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Measuring the Accuracy of Engineering Models in Predicting Energy Savings from Home Retrofits: Evidence from Monthly Billing Data

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Research Objectives

Paper evaluates **eight** residential energy efficiency rebate programs in Gainesville, Florida using a panel data set of electricity and natural gas consumption, to:

- Estimate the energy savings for individual measures
- Compare these estimates to engineering predictions
- Calculate return on investment across measures and rebate programs

“Engineering” models of energy use

Engineering models of energy use are used to:

- Design new, more efficient buildings
- Predict savings from retrofit measures
- Inform policy design and implementation
- Evaluating the accuracy of these models is important given the role they play in informing investment/ policy implementation

Energy efficiency gap:

- Can be defined as “the failure of consumers to make seemingly positive net present value energy-saving investments”
- EE gap could be explained by inaccurate engineering estiamtes

Literature

Engineering models systematically over-estimate realized energy savings:

- Graff Zivin and Novan (2015): Low-income weatherization (80%)
- Fowlie, Greenstone, Wolfram (2015): Low-income weatherization (40%)
- Davis (2013): Refrigerator (30%), Room Air conditioner (0%)

Poor return on investment and program performance:

- Low-income populations
- Expensive subsidy programs (federal grants)
- Bundling multiple retrofits per project

Contributions of this paper:

- Heterogeneity across several specific measures
- Optimal program design to target most cost-effective measures

Data from Gainesville Regional Utility

Retrofits (2006-2012)

- Eight energy efficiency measures, most available to most Gainesville residents
- Project-level rebate, cost, installation date
- Measure-specific engineering estimates

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Energy Bills (2000-2015)

- Census of ~40,000 households in GRU service area
- Monthly electricity and natural gas bills

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Housing Characteristics *(2012, County Property Appraiser)*

- Building characteristics, home improvements, home sales

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Identification

- Restrict sample to households that received a single retrofit (N=5,165)
- Control group of future program participants that have not yet installed retrofits (but ultimately do).

Summary Statistics

Variable	Super-SEER Central Air Conditioner	SEER-15 Central Air Conditioner	Room Air Conditioner	Pool Pump	Refrigerator Removal	Attic Insulation	Duct Leakage Repair	Air Conditioning Maintenance
Ex-ante energy savings (kWh per month)	160.6	46.0	19.5	146.7	127.4	129.5	107.8	37.6
Project cost	$7,291	$5,672	-	$1,452	-	$761	$863	$97
Rebate	$555	$295	$162	$284	$72	$199	$359	$55
Rebate relative to cost	8%	5%	100%	20%	100%	26%	42%	57%
Expected useful lifetime (years)	18	18	15	10	18	20	18	3
Treated houses	623	297	234	394	1,160	577	365	1,216

Installations by Retrofit and Year

Year Installed	Super-SEER Central Air Conditioner	SEER-15 Central Air Conditioner	Room Air Conditioner	Pool Pump	Refrigerator Removal	Attic Insulation	Duct Leakage Repair	Air Conditioning Maintenance
2006	2	8	0	0	0	1	15	108
2007	130	18	28	0	278	80	114	429
2008	114	23	88	50	175	114	90	455
2009	115	51	63	60	115	59	36	216
2010	114	128	55	109	235	147	20	8
2011	55	69	0	85	199	115	40	0
2012	93	0	0	90	158	61	50	0
Total	623	297	234	394	1,160	577	365	1,216

Two-Way Fixed Effects Models

$$y_{ijt} = \lambda_t + c_{im} + \tau_j \omega_{ijt} + \varepsilon_{ijt}$$

y_{ijt}	energy consumption *(kWh, therms)* for house i in period t
λ_t	indicator variable for billing period *(year*month)*
c_{im}	indicator variable for house month *(house*month-of-year)*
ω_{ijt}	indicator variable equal to one in **periods after installation** of **retrofit type** j
ε_{ijt}	error term (clustered by house)
τ_j	average treatment effect by retrofit type (which persists over time)

*Sample restricted to houses that are treated by end of study period

Estimates of Energy Savings

Variables	Super-SEER Central Air Conditioner	SEER-15 Central Air Conditioner	Room Air Conditioner	Pool Pump	Refrigerator Removal	Attic Insulation	Duct Leakage Repair	Air Conditioner Maintenance
A. Total energy consumption (kwh per month)								
Treatment Effect	**-222.9*** ** (27.6)	**-151.2*** ** (38.7)	**-23.9** (47.4)	**-98.7** ** (46.9)	**-46.6*** ** (17.5)	**-87.6*** ** (28.4)	**-39.5** (33.8)	**1.2** (18.6)
Constant	1,677*** (48.2)	1,360*** (26.9)	1,267*** (31.7)	2,575*** (37.9)	1,479*** (12.3)	1,369*** (23.8)	1,444*** (30.3)	1,724*** (13.6)
Observations	114,415	51,173	38,645	65,606	195,337	98,570	62,108	201,670
R-squared	0.72	0.72	0.58	0.65	0.66	0.65	0.68	0.67

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B. Electricity consumption (kWh per month)								
Treatment Effect	**-138.9*** (18.6)**	**-81.0*** (28.2)**	**-26.5 (32.1)**	**-125.4*** (30.3)**	**-49.8*** (12.5)**	**-28.2 (18.8)**	**-14.9 (23.9)**	**5.0 (12.7)**
Constant	1,262*** (34.1)	1,035*** (17.1)	961*** (30.3)	1,764*** (24.8)	1,106*** (8.4)	1,121*** (11.8)	1,194*** (18.6)	1,114*** (9.3)
Observations	114,156	51,046	38,332	65,483	194,544	97,837	61,923	201,004
R-squared	0.77	0.74	0.59	0.71	0.67	0.68	0.69	0.68

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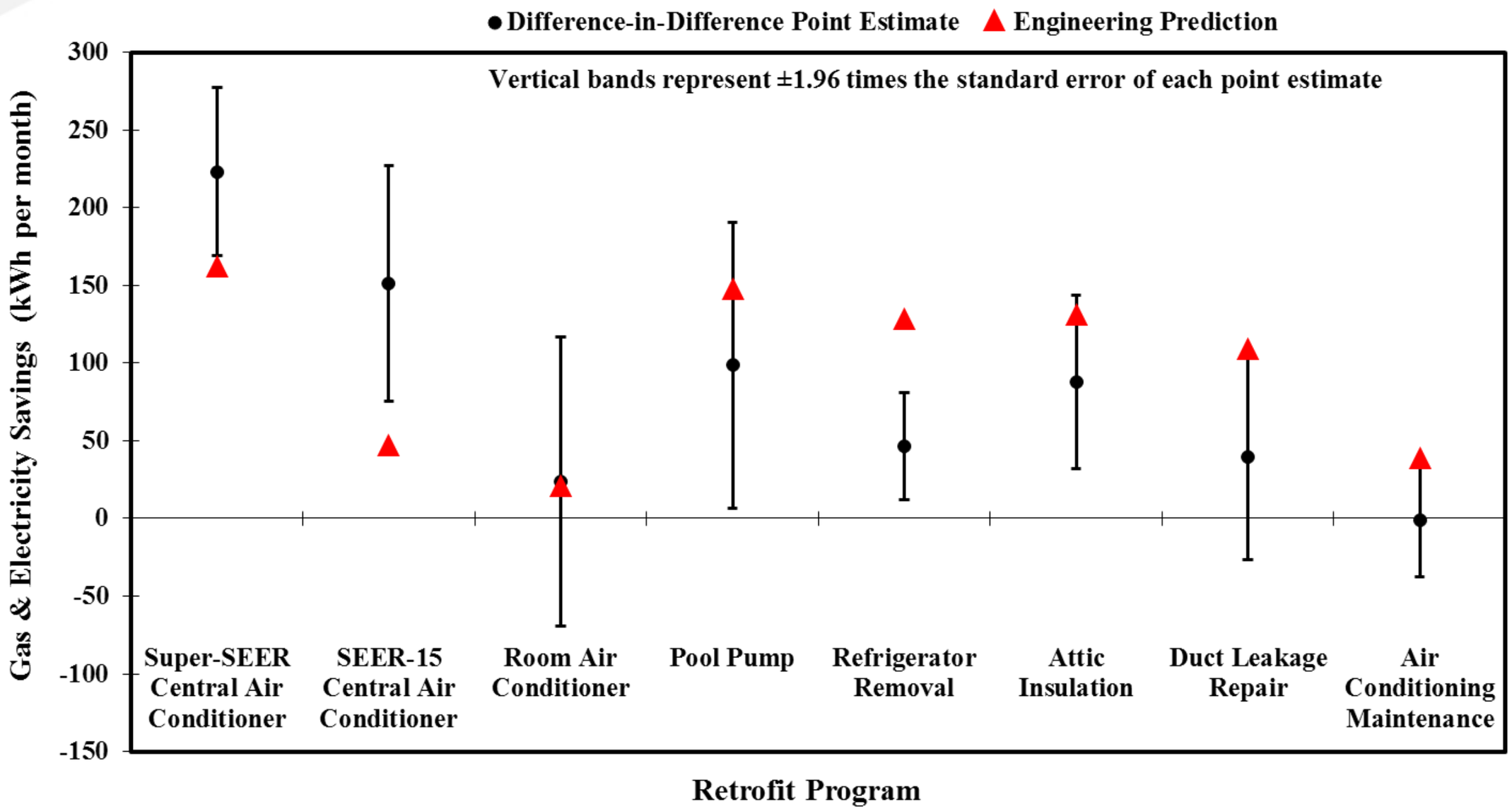
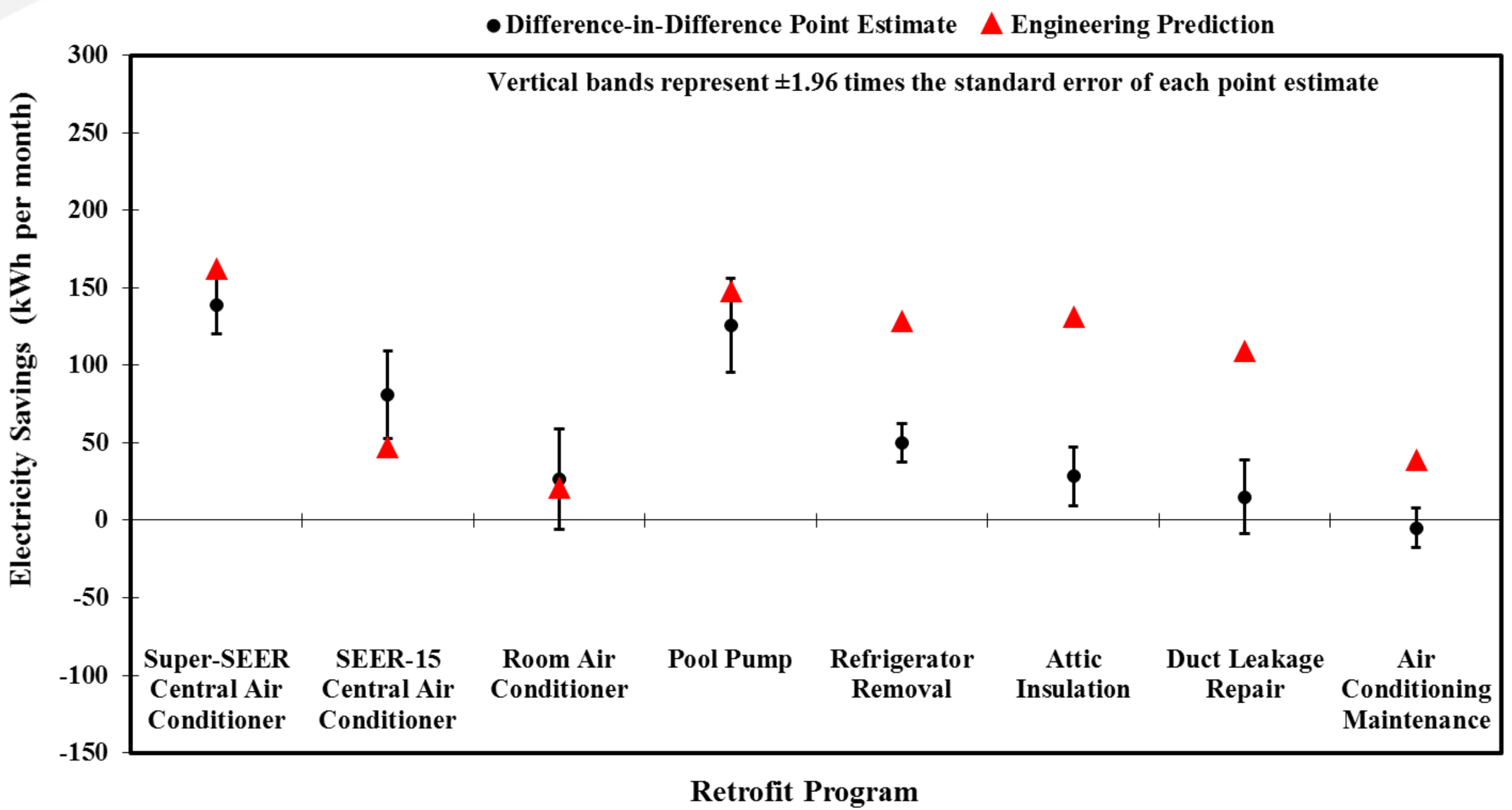
C. Natural gas consumption (therm per month)								
Treatment Effect	**-4.0*** (0.8)**	**-3.5*** (1.1)**	**-1.0 (1.6)**	**0.7 (1.1)**	**-0.1 (0.5)**	**-2.8*** (0.8)**	**-1.3 (0.9)**	**-0.2 (0.5)**
Constant	33.3*** (0.5)	23.3*** (1.0)	22.6*** (1.7)	30.5*** (2.4)	28.9*** (0.4)	23.4*** (0.7)	21.6*** (1.2)	25.4*** (0.5)
Observations	75,974	26,677	19,583	44,584	126,233	59,913	38,886	128,741
R-squared	0.80	0.80	0.68	0.75	0.77	0.76	0.80	0.80

Validation of Engineering Estimates (natural gas & electricity)



Validation of Engineering Estimates (electricity only)



Engineering versus realized energy savings

	Maher	Davis, Fuchs Gertler	Metcalf & Hassett	Fowlie, Greenstone Wolfram	Graff Zivin & Novan
Super-SEER Central Air Conditioner	140%				
SEER-15 Central Air Conditioner	330%				
Room Air Conditioner	125%	0%			
Pool Pump	70%				
Refrigerator Removal	40%	30%			
Attic Insulation	70%		20%		
Duct Leakage Repair	40%				
Air Conditioner Maintenance	5%				
Low-Income Weatherization				40%	80%
Electricity	x	x			x
Natural Gas	x			x	

Returns on Retrofit Investments

Super-SEER Central Air Conditioner	SEER-15 Central Air Conditioner	Room Air Conditioner	Pool Pump	Refrigerator Removal	Attic Insulation	Duct Leakage Repair	Air Conditioner Maintenance
Panel A: Present value of (discounted) savings							
$6,508	$4,934	$1,309	$1,264	$1,043	$3,428	$1,474	$13

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Panel B: Private internal rate of return							
4.5%	4.2%	--	3.2%	--	39.2%	14.4%	-57.2%

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Panel B: Private internal rate of return							
4.5%	4.2%	--	3.2%	--	39.2%	14.4%	-57.2%
Panel C: Private internal rate of return, after rebate payment							
5.5%	4.9%	--	7.7%	--	53.2%	26.6%	-39.4%

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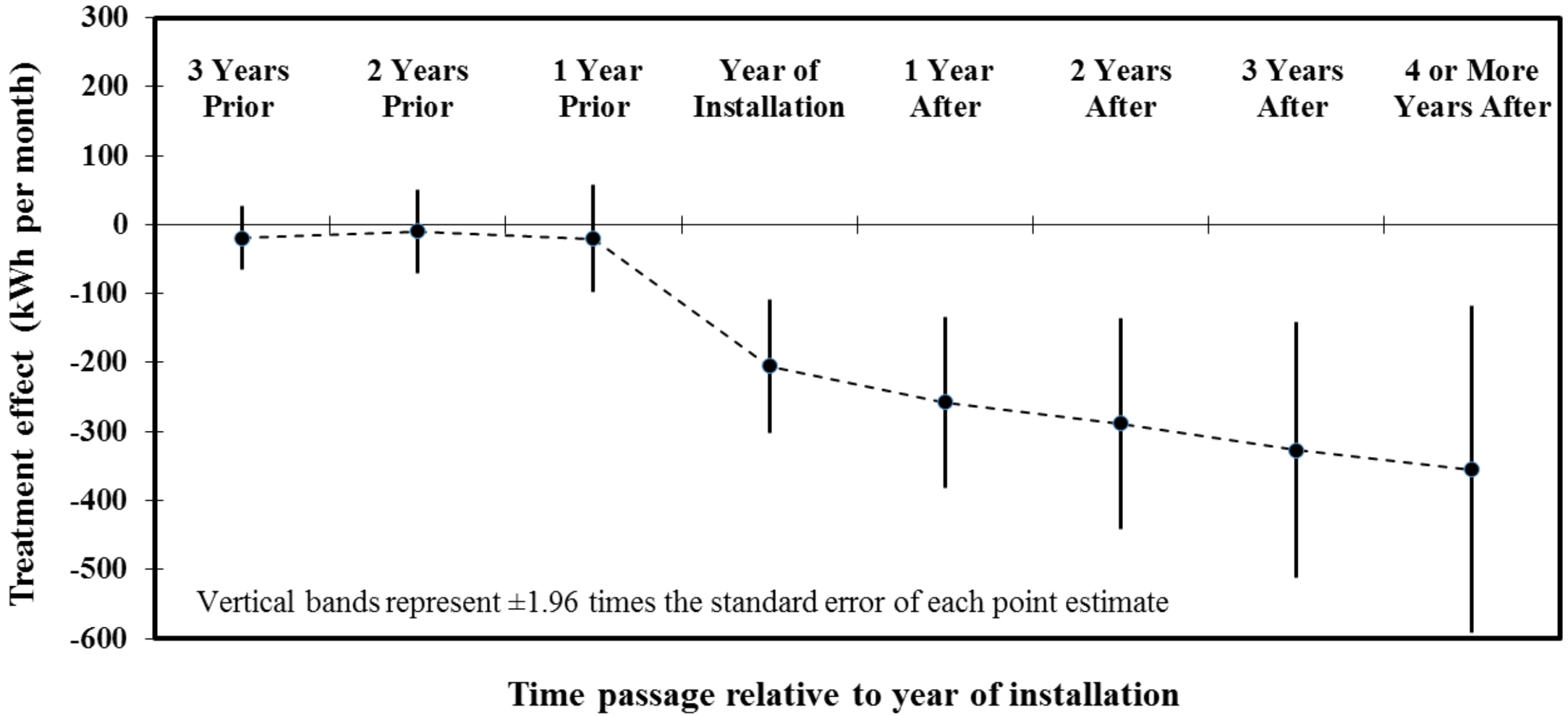
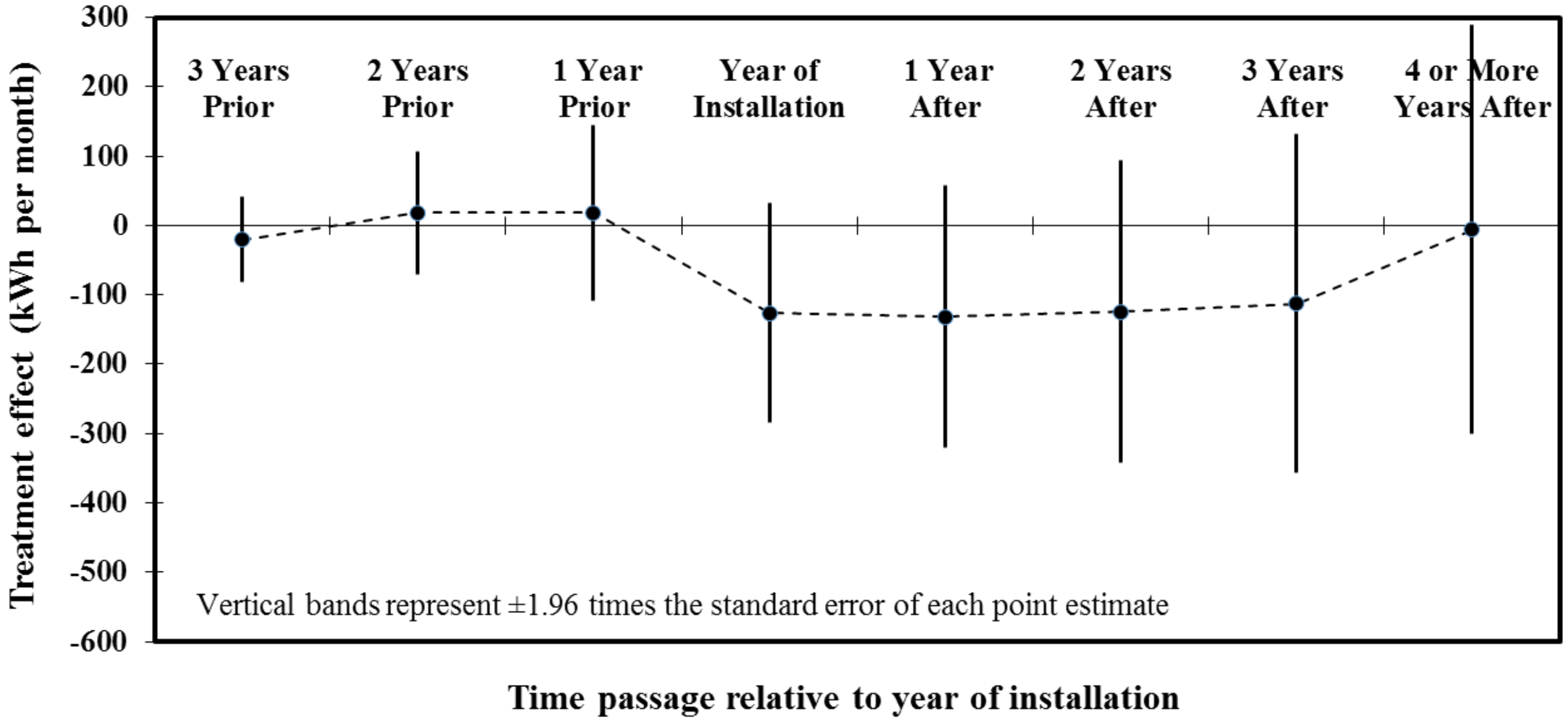
Panel C: Private internal rate of return, after rebate payment							
5.5%	4.9%	--	7.7%	--	53.2%	26.6%	-39.4%
Panel D: Cost per kilowatt hour of (discounted) energy savings							
$0.02	$0.02	$0.06	$0.03	$0.01	$0.02	$0.07	-$1.47

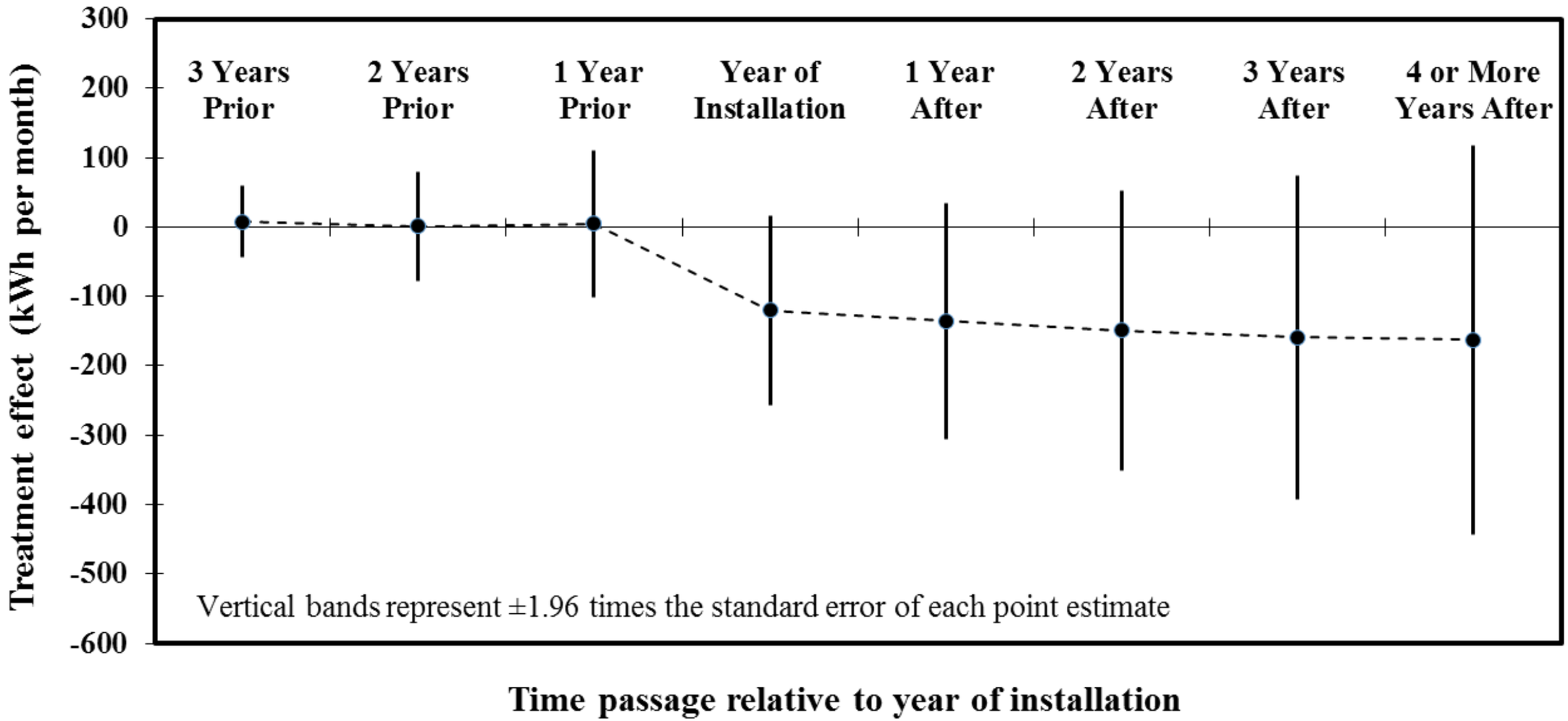
Dynamics: Super-SEER Air Conditioner (natural gas & electricity)



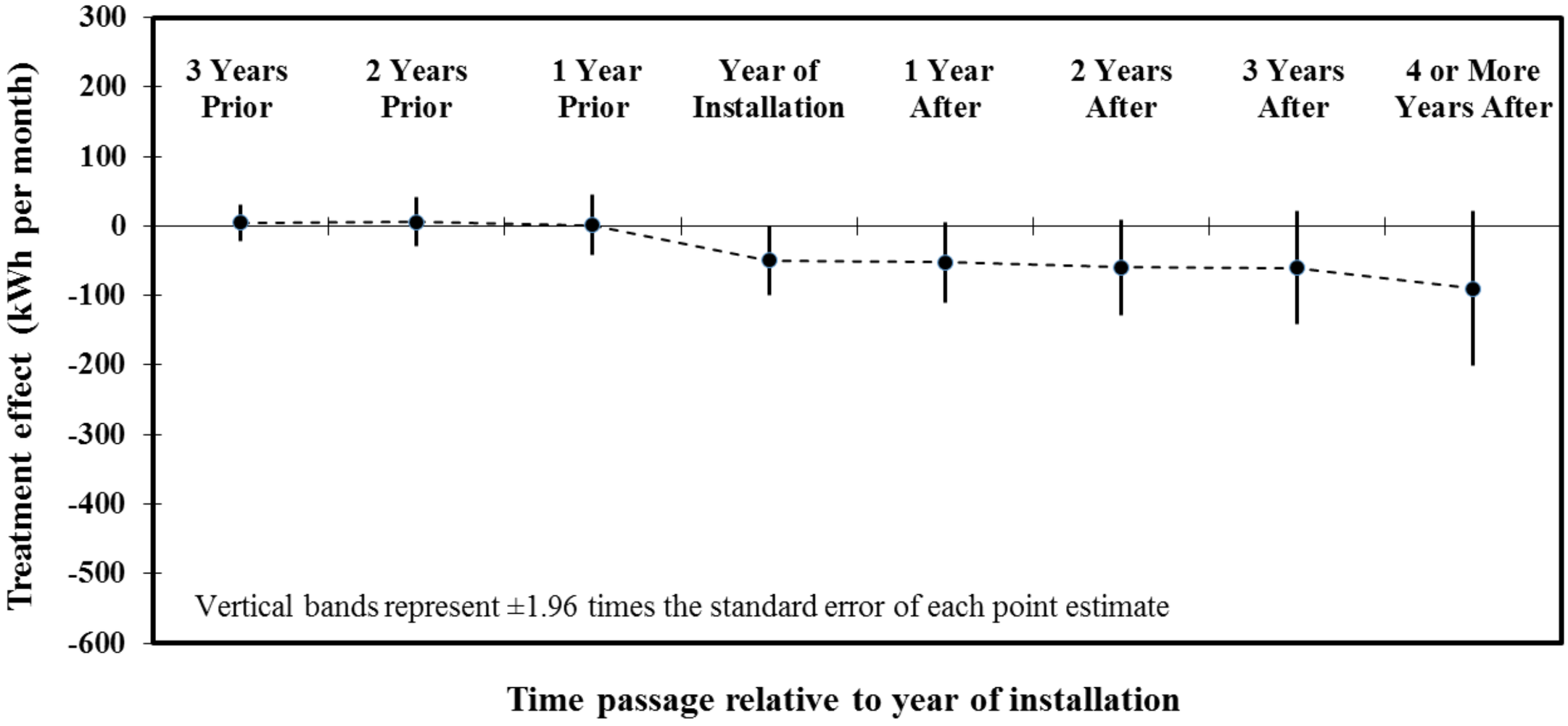
Dynamics: SEER-15 Air-Conditioner (natural gas & electricity)



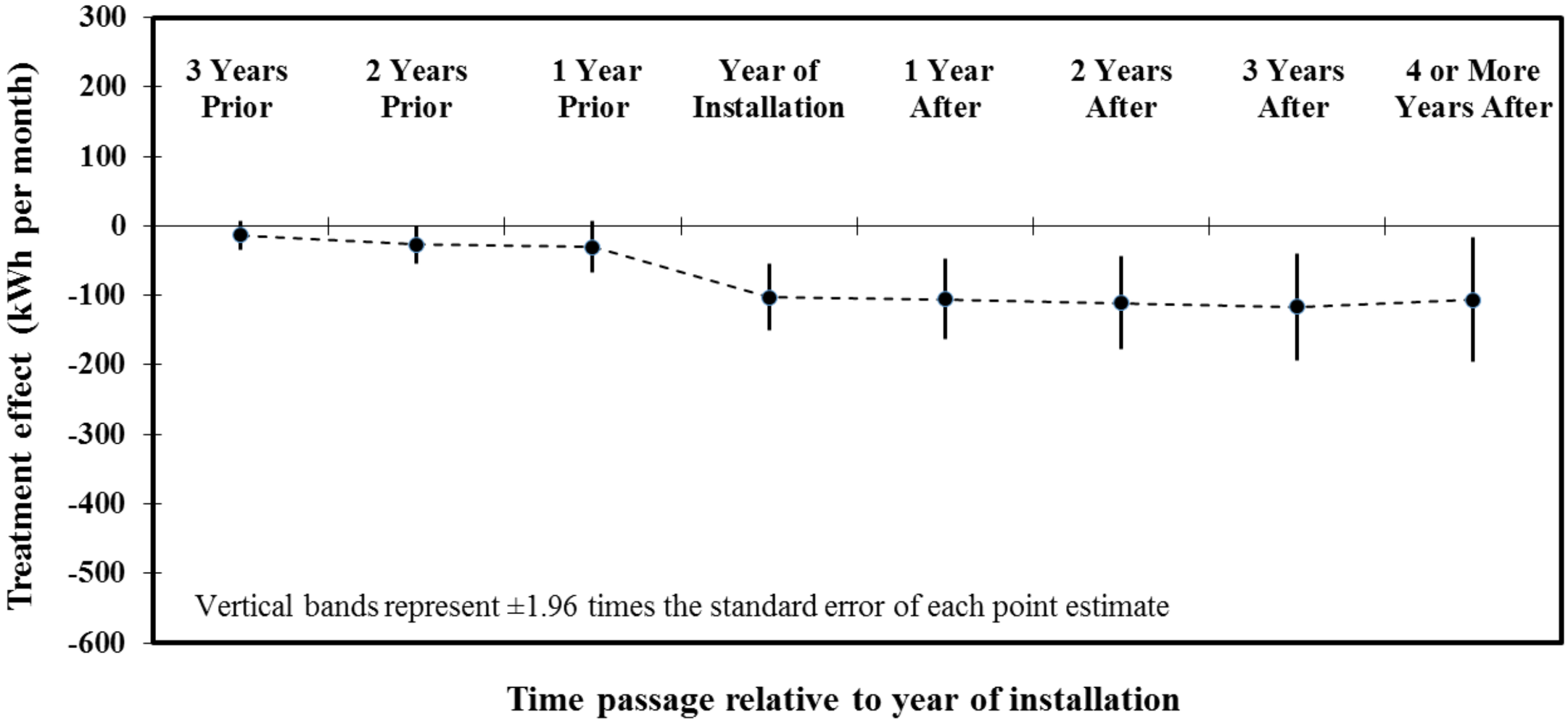
Dynamics: Pool Pump Replacement (electricity only)



Dynamics: Refrigerator Removal (electricity only)



Dynamics: Attic Insulation (natural gas only)



Conclusions

Empirical results

- Energy savings vary in magnitude and persistence over time

Validation of ex-ante engineering models

- Predictions often consistent with empirical estimates
- Engineering bias varies in sign and magnitude across measures

Validation of ex-ante engineering models

- Private returns suggest some retrofits are good investments
- Optimal program design to target cost-effective measures

Thanks.

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Seasonal Variations in Energy Savings

Variables	Super-SEER Central Air Conditioner	SEER-15 Central Air Conditioner	Room Air Conditioner	Pool Pump	Refrigerator Removal	Attic Insulation	Duct Leakage Repair	Air Conditioner Maintenance
A. Total energy consumption (kwh per month)								
Treatment Effect	-147.3***	-106.0**	-11.4	-100.1*	-23.3	-116.5***	-23.9	14.5
	(36.0)	(43.8)	(61.6)	(53.9)	(22.1)	(34.7)	(41.1)	(23.2)
Treatment Effect X May to October	-148.8***	-90.1**	-24.8	2.9	-46.2**	57.3*	-31.3	-29.5
	(32.0)	(35.8)	(48.6)	(45.1)	(19.1)	(29.5)	(39.4)	(23.5)
Observations	114,415	51,173	38,645	65,606	195,337	98,570	62,108	201,670
R-squared	0.72	0.72	0.58	0.65	0.66	0.65	0.68	0.67

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R-squared	0.72	0.72	0.58	0.65	0.66	0.65	0.68	0.67
B. Electricity consumption (kWh per month)								
Treatment Effect	-1.8	24.6	-28.3	-114.6***	-32.8***	-10.5	18.6	9.3
	(17.5)	(25.4)	(34.3)	(27.1)	(11.9)	(16.8)	(20.6)	(13.0)
Treatment Effect X May to October	-269.6***	-210.3***	3.6	-21.2	-33.6***	-35.2*	-67.6***	-9.6
	(17.3)	(26.7)	(30.8)	(25.8)	(11.2)	(18.3)	(23.8)	(14.0)
Observations	114,156	51,046	38,332	65,483	194,544	97,837	61,923	201,004
R-squared	0.77	0.74	0.59	0.71	0.67	0.68	0.69	0.68
C. Natural gas consumption (therm per month)								
Treatment Effect	-6.6***	-6.4***	-1.2	-0.2	0.2	-5.3***	-2.4	-0.1
	(1.4)	(1.7)	(3.0)	(1.7)	(0.8)	(1.4)	(1.5)	(0.8)
Treatment Effect X May to October	5.2***	5.7***	0.3	1.7	-0.6	4.9***	2.2	-0.2
	(1.3)	(1.5)	(2.9)	(1.5)	(0.7)	(1.2)	(1.4)	(0.8)
Observations	75,974	26,677	19,583	44,584	126,233	59,913	38,886	128,741
R-squared	0.80	0.80	0.68	0.75	0.77	0.76	0.80	0.80

In summary…

This paper uses monthly energy billing data from households in Florida to evaluate energy savings from energy efficiency retrofit programs.

- Engineering estimates vary widely in accuracy (and are often consistent with ex post estimates)
- Heterogeneous returns to energy efficiency investments
- Demand Side Management programs could improve performance by targeting cost-effective measures