



NATIONAL SOCIO-ENVIRONMENTAL SYNTHESIS CENTER

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



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Camp Resources | Wrightsville Beach, NC

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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 estimates

## **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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## 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 ( <i>kWh, therms</i> ) for house $i$ in period $t$
$\lambda_t$	indicator variable for billing period ( <i>year*month</i> )
$c_{im}$	indicator variable for house month ( <i>house*month-of-year</i> )
$\omega_{ijt}$	indicator variable equal to one in <b>periods after installation of retrofit type <math>j</math></b>
$\varepsilon_{ijt}$	error term (clustered by house)
$\tau_j$	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
<b>A. Total energy consumption (kwh per month)</b>								
<b>Treatment Effect</b>	<b>-222.9***</b> (27.6)	<b>-151.2***</b> (38.7)	<b>-23.9</b> (47.4)	<b>-98.7**</b> (46.9)	<b>-46.6***</b> (17.5)	<b>-87.6***</b> (28.4)	<b>-39.5</b> (33.8)	<b>1.2</b> (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

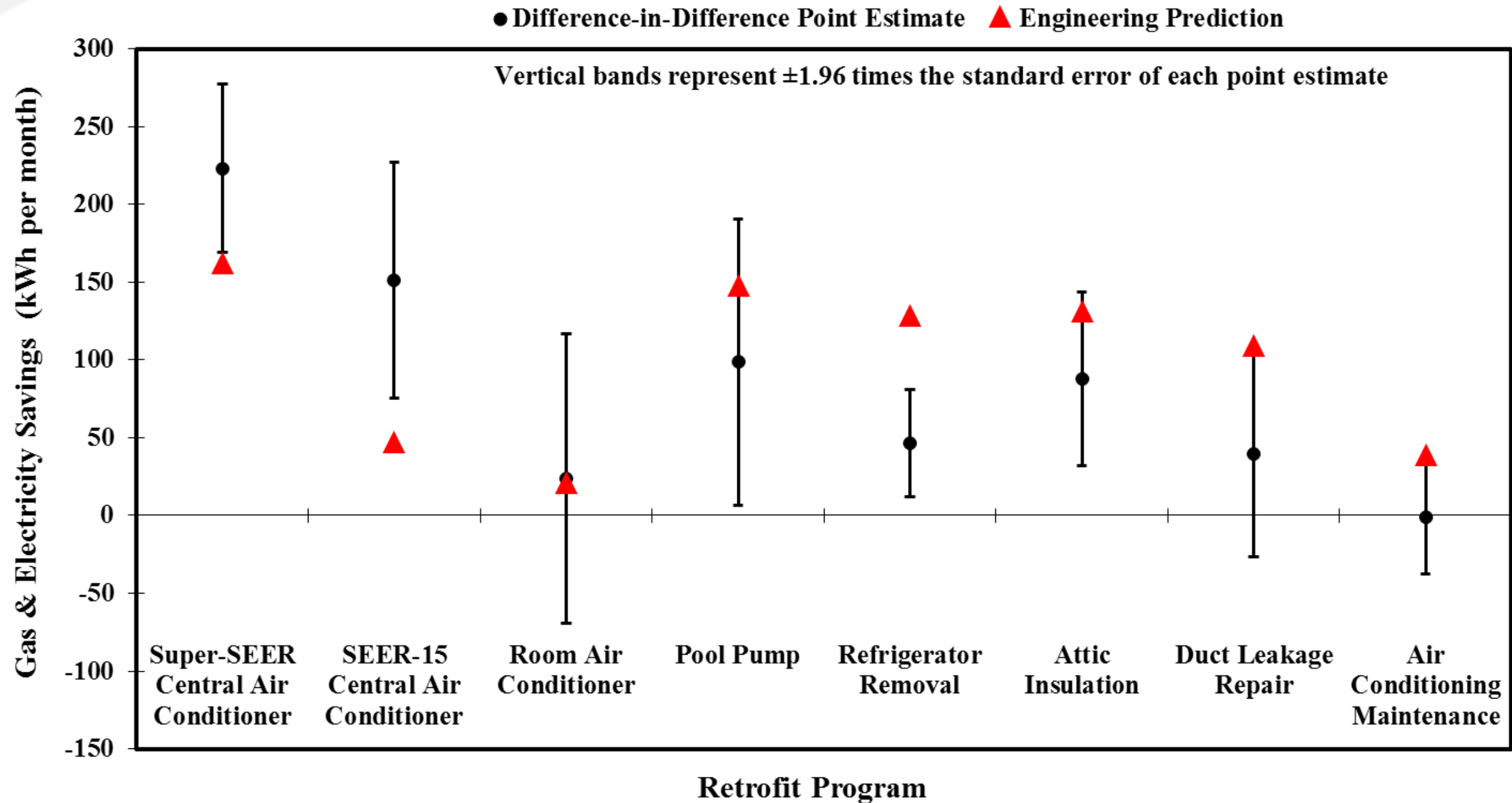
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B. Electricity consumption (kWh per month)								
<b>Treatment Effect</b>	<b>-138.9***</b> (18.6)	<b>-81.0***</b> (28.2)	<b>-26.5</b> (32.1)	<b>-125.4***</b> (30.3)	<b>-49.8***</b> (12.5)	<b>-28.2</b> (18.8)	<b>-14.9</b> (23.9)	<b>5.0</b> (12.7)
Constant	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

# Estimates of Energy Savings

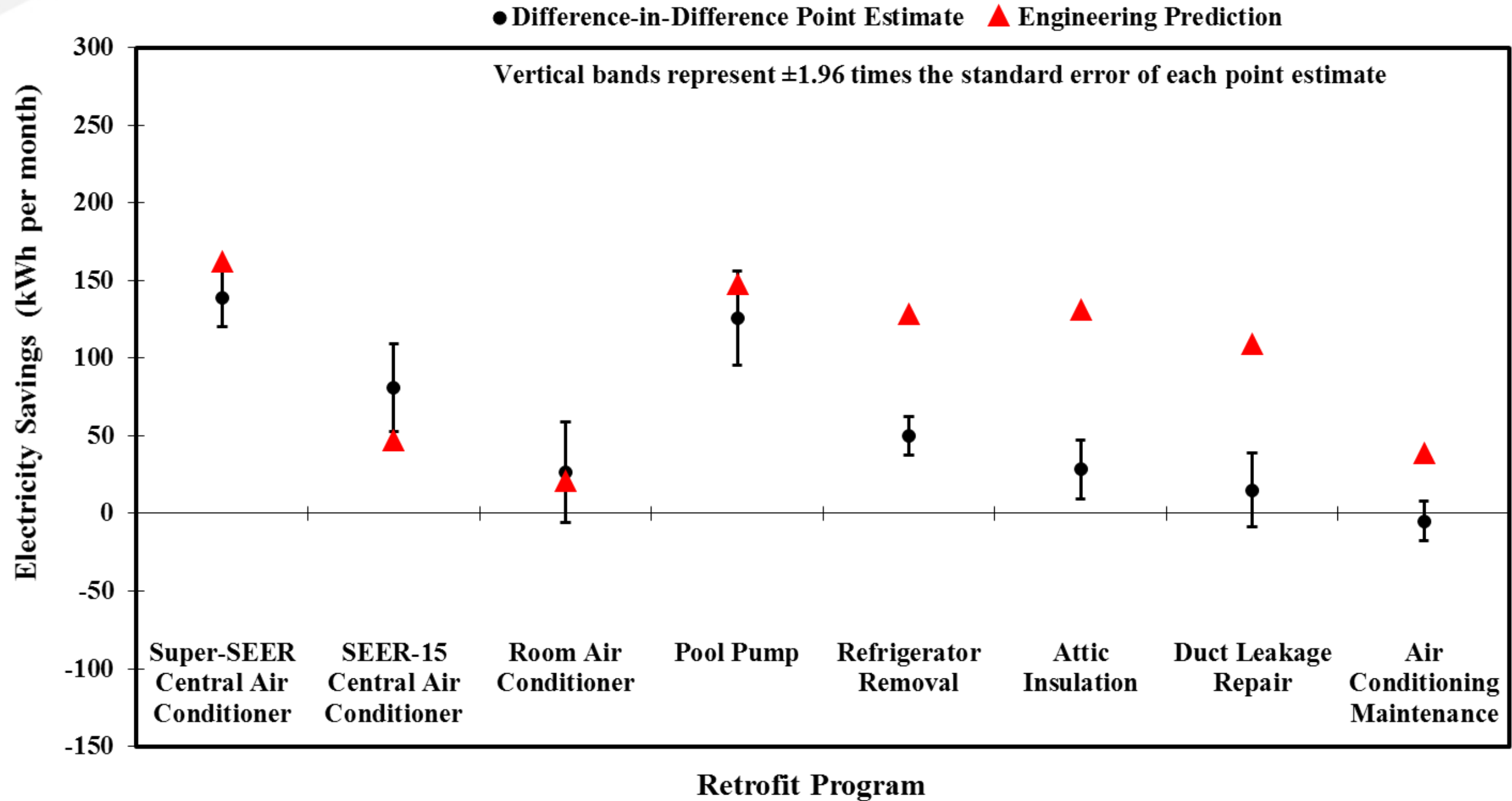
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R-squared	0.77	0.74	0.59	0.71	0.67	0.68	0.69	0.68
C. Natural gas consumption (therm per month)								
Treatment Effect	<b>-4.0***</b> (0.8)	<b>-3.5***</b> (1.1)	<b>-1.0</b> (1.6)	<b>0.7</b> (1.1)	<b>-0.1</b> (0.5)	<b>-2.8***</b> (0.8)	<b>-1.3</b> (0.9)	<b>-0.2</b> (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	SEER-15							
Central Air	Central Air	Room Air	Pool	Refrigerator	Attic	Duct	Air	
Conditioner	Conditioner	Conditioner	Pump	Removal	Insulation	Leakage	Conditioner	
						Repair	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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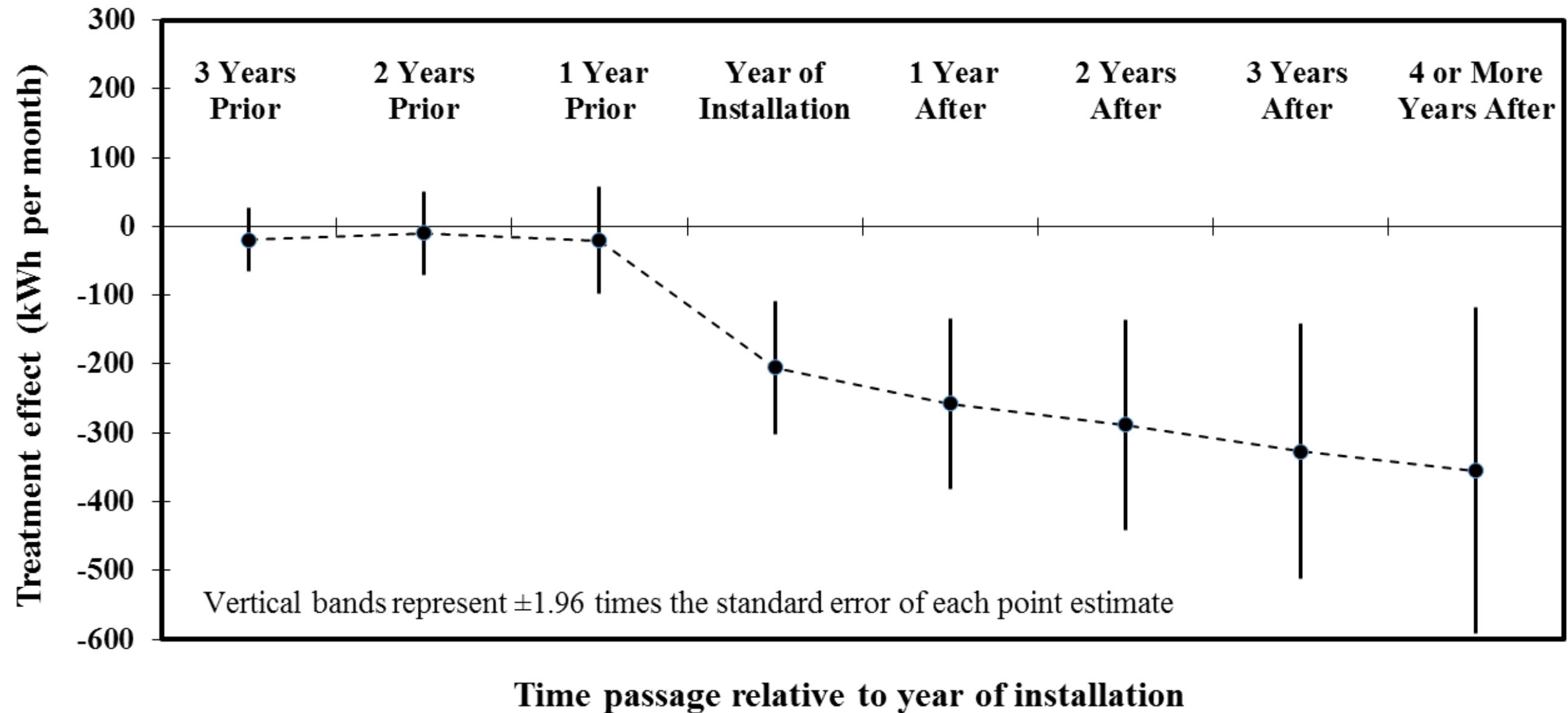
# Returns on Retrofit Investments

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
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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%

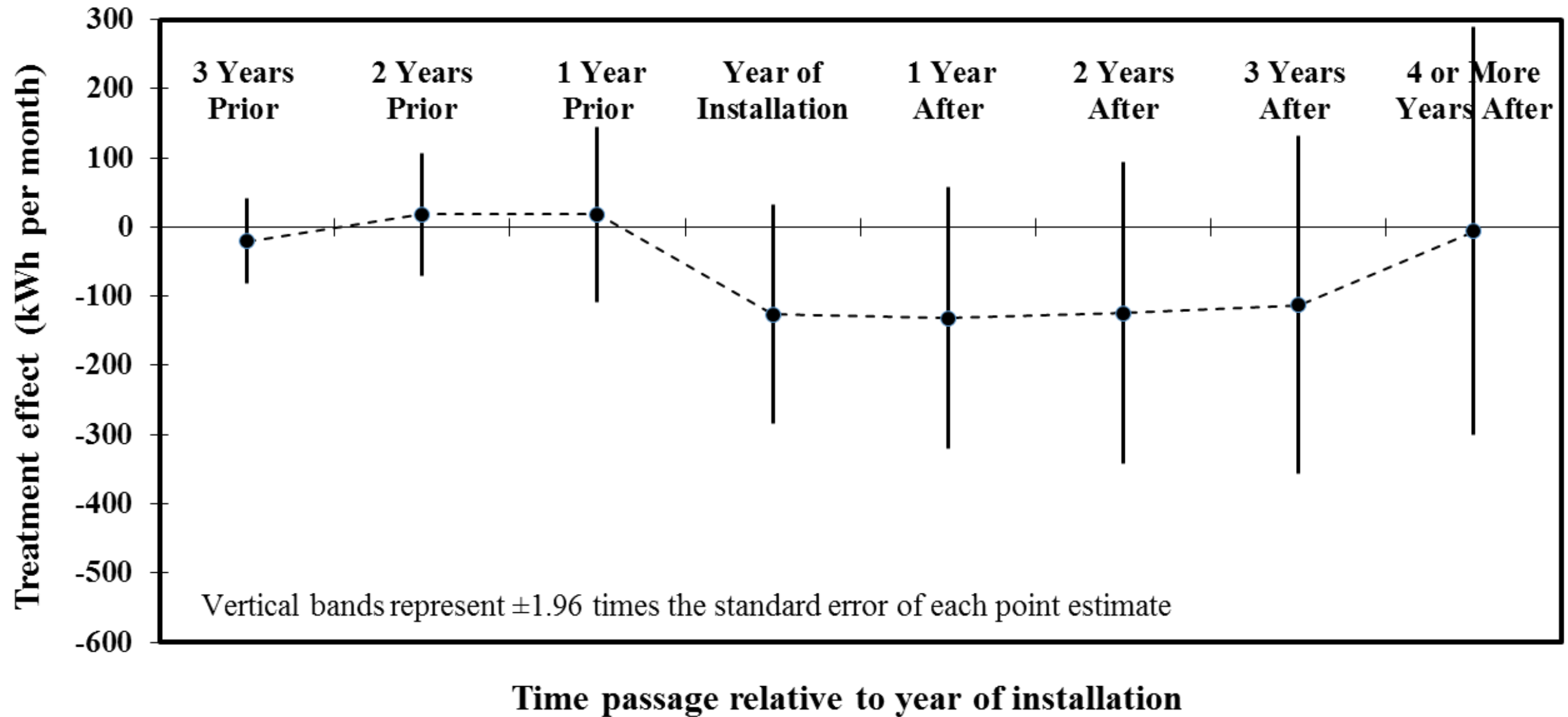
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Panel C: Private internal rate of return, after rebate payment							
5.5%	4.9%	--	7.7%	--	53.2%	26.6%	-39.4%
Panel D: Cost per kilowatt hour of (discounted) energy savings							
\$0.02	\$0.02	\$0.06	\$0.03	\$0.01	\$0.02	\$0.07	-\$1.47

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

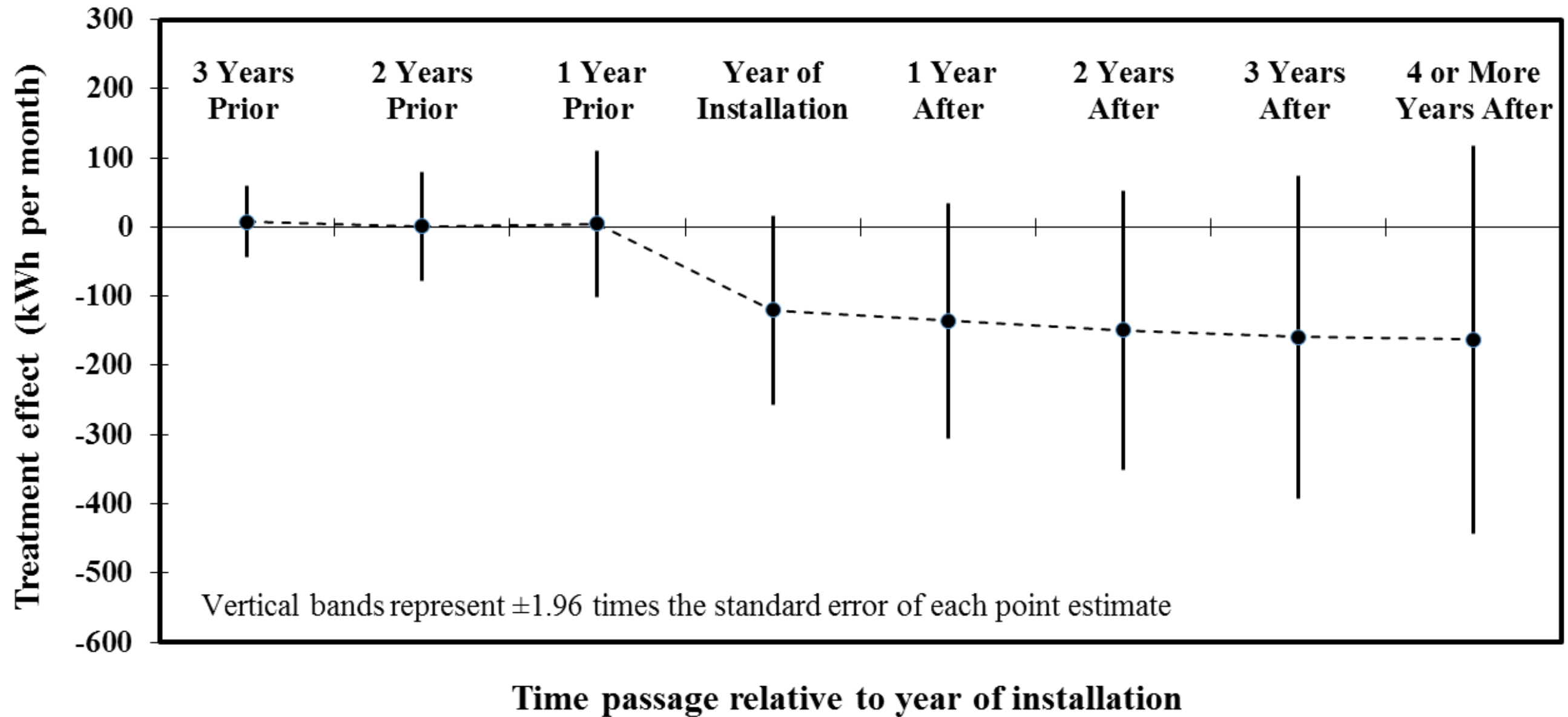


# Dynamics: SEER-15 Air-Conditioner (natural gas & electricity)

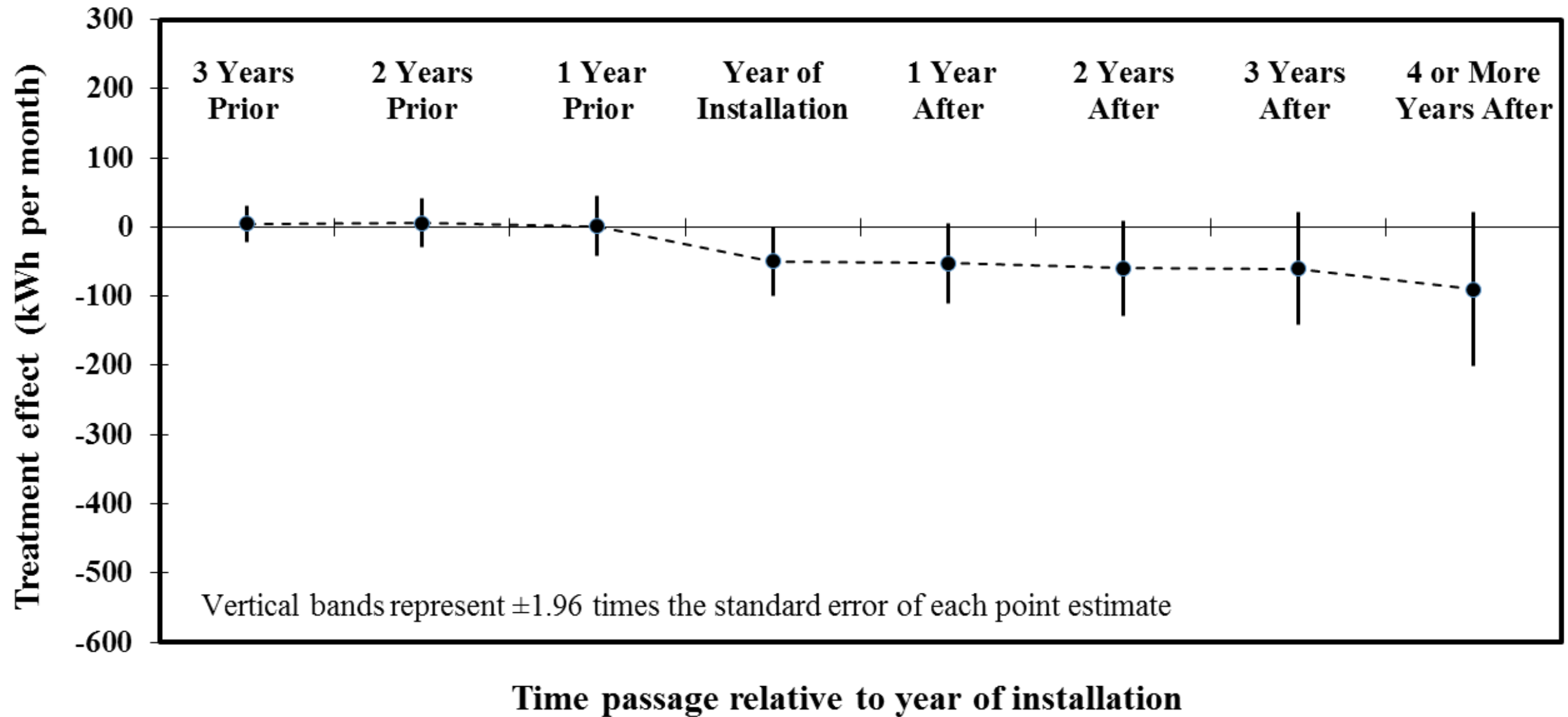




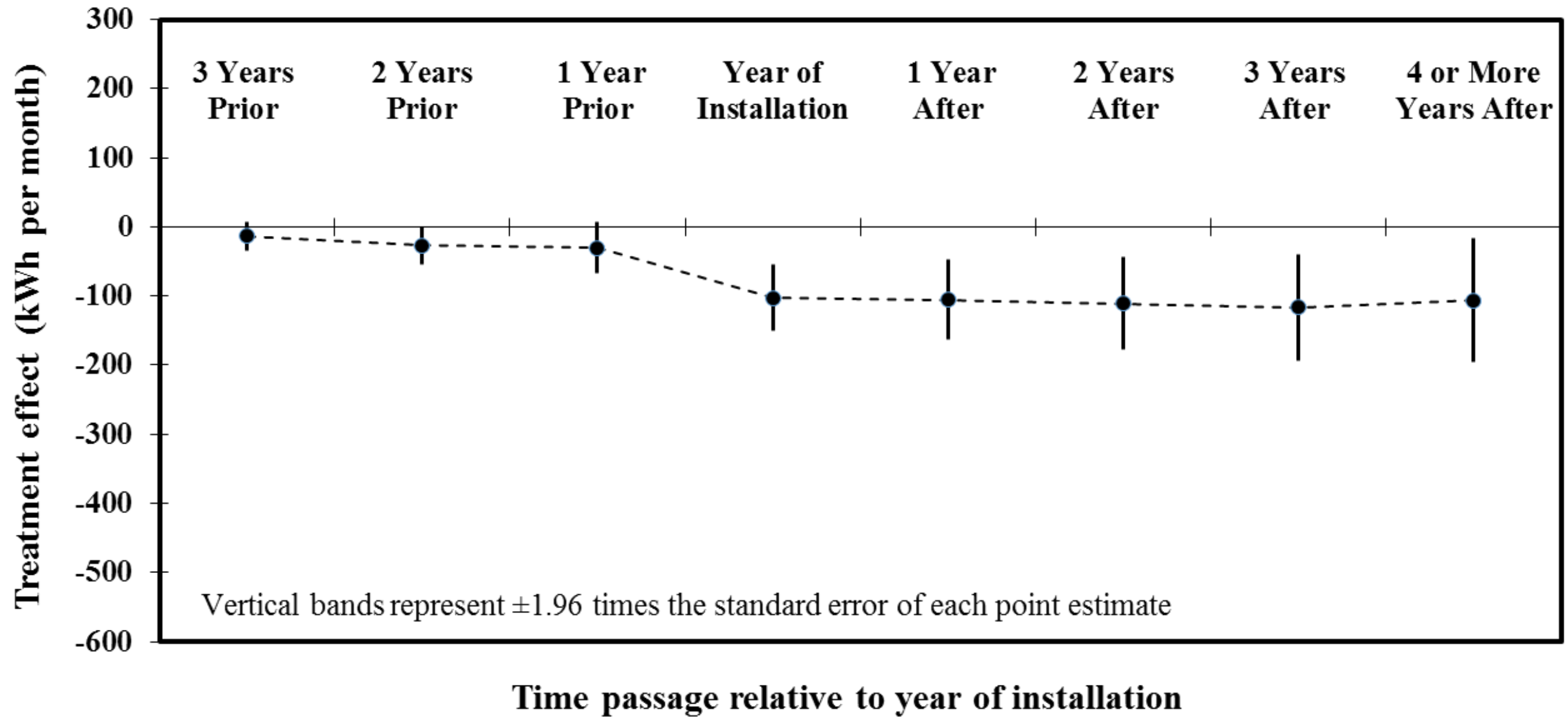
# Dynamics: Pool Pump Replacement (electricity only)



# Dynamics: Refrigerator Removal (electricity only)



# Dynamics: Attic Insulation (natural gas only)



## 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
<b>A. Total energy consumption (kwh per month)</b>								
<b>Treatment Effect</b>	<b>-147.3***</b> (36.0)	<b>-106.0**</b> (43.8)	<b>-11.4</b> (61.6)	<b>-100.1*</b> (53.9)	<b>-23.3</b> (22.1)	<b>-116.5***</b> (34.7)	<b>-23.9</b> (41.1)	<b>14.5</b> (23.2)
<b>Treatment Effect X May to October</b>	<b>-148.8***</b> (32.0)	<b>-90.1**</b> (35.8)	<b>-24.8</b> (48.6)	<b>2.9</b> (45.1)	<b>-46.2**</b> (19.1)	<b>57.3*</b> (29.5)	<b>-31.3</b> (39.4)	<b>-29.5</b> (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>B. Electricity consumption (kWh per month)</b>								
Treatment Effect	<b>-1.8</b> (17.5)	<b>24.6</b> (25.4)	<b>-28.3</b> (34.3)	<b>-114.6***</b> (27.1)	<b>-32.8***</b> (11.9)	<b>-10.5</b> (16.8)	<b>18.6</b> (20.6)	<b>9.3</b> (13.0)
Treatment Effect X May to October	<b>-269.6***</b> (17.3)	<b>-210.3***</b> (26.7)	<b>3.6</b> (30.8)	<b>-21.2</b> (25.8)	<b>-33.6***</b> (11.2)	<b>-35.2*</b> (18.3)	<b>-67.6***</b> (23.8)	<b>-9.6</b> (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
<b>C. Natural gas consumption (therm per month)</b>								
Treatment Effect	<b>-6.6***</b> (1.4)	<b>-6.4***</b> (1.7)	<b>-1.2</b> (3.0)	<b>-0.2</b> (1.7)	<b>0.2</b> (0.8)	<b>-5.3***</b> (1.4)	<b>-2.4</b> (1.5)	<b>-0.1</b> (0.8)
Treatment Effect X May to October	<b>5.2***</b> (1.3)	<b>5.7***</b> (1.5)	<b>0.3</b> (2.9)	<b>1.7</b> (1.5)	<b>-0.6</b> (0.7)	<b>4.9***</b> (1.2)	<b>2.2</b> (1.4)	<b>-0.2</b> (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