The impact of energy prices on energy efficiency: Evidence from the UK refrigerator market

François Cohen*, Matthieu Glachant** and Magnus Söderberg**

* GRI, LSE, **CERNA, MINES ParisTech
A popular concept in policy circles

- Potentially large differences between the socially and the actual level of energy consumption

Two reasons

- The standard externality problem: energy production and use generate health and environmental damages (in particular, fossil fuels)
- The potential existence of investment inefficiencies: imperfect information and other cognitive constraints may lead consumers to discard privately profitable investments in energy efficiency
Any investment in energy efficiency entails
– An upfront cost (a more expensive fridge)
– A stream of future benefits (energy savings)

Investment is inefficient if consumers use too high a discount rate
– Consumers are « myopic »

They buy too cheap refrigerators with a too low level of energy performance

A rather old literature provides some evidence of very high discount rates
– 39-300% for refrigerators: Revelt and Train, 1998; Hwang et al., 1994; McRae, 1985; Meier and Whittier, 1983; Gately, 1980; Cole and Fuller, 1980
Policy Implications

- Increasing energy prices is likely to trigger limited energy savings in the residential sector
  - Relative to energy efficiency standards or economic incentives targeting the investment decisions
- Two market failures = two instruments
  - A tax on energy use to internalize externalities
  - an instrument targeting the investment decisions (feebate for new cars, tax rebates for insulation, etc.)
The response to an increase in energy prices:

1. Consumers buy less refrigerators and, in relative terms, products that use less energy
   – A negative demand shock, stronger for less energy-efficient models

2. Manufacturers/retailers decrease refrigerators prices
   – Cuts are larger for less-energy efficient models.
   – Depends on the degree of competition in the market

3. Manufacturers/retailers change the characteristics of products supplied in the market
   – The launch of energy-efficient models, the withdrawal of less efficient ones
What is the impact of energy prices on residential energy use, taking into account both demand and supply responses?

1. How large are investment inefficiencies in energy use?
   – Which reduce the impact of energy prices on energy use
   – The level of the implicit discount rate

2. How large are refrigerator price adjustments?
   – Which reduce the impact of energy prices on energy use

3. How large are adjustments of product offers?
   – Which increase the impact of energy prices

• Using product-level panel data from 2002 to 2007 on the UK refrigerator market
  – Not available at the consumer level
• Energy efficiency matters
• The product is simple:
  – A few quality variables
• Energy consumption is completely determined at the time of purchase
  • Cannot adjust the level of consumption after purchase (no intensive margin)
  • In contrast with cars
• No markets for used fridges
  • In contrast with the car market
• Total demand is almost inelastic;
• EU Energy Label
  – Mandatory since 1995
  – « A+++ » cold appliances consume five times less energy than « D » appliances for the same cooling services.
• $T$ markets, each representing the UK refrigerator market during year $t$ with $J$ (differentiated) products

• Indirect utility of consumer $i$ who purchases a new refrigerator $j$ in year $t$

$$U_{i,j,t} = V_{j,t} + \omega_{i,j,t}$$ (1)

where $V_{j,t}$ is the average utility and $\omega_{i,j,t}$ is consumer $i$'s heterogeneity

• Under certain assumptions, Berry (1994) derives from (1):

$$\ln(s_{j,t}) - \ln(s_{0,t}) - \sigma \ln(s_{j/g,t}) = V_{j,t}$$

where $s_{0,t}$ and $s_{j/g,t}$ are respectively the market share of the outside good and of product $j$ within its nest $g$ at time $t$
Average utility

\[ V_{\downarrow j,t} = u_{\downarrow j,t} - \alpha (p_{\downarrow j,t} + \gamma C_{\downarrow j,t}) \]

with:

- \( u_{\downarrow j,t} \), the value of usage of the refrigerator \( j \) over its lifetime
- \( p_{\downarrow j,t} \), the purchase price
- \( C_{\downarrow j,t} \) is the electricity cost of the product which is forecasted at the time of purchase
- \( \alpha \) is the marginal utility of money
- \( \gamma \) is the parameter capturing the size of investment inefficiencies

A key objective of the paper is to test: \( \gamma = 1 \)
The (discounted) lifetime electricity cost of product $j$ is

$$C_{j,t} = \Gamma_j \times \sum_{s=1}^{\uparrow L_j} \mathbb{E} q_{t+s} \uparrow^* / (1+r)^s$$

Where:

- $\Gamma_j$ is the level of energy consumption per time period
- $L_j$ is product $j$’s lifetime
- is the discount rate
- $q_{t+s} \uparrow^*$ is the forecasted electricity price at time $t+s$
Econometric issues

- $q_{t+s}^\uparrow$ is not the actual price, but the price that is anticipated at the date of purchase.
  - **Solution**: Predicted with an autoregressive integrated moving-average model (ARIMA) on monthly data on real electricity prices

- $u_{j,t}$ is not observed.
  - **Solution**: We assume $u_{j,t} = u_j + \xi_{j,t}$, which can be partly controlled using first differences

- $p_{j,t}$ is endogenous because quantities and prices are simultaneously determined in the market equilibrium
  - **Solution**: IV-GMM estimation; instruments: out-of-group and within-group average capacity and out-of-group price

- The estimated specification is
  \[
  \Delta \ln(s_{j,t}) = -\alpha(\Delta p_{j,t} + \gamma \Delta C_{j,t}) + \Delta \tau_{t} + \Delta \xi_{j,t}
  \]

  Where $\Delta =$ difference operator, $\Delta \tau_{t}$ are time dummies differences absorbing the outside good market share and other time varying factors
• A reduced-form equation:

\[ p_{\downarrow j, t} = p_{\uparrow 0 \downarrow j, t} \downarrow - \eta C_{\downarrow j, t} + \epsilon_{\downarrow j, t} \]

where \( p_{\uparrow 0 \downarrow j, t} \downarrow \) is the price of product \( j \) at time \( t \) if electricity cost during its lifetime is zero and \( \epsilon_{\downarrow j, t} \) is an error term.

• We do not observe \( p_{\uparrow 0 \downarrow j, t} \downarrow \). We assume that:

\[ p_{\uparrow 0 \downarrow j, t} \downarrow = p_{\uparrow 0 \downarrow j, t} \uparrow + \nu_{\downarrow t} \]

• We estimate:

\[ \Delta p_{\downarrow j, t} = \Delta \nu_{\downarrow t} - \eta \Delta C_{\downarrow j, t} + \mu X_{\downarrow j, t} + \Delta \epsilon_{\downarrow j, t} \]

where \( X_{\downarrow j, t} \) is the vector of instruments
We observe the products in the market

A dynamic probit model:

\[
d_{j,t} = \Phi(k d_{j,t-1}^{\uparrow*} + k p_{j,t} + k c C_{j,t} + \lambda t + \omega_j)
\]

Where

- \(d_{j,t}\) is the probability product \(j\) is in the market at time \(t\)
- \(d_{j,t-1}^{\uparrow*}\) is a binary variable indicating whether the product was in the market at time \(t-1\)
- \(p_{j,t}\) and \(C_{j,t}\) are the product price and electricity cost
- \(\lambda t\) and \(\omega_j\) are time dummies and fixed effects

**Problem:** \(p_{j,t}\) is not observed when the product is not in the market

**Solution:** multiple imputations (Wooldridge, 2005)
### GfK sales data for the UK market – 2002-2007

<table>
<thead>
<tr>
<th>Variable</th>
<th>Unit</th>
<th>Mean</th>
<th>Std dev</th>
</tr>
</thead>
<tbody>
<tr>
<td>Annual sales</td>
<td># of units</td>
<td>2226</td>
<td>5054</td>
</tr>
<tr>
<td>Purchase price, $p_{j,t}$</td>
<td>real £</td>
<td>402</td>
<td>289</td>
</tr>
<tr>
<td>Appliance lifetime, $L_{j}$</td>
<td>years</td>
<td>15.38</td>
<td>2.34</td>
</tr>
<tr>
<td>Energy consumption, $\Gamma_{j}$</td>
<td>kWh/year</td>
<td>320</td>
<td>145</td>
</tr>
<tr>
<td>Height</td>
<td>cm</td>
<td>142</td>
<td>43</td>
</tr>
<tr>
<td>Width</td>
<td>cm</td>
<td>60</td>
<td>10</td>
</tr>
<tr>
<td>Capacity</td>
<td>litres</td>
<td>252</td>
<td>115</td>
</tr>
<tr>
<td>Energy efficiency rating(^a)</td>
<td></td>
<td>2.46</td>
<td>0.88</td>
</tr>
<tr>
<td>Share combined refrigerators-freezers</td>
<td></td>
<td>0.55</td>
<td>-</td>
</tr>
<tr>
<td>Share of built-in appliances</td>
<td></td>
<td>0.22</td>
<td>-</td>
</tr>
<tr>
<td>Share of appliances with no-frost system</td>
<td></td>
<td>0.24</td>
<td>-</td>
</tr>
<tr>
<td>Instrumental variables</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Within-group: capacity</td>
<td>litres</td>
<td>254</td>
<td>111</td>
</tr>
<tr>
<td>Out-of-group: capacity</td>
<td>litres</td>
<td>268</td>
<td>22</td>
</tr>
</tbody>
</table>
Investment inefficiencies are limited $= \gamma \leq 0.6 \Leftrightarrow$ implied discount rate is 10%

Much lower than previous studies. Two possible explanations:

- Energy labeling
- Methodology (panel data)
## Results (2): Price

<table>
<thead>
<tr>
<th>Dependent variables</th>
<th>Eq. (7): Price of product $j$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Impact of discounted electricity costs on appliance prices ($\eta$)</td>
<td>$-0.2860^{***}$</td>
</tr>
<tr>
<td></td>
<td>(2.83)</td>
</tr>
<tr>
<td>Out-of-nest price</td>
<td>$-3.11^{***}$</td>
</tr>
<tr>
<td></td>
<td>(-3.7)</td>
</tr>
<tr>
<td>Out-of nest capacity</td>
<td>$11.27^{***}$</td>
</tr>
<tr>
<td></td>
<td>(4.5)</td>
</tr>
<tr>
<td>Within nest capacity</td>
<td>$1.19$</td>
</tr>
<tr>
<td></td>
<td>(1.35)</td>
</tr>
<tr>
<td>Year dummies</td>
<td>Yes</td>
</tr>
<tr>
<td>Observations</td>
<td>1,623</td>
</tr>
</tbody>
</table>

Manufacturers/retailers reduces prices in response to an increase in electricity cost
The price response is asymmetric

- The impact of a 10% increase of the electricity cost is higher on less energy efficient models:

<table>
<thead>
<tr>
<th></th>
<th>A++</th>
<th>A+</th>
<th>A</th>
<th>B</th>
<th>C</th>
<th>D</th>
<th>E</th>
<th>G</th>
</tr>
</thead>
<tbody>
<tr>
<td>Price</td>
<td>+0.01%</td>
<td>+0.04%</td>
<td>-0.06%</td>
<td>+0.13%</td>
<td>-0.11%</td>
<td>+0.02‰</td>
<td>-0.01‰</td>
<td>-0.02‰</td>
</tr>
<tr>
<td>Sales</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>-3.4</td>
<td>-6.9</td>
<td>-10.1</td>
<td>-11.5</td>
<td>-11.7</td>
<td>-6.0</td>
<td>-22.6</td>
<td>-13.7</td>
</tr>
</tbody>
</table>

- Manufacturers/retailers partly compensate the electricity price increase
### Results (3): Product offer

<table>
<thead>
<tr>
<th>Dependent variables</th>
<th>Eq. (10): Availability of product $j$</th>
</tr>
</thead>
<tbody>
<tr>
<td>The product was commercialised the year before ($k_d$)</td>
<td>0.9124*** (37.16)</td>
</tr>
<tr>
<td>Appliance price ($k_p$)</td>
<td>-0.0011*** (3.89)</td>
</tr>
<tr>
<td>Expected and discounted running costs ($k_c$)</td>
<td>-0.0024*** (3.44)</td>
</tr>
<tr>
<td>The product was commercialised in 2002 ($k_1$)</td>
<td>-0.5715*** (17.70)</td>
</tr>
<tr>
<td>Nonredundant explanatory variables covering all time periods and including time-constant product features ($k_2$)</td>
<td>Yes</td>
</tr>
<tr>
<td>Year dummies</td>
<td>Yes</td>
</tr>
<tr>
<td>Observations</td>
<td>12,160</td>
</tr>
<tr>
<td>Number of imputations for appliance prices</td>
<td>10</td>
</tr>
</tbody>
</table>

1. **Electricity cost has a significant impact**
### Impact on energy use

| Relative change in average energy consumption (kWh/year) as compared to the baseline | Electricity price 10% higher |
|---|---|---|
| | Short term impact on market shares | With purchase price adjustments | With purchase price adjustments and change in product offer |
| Consumers are myopic and competition is imperfect | -2.2% | -1.2% | -2.3% |

- The long term elasticity is rather low: -0.23
- Without investment and market inefficiencies, it would be -0.6
### Size of the two inefficiencies

<table>
<thead>
<tr>
<th>Relative change in average energy consumption (kWh/year) as compared to the baseline</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Consumers are myopic and competition is imperfect</td>
<td>-2.3%</td>
</tr>
<tr>
<td>Consumers are perfectly rational but competition is imperfect</td>
<td>-3.9%</td>
</tr>
<tr>
<td>There is perfect competition but consumers are myopic</td>
<td>-3.6%</td>
</tr>
<tr>
<td>Consumers are perfectly rational and there is perfect competition</td>
<td>-6.0%</td>
</tr>
</tbody>
</table>

- In the long run, investment inefficiencies and imperfect competition have the same (negative) impact on energy efficiency
• Energy taxation may not be very effective
• Solutions?
  1. Energy labeling
     – Done since 1996. Only addresses the behavioral inefficiency.
  2. Energy standards
     – A constraint on the set of products available in the market
  3. Subsidization of investments in energy efficiency or feebates (bonus/malus)
     – Decrease the purchase price of good products
• The welfare analysis is extremely complex
  – Cannot only focus on the demand response and consumer surplus
  – Much more than the analysis carried out in several recent papers
    • E.g., Allcott and Wozny, 2014
• A welfare analysis is not feasible
  – Structural approach limited to demand
• A partial analysis focusing on demand and consumer surplus is
  – Done in several recent papers (e.g., Allcott and Wozny, 2014)
  – But our analysis that this approach is not appropriate for supply responses are important
• The long term impact of energy prices on energy use is rather low
  – Elasticity is – 0.23
• We find evidence of investment inefficiencies, but limited. The implied discount rate is 10%
  – Mandatory energy labeling?
• The impact on energy use of the asymmetric price response which partly absorbs the increase in energy price has the same order of magnitude
• Innovation – changes in product offer – partly compensates these two effects
• If competition on the refrigerator market was perfect and consumers were rational, the elasticity would be – 0.60
• Policy implications?
  – Direct regulation
  – Investment subsidies are likely to be ineffective
Thank you!