Energy Demand of U.S. Commercial Buildings: An Econometric Approach

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Introduction

- Commercial buildings: 18% of US energy consumption → Potential for energy savings
- Debate around rebound effect →
  Energy efficiency increases energy consumption?
  - Most studies do "engineering estimate" or assess "technical potential" → Hard to tell the net energy savings after rebound effect
  - Very rare empirical work using econometrics to evaluate the actual energy savings, net of all social factors
- Energy price elasticity estimates
  - Rare in commercial sector

Research Questions

- What is the net impact (net of rebound effect) of the adoption of energy efficient technologies on electricity consumption?
- What are the price elasticities of electricity consumption of commercial buildings?

Technical Challenges

Endogeneity among energy price, adoption of energy efficient technologies and electricity consumption

1. Positive correlation between energy intensity/consumption and the adoption of energy efficient technologies (Andrews and Krogmann, 2009 a) → Rebound effect really that strong?
   SAMPLE SELECTION BIAS
2. Average energy price is a function of energy consumption → Deep literature in residential, very few in commercial

Models

- Structural models
  - Average price equation $\overline{p_{ij}} = \dfrac{\int_0^{q_{ij}} f(q_{ijt}, C_j, U_i) dq_{ijt}}{q_{ij}}$
  - Technology adoption equation (probit model)

$$T_i = 1 \text{ if } S_{ij} = E[E_{ij} | T_i = 1] + r(Z_i) - E[E_{ij} | T_i = 0] \le 0$$

  - Electricity demand equation (reduced form)

$$\ln Q_{ij} = \mu + \beta \ln \overline{p_{ij}} + \gamma \ln ngp_{ij} + \delta X_i + \eta Y_j + \theta T_i + \varepsilon_{ij} + T_i \nu_{ij}$$

- Selection bias ← Modified Heckman model

$$E(\ln Q_{ij}) = E(\ln Q_{ij} | T_i = 1) \Pr(T_i = 1) + E(\ln Q_{ij} | T_i = 0) \Pr(T_i = 0)$$

$$E(\ln Q_{ij}) = \mu^0 + (\mu^1 - \mu^0) a_i + \beta \ln \overline{p_{ij}} + \gamma \ln ngp_{ij} + \delta X_i + \eta Y_i + (\sigma_{\varepsilon^0 \omega} - \sigma_{\varepsilon^1 \omega}) c_i$$

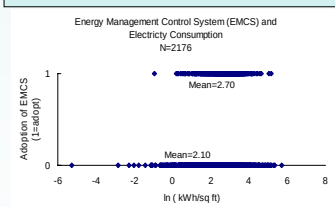
where $1 - \Phi(\psi_0 + \psi_1 C_j + \psi_2 Z_i + \psi_3 X_i + \psi_4 Y_j + \psi_5 U_i) = a_i$

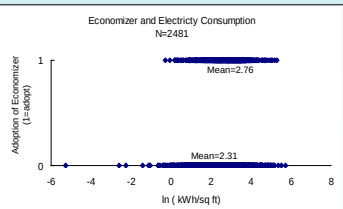
$$\Phi(\psi_0 + \psi_1 C_j + \psi_2 Z_i + \psi_3 X_i + \psi_4 Y_j + \psi_5 U_i) = b_i, \phi(\psi_0 + \psi_1 C_j + \psi_2 Z_i + \psi_3 X_i + \psi_4 Y_j + \psi_5 U_i) = c_i$$

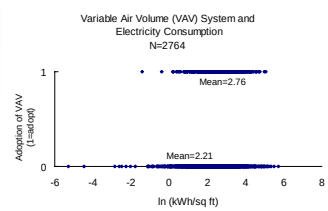
p_{ij} : marginal electricity price
q_{ij} : quantity of electricity consumption
C_j: vector of the cost shifters for electricity generation in region j
U_i: a set of dummy variables indicating where a building purchased the electricity from
E_{ij}: the expected electricity expenditure
T_i: dummy of adopting an technology
Z_i: index of energy efficiency policies
X_i: a vector of building characteristics
Y_j: a vector of region characteristics
ngp_{ij}: natural gas price

- Average price ← Two stage least squares

Data







Correlation coefficient	EMCS	Economizer	VAV system
EMCS	1	0.4708	0.4185
Economizer	0.4708	1	0.4286
VAV system	0.4185	0.4286	1
Regular HVAC maintenance	0.2609	0.2651	0.2346
Specular reflectors	0.2361	0.261	0.257
Electronic ballasts	0.2172	0.2333	0.2111
Auto controls on lighting	0.1583	0.1697	0.1853
Skylights for lighting	0.183	0.2021	0.1724
Tinted window glass	0.1751	0.2221	0.1801
Reflective window glass	0.1417	0.146	0.1753
External overhangs	-0.0296	-0.0152	0.0222
Percent daylight	-0.0574	-0.043	0.0037

Commercial Buildings Energy Consumption Survey (2003); Technologies analyzed→ HVAC, 51% of energy use

Without correcting the bias, misleading conclusion that rebound effect leads to negative energy saving!

Data Contd.

$$\widetilde{\%ERD_{economizer}} = \%ERD_{economizer} + 0.4708 \times \%ERD_{emcs} + 0.4286 \times \%ERD_{vav} + \sum_{j=others} \%ERD_j \times \rho_{ji}$$

$$\widetilde{\%ERD_{emcs}} = \%ERD_{emcs} + 0.4708 \times \%ERD_{economizer} + 0.4185 \times \%ERD_{vav} + \sum_{j=others} \%ERD_j \times \rho_{ji}$$

$$\widetilde{\%ERD_{vav}} = \%ERD_{vav} + 0.4185 \times \%ERD_{emcs} + 0.4286 \times \%ERD_{economizer} + \sum_{j=others} \%ERD_j \times \rho_{ji}$$

The direct estimate is a combined effect

Upper bound: ignore other technologies

Lower bound: all lighting energy use (21%) reduced

Detailed Model Results

Model number		1		2		3		4	
LHS=ln (electricity consumption / area)		No technology		EMCS		Economizer		VAV system	
Normalized average energy price	ln (Electricity price)	-0.8431	***	-0.6854	***	-0.7232	***	-0.9034	***
	ln (Natual gas price)	-0.0301		-0.0405		0.0011		-0.0152	
Technology adoption	a_i	NA		-0.5709	***	-0.4343	***	-0.5552	**
	c_i			0.4540	**	0.4890	**	0.4561	*
Regional characteristics	HDD	0.0000		0.0000	**	0.0000		0.0000	**
	CDD	0.0001	***	0.0001	***	0.0002	***	0.0001	***
Owner type	owner occupies or not	-0.0161		-0.0827	**	-0.0312		-0.0322	
Size of the building	Number of floors	0.0000		-0.0001		0.0000		-0.0001	
	Area (square feet)	-4.94E-07	***	-6.80E-07	***	-5.53E-07	***	-6.77E-07	***
Building usage	months in use past year	0.0469		0.0403	***	0.0234	**	0.0403	***
	hours in use per week	0.0054	***	0.0045	***	0.0047	***	0.0046	***
	number of workers	0.0002		0.0002	***	0.0002	***	0.0002	***
Principal building activities (Base case: Shopping mall and Other)	Vacant	-0.7732	***	-0.9317	***	-0.5962	***	-0.8899	***
	Office	0.2042	*	0.0341		0.1644		0.0944	
	Laboratory	0.6189	***	0.5987	***	0.5558	***	0.4827	***
	Nonrefrigerated warehouse	-0.7694	***	-0.7291	***	-0.6688	***	-0.6925	***
	Food sales	0.9949	***	0.9603	***	1.0299	***	1.0537	***
	Public order and safety	-0.2536	*	-0.3237	*	-0.2415	*	-0.2892	*
	Outpatient health care	0.2894	**	0.0714		0.2389	*	0.1497	
	Religious worship	-0.7180	***	-0.7229	***	-0.5922	***	-0.7236	***
	Public assembly	-0.1745		-0.3684	***	-0.1017		-0.2412	*
	Education	-0.2507	**	-0.4764	***	-0.2993	**	-0.3800	***
	Food service	1.0680	***	1.0882	***	1.1796	***	1.1281	***
	Inpatient health care	0.0126		-0.0710		0.0379		-0.1276	
	Nursing	-0.3961	***	-0.4036	**	-0.2830	*	-0.4433	***
	Lodging	-0.6508	***	-0.5304	***	-0.4950	***	-0.5134	***
	Retail other than mall	0.0827		0.0315		0.1394		0.1857	
	Service	-0.0893		-0.0438		-0.0145		-0.0496	
Building age (Base case: 2000-2004)	Before 1920	-0.7907	***	-0.7030	***	-0.4785	***	-0.6030	***
	1920 to 1945	-0.3915	***	-0.3592	***	-0.2185	***	-0.2190	**
	1946 to 1959	-0.3443	***	-0.2772	***	-0.1597	***	-0.1723	*
	1960 to 1969	-0.2527	***	-0.2849	***	-0.1340	**	-0.0868	
	1970 to 1979	-0.0963		-0.0781		-0.0062		0.0048	
	1980 to 1989	-0.0724		-0.0919		-0.0169		-0.0124	
	1990 to 1999	-0.0437		-0.0477		0.0153		-0.0180	
Wall construction material	The categories include:1) Brick, stone, or stucco; 2) Pre-cast concrete panels;3) Concrete block or poured concrete; 4) Siding, shingles, tiles, or shakes; 5) Sheet metal panels;6) Window or vision glass;7) Decorative or construction glass. None of these are significant.								
Roof construction material	The categories include:1) Built-up; 2) Slate or tile shingles; 3) Wood shingles/shakes/other wood; 4) Asphalt/fiberglass/other shingles; 5) Metal surfacing; 6) Plastic/rubber/synthetic sheeting; 7) Concrete; 8) No one major type; 9) Other. None of these are significant.								
Percentage of exterior glass	The categories include: 1) 10 percent or less; 2) 11 to 25 percent; 3) 26 to 50 percent; 4) 51 to 75 percent; 5)76 to 100 percent. None of these are significant.								
Constant		-5.8825	***	-4.1378	***	-4.3335	***	-5.9332	***
	Number of observations	2815		2176		2481		2764	
	Adj R-squared	0.5186		0.5142		0.5043		0.5213	
	F-statistic	58.20		42.85		46.87		55.71	

Note: *** p<0.01, ** p<0.05, * p<0.1.

Major Findings

Technology		EMCS	Economizer	VAV
% electricity consumption reduction		16.22~27.22	0.26~11.03	14.69~26.47
Price Elasticties	Own price	-0.8431	-0.6854	-0.7232
	Natural gas	Not significant		

Conclusions

- After rebound effect, there are still net energy savings of adopting energy efficient technologies for commercial buildings → Promote energy efficiency
- Commercial buildings are price sensitive in terms of their electricity consumption → Pricing or tax policies will be effective