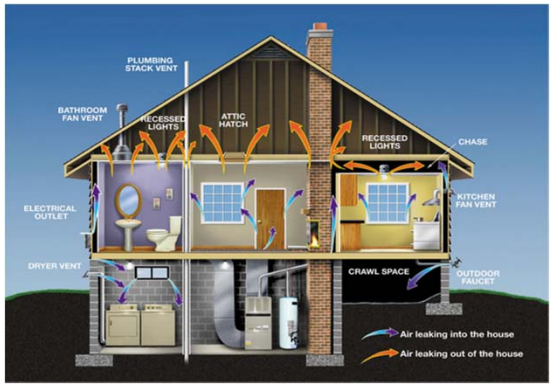
Reconcilable differences? Examining the gap between engineering projections and ex post realized gains from energy-efficiency investments

Meredith Fowlie and Catherine Wolfram
(UC Berkeley)
Michael Greenstone (MIT)



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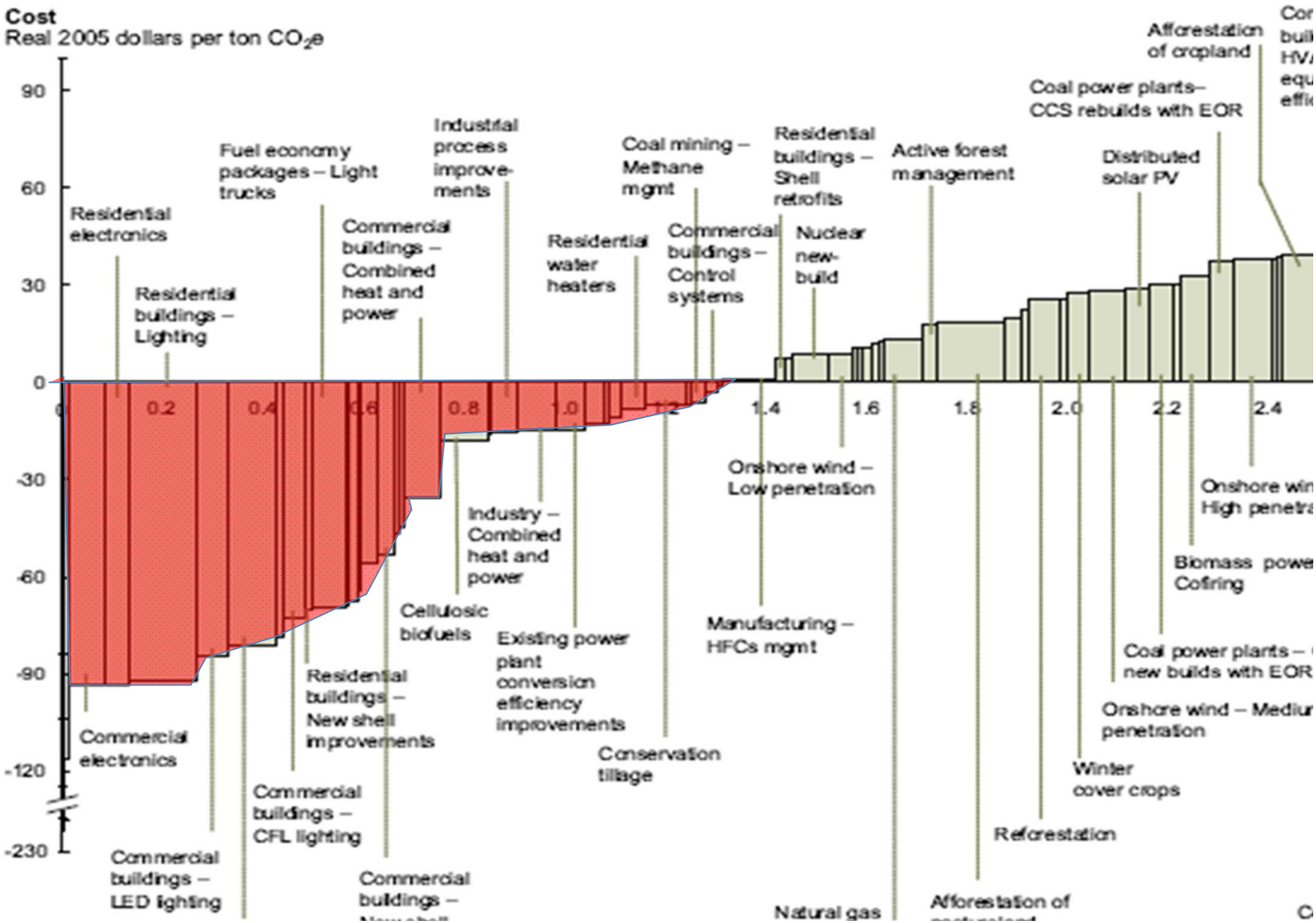
U.S. MID-RANGE ABATEMENT CURVE – 2030



Negative costs?!?!?

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Engineering-economic modeling may overstate true economic potential

- Transaction costs associated with identifying and coordinating cost effective energy efficiency improvements can be substantial.
- Technologies may not perform as well as engineering models predict due to model misspecification or mis-calibration.
- Behavioral response to energy efficiency improvements (i.e. lower costs of energy services) may “take back” some portion of expected energy savings.

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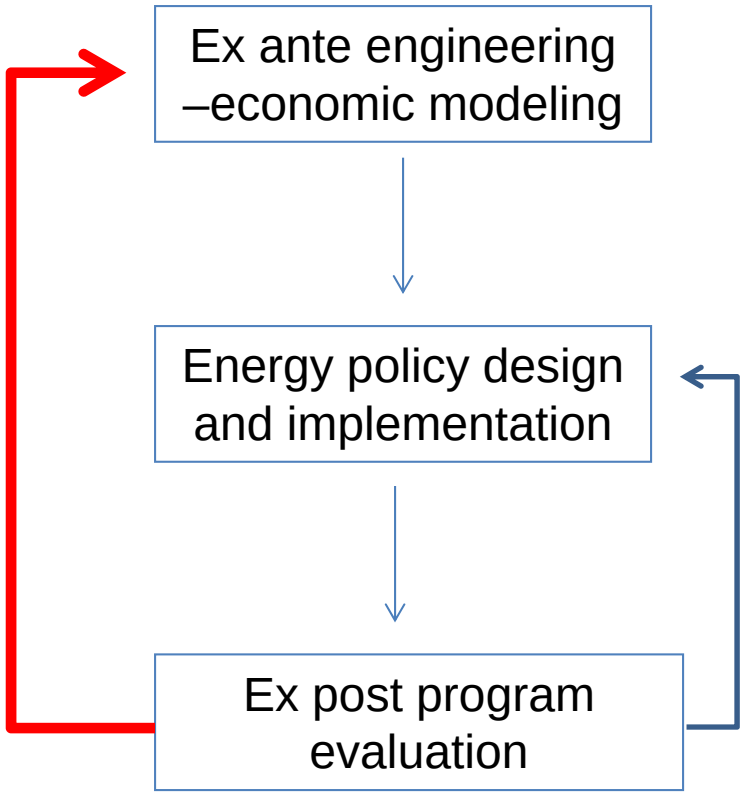
A potentially important feedback loop

- Bottom-up engineering-economic modeling tools play an important role in informing policy.
- Ex post empirical evaluation can improve /inform ex ante modeling.
- Relatively few empirical studies try to close this loop.



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Federal weatherization assistance program

- Energy efficiency audits and retrofits are provided for free to eligible households.
- The maximum average expenditure per household was raised to $6,500 under ARRA.
- It is estimated that the average household receiving weatherization assistance will reduce heating costs by 20-25 percent.

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The Federal Weatherization Assistance Program

- Over the past 30 years, an estimated 6.2 million households have received weatherization assistance.
- The American Recovery and Reinvestment Act allocated $5 billion to weatherization assistance (DOE funding for WAP was $227 million in 2008).
- Funding increase generated substantial interest in the program, the population it serves, the energy and cost savings it produces, and its cost-effectiveness.

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Engineering analysis is an integral part of weatherization assistance

- 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.

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Research agenda

<u>Program evaluation component</u>

- What is the average effect of weatherization assistance on household energy consumption and expenditures?

<u>Integration of engineering analysis</u>

- How do empirical estimates of efficiency impacts compare to ex ante engineering estimates?
- What factors explain discrepancies between engineering predictions and realized savings?

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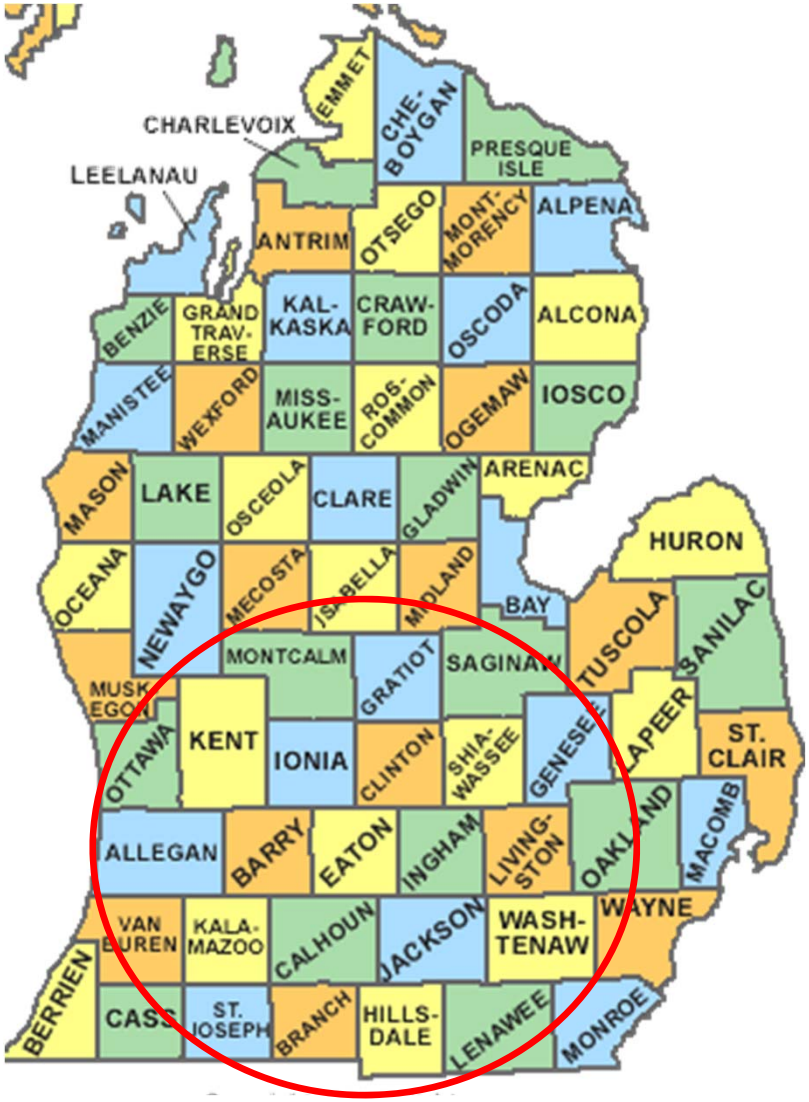
Study location: South central Michigan

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



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A randomized encouragement design (RED)

Rather than randomize over the intervention itself, we randomly manipulate *encouragement* to participate.

REDs are particularly useful when:

- Randomization of access or mandatory participation is not practical /desirable/feasible.
- Encouragement can significantly affect probability of treatment.

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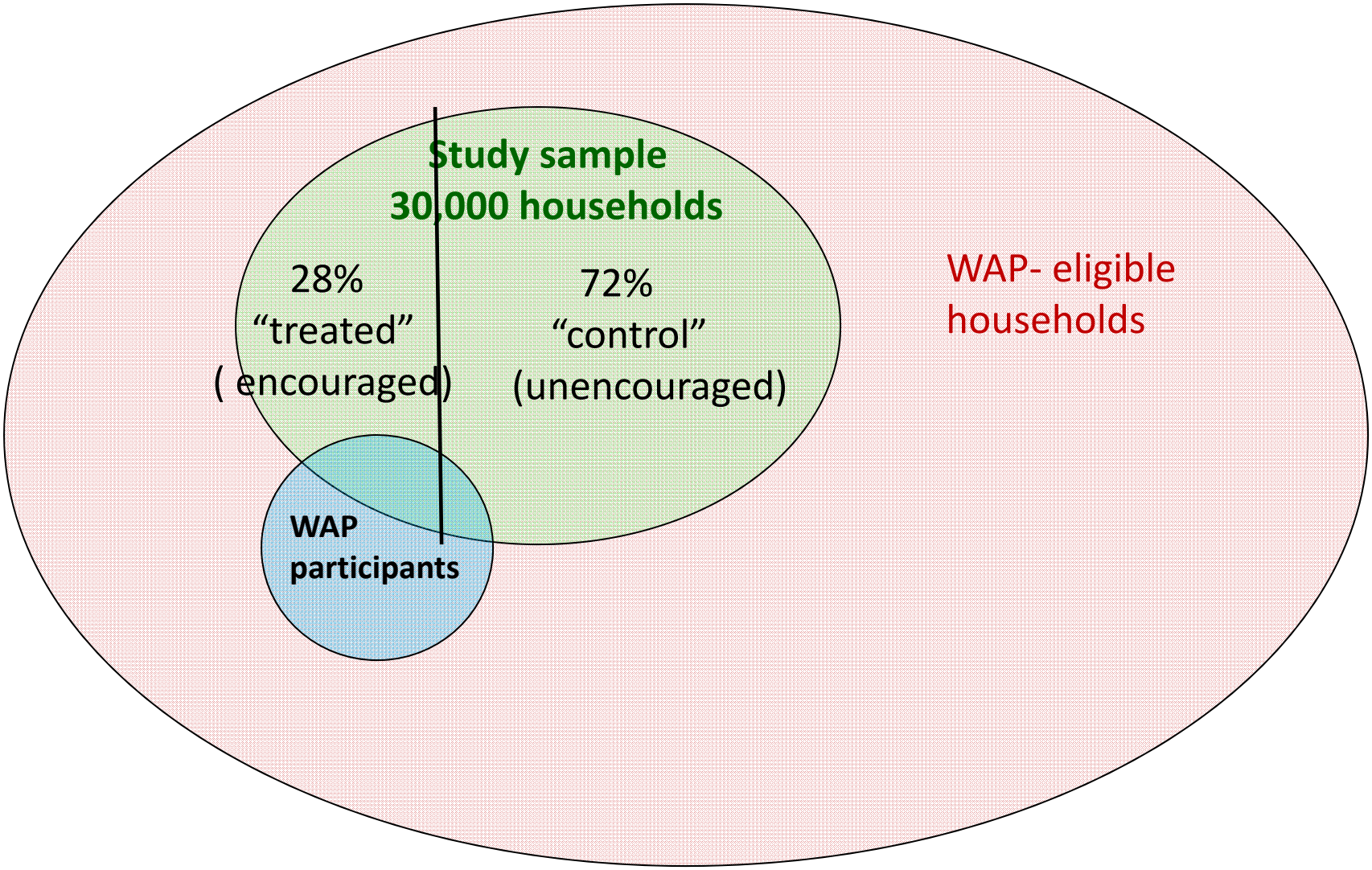
Our randomized encouragement design



Encouragement Effort : Genesee county	
Encouraged group (households)	7,261
House visits/canvassing	6,694
Number of robo calls	23,500
Number of personal calls	9,171
Follow up in-person appointments	2,720
Returns on this encouragement effort	
Number of applications started (share)	1,425 (20%)
Number of applications completed (share)	987 (14%)
Denied/voided (as a share of applicants)	320 (!) (32%)
Weatherizations to date (share)	395 (5%)

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Factors predicting application in our encouraged group (conditional on opening the door)

African American	.066**
	(.010)
Male	-.046**
	(.009)
Senior	-.073**
	(.011)
Active Voter	-.029*
	(.013)
Outdoor Temperature	.003**
	(.001)
Days Until Bill Due	>-.001
	(.001)
Most Recent Bill Percentile	.119*
	(.046)
Number of Observations	1855
R^2	.05

Further incentivizing weatherization

- Limited experimentation with augmenting our encouragement using cash incentives.

- Cash incentives appear to have no effect on our application rates.

Cash incentive	Households	Success rate
$60	1689	4.8%
$25	1689	5.5%
$0 (control)	1689	5.4%

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We can't pay people to save energy!

- Low income households are entitled to up to $6500 in free energy efficiency retrofits.
- Projected savings exceed $300 per household per year.
- We find it to be very difficult to encourage people to enroll in this program.
- "Hidden" implementation costs are large!

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Who is receiving weatherization assistance?

	Nationwide* (expected)	Weatherized households in our Michigan sample
Household percent of poverty	< 200 % required	106% (55%)
Average annual income among eligible households	$18,624	$21,349 ($18,391)
Average annual energy expenditure	$1800	$2,323 ($1,088)

- Nationwide numbers taken from a 2010 WAP needs assessment.
- Average Michigan household spent $2330 on natural gas/electricity in 2011.

Research agenda

Program evaluation component

- What is the average effect of weatherization assistance on household energy consumption/expenditures?

Integration of engineering analysis

- **How do empirical estimates of efficiency impacts compare to ex ante engineering estimates?**
- **What factors explain discrepancies between engineering predictions and realized savings?**

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Basic approach

- Summarize the results of the detailed audits used to select cost effective weatherization measures in Michigan.
- Compare ex ante estimated savings with our empirical estimates.
- If we find a discrepancy between the two, investigate possible explanations.

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NEAT audit tool

- Designed specifically to help states and local weatherization agencies implement the U.S. Department of Energy (DOE) Weatherization Assistance Program.
- Uses engineering calculations and weather data to compute annual heat loss and heat gain, and the annual space-heating and space-cooling energy consumption required to keep the home at a specific thermostatic set point.
- Many building energy consumption algorithms are taken from Lawrence Berkeley Laboratory's Computerized Instrumented Residential Audit (CIRA)

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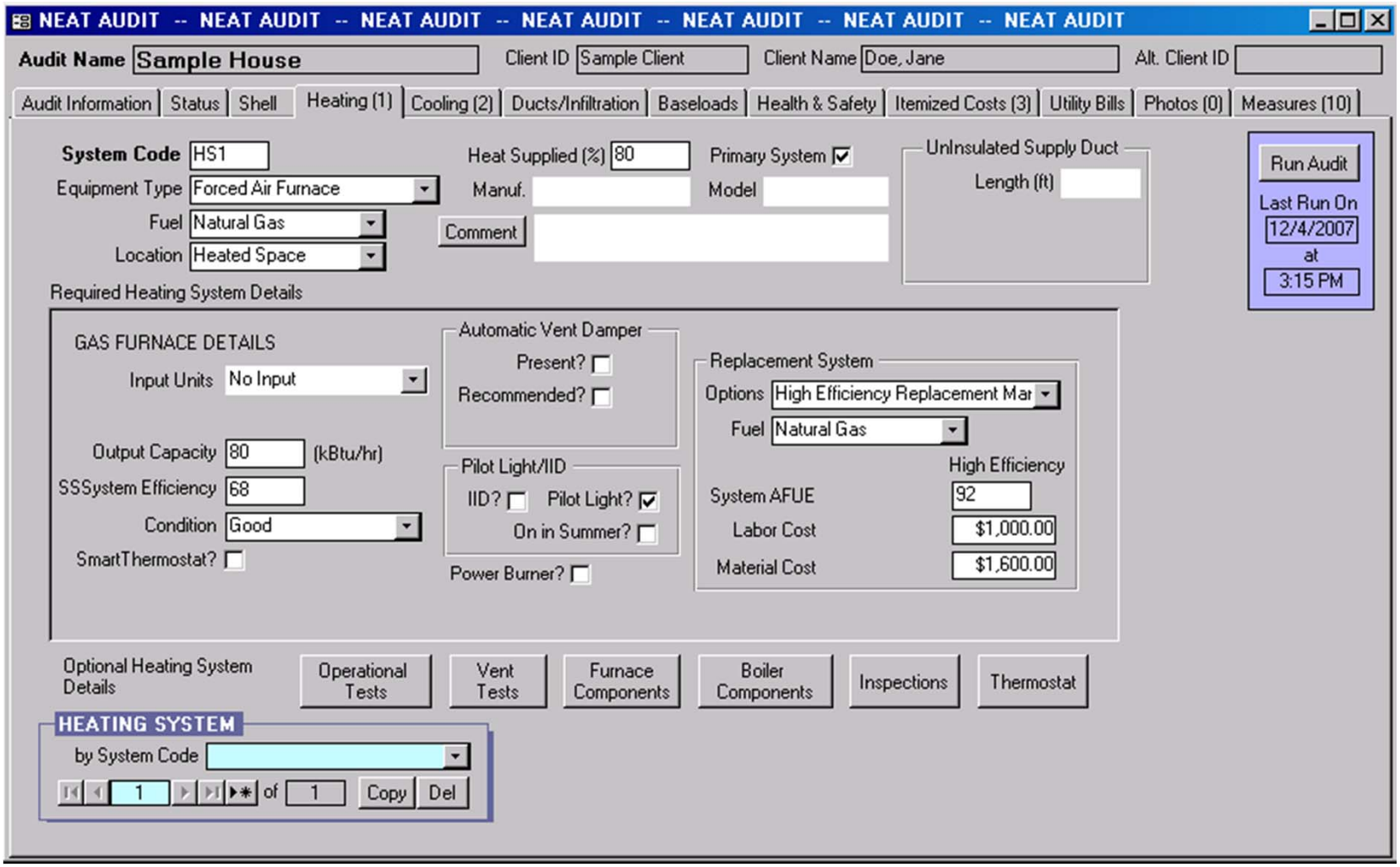
NEAT audit tool



The NEAT audit

- 40+ building envelope, space-heating and space-cooling system, and base load energy efficiency measures are evaluated.
- Energy savings and discounted SIR for each applicable measure are computed.
- Beginning with the highest SIR measure, measures are added incrementally until threshold SIR=1 reached.
- A report of recommended energy efficiency measures identifies—both individually and cumulatively—the energy savings, installation cost, and SIR of the recommended measures.

NEAT fixed parameters (Michigan)

Parameter	Assumed value
Discount rate	3%
Heat set point	68° F
Cooling set point	78° F
Night set back	3° F
Electricity cost	11 cents/ kWh
Natural gas cost	11.5 cents / mcf

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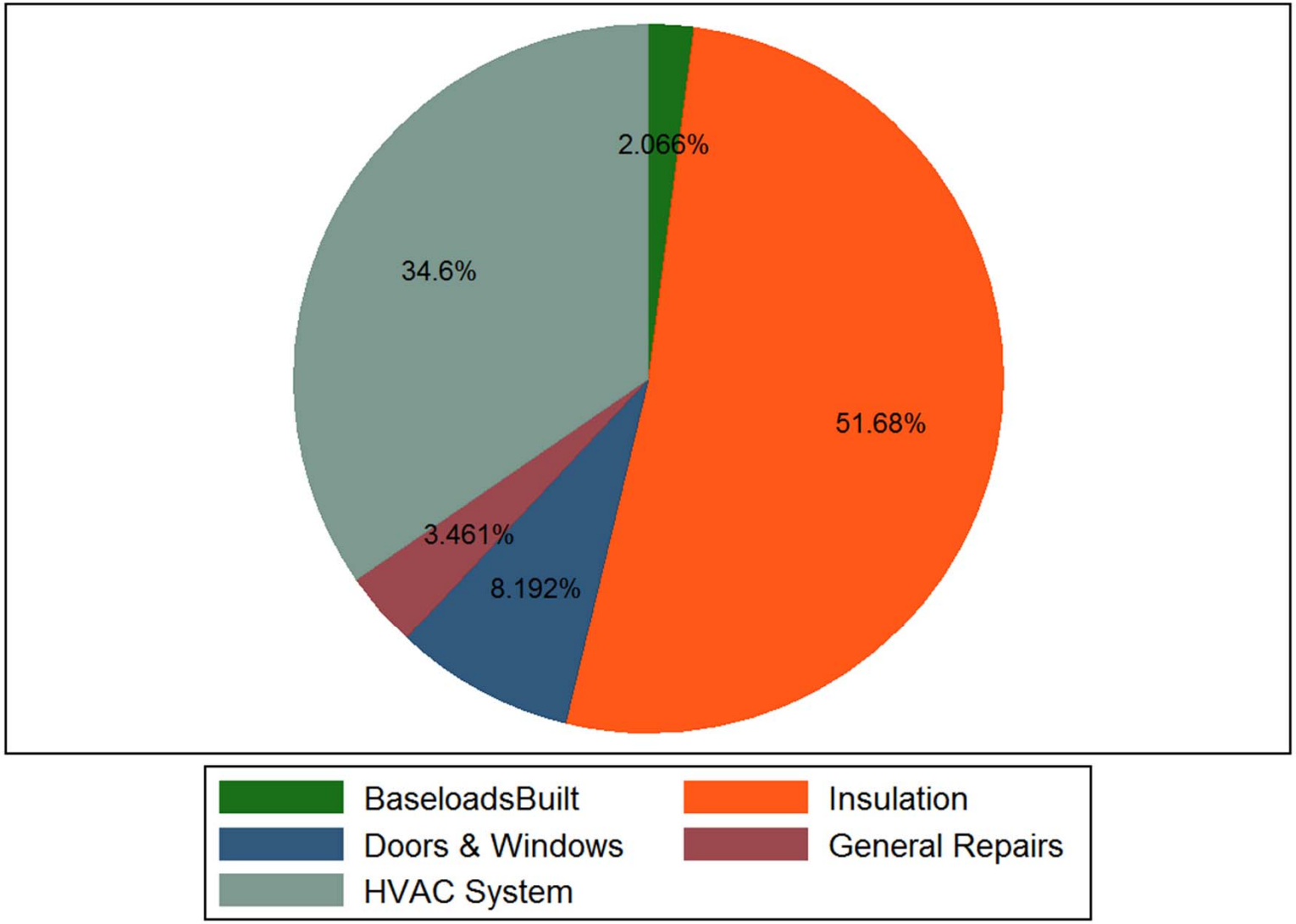
Data!

- We are working with 6 agencies who account for over 20 percent of weatherization activities in Michigan.
- Collecting data for @ 5000 hh receiving assistance Jan. 2011- March 2012.
- Household-level data include:
  - Monthly billing data (2 years pre- and 2 years post)
  - Household energy audit data.
  - Engineering estimates of costs and savings.
  - Work order/job report information.
  - Detailed demographic information.

What does weatherization assistance involve? (proportions measured in $ terms)

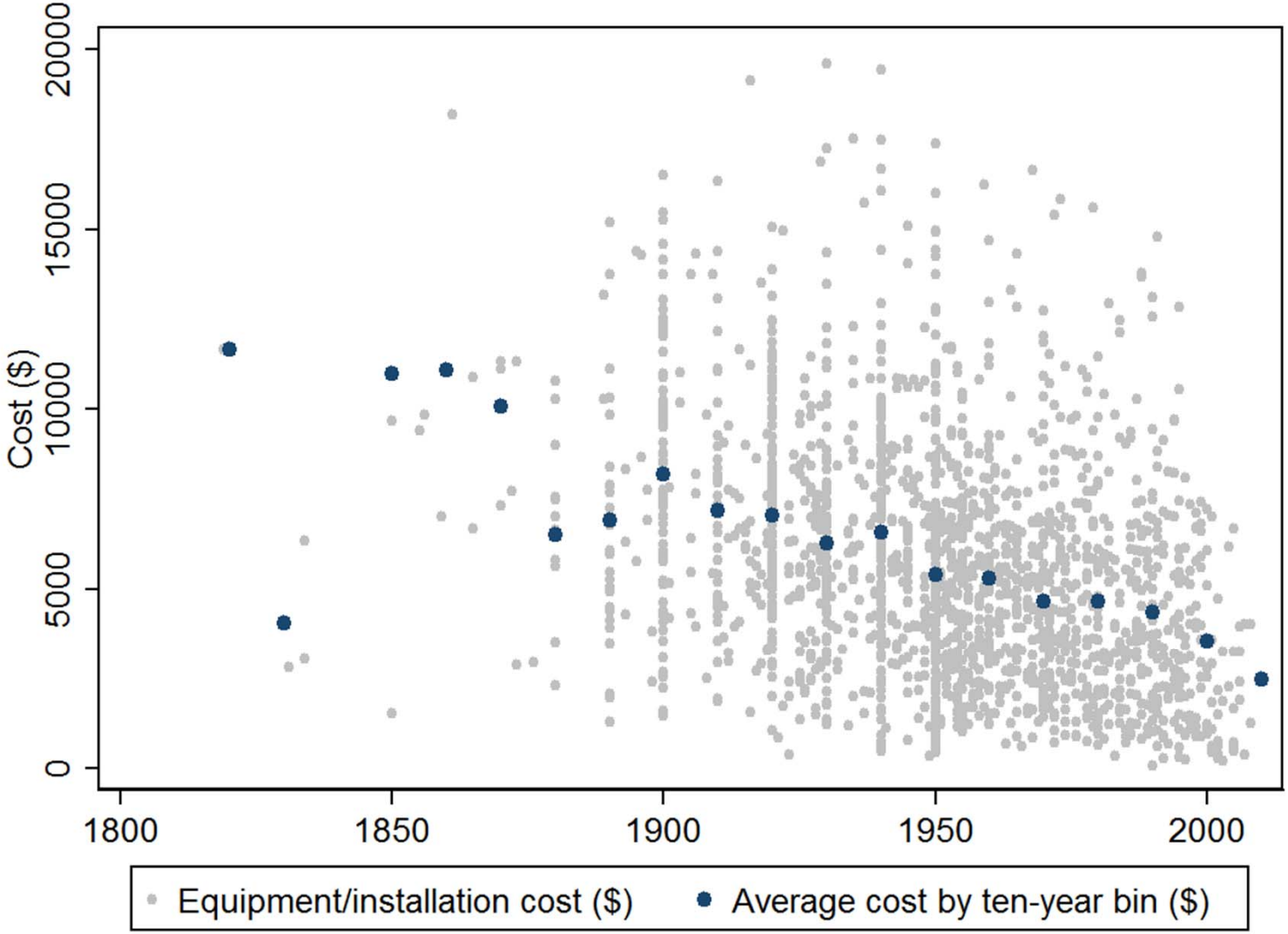


Ex ante estimated costs and benefits
(household level summary statistics)

	Projected nationwide savings/costs*	Our Michigan sample**
Average annual energy savings (MBtu)	29 MBtu	59 MBtu (59 MBtu)
Average first-year energy bill reductions (heating and cooling)	$437	$997.22 ($1,022)
Average cost	Not reported	$5436.02 ($3327.18)
Average cost of energy saving measures	Not reported	$4445.85 ($2858.29)
Benefit/cost ratio	1.8	2.1 (2.4)

* Nationwide numbers taken from a 2010 WAP needs assessment.
** Michigan numbers represent a subset (@2700) of our data.

Larger EE investments in older houses



Compare NEAT audit projected savings with empirical estimates of realized savings

If the two sets of estimates do not agree, what are some likely explanations?

1. Engineering model is correctly specified but mis-calibrated.
2. Engineering model is incorrectly specified.
3. Engineering model correctly captures pre-treatment building/behavior but fails to account for behavioral change/rebound.

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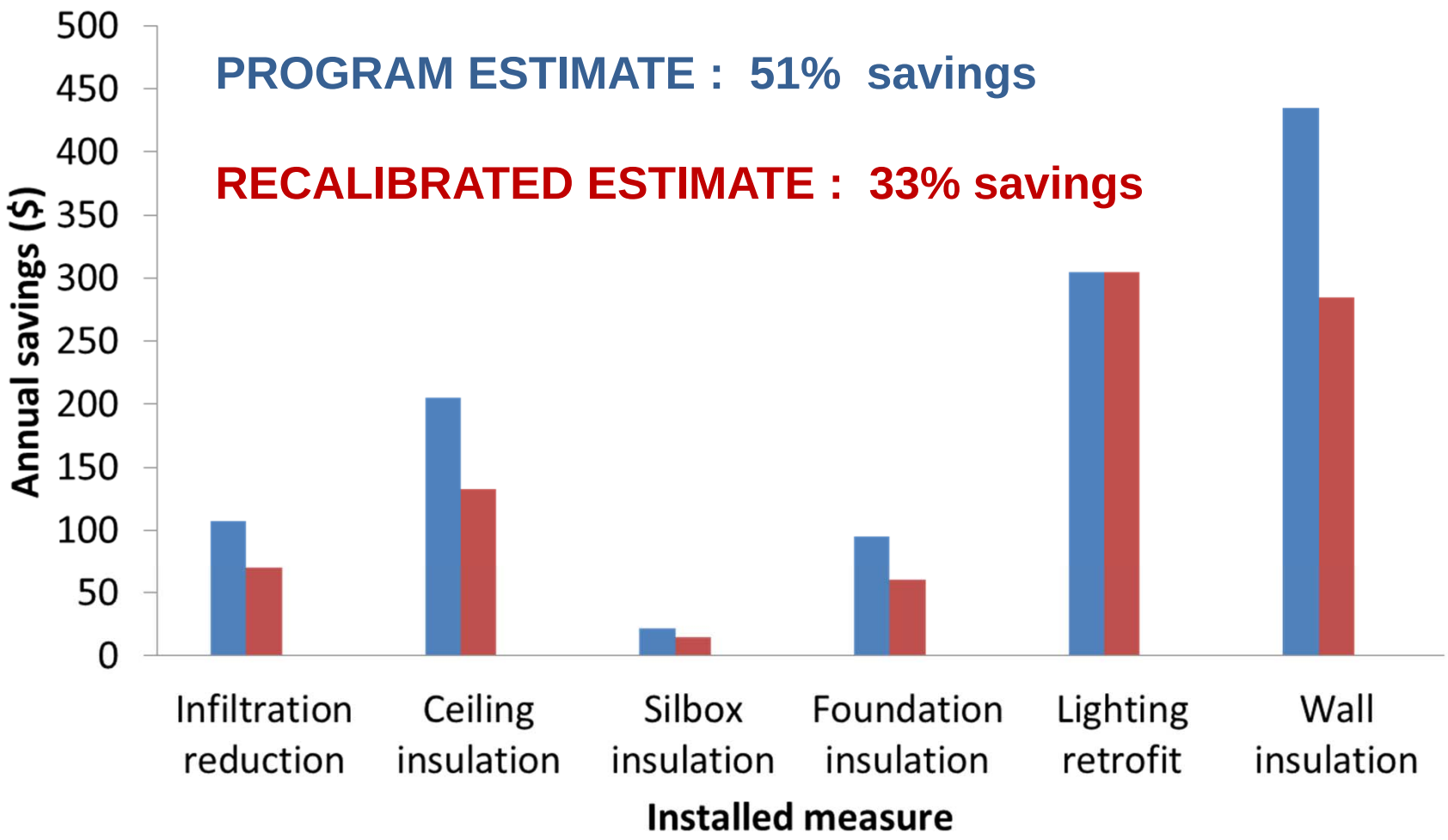
Some miscalibration is intentional

- NEAT attempts to find energy conservation retrofits that are cost effective for "average" occupants.
- Efforts to adjust parameters to match life-styles of individual occupants forbidden.
- Weatherizing the house based on the “adjusted” recommendations may lead to inequities among houses because of lifestyle differences among occupants.

Step 1: Recalibration

Example: A household receiving a typical set of energy efficiency improvements (retrofit cost : $5600)



Step 2. Model misspecification?

- A balance must be struck between state-of-the-art energy modeling and user-friendly audit protocols that are easily implemented in the field.

- The rich data collected during a WAP audit can be used to calibrate more sophisticated, more precise engineering models.

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A question for the experts

- Objective: Take the rich data we have and re-estimate energy savings using an alternative building simulation model.
- What other modeling/audit tools should we consider using?
- With 5000+ households, important that we can automate the calibration/estimation process.

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Step 3. Behavioral “take back”?

- Engineering models can be used to project energy use under a range of assumptions regarding heating demand.
- We hope to leverage our quasi-experimental research design to test for a behavioral response to weatherization.

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How to best construct an empirical estimate of behavioral response?

"Drive by" thermal imaging?

Occupant surveys + temperature/humidity measurement?

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A work in progress….

- Working closely with implementing agencies to capture results of energy efficiency audits and document weatherization activities.
- We hope to design an empirical test for rebound effects.
- In spring 2013 we can begin to construct our ex post estimates of program impacts and contrast these with ex ante estimates.

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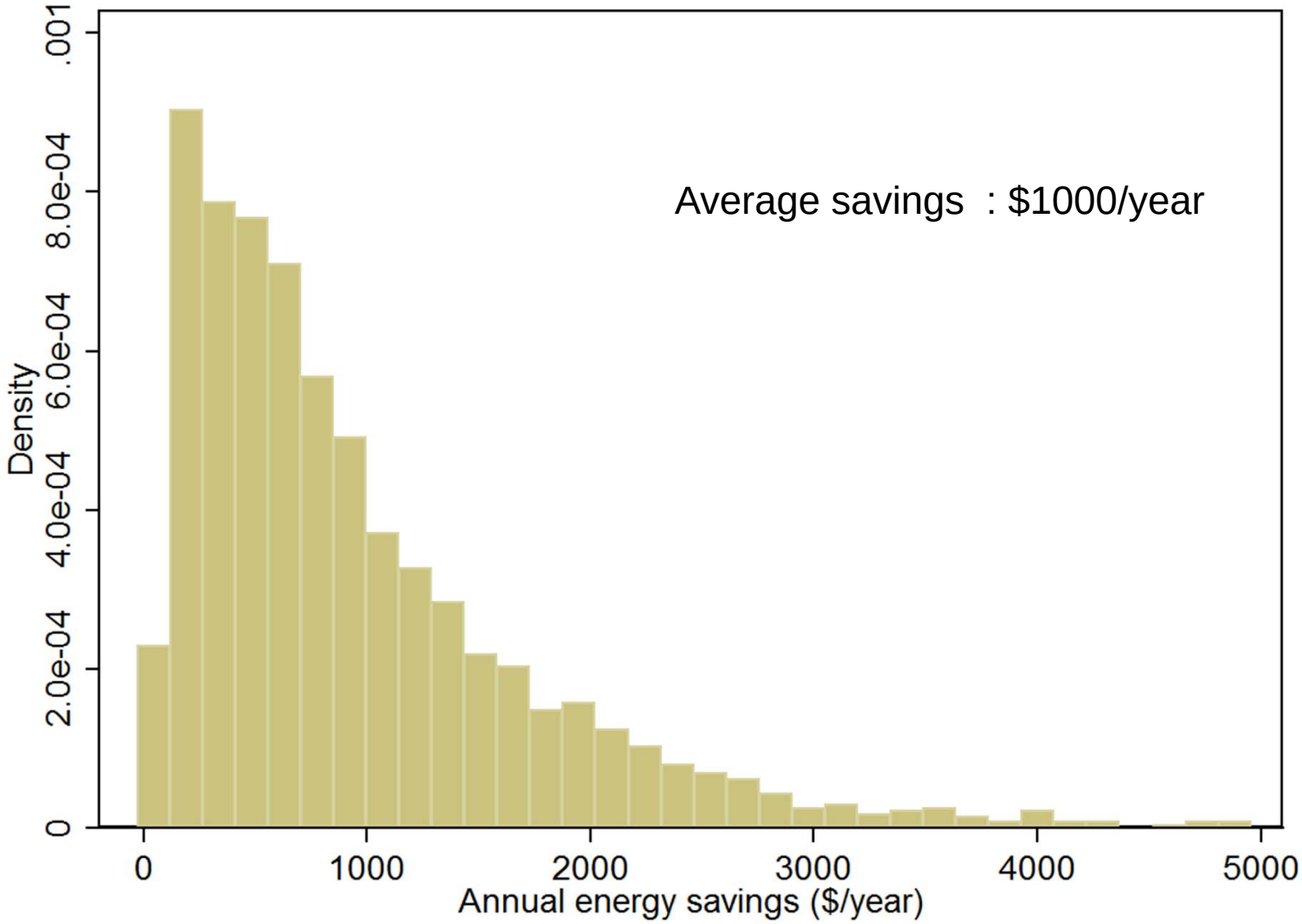
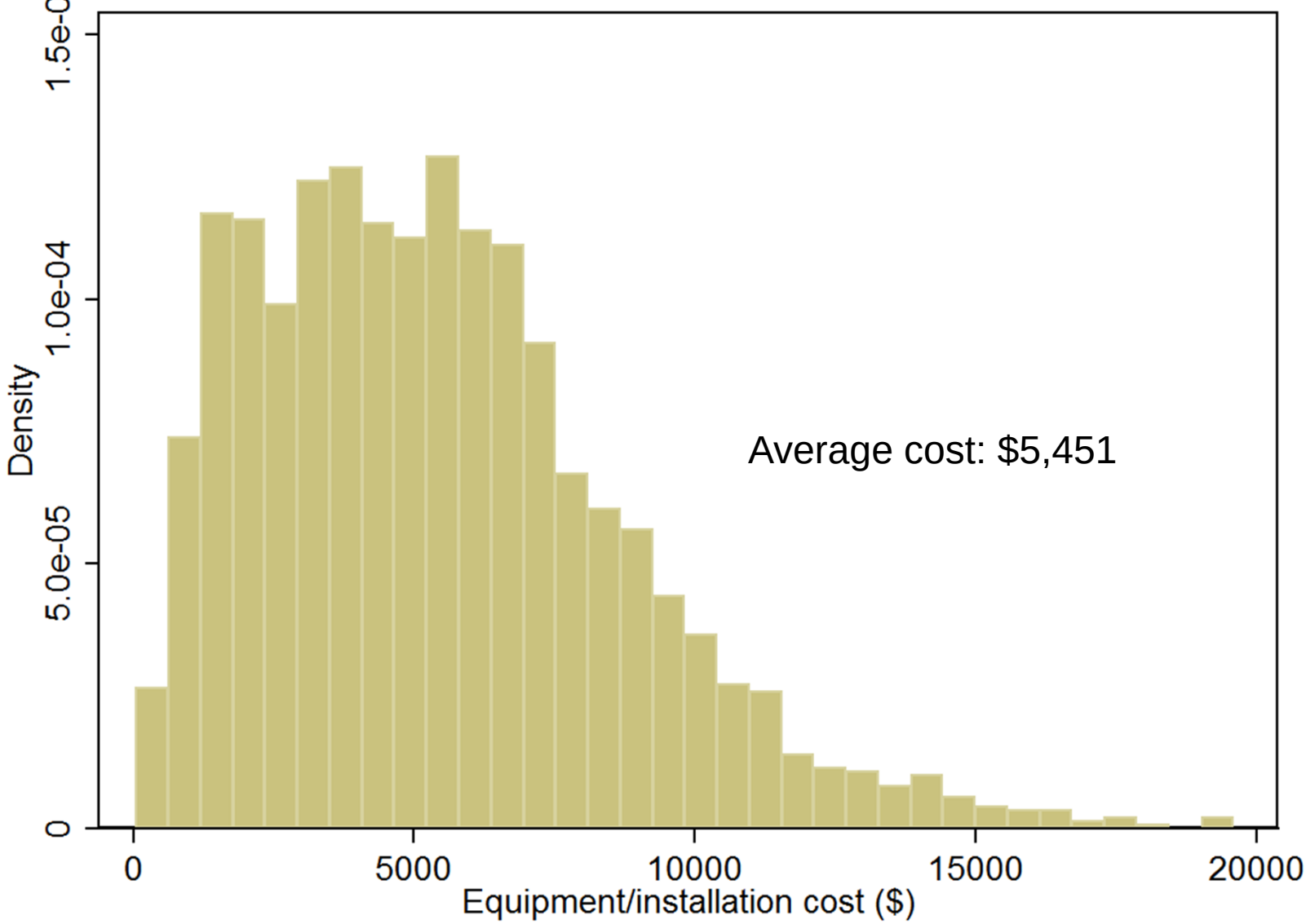
Estimated energy savings ($/year)



Estimated costs ($)



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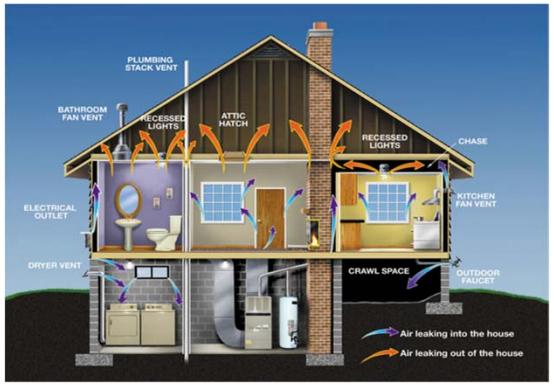
Integrating ex ante engineering estimates and ex post empirical estimates of household energy savings



Households receive weatherization assistance

Experimental and quasi-experimental research designs used to construct an estimate of the average household-level savings that are actually realized

NEAT audit conducted generates household- specific estimates of energy savings and costs. Results determine which measures are implemented.

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