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Do Energy Efficiency Investments Deliver?

Short Course: Physics of Sustainable Energy

Michael Greenstone

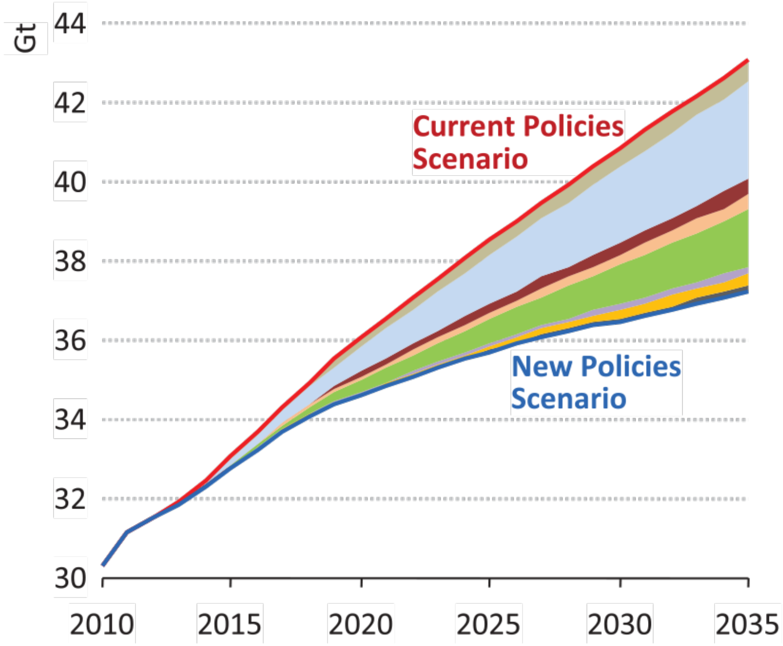
Milton Friedman Professor in Economics and the College
University of Chicago

Director
Energy Policy Institute at the University of Chicago

Understanding the Energy Efficiency Gap

Energy Efficiency is Part of Every GHG Mitigation Plan

GHG Mitigation Scenario



CO_2 abatement	2020	2035
Energy service demand	16%	9%
End-use efficiency	42%	42%
Supply efficiency	8%	7%
Fuel and technology switching in end-uses	6%	6%
Renewables	21%	25%
Biofuels	3%	3%
Nuclear	3%	5%
CCS	1%	2%
Total (Gt CO_2)	**1.5**	**5.9**

Source: IEA World Energy Outlook 2015

Politicians agree on energy efficiency

Barack Obama @BarackObama
Following

FACT: 78% of Americans agree with increasing energy efficiency standards for new appliances and buildings (via @NRDC). #ActOnClimate

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We must move aggressively toward energy efficiency and the development of sustainable energy sources.

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We must move aggressively toward energy efficiency and the development of sustainable energy sources.

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Rob Portman @robportman · Follow

The Energy Efficiency Improvement Act was passed today. I'm proud of our bipartisan effort to improve the economy & protect the environment.

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6:27 PM - 21 Apr 2015

Sen. McConnell Press @McConnellPress · Follow

McConnell blames Dems for stalled energy efficiency bill | TheHill thehill.com/policy/energy- … via @TheHill

McConnell blames Dems for stalled energy bill
McConnell assailed Democrats for blocking amendments to the energy bill.
thehill.com

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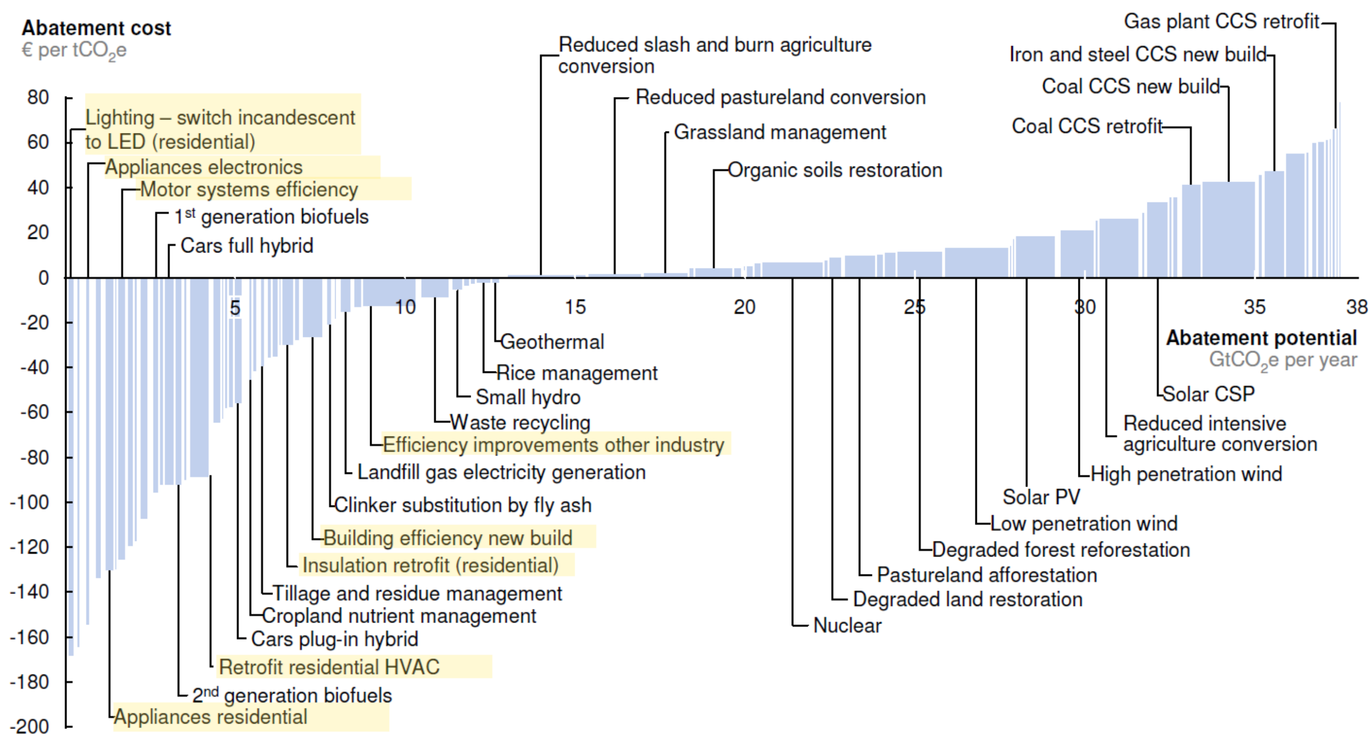
Utility programs promote energy efficiency

ComEd	Nationwide
Rebates on	Utilities spent $7 billion on EE in 2014
↓ Lighting, HVAC, boilers & water heating, refrigeration, etc.	State and federal governments set efficiency standards

What drives this support for energy efficiency?

McKinsey Global GHG Abatement Cost Curve



Key Characteristics of Energy Efficiency

(1) Economically and Environmentally Attractive (Especially Relative to Alternative Options)

» Classic win-win: (a) it's an investment consumers should want to make; (b) provides GHG and pollution benefits

» There should be a clear private sector motivation, so very low cost approach to GHG mitigation

(2) Technologically Feasible and Available

» While many of the most significant opportunities for GHG reduction still require technological innovation and cost reduction (CCS, biofuels, etc.), energy efficiency measures are available and market-ready today.

Key Characteristics of Energy Efficiency

And yet…

(3) There is an Energy Efficiency Gap

- Energy efficiency measures are not as widely adopted in the marketplace as expected
- Public policy in the United States and globally is required to drive efficiency improvements

How can this be?

(1) Numerous market failures and/or behavioral biases could explain why negative-cost investments are not being made

- Lack of information
- Principal-agent problems (owner-renter, manager owner)
- Behavioral biases: Inattention, myopia, loss aversion, etc.

(2) Another possibility: consumers absorb the efficiency gains through higher levels of consumption given reduced costs (the rebound effect).

How can this be?

(3) It's also possible that costs have been understated and gains have been overstated in some instances

Energy efficiency measurement gap?

Utilities	…want programs to look successful
Consultants	…hired by utilities to measure savings want to satisfy customers
Regulators	…with Clean Power Plan, will want to satisfy requirements

"Do Energy Investments Deliver? Evidence from the Weatherization Assistance Program" (2015)

Fowlie, Greenstone and Wolfram

Experiment Overview and Design

Research Questions

1. What increases household participation in the Weatherization Assistance Program?
2. What is the average effect of weatherization assistance on household energy consumption?
3. How do experimental estimates of real-world efficiency impacts compare to ex ante engineering estimates?
4. Is there evidence of a rebound effect?
5. What is the rate of return to residential energy efficiency investments, privately and socially?

Our Research Objectives

1. Conduct a large-scale field experiment designed to measure the real-world returns on investments in residential energy efficiency improvements

2. Construct valuation measures that account not only for energy savings, but also consumers' valuation of warmer indoor temperatures

3. Assess the rate of return on investments in energy efficiency from both a private and social perspective

The Federal Weatherization Assistance Program

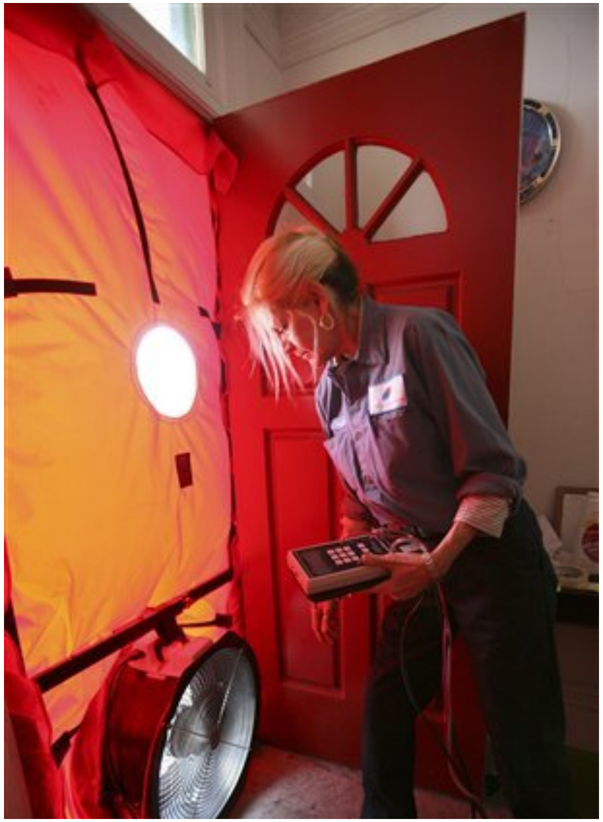
(1) The United States' largest residential energy efficiency program

- Since its inception in 1976, more than 7 million low-income households have received weatherization assistance through the program.
- Weatherization retrofits (including insulation, furnace replacement, infiltration reduction) are provided for free to eligible households.
- Multiple purposes, including to reduce the energy burden of low-income Americans by installing energy efficiency upgrades in their homes.

(2) Experienced a significant increase in funding and activity

- American Recovery and Reinvestment Act of 2009 significantly increased WAP spending from roughly $450 million in 2009 to nearly $5 billion for the 2011-2012 program years.

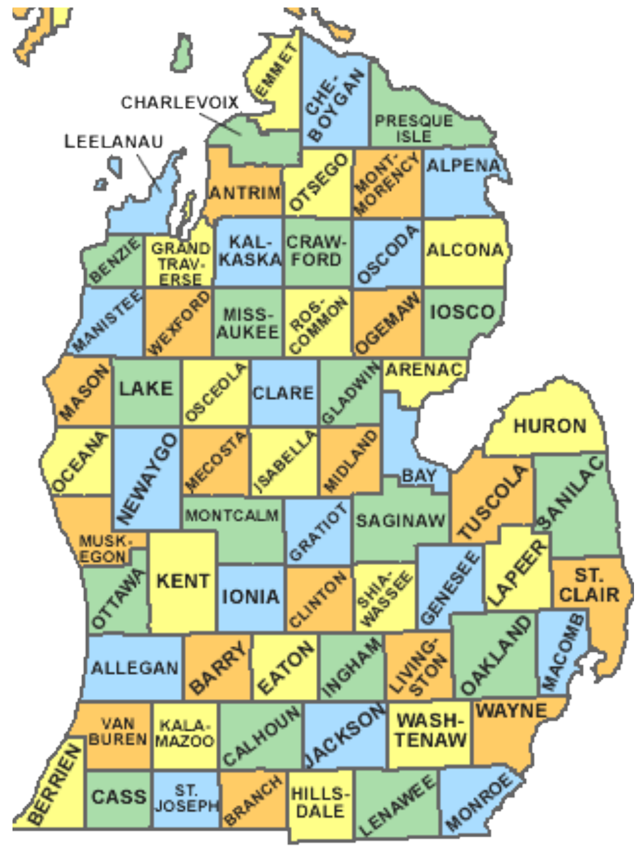
Engineering Analysis is an Integral Part of WAP



- Before implementing a WAP efficiency retrofit, program engineers conduct a detailed household energy audit
- The National Energy Audit Tool (NEAT) is used to estimate potential savings and identify energy efficiency measures deemed to be cost effective.
- In order for a measure to be implemented, the cumulative savings to investment ratio must be equal to or greater than 1

Study Location: South Central Michigan

- Michigan's cold winters and large low-income population put it atop the list of "most deserving" recipients of WAP funding.
- Michigan received over $200M in ARRA funding to support the weatherization of over 35,000 homes between April 2009 – March 2012.
- Maximum expenditure raised to $6,500 per home under ARRA



Visual Overview of Our Experiment

Start with a sample of **34,161** presumptively eligible households

Visual Overview of Our Experiment

Randomly assign 25 percent to an encouragement treatment **N = 8,648**	Simply observe the control group **N = 25,513**

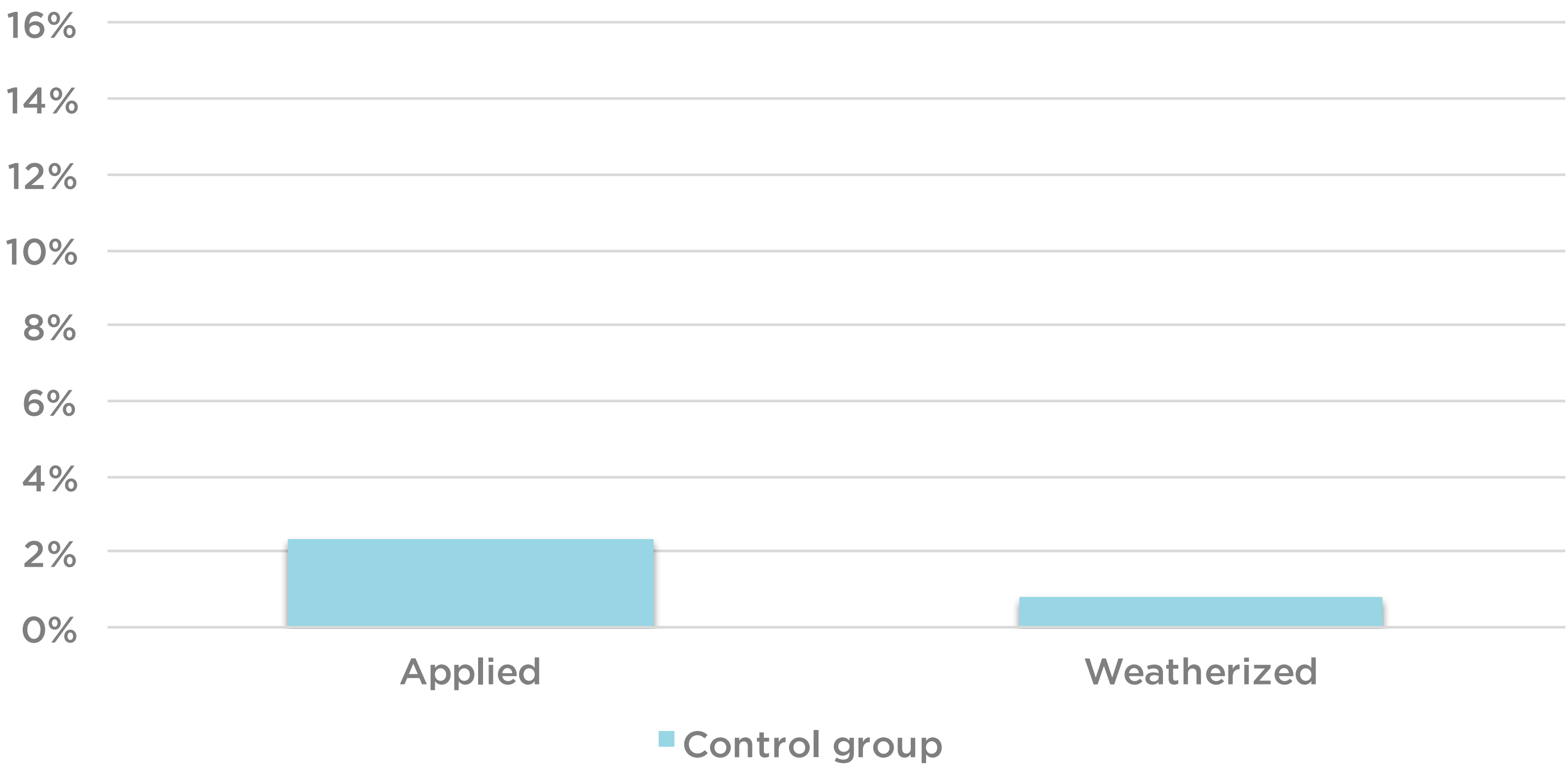
We Worked Hard to Encourage Participation

Encouragement Effort	
Encouraged group (households)	8,648
House visits/canvassing	6,694
Number of robo-calls	23,500
Number of personal calls	9,171
Follow up in-person appointments	2,720
Average cost/hh	$55.10

- We made contact with roughly two-thirds of the households in the treatment group.
- We worked with Fieldworks, LLC, a nationally recognized firm specializing in grass roots outreach
- Michigan-based Fieldworks staff helped us develop a persuasive recruit-and-assist strategy, cut turf, hire local people from the community, support staff on the ground, and manage field operations.

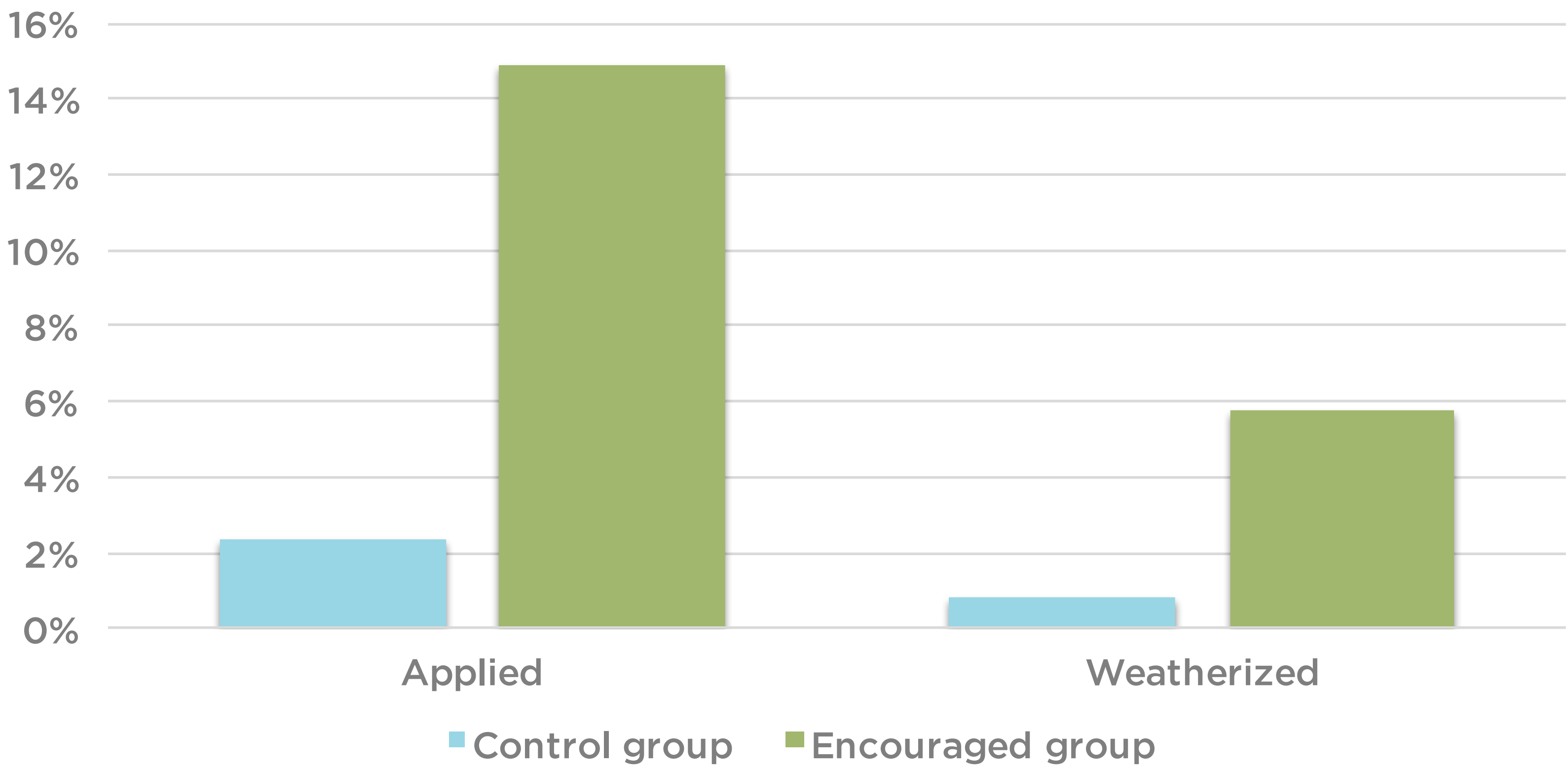
Our Outreach Efforts had an Impact…

Program Response Rate



…Increasing Weatherization Uptake by 5 Percentage Points

Program Response Rate



However, 6 Percent Participation is Low

We can rule out some of the standard explanations for the energy efficiency gap:

1) Capital Constraints
2) Information Costs/Lack of Information
3) Split Incentive Problems

Bottom lines:

1) It costs about $1,000 per additional weatherized household in encouragement costs
2) Results suggest that the hard-to-measure "process" costs of pursuing residential energy efficiency improvements are substantial

Data Collected

For all households that applied for weatherization between February 2011 and May 2012, we collected:

1) Raw household energy consumption data
   - Monthly energy consumption (natural gas and electricity) data from partner utility: 2008-2014.
2) Application and efficiency audit data obtained from implementing agencies
   - Engineering estimates of baseline energy use, installation costs, and energy savings
   - Which measures passed the cost-benefit analysis
3) Implementation data, including the cost of the specific measures implemented
   - Work order and job report data

Pre-Experiment Energy Consumption

	Experimental Encouraged	Experimental Controls
Winter gas (MMBtu)	10.40 (5.36)	10.38 (5.23)
Summer gas (MMBtu)	2.84 (3.87)	2.79 (1.93)
Winter elec (MMBtu)	2.12 (1.17)	2.10 (1.20)
Summer elec (MMBtu)	2.17 (1.30)	2.17 (1.28)
Total Households	7,549	21,339

Notes: Columns report average consumption, standard deviations are in parentheses.

Excerpt from a Detailed WAP Audit Report

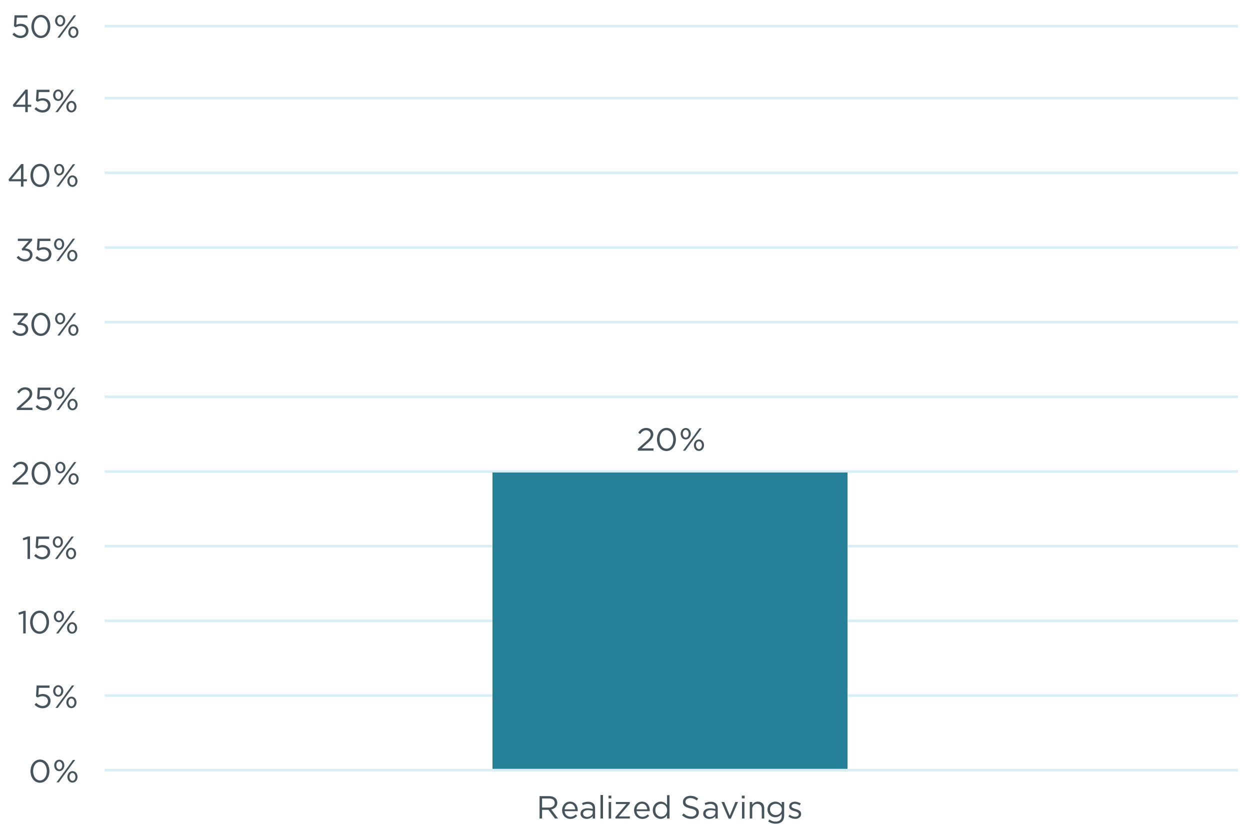
Annual Energy and Cost Savings

Index	Recommended Measure	Components	Heating (MMBtu)	Heating ($)	Cooling (kWh)	Cooling ($)	BaseLoad (kWh)	BaseLoad ($)	Total (MMBtu)
1	Infiltration Redctn		7.6	87	0	0	0	0	7.6
2	High Eff Furnace	H1	28.5	327	0	0	0	0	28.5
3	Kneewall Insulation	A4,A5	15.5	177	0	0	0	0	15.5
4	Lighting Retrofits	LT1,LT2,LT3,LT4,LT5	0.0	0	0	0	755	83	2.6
5	Sillbox Ins.	F1	0.8	10	0	0	0	0	0.8
6	Attic Ins. R-38	A1,A2	9.8	112	0	0	0	0	9.8
7	Wall Insulation	WL1,WL2,WL3,WL4, WL5,WL6	10.2	117	0	0	0	0	10.2

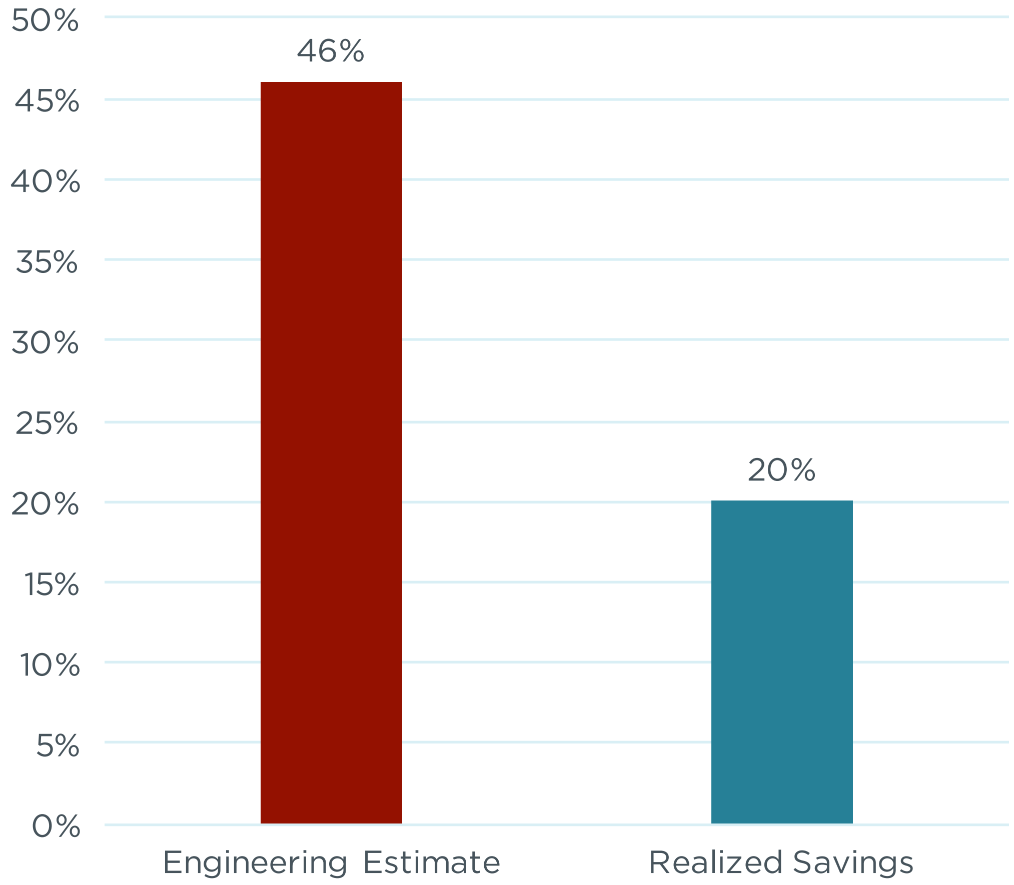
**Audit-based modeling predicts this household will reduce annual heating costs by $913.

Impact of Weatherization on Household Energy Consumption and Cost-Benefit Analysis

Weatherization Reduced Energy Consumption...

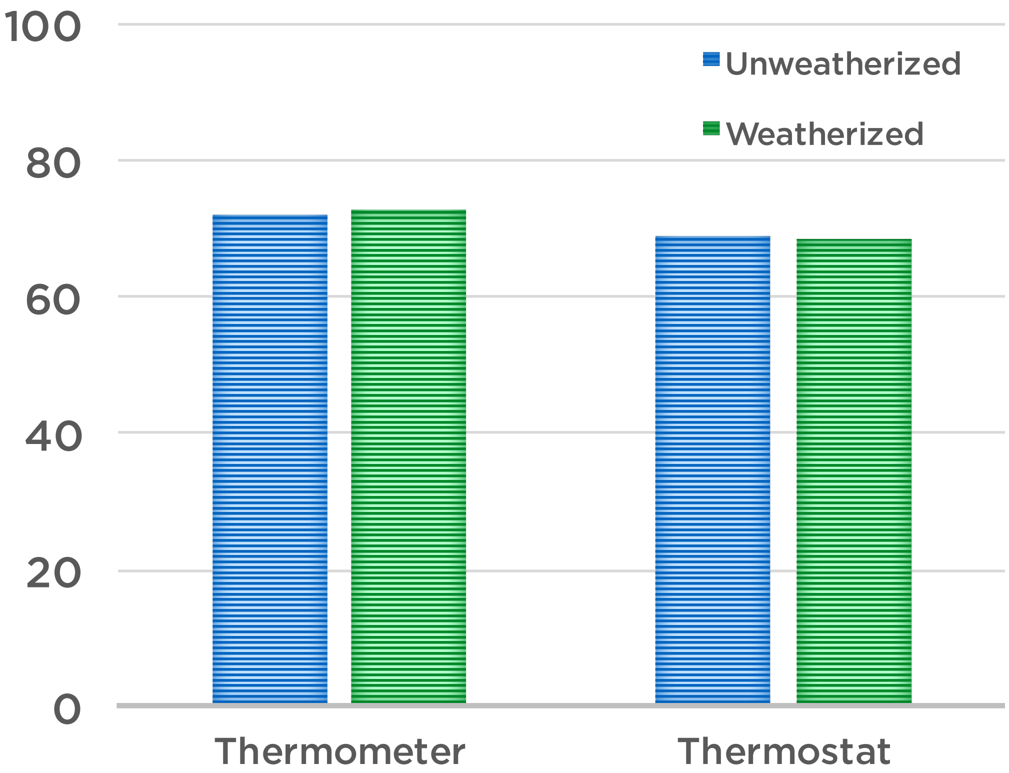


…But not as much as the Engineering Models Predicted



No Evidence of a Rebound Effect

Average Indoor Temperature (°F)



- We independently verified thermostat settings and indoor temperature through follow-up visits.
- For both thermometer and thermostat readings, there was **less than a 1 percent difference** in temperature between weatherized and unweatherized households.

Costs Outweighed Efficiency-Related Benefits

Present Value of Discounted Savings

	Discount Rate		
Time Horizon	3 Percent	6 Percent	10 Percent
10 Years	$2,003	$1,728	$1,443
16 Years	$2,949	$2,373	$1,837
20 Years	$3,493	$2,693	$1,999

**Average Investment in Efficiency Measures: $4,580

- Savings-weighted average of engineers' estimates of measure lifespan: 16 years.
- Table uses average retail energy prices in 2013 (in $2013) to value energy savings.
- No consideration of price volatility.

Costs Outweighed Efficiency-Related Benefits

Private Internal Rates of Return

Time Horizon	NEAT Projection	Experimental Estimates
10 Years	7.0%	-10.5%
16 Years	11.8%	-2.2%
20 Years	12.8%	0.3%

- Column (1) uses NEAT projected energy savings
- Column (2) uses estimated energy savings + the upper bound of monetized benefits from increased warmth
- All calculations use 2013 prices; realized costs associated with efficiency measures only

Costs Outweighed Efficiency-Related Benefits

Social Internal Rates of Return		
Time Horizon	NEAT Projection	Experimental Estimates
10 Years	-1.0%	-20.0%
16 Years	5.4%	-9.5%
20 Years	7.0%	-6.1%

- Column (1) uses NEAT projected savings and emissions reductions (CO_2 at $38/tonne)
- Column (2) uses estimated savings ad emissions reductions

Costs Outweighed Efficiency-Related Benefits

Cost per Ton of Avoided CO2

	3% Discount Rate		7% Discount Rate	
Time Horizon	NEAT Projection	Experimental Estimates	NEAT Projection	Experimental Estimates
10 Years	$29	$552	$61	$701
16 Years	-$19	$329	$14	$484
20 Years	-$35	$255	$0	417

» Column (1) uses NEAT projected energy savings

» Column (2) uses estimated energy savings + the upper bound of monetized benefits from increased warmth

» All calculations use 2013 prices; realized costs associated with efficiency measures only

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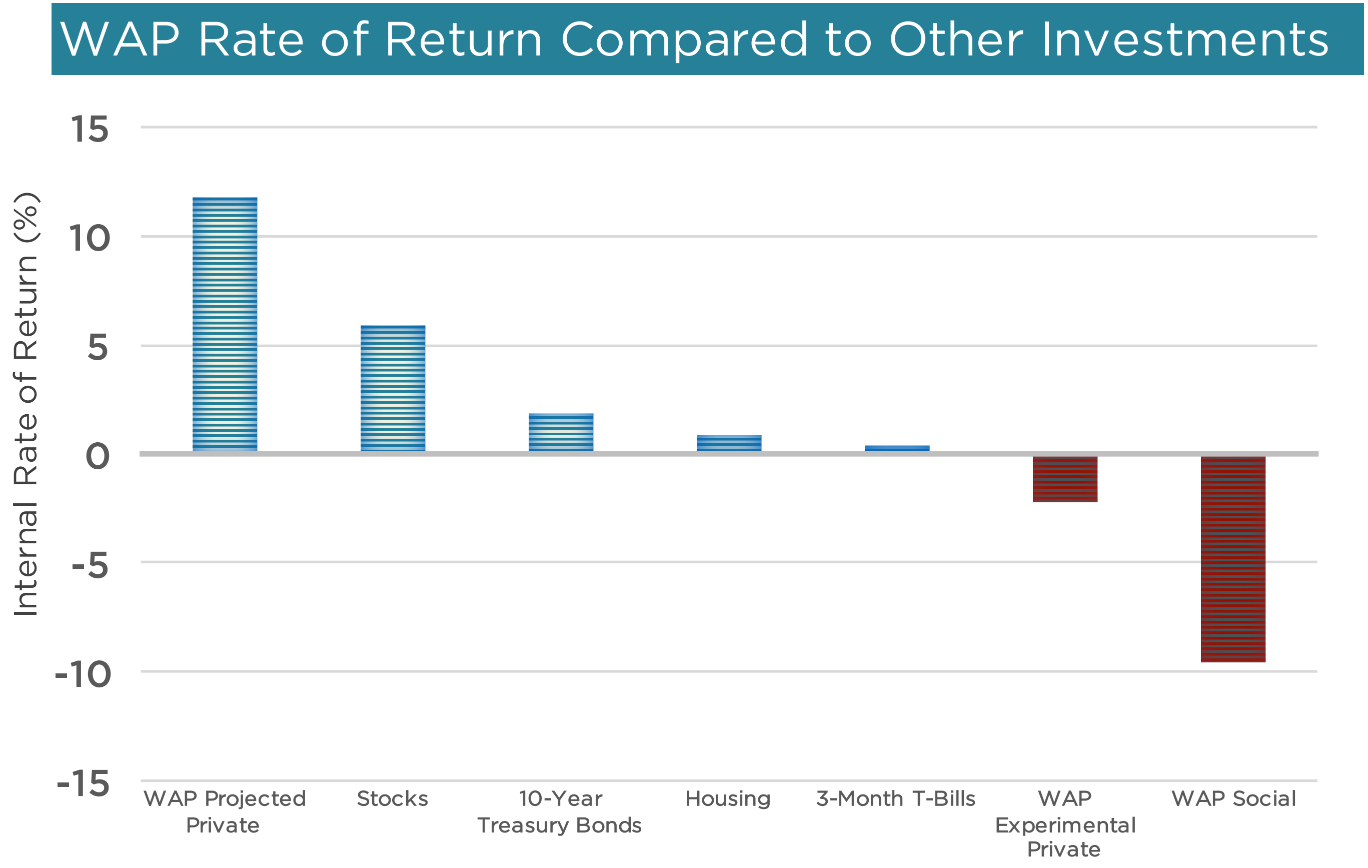
Costs Outweighed Efficiency-Related Benefits



Conclusions

(1) Evaluate and Work to Improve the Engineering Models

» It appears that the engineering models systematically overstate potential benefits

(2) Work to ensure that energy efficiency investments deliver as promised

» Conduct ex-post performance evaluations using state-of-the-art methods

(3) Rely on the most efficient approaches to reducing greenhouse gas emissions

(4) Further research is needed!

Bonus Findings:

"Measuring the Welfare Effects of Energy Efficiency Programs" (2016)

Allcott and Greenstone

Overview of Field Experiment

- Field experiment targets single-family homes in Madison and Milwaukee eligible for the Green Madison and Me2 energy efficiency programs.

- Experimental population of 102,000 households randomly divided into treated and control groups. 80,000 households are mailed two identical marketing letters. Letter variations include informational/behavioral treatments and audit subsidies.

- We track natural gas and electricity usage for almost all households in the experimental sample that receive an audit.

Overview of Sample

Experimental Sample

101,881 households in experimental sample

79,994 households randomly assigned to treatment

Audit Sample

1,394 audited households

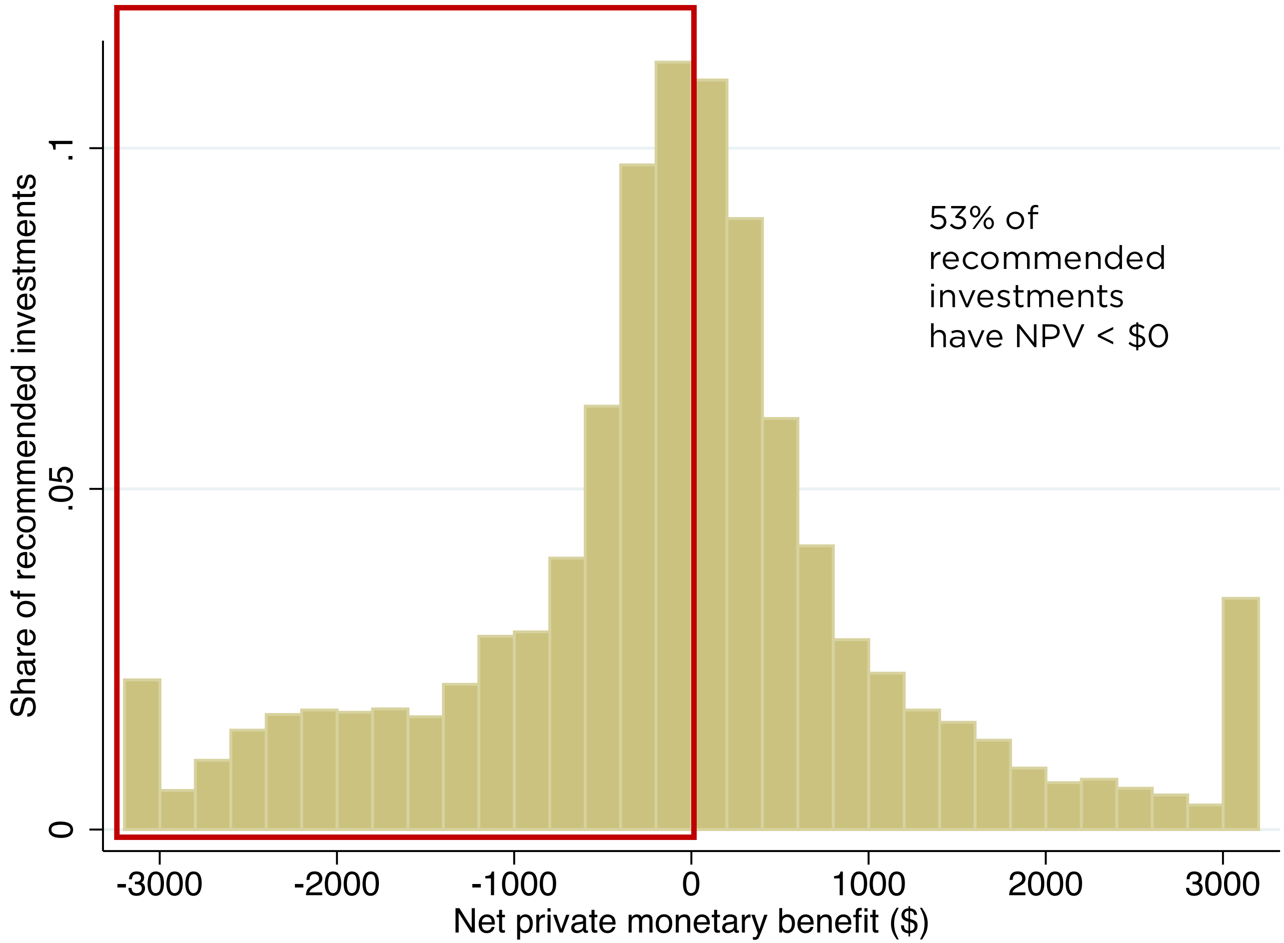
4.4 recommended investments, 2.8 adopted investments on average

Energy Usage Sample

1,258 audited households with release forms

Observed gas and electricity usage

Over Half of Recommended Investments had Negative NPV



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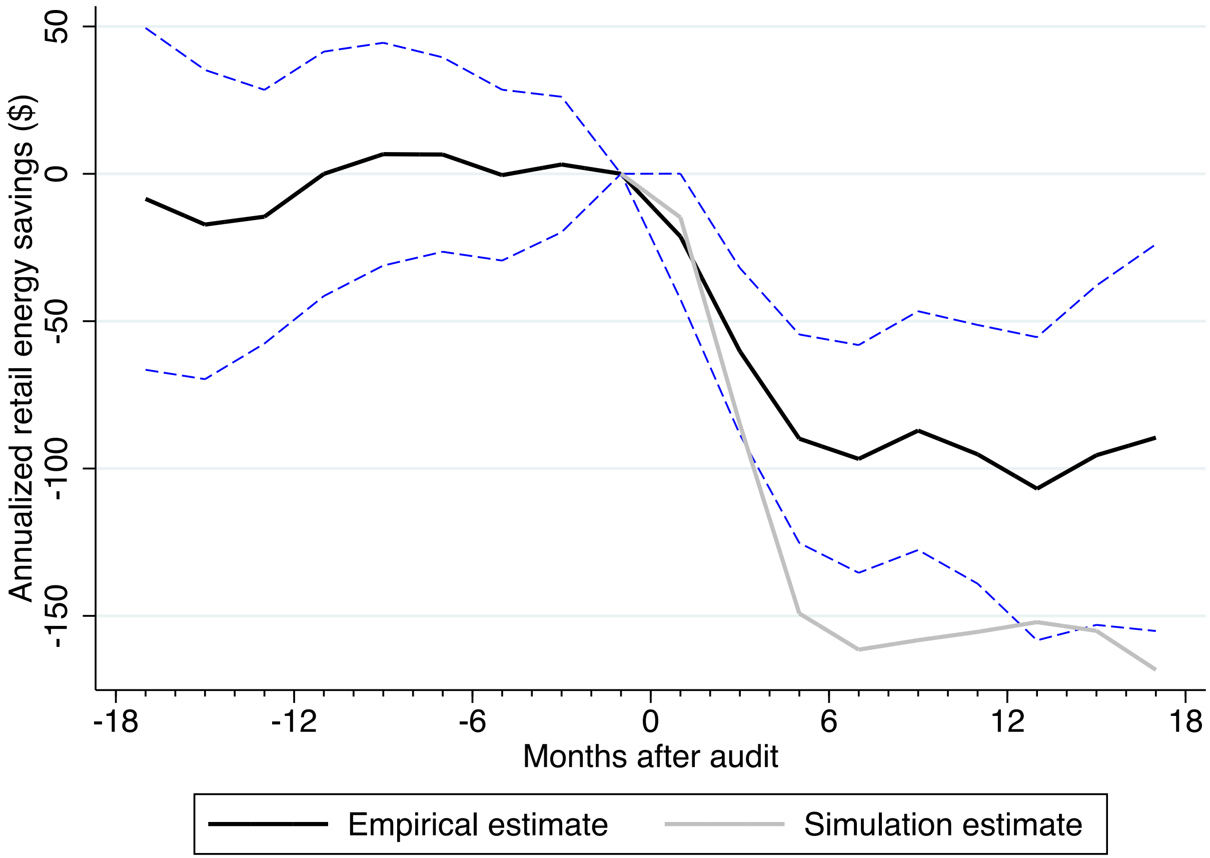
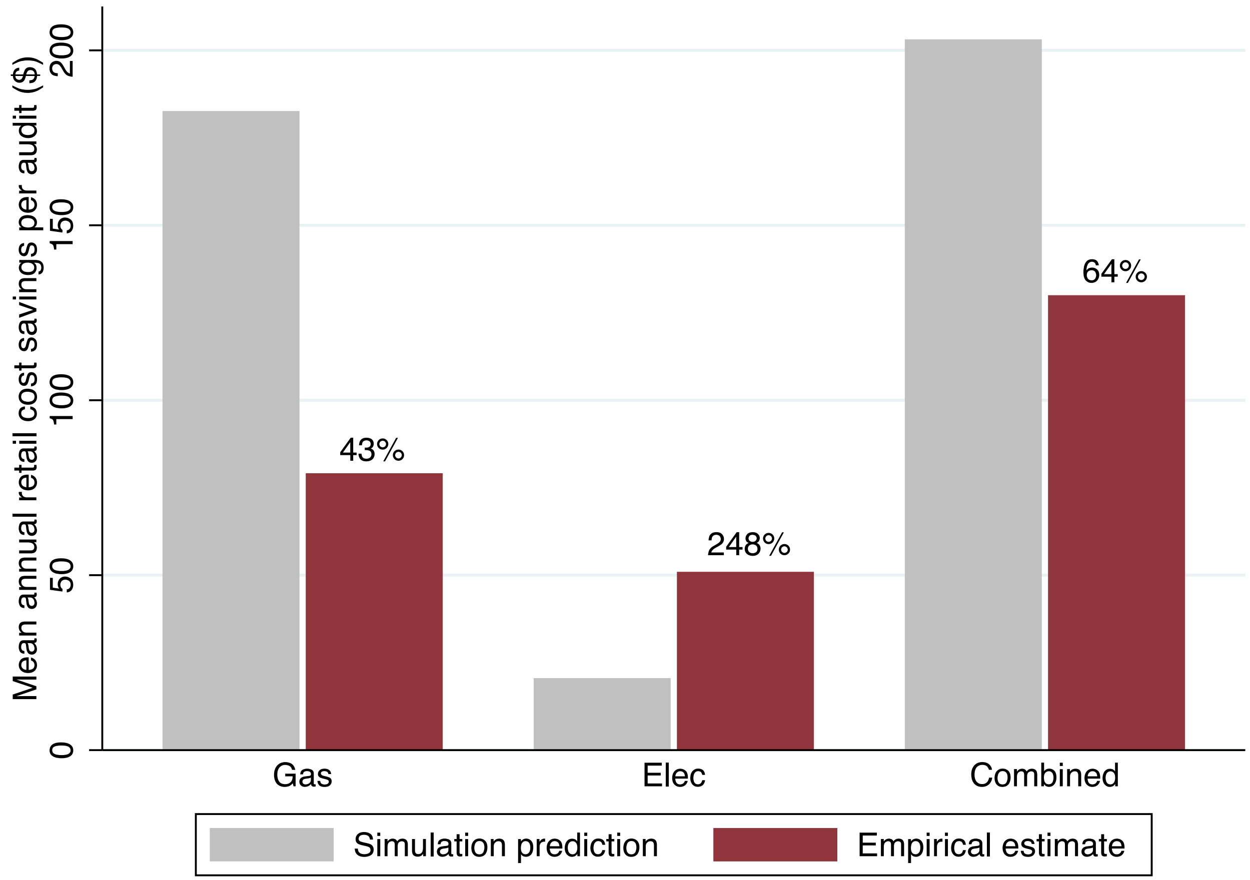
Large Empirical Shortfall in Post-Audit Energy Savings



Simulated vs. Empirical Estimates of Post-Audit Savings



Future Research

The E2e Project

Faculty

Michael Greenstone
University of Chicago

Chris Knittel
MIT

Catherine Wolfram
UC Berkeley

18 affiliated professors from top universities

Board

John Deutch **George P. Shultz** **Cass Sunstein**

Susan F. Tierney **Daniel Yates**

Current E2e Project Work

(1) RCT of data analytic product for large-scale industrial customers (LightApp, CEC)

(2) Big data study of EE investments in school (CA)

(3) Information provision for automobile choice (Ford)

(4) Information provision among commercial firms (EnerNOC and Eversource)

(5) Many others…