Cost Effectiveness of Electricity Energy Efficiency Programs

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Motivation

Utility EE DSM programs have been around since 70's

- Renewed interest in EE in recent years
  - Energy security
  - Climate
  - Help consumers avoid high costs of energy
- How much electricity do EE programs save and at what cost?
- Range of recent savings estimates:
  - 1.8% (EIA 861 for 2007):
  - 1.2% (CEC for 2005)
  - 2.5% *incremental* savings (Efficiency Vermont for 2008)
- Range of recent average cost estimates
  - ACEEE (2009): 2.5 cents per kWh
  - PG&E (2009) 4.5 cents per kWh
  - Loughran & Kulick (2004): between 7 and 25 cents per kWh
  - Auffhammer , Blumstein and Fowlie (2008): 5.1 to 14.6 cents per kWh

Literature Review

- Extensive literature reviewed in Gillingham et al. (2006, 2009) - big range of cost effectiveness estimates (< 1 cent to 30 cents per kWh saved)
- This paper draws on work by Loughran and Kulick (2004) and Auffhammer, Blumstein and Fowlie (2008)
  - Incorporate energy efficiency expenditures into electricity demand function
  - L&K find that EE DSM costs are 2 to 6 times what utilities report and savings are commensurately less *but approach is flawed*
  - ABF adjust L&K results to recalculate weighted aggregate savings, construct confidence intervals and find L&K can't reject utility reports of savings and average cost
  - None of these prior studies deals with the potential endogeneity of EE DSM spending.
- We use more recent and more complete data, additional variables and a technique that explicitly addresses endogeneity.

Description of the Model

- Demand for electricity is a logarithmic function of
  - fuel prices,
  - demand shifters (income, # of customers, housing starts, population),
  - weather
  - EE DSM capital stock .
- DSM capital depends on past EE DSM spending per customer
  - Use the pdf of a Gamma distribution to specify timing of effects
- Decoupling and building codes are also considered
- Demand equation estimated in first differences
- Demand equation used to derive expressions for:
  - % change in total demand due to EE DSM spending
  - Average cost per kWh saved

The Model

Aggregate electricity demand for utility *u* in year *t:*

- $Q_{ut} = f(X_{ut}, D_{ut}, \xi_u, \mu_t, \varepsilon_{ut})$

where Q_{ut} is aggregate electricity demand.

X_{ut} is vector that includes number of customers, level of economic activity, energy prices, weather conditions, and regulatory variables influencing electricity demand.

$D_{ut} = \{d_{ut}, d_{u,t-1}, d_{u,t-2}, \ldots, d_{u,t_0}\}$ is vector of DSM spending per customer in current and prior years, (DSM capital stock is a function of past spending)

ξ_u is a vector of utility-level fixed effects,

μ_t is a vector of year fixed effects, and

ε_{ut} captures idiosyncratic demand shocks.

The Model (cont'd)

$$\ln(Q_{ut}) = X_{ut}\alpha + \xi_u + \eta_t + \sum_{j=0}^{t-t_0} \lambda(j)[1 - \exp(\gamma d_{u,t-j}))] + \varepsilon_{ut} \quad (2)$$

where $\lambda(j)$ gives effects of individual DSM variables

t_0 is the first year of DSM spending at utility u

γ gives the rate of diminishing (or increasing) returns

Long-term effect of DSM spending (gamma pdf):

$$\lambda(j, \eta_1, \eta_2) = \eta_1 {}^{\eta_2}(j+1)^{\eta_1 - 1}\exp[-\eta_2(j+1)\,]/\Gamma\left(\eta_1\right) \quad (3)$$

Dealing with missing EE DSM spending data:

$$\ln(Q_{ut}) = X_{ut}\alpha + \xi_u + \eta_t + \sum_{j=0}^{t-t_0} \lambda(j)[1 - \exp(\gamma d_{u,t-j})] + f(\overline{d}_{u,t_0-1}, \tau_t) + \varepsilon_{ut} \quad (4)$$

where $f(\overline{d}_{u,t_0-1}, \tau_t)$ is a control function to capture effects of EE DSM spending prior to our data period

Estimation Strategy

Take first differences:

$$\ln\left(\frac{Q_{ut}}{Q_{u,t-1}}\right) = \Delta X_{ut}\alpha + \Delta\mu_t + \sum_{j=0}^{t-t_0} \lambda(\eta_1, \eta_2, j)[1 - \exp(\gamma d_{u,t-j})] - \sum^{t-t_0-1} \lambda(\eta_1, \eta_2, j)[1 - \exp(\gamma d_{u,t-1-j})] + \Delta f(\bar{d}_{u,t_0-1}, \tau_t) + \Delta\varepsilon_{ut}, \quad (5)$$

- DSM spending could be correlated with unobserved demand shocks (e.g. higher demand growth leads to higher DSM).
- In this case, NLLS estimation would yield biased estimates.
- We use GMM method with optimal instruments:
  - Using distant lagged DSM and polynomials to construct instruments
  - Using LCV scores and % Republican votes in last presidential election together with lagged DSM spending to construct instruments

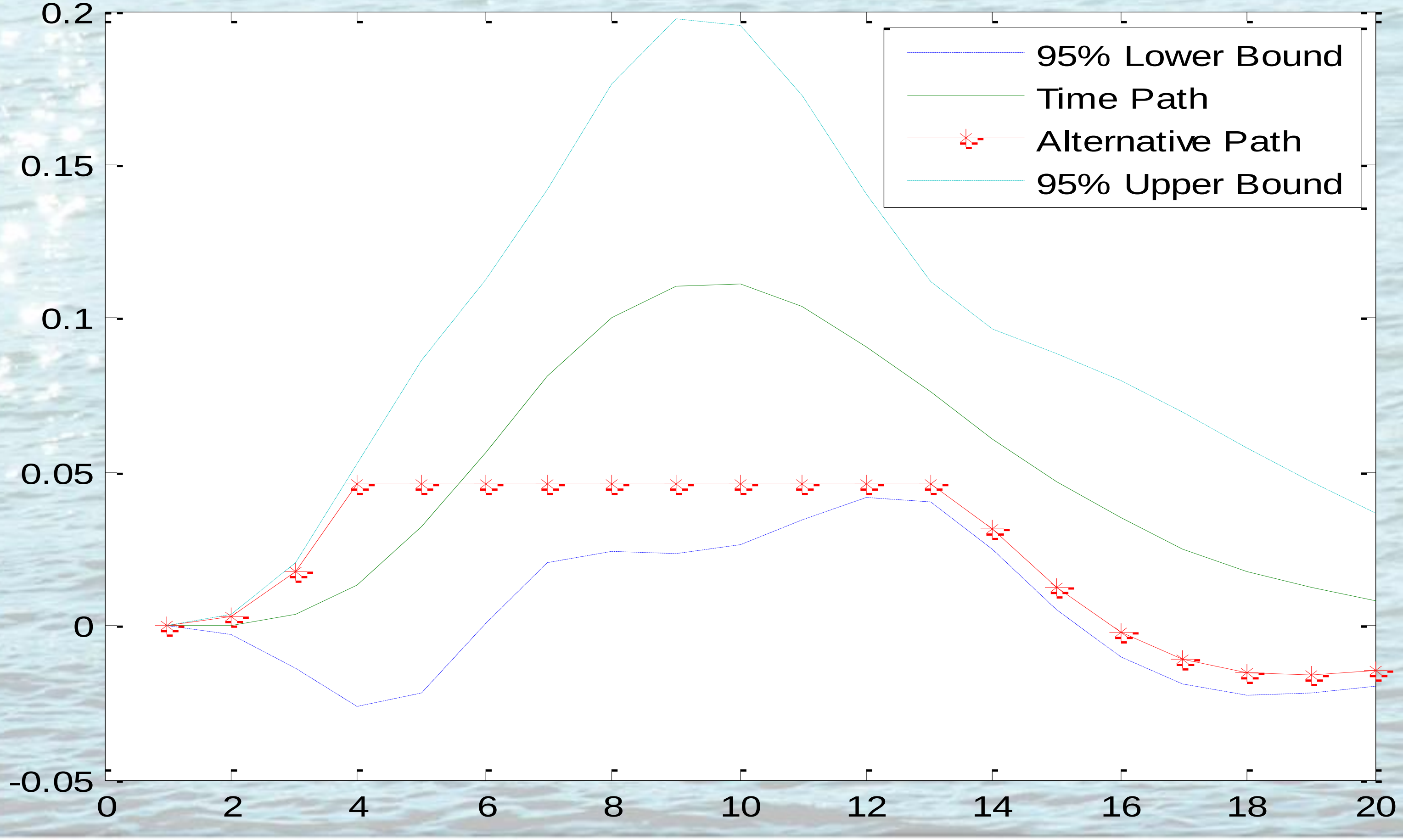
Data

- Data are for 1989 – 2006
- Main data source is EIA 861 database:
  - Utility level annual sales and customer count data
  - Utility level annual expenditures on energy efficiency DSM (not peak trimming or shifting DSM)
- Other data include:
  - Prices of electricity, natural gas and oil (EIA)
  - State ratepayer funded DSM expenditures (states)
  - Income (BEA)
  - Population (Census)
  - Heating and cooling degree days (NOAA)
  - Decoupling indicator (NARUC, ACEEE)
  - Residential building codes (Mitsubishi Bank)
  - LCV Scores (League of Conservation Voters)
  - Percent Republican Votes in last presidential election

Estimation Results from Baseline Model

Variables	Model 1: NLS		Model 2: GMM		Model 3: GMM	
	Para.	S.E.	Para.	S.E.	Para.	S.E.
DSM spending per customer (γ)	-0.0016	0.0010	-0.0015	0.0010	-0.0016	0.0010
η_1 in Gamma probability density function	8.4155	5.7705	8.8819	6.1876	8.3271	5.7275
η_2 in Gamma probability density function	0.7768	0.5972	0.8282	0.6409	0.7672	0.5930
Log(number of customers)	0.3617	0.0453	0.3617	0.0454	0.3617	0.0454
Log(population)	0.4573	0.0921	0.4574	0.0921	0.4573	0.0921
Log(gross state product)	0.2003	0.0436	0.2004	0.0436	0.2002	0.0436
Log(house starts)	0.0381	0.0080	0.0381	0.0080	0.0381	0.0080
Log(electricity price)	-0.4660	0.1905	-0.4655	0.1908	-0.4661	0.1909
Log(electricity price) squared	0.0911	0.0406	0.0910	0.0407	0.0911	0.0407
Log(natural gas price)	0.1229	0.0589	0.1228	0.0588	0.1229	0.0589
Log(natural gas price) squared	-0.0349	0.0143	-0.0349	0.0143	-0.0349	0.0143
Log(fuel oil price)	0.3451	0.2213	0.3460	0.2213	0.3449	0.2212
Log(fuel oil price) squared	-0.0344	0.0232	-0.0345	0.0232	-0.0344	0.0232
Log(climate)	0.0962	0.0066	0.0962	0.0066	0.0962	0.0066
Building codes and interactions	Yes		Yes		Yes	
Year dummies (14)	Yes		Yes		Yes	
Control function for early DSM	Yes		Yes		Yes	

Long-term Effect of DSM Spending from Baseline Model



Effectiveness and Cost Effectiveness from Baseline Model.

	Model 1: NSL		Model 2: GMM		Model 3: GMM	
	Est.	S.E.	Est.	S.E.	Est.	S.E.
Demand effect of DSM spending (data period)	-0.009	0.005	-0.009	0.005	-0.009	0.005
Demand effect of DSM spending (total effect)	-0.018	0.011	-0.017	0.011	-0.018	0.011
Cost-effectiveness (no discounting)(cents per kwh saved)	-3.0	1.8	-3.2	1.9	-3.0	1.8
Cost-effectiveness using 3% discount rate	-4.1	2.4	-4.3	2.6	-4.1	2.4
Cost-effectiveness using 5% discount rate	-5.0	2.9	-5.2	3.1	-5.0	2.9
Cost-effectiveness using 7% discount rate	-6.1	3.5	-6.3	3.7	-6.0	3.5

Choice of discount rate matters to cost effectiveness estimate
Average cost at preferred discount rate of 5% is 5 cents per kWh saved.
Controlling for endogeneity has virtually no effect on cost effectiveness results.

Putting the results in context

- Compare average cost estimate to
  - National average retail price in 2006 of 9.1 cents per kWh
  - Marginal cost of power in PJM in December 2006 ranged from 2 cents to 27 cents per kWh
  - Long-run marginal cost of 8 – 9 cents for base load capacity and 13 cents for peaking capacity.
- Suggests that, depending on customer costs, EE DSM programs may have produced zero cost or low cost CO_2 emissions reductions
- Cost effectiveness estimates include cost to program administrators only.
  - Prior literature indicates that including customer costs could add up to 70% to administrator cost alone, but these estimates are old and based on very little data, so not particularly reliable.
  - Nonetheless, suggest that for our preferred estimate, total cost is below price of electricity.

Other Results and Sensitivities.

- Stringent building codes reduce electricity demand and that effect is stronger in states with higher levels of housing starts.
- The demand reducing effect of EE DSM spending appears stronger for utilities that have decoupling regulation, but not statistically significantly so.
- Econometric estimates are robust to:
  - Specification of control function for early DSM spending.
  - Restrictions on sample size.
  - Functional form used to capture effects of DSM spending over time.

Thank you

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