The Impact of Energy Policy Instruments on the Level of Energy Efficiency

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• Alberini A. and Filippini M. “Underlying Energy efficiency” in the US Residential Sector and Potential CO2 Savings
Outline

- Motivation
- Energy Efficiency
- Underlying Energy efficiency” in the EU
- Underlying Energy efficiency” in the US
- Energy policy measures and energy efficiency in the EU
- Conclusions
A) Motivation and Goals

- All countries around the world are implementing energy efficiency policy instruments

- Improving energy efficiency is one of the most cost-effective ways of
  - reducing CO$_2$ emissions
  - reducing air pollution
  - increasing security of energy supply
• In the **new EU energy strategy** (Energy 2020) energy-efficiency is listed among the first 5 priorities: **20% energy savings to be achieved by 2020** (EC, 2010)

• The majority of **the US states** are implementing energy efficiency policies although with different approaches

• **Federal state**: Energy efficiency improvement Act (2014)
House passes Welch bipartisan energy efficiency legislation

(passed the House of Representatives, but has not come to a vote in the Senate yet)

March 5, 2014

WASHINGTON, D.C. – By a vote of 375-36, the U.S. House of Representatives this afternoon approved energy efficiency legislation authored by Representative Peter Welch. The Energy Efficiency Improvement Act, H.R. 2126, is the first significant bipartisan energy initiative approved by the House in the 113th Congress.

The Energy Efficiency Improvement Act has four key components:

- Establishes energy efficiency best practices for commercial tenants renting space in commercial buildings and creates a new TENANT STAR certification program. TENANT STAR will be modeled after the existing ENERGY STAR program which certifies commercial buildings as highly energy efficient.

http://vtdigger.org/2014/03/05/house-passes-welch-bipartisan-energy-efficiency-legislation/
- Residential sector (30-40 % of the final energy consumption) is identified as being one of the areas with the greatest potential for energy savings

- McKinsey (2009) estimated that the United States by 2020 could reduce annual energy consumption by 23 % from a Business-as-usual projection

- Electric Power Research Institute (2009) ~10%
In order to increase the level of efficiency in the use of energy it is important to measure in a precise way the level of efficiency in the use of energy (aggregate/disaggregate) to analyze the impact of energy policy instruments on the level of efficiency in the use of energy.
Measurement of energy efficiency in the residential sector using simple indicators

- Energy consumption per household
- Energy consumption per square meter
- Energy consumption per dwelling
- .....
Residential energy consumption (BTU) per square foots (2009)
Residential energy consumption (Kwh) per square meters (2011)

Weather
Income
Prices
Household size
......
Level of efficiency
Limitations of the Energy-Intensity Indicators

- "Four energy-intensity indicators were presented in this chapter that may be used as the basis for the measurement of energy efficiency. All four indicators are imperfect...."

- Changes in energy intensity are a function of changes in several factors.

http://www.eia.doe.gov/emeu/efficiency/ee_ch3.htm
Factors that influences the level of energy intensity

- Climate
- Population
- Household size
- Income Prices
- .........
- Technology/production
  - Technical change
  - Productive efficiency «underlying energy efficiency»

Differences over time and across households of the energy intensity
Goals

• **Methodological:**

  ➔ To estimate the level of energy efficiency applying a relatively novel approach based on: 1. the microeconomics of production; 2. the use of econometric methods and stochastic frontier analysis for panel data (Filippini and Hunt (2011, 2012));

• **Policy-oriented:**

  ➔ To analyze at the aggregate level the **impact of energy policy instruments** on the level of residential energy efficiency
  ➔ Impact on CO2 emissions
B) Energy-efficiency and productive efficiency
Energy services

- Households are not consuming directly energy
- Households are consuming energy services:
  - Cooking, lighting, washing, heating ,......
  - .................
- Behind any energy service we have a production process and an associated production function.
- Use of capital, energy, labor
- Different combinations that should depend from prices
Energy services and production function

**Standard technology**

More capital and less energy

More energy and less capital
Heat loss and insulation (thermal image)

Good insulation

Bad Insulation: heat loss from the old (right) part of the building

Choice should depend on prices
microeconomics
• **New technology**: Low-energy-consumption building

- High insulation
- Continuous renewal of air in the building using an energy-efficient ventilation system
- Partially Renewable energy sources

• **Swiss Label**: MINERGIE
Microeconomics of production and technical change
Productive efficiency

- **Productive efficiency**: Measures the ability of an household/region/country to minimize the use of capital, labor and energy, given a level of energy services.

- In the production of energy services we can observe:
  - *Inefficiency in the use of energy and capital*
  - *Inefficiency in the choice of the technology*

- From the microeconomics point of view the term energy efficiency is not precise ➔ related to the concept of **productive efficiency** (Farrell 1957)
Productive efficiency

- **Situation 1**: Household $A$ is using in an inefficient way a technology $\Rightarrow$ inefficient use of the inputs (capital and energy)

- **Situation 2**: Household $A$ is using an old technology $\Rightarrow$ inefficient use of the inputs (capital and energy)
An energy demand frontier model

simplified model \( E = f(\text{energy services}) \)

Energy efficiency measures the ability of an household to minimize the energy consumption, given a level of GDP

Estimation an energy demand frontier equation

\[
EF_i = \frac{E_{fro}}{E_{obs}} \leq 1
\]
C) Model specification and econometric approaches *(European study)*
Empirical analysis

Estimation of an aggregate energy demand frontier function for the residential sector

Three econometric approaches (BC95, BC95 with Mundlak, TFE)
panel data set, 27 EU member states, 1996 to 2010

Estimation for each country of an indicator of the level of energy efficiency for the residential sector

Analysis of the impact of the energy policy measures on the level of energy efficiency
Model Specification & Data (1)

\[ \ln ED_{it} = \alpha + \beta_{PE} \ln PE_{it} + \beta_{Y} \ln Y_{it} + \beta_{POP} \ln POP_{it} + \beta_{DSIZE} \ln DSIZE_{it} + \beta_{HDD} \ln HDD_{it} + \beta_{HOT} HOT_{i} + \beta_{t} t + \nu_{it} + \mu_{it} \]

where:

- \( ED_{it} \) – final residential energy consumption (in toe)
- \( Y_{it} \) – GDP in PPP (in constant US$ prices)
- \( PE_{it} \) – real energy price (2005 = 100)
- \( POP_{it} \) – population
- \( DSIZE_{it} \) – average size of a dwelling (in m\(^2\))
- \( HDD_{it} \) – heating degree days
- \( HOT_{i} \) – hot climate dummy
- \( T \) – time trend (technical change)
- \( \nu_{it} \) – random noise
- \( \mu_{it} \) – indicator of the inefficient use of energy
Preferred econometric models (BC95 + Mundlak)

\[ \ln ED_{it} = \alpha_i + \alpha_y \ln Y_{it} + \ldots + \nu_{it} + u_{it} \quad u_{it} \geq 0 \]

- Individual Heterogeneity
- Mundlak

\[ \alpha_i = \alpha_y \ln \bar{Y}_{it} + \gamma_i \]

- a symmetric disturbance capturing the effect of noise and as usual is assumed to be normally distributed
- is interpreted as an indicator of energy efficiency and is assumed to be half-normal distributed
- Time varying inefficiency
Frontier energy demand model

Energy efficiency: measures the ability of a state to minimize the energy consumption, given a level of $Y$

$$EF_i = \frac{E_{\text{Frontier}}}{E_{\text{Observed}}} \leq 1$$
## Results (1)

### Table 3: Estimation results of energy demand model

<table>
<thead>
<tr>
<th>Parameter</th>
<th>BC95 model</th>
<th>BC95M model</th>
<th>TFE model</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Constant</strong></td>
<td>5.4989***</td>
<td>0.3779</td>
<td>-8.3131***</td>
</tr>
<tr>
<td><strong>LPE</strong></td>
<td>0.0449</td>
<td>-0.2561***</td>
<td>-0.1857***</td>
</tr>
<tr>
<td><strong>LY</strong></td>
<td>0.6962***</td>
<td>0.3318***</td>
<td>0.4199***</td>
</tr>
<tr>
<td><strong>LPOP</strong></td>
<td>0.3014***</td>
<td>0.7252***</td>
<td>1.2598***</td>
</tr>
<tr>
<td><strong>LDS</strong></td>
<td>-0.3193***</td>
<td>0.3428</td>
<td>-0.4327**</td>
</tr>
<tr>
<td><strong>LHDD</strong></td>
<td>0.3348***</td>
<td>0.3473***</td>
<td>0.3708***</td>
</tr>
<tr>
<td><strong>t</strong></td>
<td>-0.0146***</td>
<td>0.0006</td>
<td>-0.0028</td>
</tr>
<tr>
<td><strong>HOT</strong></td>
<td>-0.4225***</td>
<td>-0.5839***</td>
<td>/</td>
</tr>
<tr>
<td><strong>MLPE</strong></td>
<td>/</td>
<td>1.1016***</td>
<td>/</td>
</tr>
<tr>
<td><strong>MLY</strong></td>
<td>/</td>
<td>0.3165***</td>
<td>/</td>
</tr>
<tr>
<td><strong>MLPOP</strong></td>
<td>/</td>
<td>-0.3746**</td>
<td>/</td>
</tr>
<tr>
<td><strong>MLDS</strong></td>
<td>/</td>
<td>-0.0189</td>
<td>/</td>
</tr>
<tr>
<td><strong>MLHDD</strong></td>
<td>/</td>
<td>-0.4596</td>
<td>/</td>
</tr>
</tbody>
</table>

Note: ***, **, * - significant at 1%, 5% and 10% level, respectively
## Results (3)

Table 4: Descriptive statistics of energy efficiency estimates

<table>
<thead>
<tr>
<th>Variable</th>
<th>Mean</th>
<th>Std. Dev.</th>
<th>Min</th>
<th>Max</th>
<th>N</th>
</tr>
</thead>
<tbody>
<tr>
<td>EFBC95</td>
<td>0.8340</td>
<td>0.0989</td>
<td>0.6230</td>
<td>0.9708</td>
<td>349</td>
</tr>
<tr>
<td>EFBCM95</td>
<td>0.8961</td>
<td>0.0453</td>
<td>0.8590</td>
<td>0.9882</td>
<td>349</td>
</tr>
<tr>
<td>EFTFE</td>
<td>0.9398</td>
<td>0.0437</td>
<td>0.8607</td>
<td>0.9926</td>
<td>349</td>
</tr>
</tbody>
</table>
Member states and estimated average energy efficiency (~12%)

<table>
<thead>
<tr>
<th>Energy efficiency score (EFBCM)</th>
<th>Group</th>
<th>Member states</th>
</tr>
</thead>
<tbody>
<tr>
<td>Below 86%</td>
<td><em>Inefficient states</em></td>
<td>BE, CY, DE, DK, EE, FI, GR, HU, IT, LV, PT</td>
</tr>
<tr>
<td>From 86% to 93%</td>
<td><em>Moderately efficient states</em></td>
<td>AT, FR, LU, PL, RO, SE, SI, SK</td>
</tr>
<tr>
<td>Above 93%</td>
<td><em>Efficient states</em></td>
<td>BG, CZ, ES, IE, LT, NL, UK</td>
</tr>
</tbody>
</table>

The efficiency estimates are found to be very poorly correlated (-0.07) with energy intensity ($EI$),
D) Model specification and econometric approaches *(US study, data households)*
Empirical strategy

Estimation of an energy demand frontier function for the US residential sector

Three econometric approaches (Pooled, Pitt&Lee, TRE)

Unbalanced panel data set, 11330 households, 1996 to 2010

N = 41040

American Housing Survey

Estimation for each household of an indicator of the level of energy efficiency (benchmarking)

Analysis of the impact of the energy policy measures on the level of energy efficiency
Model Specification

\[ \ln E_{it} = \alpha + \alpha^p \ln P_{it} + \alpha^Y Y_{it} + \alpha^\text{SIZE} \ln \text{SIZE}_{it} + \alpha^\text{ROOMS} \ln \text{ROOMS}_{it} + \alpha^\text{PERS} \ln \text{PERS}_{it} \]
\[ + \alpha^\text{HDD} \ln \text{HDDCDDD}_{it} + \alpha^\text{AGEH} \ln \text{AGEH}_{it} + \alpha^{\text{GAS-HEAT}}_{it} + \alpha^{\text{GAS-HEW}}_{it} + \alpha^{\text{GAS-DRY}}_{it} \]
\[ + \alpha^{\text{DAC}} \text{AC-ROOM}_{it} + \alpha^{\text{DAC}} \text{AC-CENTRAL}_{it} + \alpha^{\text{DFLOOR}} \text{DFL1}_{it} + \alpha^{\text{DFLOOR}} \text{DFL2}_{it} + \alpha^{\text{DFLOOR}} \text{DFL3}_{it} \]
\[ + \alpha^{\text{CITY}} \text{DCITY}_{it} + \alpha^t D_t + v_{ii} + u_{ii} g \]

where

- **E** is energy consumption in thousand BTU
- **Y** is real income,
- **P** is the real energy price per thousand BTU,
- **SIZE, ROOMS, PERS,**
- **GAS-HEAT, GAS-HEW, GAS-DRY** dummy variables for a gas
- **DAC** dummy variables for AC Central and rooms
- **DFLOOR1, DFLOOR2, DFLOOR3**
- **HDDCDDD** heating and cooling degree days
- **DCITYj** is a city-specific effect,
- **D_t** is a series of time dummy variables
Level of inefficiency

Descriptive Statistics for 3 variables

<table>
<thead>
<tr>
<th>Variable</th>
<th>Mean</th>
<th>Std.Dev.</th>
<th>Minimum</th>
<th>Maximum</th>
<th>Cases Missing</th>
</tr>
</thead>
<tbody>
<tr>
<td>PITT</td>
<td>.320770</td>
<td>.193659</td>
<td>.025392</td>
<td>1.695780</td>
<td>41040</td>
</tr>
<tr>
<td>TRET</td>
<td>.229371</td>
<td>.085446</td>
<td>.033726</td>
<td>1.106867</td>
<td>41040</td>
</tr>
<tr>
<td>POOL</td>
<td>.299470</td>
<td>.128452</td>
<td>.040956</td>
<td>1.361314</td>
<td>41040</td>
</tr>
</tbody>
</table>

Level of efficiency

Descriptive Statistics for 3 variables

<table>
<thead>
<tr>
<th>Variable</th>
<th>Mean</th>
<th>Std.Dev.</th>
<th>Minimum</th>
<th>Maximum</th>
<th>Cases Missing</th>
</tr>
</thead>
<tbody>
<tr>
<td>EPITT</td>
<td>.738315</td>
<td>.128816</td>
<td>.183456</td>
<td>.974928</td>
<td>41040</td>
</tr>
<tr>
<td>ETRE</td>
<td>.797790</td>
<td>.063282</td>
<td>.330593</td>
<td>.966836</td>
<td>41040</td>
</tr>
<tr>
<td>EPOOL</td>
<td>.746938</td>
<td>.087161</td>
<td>.256324</td>
<td>.959872</td>
<td>41040</td>
</tr>
</tbody>
</table>

The efficiency estimates are found to be very poorly correlated (-0.10) with energy intensity (EI),
D) Energy policy measures and energy efficiency in the EU
Energy Policy instruments

- **Traditional regulation** (‘command & control’)
  - Emission limits, technology standards, energy performance standards…

- **Economic instruments**
  - Energy taxes, targeted subsidies, tax credits ….

- **Promotion of information**
  - Labeling, rating and certification…
Market failures related to energy inefficiency

- Energy use negative externalities

  - Energy tax

- Investment inefficiencies (consumers’ lack of economic information, principal–agent problems, liquidity constraints, myopic behavior, bounded rationality, positive externalities in the adoption of new technologies)

- Information

- Subsides

- Standard
EU Energy policy

- Until 1996 ➔ large autonomy of the EU Member states in the definition of the energy policy

- Directive on the internal energy markets (1996)

- Directive on the promotion of electricity from renewable energy sources (2001)


Table 1: Adopted energy-efficiency policy measures in the EU countries

<table>
<thead>
<tr>
<th>Member state (MS)</th>
<th>Legislative/ Normative</th>
<th>Legislative/ Informative - Labelling</th>
<th>Information/ Education</th>
<th>Financial/ Fiscal</th>
<th>Other</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>Austria</td>
<td>7</td>
<td>2</td>
<td>6</td>
<td>7</td>
<td>1</td>
<td>23</td>
</tr>
<tr>
<td>Belgium</td>
<td>9</td>
<td>6</td>
<td>6</td>
<td>16</td>
<td>0</td>
<td>37</td>
</tr>
<tr>
<td>Finland</td>
<td>8</td>
<td>6</td>
<td>10</td>
<td>7</td>
<td>1</td>
<td>32</td>
</tr>
<tr>
<td>France</td>
<td>15</td>
<td>8</td>
<td>5</td>
<td>24</td>
<td>1</td>
<td>53</td>
</tr>
<tr>
<td>Germany</td>
<td>18</td>
<td>12</td>
<td>4</td>
<td>7</td>
<td>4</td>
<td>45</td>
</tr>
<tr>
<td>Greece</td>
<td>11</td>
<td>6</td>
<td>3</td>
<td>13</td>
<td>2</td>
<td>35</td>
</tr>
<tr>
<td>Italy</td>
<td>17</td>
<td>10</td>
<td>2</td>
<td>5</td>
<td>0</td>
<td>34</td>
</tr>
<tr>
<td>Spain</td>
<td>42</td>
<td>9</td>
<td>6</td>
<td>25</td>
<td>3</td>
<td>85</td>
</tr>
<tr>
<td>Sweden</td>
<td>4</td>
<td>7</td>
<td>4</td>
<td>6</td>
<td>2</td>
<td>23</td>
</tr>
<tr>
<td>United Kingdom</td>
<td>25</td>
<td>3</td>
<td>10</td>
<td>15</td>
<td>2</td>
<td>55</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>302</strong></td>
<td><strong>123</strong></td>
<td><strong>106</strong></td>
<td><strong>253</strong></td>
<td><strong>25</strong></td>
<td><strong>809</strong></td>
</tr>
</tbody>
</table>

Source: MURE II database.
## Energy-efficiency (EE) policy measures in the EU

<table>
<thead>
<tr>
<th>Measure type</th>
<th>Share in %</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Legislative/Normative</td>
</tr>
<tr>
<td>1.1</td>
<td>Mandatory standards for buildings</td>
</tr>
<tr>
<td>1.2</td>
<td>Regulation for heating and hot water systems</td>
</tr>
<tr>
<td>1.3</td>
<td>Other regulation in the field of buildings</td>
</tr>
<tr>
<td>1.4</td>
<td>Mandatory standards for electrical appliances</td>
</tr>
<tr>
<td>2</td>
<td>Legislative/Informative - labelling</td>
</tr>
<tr>
<td>3</td>
<td>Information/education</td>
</tr>
<tr>
<td>4</td>
<td>Financial</td>
</tr>
<tr>
<td>4.1</td>
<td>Financial - grants, subsidies</td>
</tr>
<tr>
<td>4.2</td>
<td>Financial - loans, other</td>
</tr>
<tr>
<td>4.3</td>
<td>Financial - Tax Exemption/Reduction</td>
</tr>
<tr>
<td>6</td>
<td>Others measures</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>100.0</strong></td>
</tr>
</tbody>
</table>

Source: Mure II database
Model Specification

Evaluation of the effectiveness of introduced EE policy measures

- **Model I: Battese and Coelli (1995) model (BC95) employed:**

\[
u_{it} = \eta' z_{it} + e_{it}
\]

where \( z_{it} \) is a vector of policy measures, introduced as dummy variables.

**Energy-efficiency policy measures considered:**

- performance standards of buildings and heating systems \((BH_{it})\)
- performance standards of electrical appliances \((APP_{it})\)
- informative measures \((INFO_{it})\)
- financial incentives and fiscal measures \((FIN_{it})\)
## Results (2)

Table 3: Estimation results of energy demand model (continuation)

<table>
<thead>
<tr>
<th>Parameter</th>
<th>BC95 model</th>
<th>BC95M model</th>
<th>TFE model</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Parameters in the one-sided error</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Constant</td>
<td>0.3378***</td>
<td>0.3570***</td>
<td>/</td>
</tr>
<tr>
<td>BH1</td>
<td>-0.1636**</td>
<td>-0.1798*</td>
<td>0.0063</td>
</tr>
<tr>
<td>BH2</td>
<td>-0.1315*</td>
<td>-0.1170</td>
<td>-0.2273</td>
</tr>
<tr>
<td>APP</td>
<td>-0.1782</td>
<td>-0.1714*</td>
<td>0.1131</td>
</tr>
<tr>
<td>INFO</td>
<td>0.1384**</td>
<td>0.1749*</td>
<td>-0.0154</td>
</tr>
<tr>
<td>FIN1</td>
<td>-0.2926***</td>
<td>-0.4873**</td>
<td>-0.3305***</td>
</tr>
<tr>
<td>FIN2</td>
<td>-0.2170***</td>
<td>-0.4698***</td>
<td>-0.8559***</td>
</tr>
</tbody>
</table>

| **Variance parameters for the compound error** | | | |
| Sigma | 0.1872*** | 0.2369*** | 0.1966*** |
| Lambda | 1.8263*** | 9.2408*** | 7.7338*** |

Note: ***, **, * - significant at 1%, 5% and 10% level, respectively
Impact of the energy policy instruments on the level of efficiency

- The results show that

  financial incentives seem to have an important influence on reducing energy inefficiency of the residential sector (financial dummies $FIN1$ and $FIN2$ highly significant)

- There is also some evidence that performance standards of buildings, heating systems and appliances contribute to improved efficiency (standard dummies significant only at 10%)

- similar results obtained by Bigano et al. (2011) using another approach
E) Conclusions

- Residential sector holds a relatively high potential for energy savings
- Energy intensity indicator cannot be considered as a good proxy for energy efficiency and should be combined with other indicators
- The estimates for the *underlying energy efficiency* using an approach based on microeconomics and frontier analysis seems appealing
E) Conclusions

- Potential energy saving
  - In Europe 10-15%
  - In the US 20/25%
- Less evidence of an impact of the effect of informative measures such as labelling and educational campaigns

- Improved energy efficiency can be linked to
  - the introduced financial incentives and energy performance standards
- Less evidence of an impact of the effect of informative measures such as labelling and educational campaigns
Thank you for your attention