Revisiting the Energy Efficiency Paradox:
Do energy prices and interest rates affect the cost of energy efficiency?

Hyun-gyu Kim and Michael Roberts

University of Hawaii at Manoa

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Motivation: Energy Efficiency Paradox

- Consumers and businesses tend to underinvest in energy efficiency even with seemingly high returns,
  - "Energy efficiency paradox"(Jaffe & Stavins,1994)
- Present value of cost savings equals extra upfront cost only with high implicit discount rates

Estimated Implicit Discount Rates of Durable Goods

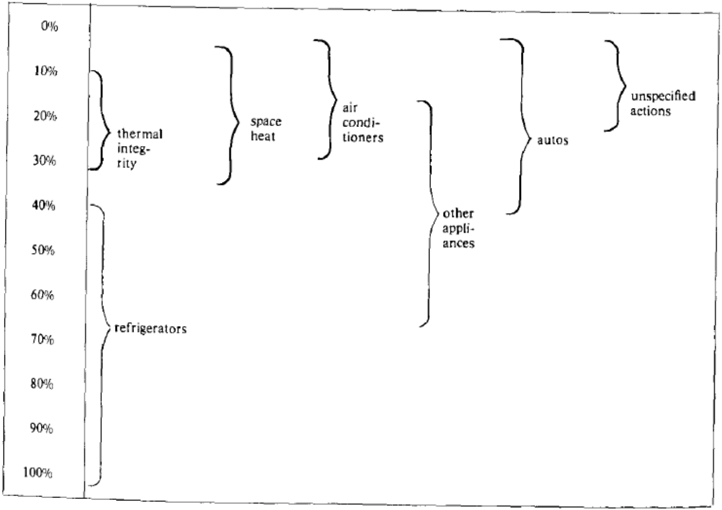


Fig. 1. Estimates of average discount rates.

Source: Train, 1985

Motivation: Possible Explanations of High Implicit Discount Rates

- External barriers
  - Credit constraints
  - Lack of information
  - Imperfect competition
  - Different incentives (e.g. landlord vs. tenant)
- Behavioral error
  - Bounded rationality
- Estimates may be confounded by unobservable characteristics

Consequences of Energy Efficiency Paradox

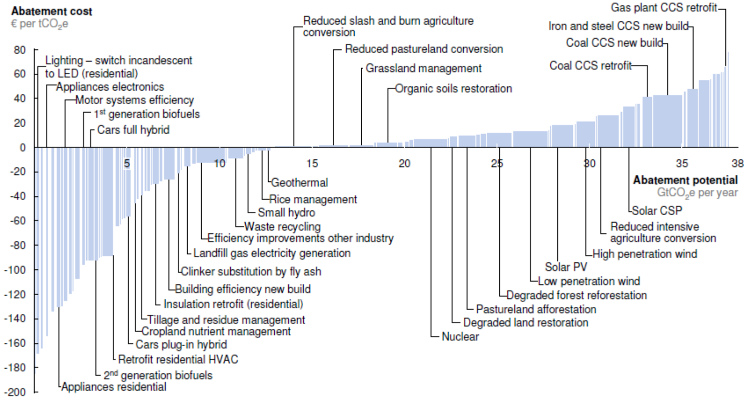
- Private welfare loss
- Externalities

Current Policy Motivation

Improving energy efficiency standards

- A potentially low-cost way to reduce air pollution, CO_2.

Greenhouse Gas Abatement Costs Can Be Negative with Energy Efficiency Improvements



Souce: Mckinsey(2010)

Current Policy Motivation

Improving energy efficiency standards

- Political constraints prevent favored tools (pigouvian tax or cap and trade)
- Big push on energy standards by Obama administration
  - Efficiency standards of cars, trucks and home appliances

- Arguments on energy efficiency paradox remain
  - A case of market failures
  - Does energy efficiency paradox exist and does it matter?

Why Do We Revisit Energy Efficiency Paradox?

Previous literature has some limitations

- Previous literature does not meet modern standards of credibility (Allcott and Greenstone[2012])
    - Cross-sectional
    - Unobservable characteristics
    - Omitted variable biases
- Evidence is somewhat outdated
    - Time period: 1980s and 1990s
    - Updated energy efficiency standards
    - Different electricity prices and interest rates

Motivation: Trend of Recent Studies

- Employ panel data
  - Allcott & Wozny (2012), Sallee et. al (2009), and Busse et al. (2013)
  - Address omitted variable biases by using fixed effects
- Use time series variations in interest rates and energy prices
- Focus only on automobile market

This Paper

- Examine how conumsers value energy efficiency of appliance using the changes in interest rates and electricity prices

Contributions

- Focus on appliance market
- Using the fact that interest rate and electricity price changes differentially affect appliances depending on energy efficiency status
- Panel study design
  - First time in appliance market to study energy efficiency paradox
- Big and recent micro-level data set (i.e individual appliance model)

Outline

1. Theory
2. Data
3. Empirical estimation strategy
4. Results
5. Conclusion

Implications of Economics Theory

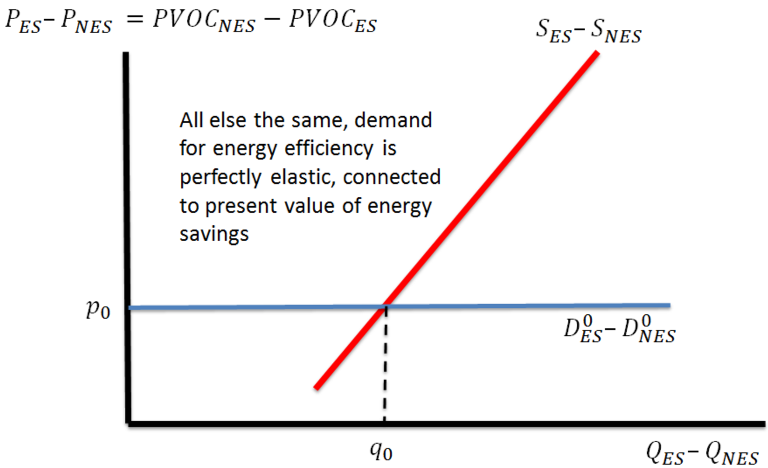
Assumptions

- Market is perfectly competitive
- Consumers have same preference for energy efficiency
- All attributes of products are same except energy efficiency rate

$$P_{ee} = -\frac{\partial PVOC_j}{\partial ee_j}$$

Implications of Economics Theory

Figure: Hedonic Equilibrium and Price of Energy Efficiency



Implications of Economics Theory

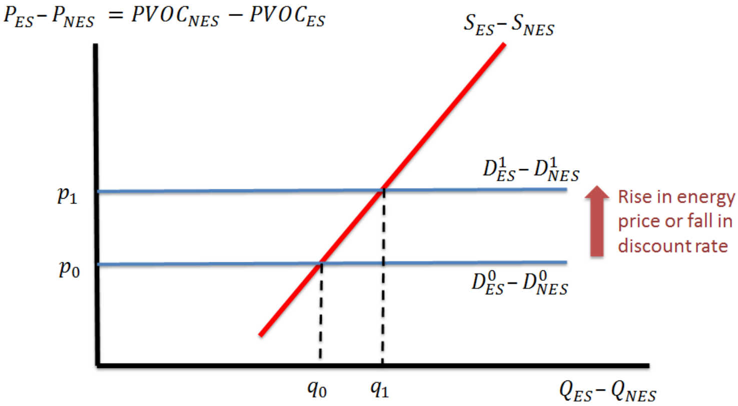
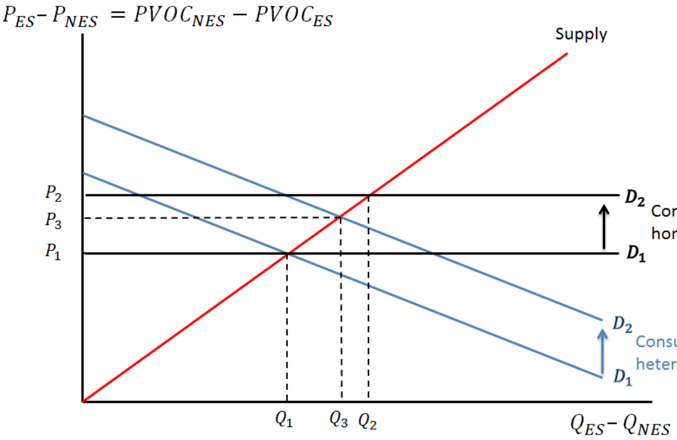


Figure: Shift of Hedonic Equilibrium

Implications of Economics Theory

Figure: Hedonic Equilibrium with Heterogenous Consumers



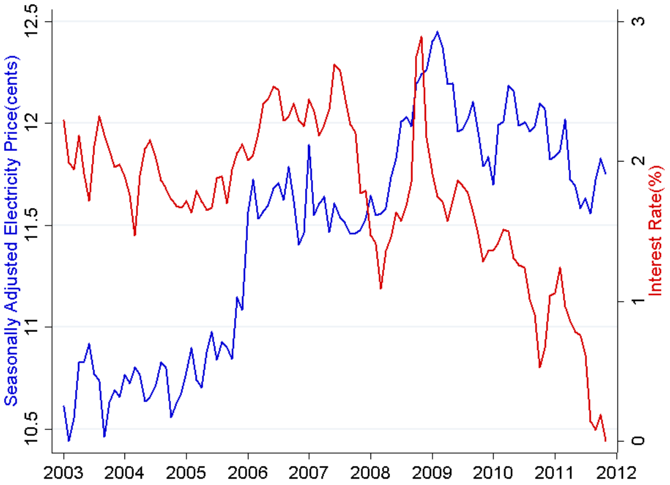
Identification Strategy of Empirical Study

- Using relative PVOC changes, purely driven by fluctuations of interest rates and electricity prices, of more versus less energy efficient products.
- Estimate how the relative price changes are associated with the relative PVOC changes depending on energy efficiency status.

Data

- Point-of-sale data
  - NPD Group
  - Monthly revenues and sales by appliance models
  - Refrigerator, clothes washer, dishwasher, room air conditioner(AC)
  - Characteristics
  - Price=monthly revenue/number of sale
  - Jan 2003 - Dec 2011
- Federal Trade Commission(FTC)
  - Annual energy consumption
  - Energy efficiency rate
- Seasonally adjusted average electricity prices(national)
- Risk-free market interest rates

Trends of Interest Rate and Electricity Price



Present Valued Operating Cost(PVOC)

$$PVOC_{jt} = \sum_{y=0}^{Y} EC_j \times EP_t \times (1 + r_t)^{-(y+0.5)}$$

- EC_j: annual electricity consumption(kwh)
- EP_t: electricity prices(dollar/kwh)
- r_t: discount rates
- y: the number of years to use
- Y: maximum life-cycle of appliance(15 years)

Summary Statistics(Clothes Washer)

		Without Weight		Weighted by Sales		Within Model	Number of
		Mean	SD	Mean	SD	SD	Obs.
Real Price ($)	Estar	741.43	276.06	719.94	233.23	149.37	11,586
	Non Estar	449.92	216.84	391.02	149.56	52.14	6,023
PVOC ($)	Estar	358.68	170.30	331.01	141.23	13.26	
	Non Estar	742.01	281.54	720.98	276.48	23.95	
Capacity (Cu.Ft.)	Estar	3.42	0.38	3.47	0.35		
	Non Estar	3.10	0.28	3.22	0.24		
Sales (Unit)	Estar	886	2,008			1,530	
	Non Estar	1,128	2,260			1,499	

Note: The sampled clothes washers includes Includes full-size, bigger than 2.5 cu.ft., front and top load clothes washer.

[a] Deflated to 2011 December by using consumer price index(CPI) from the Bureau Labor Statistics(BLS).

[b] Present Valued Operating Cost(PVOC)

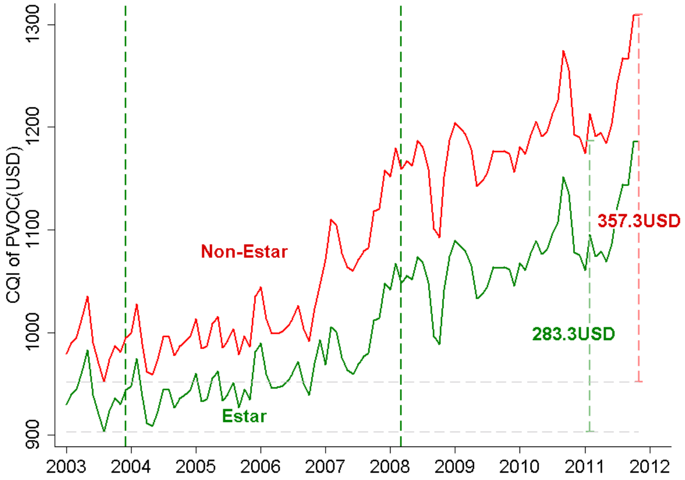
▸ Bunching Evidence

Constant Quality Index

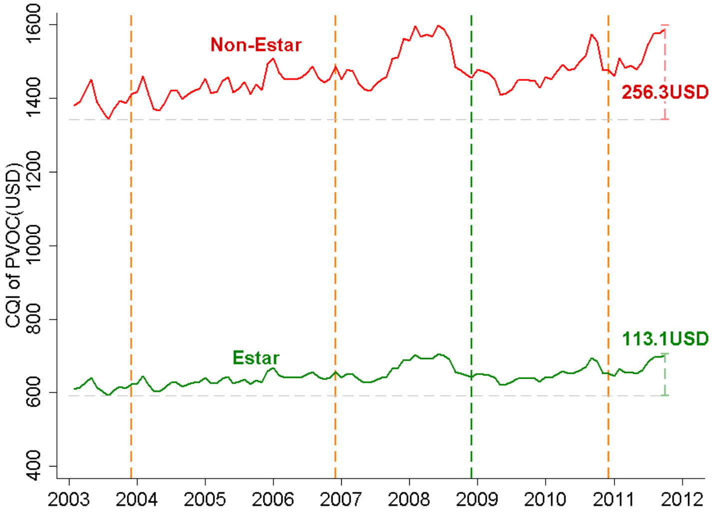
- Construct the index shows average price or PVOC trend when the quality of products is fixed
- Show the effects of electricity prices and interest rates on appliances' prices or PVOCs

CQPI Equation

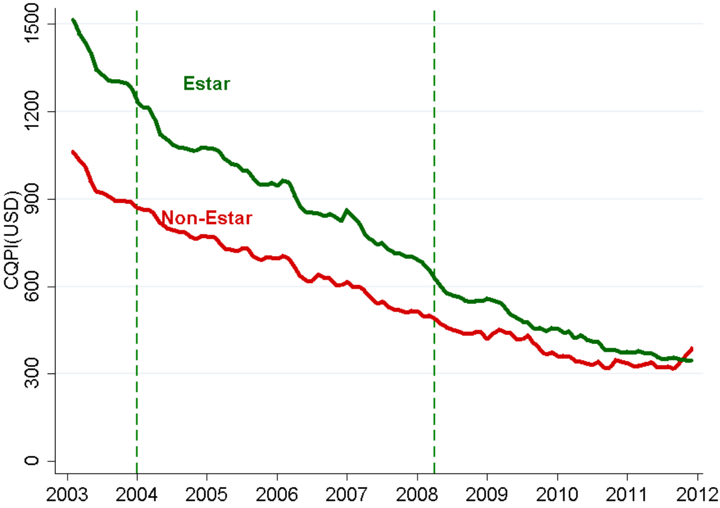
Trend of CQI of PVOC(Refrigerator)



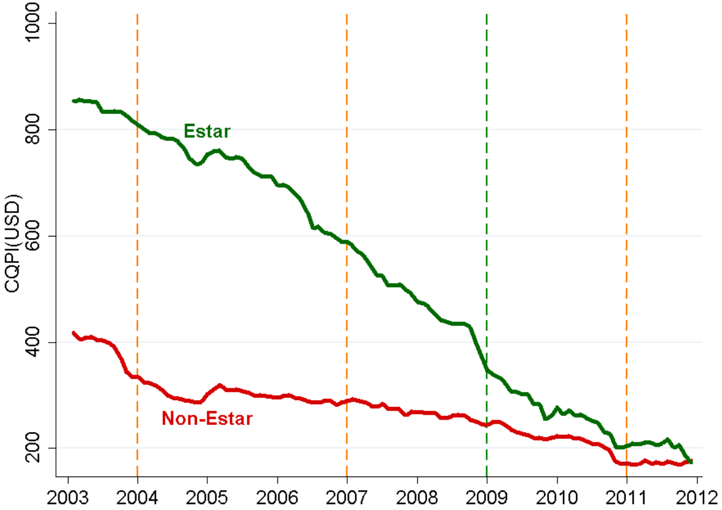
Trend of CQI of PVOC(Clothes Washer)



Trend of CQI of Price(Refrigerator)



Trend of CQI of Price(Clothes Washer)



Empirical Estimation(Prices)

$$P_{gjt} = \beta PVOC_{gjt} + \alpha_j + \delta_{tg} + \varepsilon_{gjt}$$

- P_{gjt}: prices of g type product j at time t
- PVOC_{gjt}: present valued operating costs
- α_j: model fixed effects
- δ_{tg}: group by time fixed effects
- β: Changes in relative appliance prices as the relative PVOC gap increases by $1
- β=-1, β > -1, or β <-1

▸ Identification1 ▸ Identification2

Empirical Estimation(Sales)

$$logQ_{gjt} = \gamma PVOC_{gjt} + \alpha_j + \delta_{tg} + \varepsilon_{gjt}$$

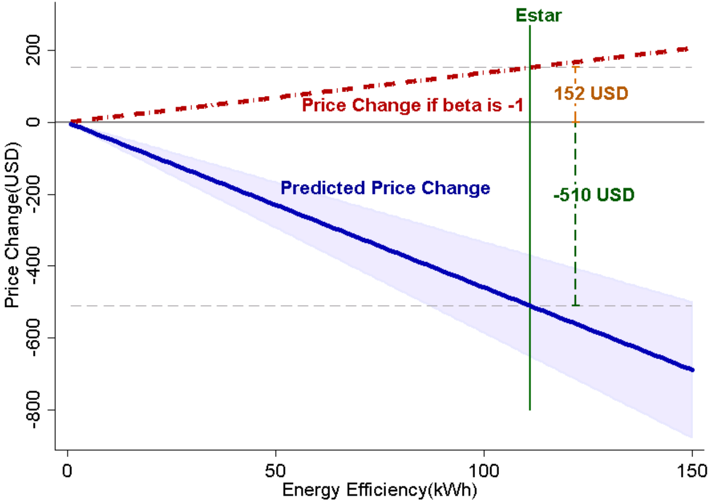
- Q_{gjt}: monthly sales of g type product j at time t
- PVOC: function of present valued operating cost
- α_j: model fixed effect
- δ_{tg}: group by time fixed effects
- γ: Changes in relative percentage appliance sales as the relative PVOC gap increases by $1

Results: Effects of PVOC on Prices and Sales

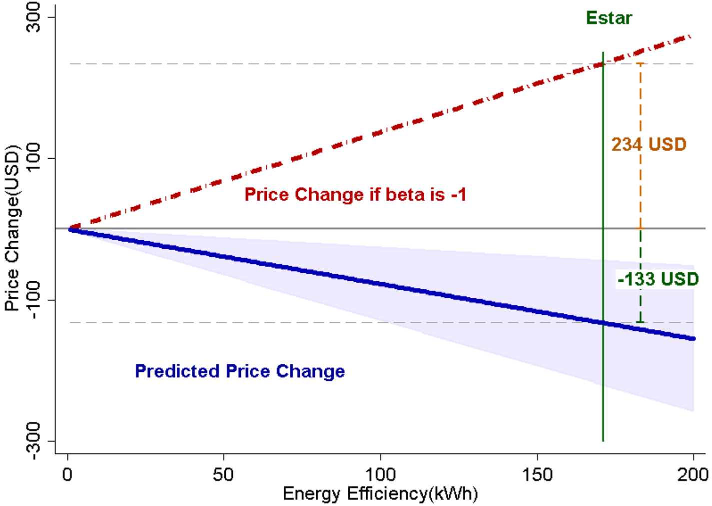
	Appliance	Coeff. of PVOC	SE	Adj. R^2	N	Lower bound 95%	Lower bound 99%
Panel A. Dependent Variable: Monthly Average Prices							
1	Refrigerator	3.350	(0.557)	0.985	55,362	2.258	-1.994
2	Clothes Washer	0.564	(0.226)	0.977	17,609	0.121	-0.809
3	Dishwasher	1.390	(0.508)	0.971	33,664	0.394	-1.819
4	Room AC	0.012	(0.111)	0.99	7,257	-0.206	-0.397
Panel B. Dependent Variable: Logged Monthly Sales							
1	Refrigerator	-0.006	(0.004)	0.741	55,362	-0.014	-0.014
2	Clothes Washer	-0.019	(0.008)	0.679	17,609	-0.035	-0.029
3	Dishwasher	-0.047	(0.007)	0.759	33,664	-0.061	-0.025
4	Room AC	-0.0003	(0.030)	0.661	7,257	-0.059	-0.107

Note: Robust, clustered by model, standard errors are reported in the parenthesis. All specifications include the model and time fixed effects as well as the interaction term of group and time.

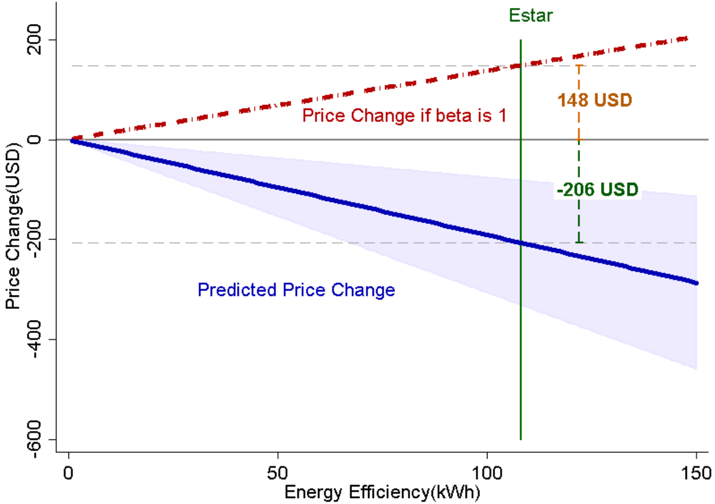
Price Changes with 10cent Electricity Price Increase (Refrigerator; SSA, 22-24cu.ft.)



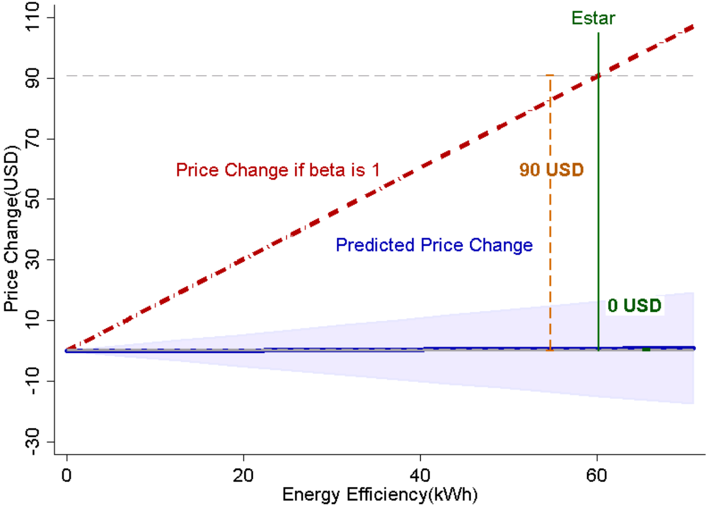
Price Changes with 10cent Electricity Price Increase (Clothes Washer, Top-load, 3.3-3.5cu.ft.)



Price Change with 10cents Electricity Price Increase (Dishwasher; Standard, 24inches)



Price Change with 10cents Electricity Price Increase (Room AC; 8,800BTUs)



Results: Alternative Specifications

Table: The Results in Refrigerators

		Dependent Variable: Price of Individual Product[a]			Dependent Variable: Logged Sales of Product			Number of
		$\hat{\beta}$	SE($\hat{\beta}$)	Adj.R^2	$\hat{\gamma}$	SE($\hat{\gamma}$)	Adj.R^2	Obs.
Panel A Baseline								
1	Whole Sample	3.35	(0.557)	0.985	-0.006	(0.004)	0.741	55,362
Panel B. Control Other Characteristics								
2	Add Door Option	3.30	(0.558)	0.985	-0.006	(0.004)	0.741	55,362
Panel C. Different Estar Standard[b]								
3	2003.01 - 2003.12	0.59	(1.578)	0.994	0.005	(0.007)	0.844	3,143
4	2004.01 - 2008.03	1.66	(0.598)	0.989	-0.021	(0.005)	0.791	22,055
5	2008.04 - 2011.12	1.77	(0.526)	0.980	-0.006	(0.005)	0.744	30,164
Panel D. Depending on Door Type								
6	Side-by-side	4.41	(0.810)	0.975	-0.0003	(0.004)	0.723	34,412
7	Top Freezer	1.47	(0.393)	0.965	-0.017	(0.005)	0.754	20,950

Note: Robust, clustered by model, standard errors are reported in the parenthesis. All specifications include the model and time fixed effects as well as the interaction term of group and time.

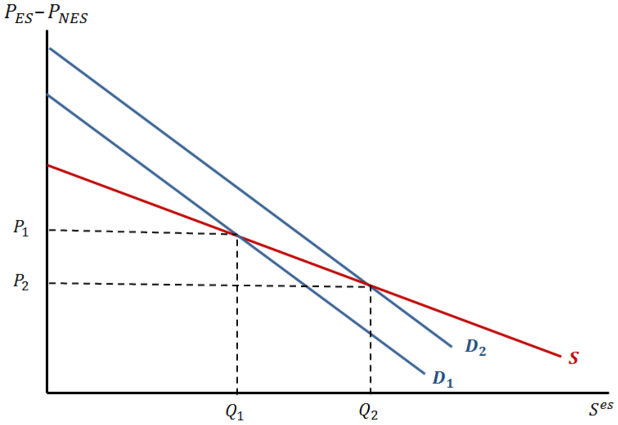
Results: Summary

With increasing PVOC gap of more vs. less energy efficient appliances,

- relative sales of energy efficient products increase.
- relative prices of more vs. less energy efficient appliances down, not up.

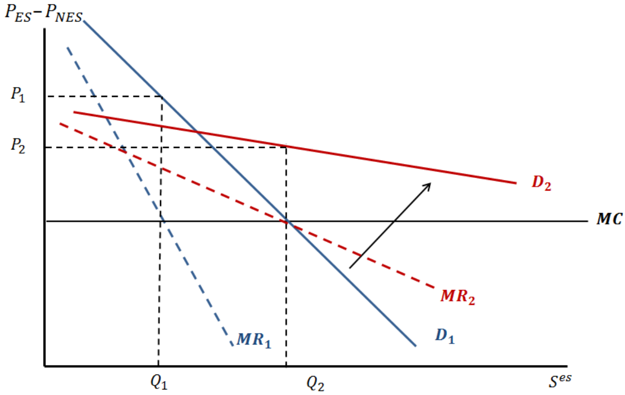
Possible Explanations of the Results?

- Increasing returns to scale
- Technological Improvements



Possible Explanations of the Results?

- More elastic demand curve of energy efficient appliances with rising energy costs

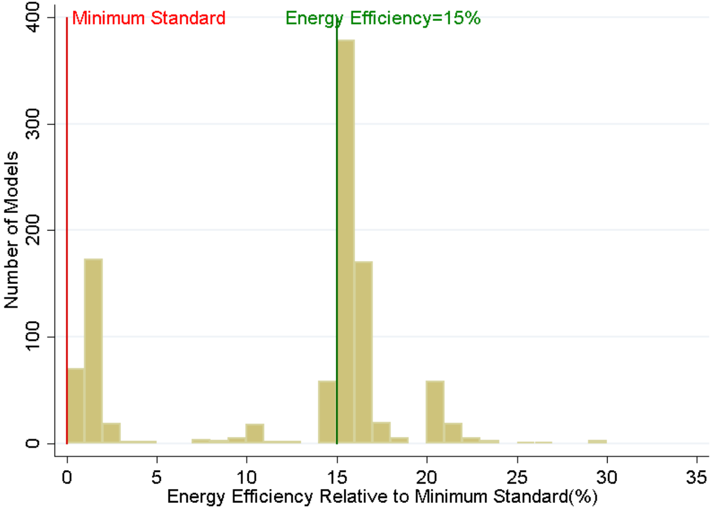


Conclusion

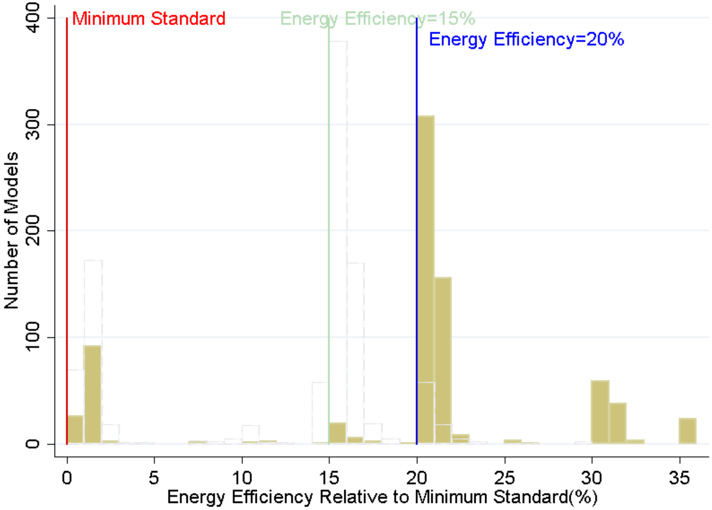
- Consumers tend to respond to benefits from using energy efficient products
- Persistence of large energy efficiency gap
- Increasing economies scale and imperfect competition likely complicate the analysis of energy efficiency and standards

Appendix

Bunching Energy Efficiency Rate(Refrigerator)



Bunching Energy Efficiency Rate(Refrigerator)



▸ Summary Stat

Constant Quality Index for PVOC

$$CQOI_t =$$

$$CQOI_{t-1} + CQOI_{t-1}\left(\frac{\sum_i W_{it}\left(\frac{PVOC_{it}-PVOC_{it-1}}{(PVOC_{it}+PVOC_{it-1})/2}\right)}{\sum_i W_{it}}\right), \forall t > 0$$

where :

$$W_{it} = \frac{q_{it} + q_{it-1}}{2}, \forall i \text{ that exist in } t \;\&\; t-1.$$

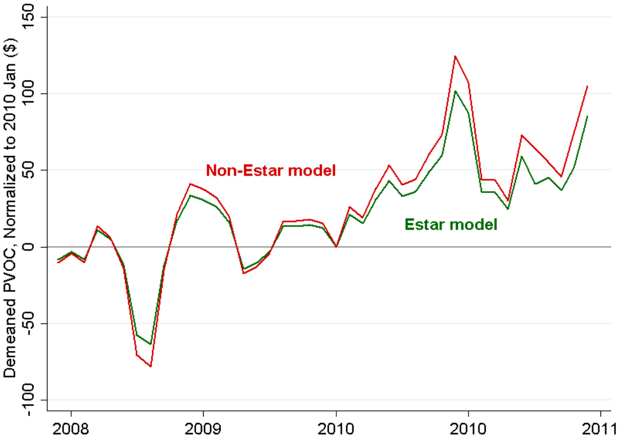
and:

$$CQOI_0 = \frac{\sum_i q_{i0} PVOC_{i0}}{\sum_i q_{i0}}$$

▸ CQPI

PVOC Varies Over Time and Changes Are Different Depending on Energy Efficiency Rate

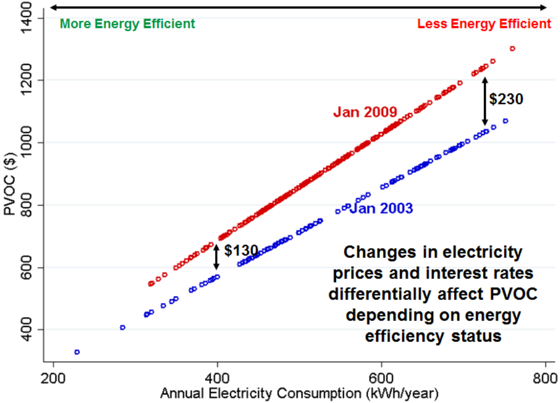
Figure: PVOC Trends of Two Fixed Refrigerator Models



▸ Estimation Model

Changes in PVOC Vary Depending on Energy Efficiency Rate

Figure: PVOC of Individual Models across Energy Efficiency Rate (Refrigerator)



Estimation Model