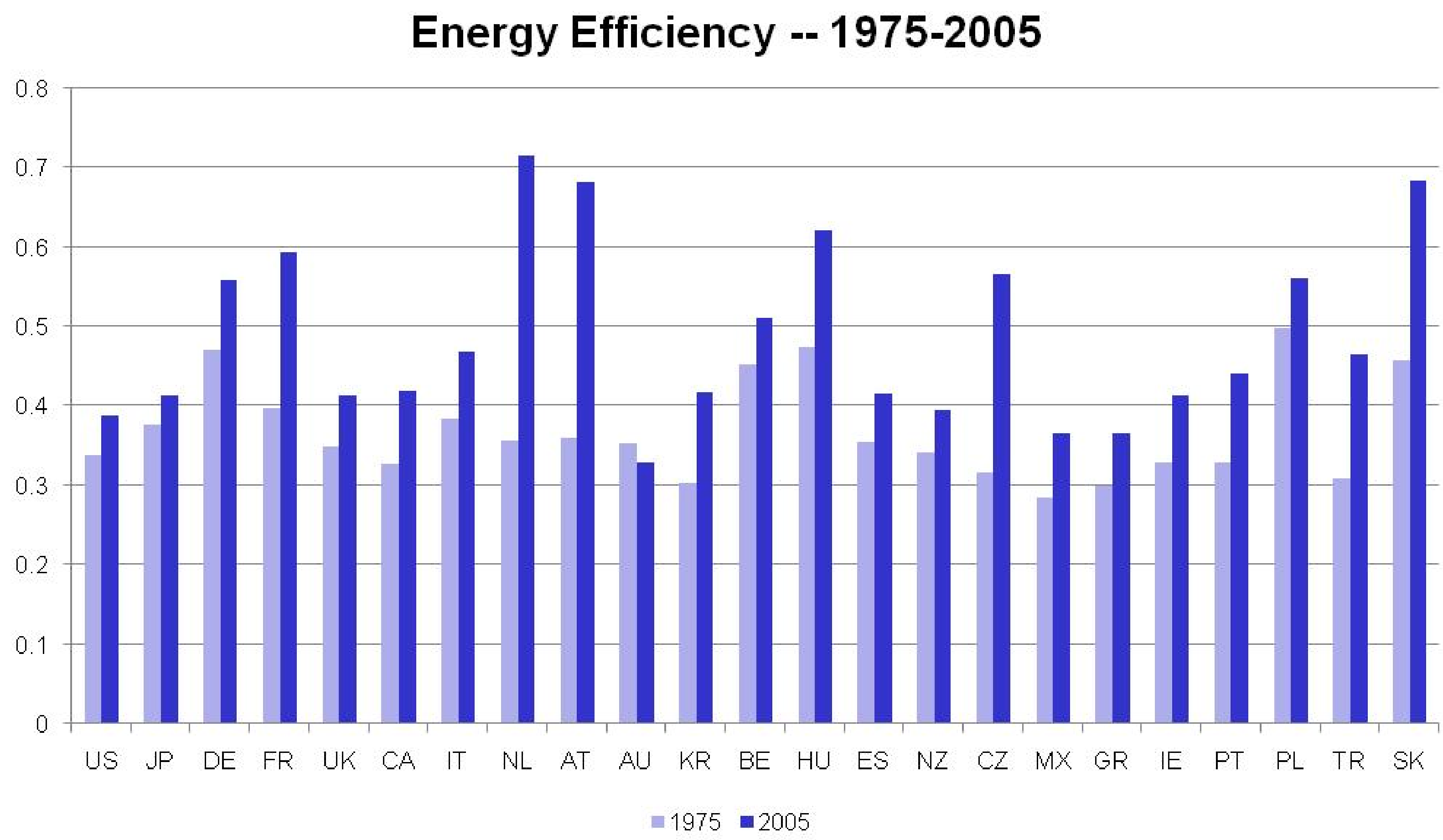
$$EE_{i,t}^{ff} = \frac{Ele_{i,t}^{ff} + (Heat_{i,t}^{ff} * s)}{Input_{i,t}^{ff}}$$

- *Ele = Electricity produced with FF (GWh*3.6)*
- *Heat = Heat produced with FF (TJ)*
- *s = Correction factor between electricity and heat (s=1.75)*
- *Input = FF inputs (coal, gas, oil) (TJ)*

Electricity (and Heat) are highly homogenous product

- allow for use of ‘physical’ units to measure efficiency
- Allow for comparison across countries

# 2. Energy Efficiency in selected OECD countries



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# 2. Previous Literature

Focus: entire electricity industry or components

- 1980s: rate of return regulation, environmental controls
- 1990s: natural monopoly (distribution), ownership restructuring of the industry, break in constituent parts (transmission, distribution, retail) and competition introduced in wholesale market and retail component

Total Factor Productivity: Kendrick (1961), Barzel (1963)

Partial productivity index (FF inputs): some recent descriptive work (Grauss et al 2007, IEA 2008)

To our knowledge, no work to date has sought to assess linking measures of availability of technologies to increases in energy efficiency

# 2. Factors affecting energy efficiency in FF power plants

Capital intensive industry where increase in efficiency likely from embodied technical change

- **Price of inputs and endowment of natural resources**: affecting the input mix
- **Different potential efficiency depending upon mix**: coal-fired *vs* gas-fired plants
- **Vintage of the plants**: rate of capital turnover has an impact on the level of efficiency of the stock
- **Capacity**: efficiency affected by capacity utilization ratio
- **Ability to trade (Connectedness)**
- **Policy**: environmental requirements can lower efficiency, energy policy can create incentives to increase efficiency
- **New energy-efficient technologies**: allow for the improvement of existing plants or construction of more efficient ones (Capital intensive industry embodied technical change)

2\.

## The empirical model

$$\ln EE^{FF}_{i,t} = \alpha + \beta \ln E^{C}_{i,t} + \gamma \ln Cap_{i,t} + \delta \ln FS_{i,t} +$$
$$+ \rho \ln V + \phi P_{i,t}\lambda + KStock_{t} + \varphi \ln Conn_{i,t} + \mu Controls$$

**E:** endowment of coal, experiment with different indicators

**Cap:** capacity utilization ratio (*MWh/MWe*8766*)

**FS:** Fossil-fuel electricity over total electricity produced

**V:** proxy for vintage of the stock. Experiment with different indicators

**Conn:** measure of connectedness with other countries, defined as maximum of electricity import or export

**KStock:** is a measure of knowledge stock, or supply of new technologies for electricity production

**Controls:** country and year dummies

## 2. The use of patent data (1)

**Patents** are a set of exclusionary rights (territorial) granted by a state to a patentee:

- For a fixed period of time (usually 20 years)
- In exchange for the disclosure of the details of the invention

**Granted on inventions** (devices, processes) that are:

- New (not known before the application of the patent)
- Involve a non-obvious inventive step
- Useful or industrially applicable

# The use of patent data (2)

**Patents are imperfect but useful indicator of inventive activity** - Griliches [1990]. Main limitations:

- Not all innovation are patented
- Not all patented innovations have the same economic value
- Propensity to patent may vary across countries and technological fields

**Patenting is costly:** the more the countries in which you apply, the higher the costs you have to face

**Innovations:** are patented with the purpose of introducing them into the market and benefit from temporary monopoly power

***For these reasons, patents are a good measure for the availability of new energy-efficient techniques for FF power generation***

## 2. Knowledge stocks using patent data (1)

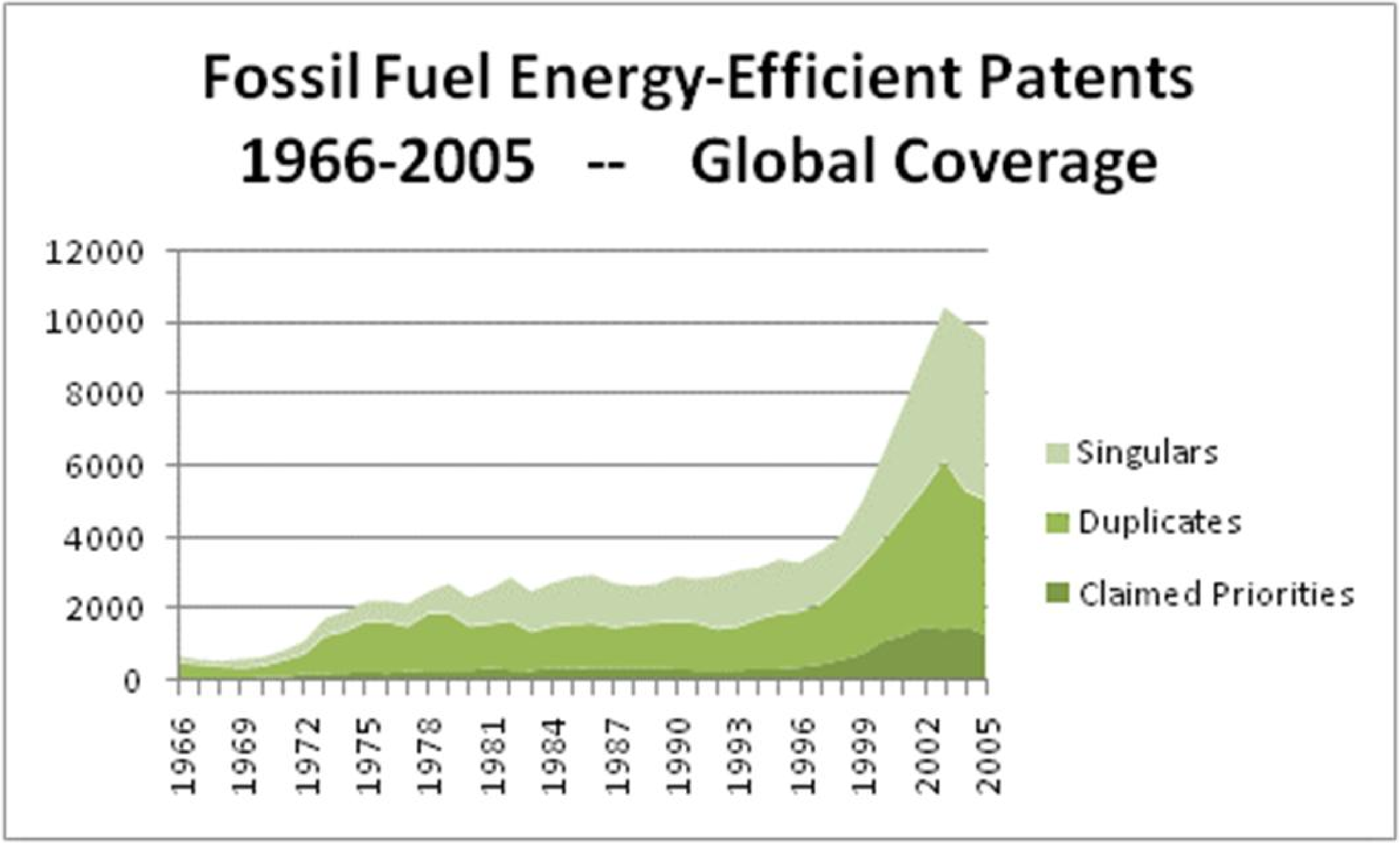
- Patent data: used to construct measures of knowledge stock (Popp 2002, Bottazzi and Peri 2005, etc.)
- Perpetual inventory method to construct a **global** knowledge stock for each time *t*:

$$KStock_t = FFPat_t + (1 - \delta)KStock_{t-1}$$

$$KStock_{t_0} = \frac{FFPat_{t_0}}{\bar{g} + \delta}$$

- Distinction between claimed priorities, duplicates and singulars to account for different value of patents
- Effect lagged (10 years) to account for time differences between innovation and deployment

# Knowledge stocks using patent data (2)



# 2. The sample

Sample of 23 OECD countries over the period 1976-2005:

- 23x30 = 960 potential observations

Data on inputs, outputs and capacity installed in the electricity sector from IEA – *Electricity Information Database 2008*

Data on patents from EPO/OECD PATSTAT Database, version 2008

Pooled OLS estimation with robust standard errors

# 2. Results (1)

| | A2 | B2 | C2 | D2 | E2 | F2 |
|---|---|---|---|---|---|---|
| Coal Share | -0.025*** | -0.026*** | -0.019*** | -0.018*** | -0.028*** | -0.028*** |
| | -0.005 | -0.005 | -0.005 | -0.005 | -0.005 | -0.005 |
| Capacity Ratio | 0.046*** | 0.049*** | 0.030* | 0.028* | 0.063*** | 0.064*** |
| | -0.016 | -0.016 | -0.016 | -0.016 | -0.016 | -0.016 |
| FF Electrcity | 0.781*** | 0.782*** | 0.774*** | 0.774*** | 0.780*** | 0.781*** |
| Production Ratio | -0.042 | -0.041 | -0.042 | -0.042 | -0.041 | -0.041 |
| Oil Price | 0.068*** | 0.069*** | 0.058*** | 0.058*** | 0.072*** | 0.073*** |
| | -0.008 | -0.008 | -0.008 | -0.008 | -0.008 | -0.008 |
| Knowledge Stock | 0.138*** | | | | | |
| (CP) | -0.009 | | | | | |
| Knowledge Stock | | 0.159*** | | | | |
| (CP - LIM) | | -0.011 | | | | |
| Knowledge Stock | | | 0.129*** | | | |
| (CP+Dup) | | | -0.008 | | | |
| Knwledge Stock | | | | 0.142*** | | |
| (CP+Dup - LIM) | | | | -0.009 | | |
| Knowledge Stock | | | | | 0.074*** | |
| (CP+Dup+Sin) | | | | | -0.005 | |
| Knowledge Stock | | | | | | 0.081*** |
| (CP+Dup+Sin - | | | | | | -0.006 |
| Constant | -3.366*** | -3.520*** | -3.421*** | -3.531*** | -3.022*** | -3.082*** |
| | -0.104 | -0.112 | -0.107 | -0.112 | -0.09 | -0.093 |
| Adj.R-Square | 0.91 | 0.91 | 0.91 | 0.91 | 0.91 | 0.91 |
| Nr of Cases | 596 | 596 | 596 | 596 | 596 | 596 |

# 2. Results (2)

| | A | B | C | D |
|---|---|---|---|---|
| Coal Share | -0.031*** | -0.026*** | -0.025*** | -0.038*** |
| | -0.005 | -0.004 | -0.004 | -0.006 |
| Capacity Ratio Utilization | 0.058*** | 0.052*** | 0.053*** | 0.050*** |
| | -0.021 | -0.015 | -0.015 | -0.016 |
| Avg Capacity Increase (1yr) | -0.001 | | | |
| | -0.002 | | | |
| Avg Capacity Increase (5yrs) | | 0.054 | | 0.043 |
| | | -0.04 | | -0.053 |
| Avg Rate of Capacity Increase | | | 0.042* | |
| | | | -0.024 | |
| FF Electricity Production Ratio | 0.731*** | 0.760*** | 0.757*** | 0.759*** |
| | -0.058 | -0.041 | -0.041 | -0.042 |
| Oil Price | 0.071*** | 0.065*** | 0.064*** | 0.054*** |
| | -0.01 | -0.008 | -0.008 | -0.008 |
| Knowledge Stock (CP) | 0.135*** | 0.140*** | 0.140*** | 0.151*** |
| | -0.01 | -0.009 | -0.009 | -0.011 |
| Electricity Exports | | | | 0.007** |
| | | | | -0.003 |
| Constant | -3.291*** | -3.346*** | -3.330*** | -3.343*** |
| | -0.138 | -0.106 | -0.103 | -0.132 |
| Adj.R-Square | 0.90 | 0.92 | 0.92 | 0.93 |
| Nr of Cases | 433 | 565 | 565 | 439 |

# 2. Results (3)

| | A1 | B1 | C1 | D1 | E1 | F1 |
|---|---|---|---|---|---|---|
| Coal Share | -0.026*** | | | | | |
| | -0.004 | | | | | |
| Production | | -0.021*** | | | | |
| | | -0.008 | | | | |
| TPES - Coal | | | -0.034*** | | | |
| | | | -0.009 | | | |
| Exports/Production | | | | 0.004 | | |
| | | | | -0.003 | | |
| Proved Reserves | | | | | -0.001* | |
| | | | | | 0.000 | |
| Accessible Reserves | | | | | | -0.002*** |
| | | | | | | 0.000 |
| Capacity Ratio | 0.052*** | 0.056*** | 0.064*** | 0.049*** | 0.047*** | 0.038** |
| | -0.015 | -0.017 | -0.017 | -0.017 | -0.016 | -0.017 |
| lnmeancap5 | 0.054 | 0.065 | 0.068 | 0.077 | 0.080* | 0.063 |
| | -0.04 | -0.042 | -0.041 | -0.048 | -0.044 | -0.044 |
| FF Electricity Production Ratio | 0.760*** | 0.677*** | 0.772*** | 0.766*** | 0.764*** | 0.757*** |
| | -0.041 | -0.087 | -0.042 | -0.099 | -0.041 | -0.041 |
| Oil Price | 0.065*** | 0.050*** | 0.050*** | 0.051*** | 0.055*** | 0.051*** |
| | -0.008 | -0.008 | -0.009 | -0.009 | -0.009 | -0.009 |
| Knowledge Stock (CP) | 0.140*** | 0.117*** | 0.138*** | 0.128*** | 0.137*** | 0.160*** |
| | -0.009 | -0.011 | -0.009 | -0.011 | -0.01 | -0.012 |
| Constant | -3.346*** | -2.829*** | -3.016*** | -3.182*** | -3.271*** | -3.418*** |
| | -0.106 | -0.175 | -0.112 | -0.194 | -0.108 | -0.127 |
| Adj.R-Square | 0.92 | 0.91 | 0.92 | 0.91 | 0.91 | 0.92 |
| Nr of Cases | 565 | 528 | 568 | 471 | 568 | 568 |

# 2. Conclusions

- Good fit of the model (but problems with some of the proxies)
- Confirms importance of supply determinants of energy-efficiency
- Consistent results with expectations, robust to different specifications of the Kstock
- Need to improve
  - Sample size: unreliable data
  - Better proxy for endownment
  - Measures of environmental regulation
  - Construct national knowledge stocks (autarchy vs spillovers)
- Further examine how technical change and innovation contribute to $CO_2$ emissions reductions

# The Determinants of Innovation in Electricity Generation Technologies

Elisa Lanzi



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1.

# Outline

- Introduction
- Literature
- Data
- Estimation method
- Results
- Conclusion
- Next steps

# Introduction

## Importance of innovation in electricity generation

QUESTION 1: What are the determinants of innovation in electricity generation technologies?

## Two types of energy-efficient technologies

- Fossil-fuel based

  (coal gasification, fluidised-bed combustion, combined cycles, superheaters, compressed ignition engines, gas turbines, fuel cells)
- Renewables

  (wind, solar, geothermal, ocean, biomass/waste)

QUESTION 2: What can determine a switching of the focus of innovation in the electricity supply industry?

3.

# Literature

## Country-specific on innovation induced by environmental policy

- Lanjouw and Mody (1996): relationship between number of patents granted and stringency of environmental policy, patents increase as policies become more stringent with 1-2 years of lag
- Jaffe and Palmer (1997): US-industry level data, no support for induced innovation hypothesis
- Brunnermeier and Cohen (2003): US manufacturing industry data, patent counts increase as pollution abatement expenditure increases

## Cross-country studies on instrument choices

- De Vries and Withagen (2005): relationship between $SO_2$ abatement policies and patent applications, they find evidence that strict environmental policies lead to innovation
- Popp (2006): patents and $SO_2$ and $NO_x$ abatement in US, Japan and Germany

## Studies on energy-efficient technologies

- Popp (2002): energy prices have a strong impact on innovation
- Johnstone, Hascic and Popp (2008) – renewable energy sources, climate policy and innovation

# 4. The Determinants of Innovation

## Fossil-fuel prices

- An increase in the price of the production inputs or of the production costs of a substitute should lead to higher innovation

## R&D expenditure

- Fundamental input for innovation, the higher the R&D expenditures, the more innovation

## Electricity market size

- The greater the market to be served, the more innovation is expected

## General innovative capacity

- Some countries have a greater capacity to innovate, and these are expected to produce more innovation

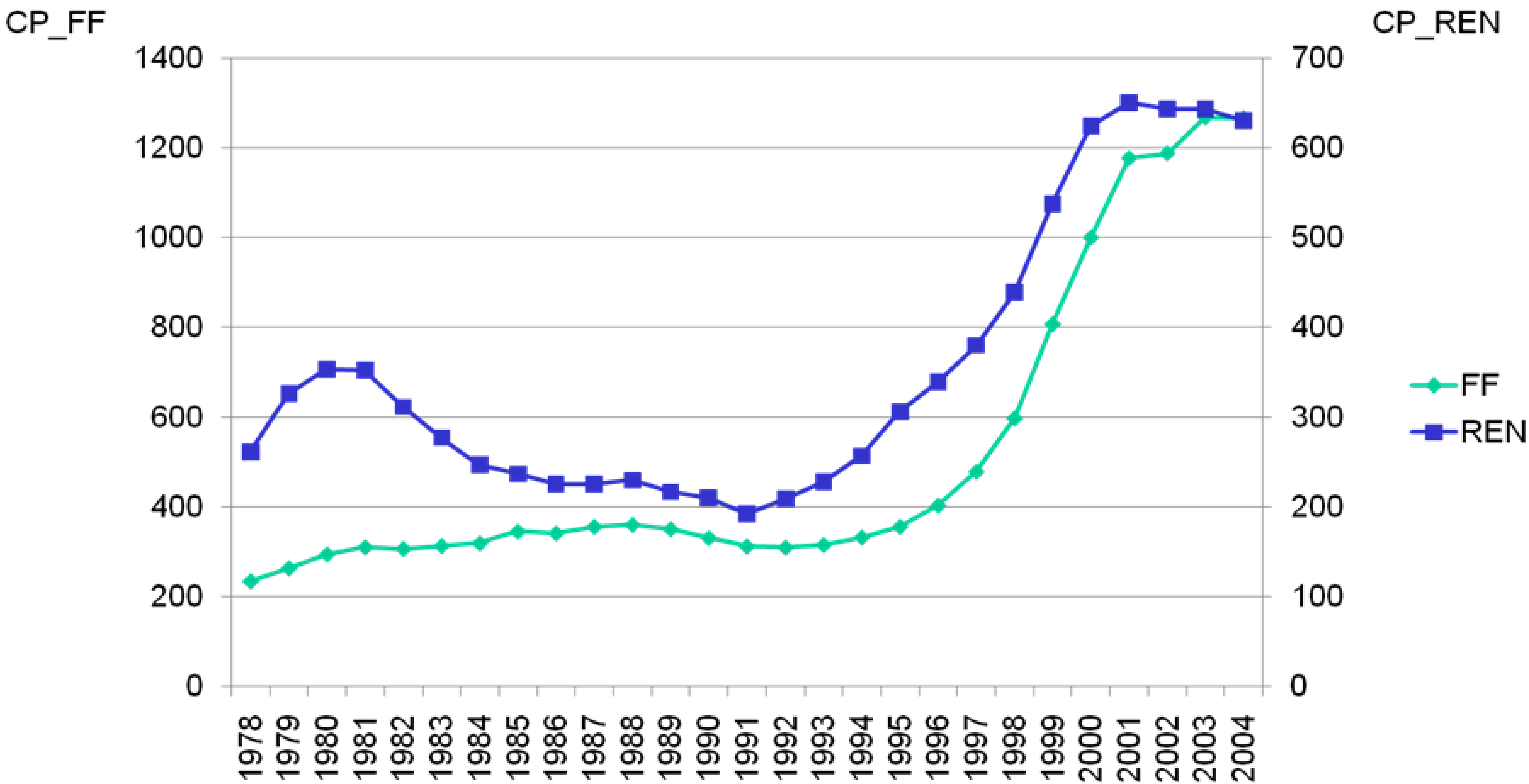
## Existing Knowledge

5.

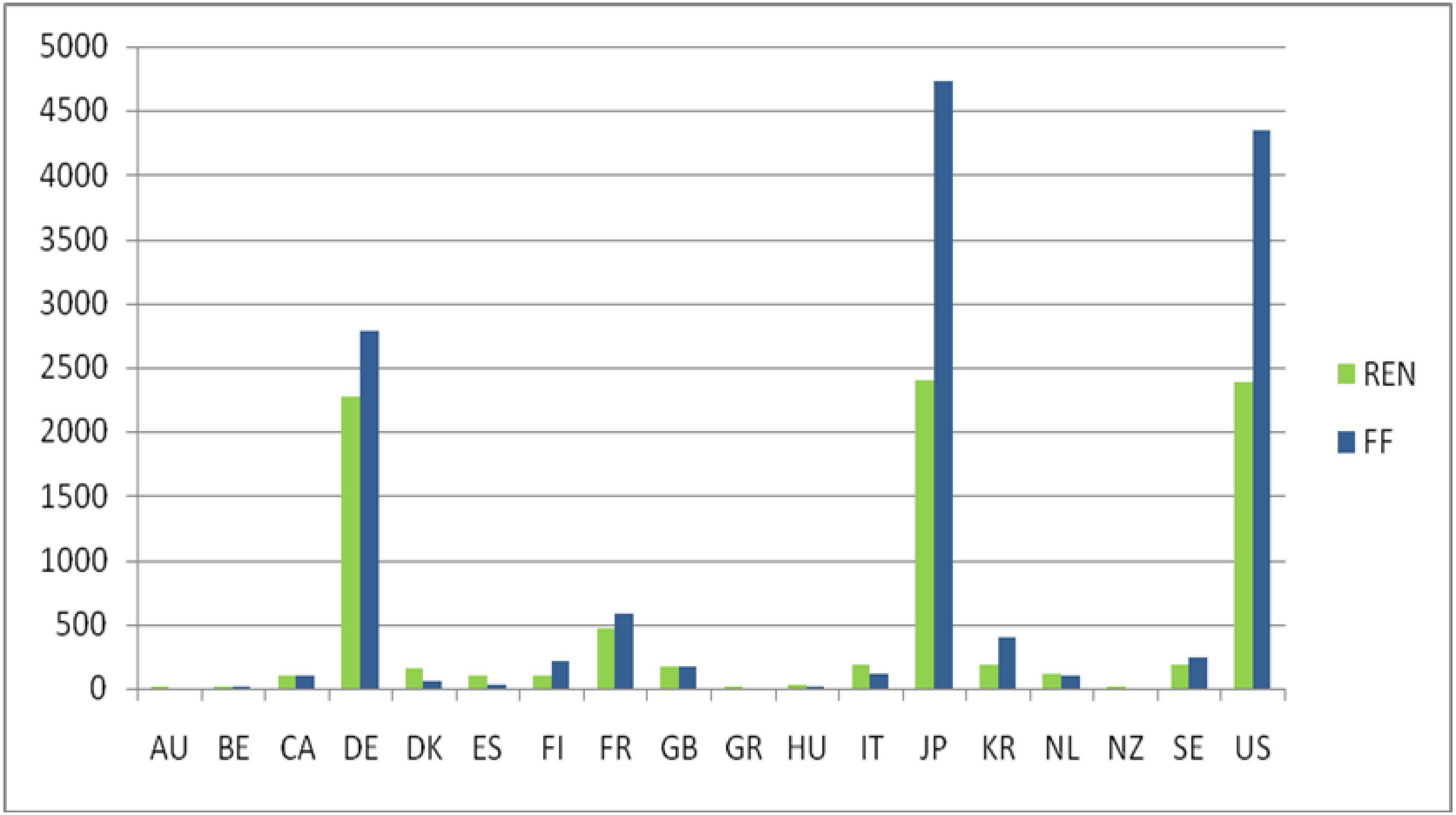
# Data – The Dependent Variable

- Patents as an indicator of innovative activity
- OECD/EPO Worldwide Patent Statistical Database (PATSTAT)
  - Covers 80 patent offices worldwide since 1970s
- Development of a search strategy for patented energy-efficient technologies for the production of electricity
- Selection of International Patent Classification (IPC) classes allows us to select patents relative to the technologies of interest
- Use of claimed priorities

# 5.1. Data – claimed priorities (country aggregate)



# 5.2. Data – claimed priorities by country (1978-2005)



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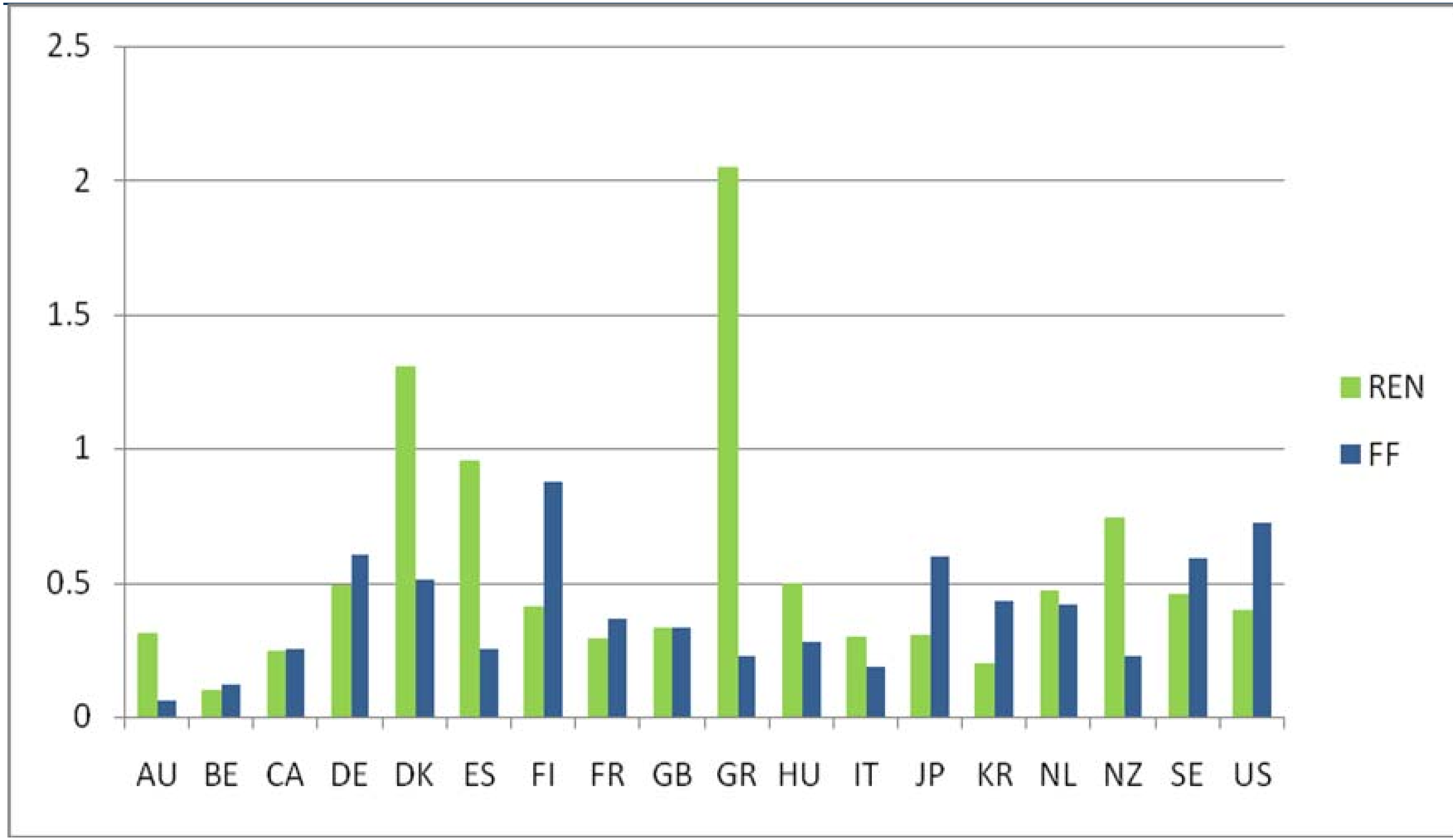
# 5.3. Data – claimed priorities normalised by total (1978-2005)







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# 5.4. Data – determinants of innovation

| | |
|---|---|
| Fossil-fuel prices | Price of oil (IEA) |
| R&D | Public technology-specific energy R&D (IEA)<br>General R&D (GERD, OECD)<br>Industry R&D (BERD, OECD) |
| Electricity market size | Electricity consumption (IEA)<br>GDP  (OECD)<br>GDP p.c. (OECD) |
| General innovative capacity | Total number of patents (PATSTAT)<br>Number of researchers (OECD)<br>Total number of patents/GDP<br>Researchers/GDP |
| Knowledge stock | Built with perpetual inventory method (Verdolini, 2009) |

# 6. Model

$$(CP_{i,t}) = \beta_1(R\&D_{i,t}) + \beta_2(P_{i,t}) + \beta_3(MARK_{i,t}) + \beta_3(INN\_CAP_{i,t}) + \alpha_i + \varepsilon_{i,t}$$

$i = 1,\ldots,18$ cross-sectional unit (country)

$t = 1978,\ldots,2005$

$CP_{i,t}$ number of claimed priorities in the relevant technology areas ($CP\_FF_{i,t}$ and $CP\_REN_{i,t}$)

$R\&D_{i,j}$ R&D expenditures

$P_{i,t}$ fossil fuel prices

$MKT_{i,t}$ indicator for market size

$INN\_CAP_{i,t}$ indicator for innovative capacity

$\alpha_i$ country-specific effects

$\varepsilon_{i,t}$ error term

7.

# Estimation Method

- Negative binomial estimation
- Fixed effects are included to control for country-specific heterogeneities
- Robust estimation to correct for the heteroskedasticity in the data

# 8.1. Results – Fossil Fuels

| CP FF | FF (1) | FF (2) | FF (3) |
|---|---|---|---|
| Oil price (index) | .0052*** (0.001) | .0045*** (0.003) | .0042*** (0.007) |
| GERD | .0057*** (0.006) | | |
| GDP p.c. | .7015*** (0.000) | .6091*** (0.000) | .4704*** (0.0034 |
| Total patents/GDP | .2208*** (0.000) | .2167*** (0.000) | .2199*** (0.000) |
| Knowledge stock | | .0008*** (0.003) | .00083*** (0.003) |
| External knowledge stock | | | .000052 (0.418) |
| Observations | 939 | 485 | 485 |
| Log-likelihood | -1013.77 | -1115.77 | -1115.47 |

# 8.2. Results – Renewable

| CP REN | REN (1) | REN (2) | REN (3) |
|---|---|---|---|
| Oil price (index) | .0078***<br>(0.000) | .0064***<br>(0.000) | .0073***<br>(0.000) |
| R&D Renewables | .8093***<br>(0.002) | | |
| GDP p.c. | .9391***<br>(0.000) | .9636***<br>(0.000) | .1331***<br>(0.000) |
| Total patents/GDP | .1989***<br>(0.000) | .1987***<br>(0.000) | .1945***<br>(0.000) |
| Knowledge stock | | .0013***<br>(0.000) | .0012***<br>(0.001) |
| External knowledge stock | | | .00020**<br>(0.024) |
| Observations | 427 | 532 | 532 |
| Log-likelihood | -1114.421 | -1282.15 | -1278.95 |



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# 9. Conclusions

- Innovation for both fossil-fuel based and renewable technologies is positively influenced by
  - Oil price
  - Market size measured as GDP p.c.
  - Innovative capacity measured as total patent counts/GDP
  - Sotck of knowledge

- General R&D positively influences fossil-fuel based technologies, while technology-specific public R&D influences renewables



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# 10. Extensions

- Econometrics
  - Joint estimation of the two equations (Seemingly Unrelated Negative Binomial Regression – SUNB) to study switching between technologies

- Application to WITCH
  - Construction of knowledge stocks for the single technologies (following Elena's work) to make the knowledge stock technology-specific



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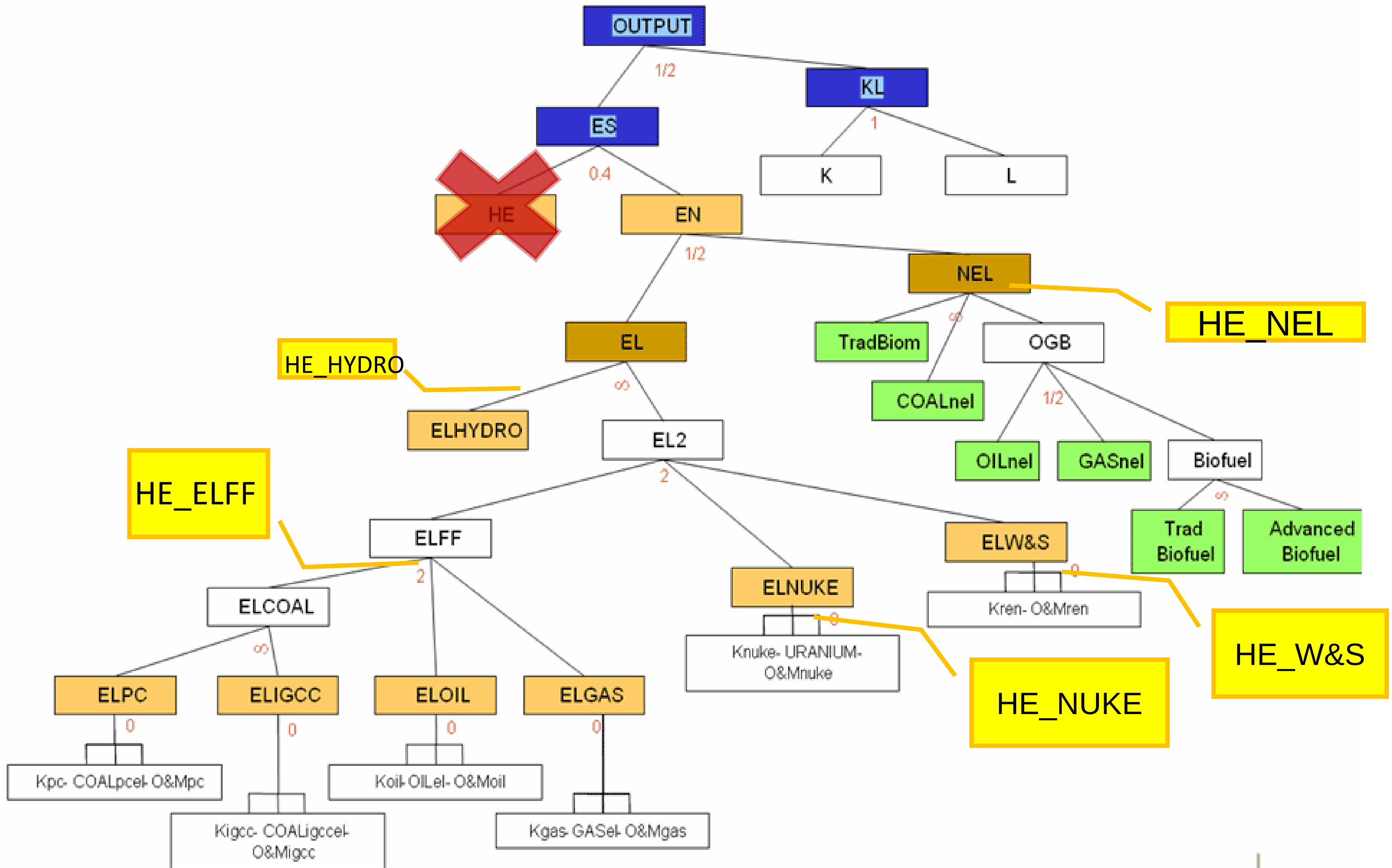
# Extensions - application to WITCH



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# Thank you!

**Elisa Lanzi & Elena Verdolini**
**Fondazione Eni Enrico Mattei**