Information v. Energy Efficiency Incentives: Evidence from Residential Electricity Consumption in Maryland

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Motivation and Background

- Residential energy efficiency programs in place in the US, Canada, Europe and Australia
- Can they mitigate the "Energy Efficiency Gap?"
- Attempt to address possible causes of the "Energy Efficiency Gap"
  - Lack of physical/economic information
  - Liquidity constraints
  - …

Literature 1

- Little empirical work on EE incentives
  - Hassett and Metcalf (1995); Boomhower and Davis (2013), Mauraux (2013)
- Adverse selection and free riding
  - Joskow and Marron (1992); Grosche and Vance (2009); Grosche et al. (2012);
- Rebound Effect:
  - Sorrell (2009); Linares and Labandeira (2010); Gillingham et al. (2013)

Literature 2
Information

- Information on energy efficiency
  - Labels (Houde, 2014; Newell and Siikamaki, 2013; Brounen and Kok, 2011; Eichholtz et al., 2010; Alberini et al., 2014)
  - Energy audits (Gamtessa, 2012)
- Real-time or frequent feedback about energy usage
  - Faruqui et al. (2010); Darby (2006, 2010); Gleerup et al. (2010); Gans et al. (2013); Jessoe and Rapson (2013)

Approaches

- Randomized controlled trials
  - Utility pilots
  - Usually small sample and short duration
- Natural Experiments
  - Not easy to find
- Observational studies or voluntary programs
  - Selection bias
  - Unobserved heterogeneity
  - Seek to restore random assignment to treatment via matching, PSM, regression discontinuity, IV estimation

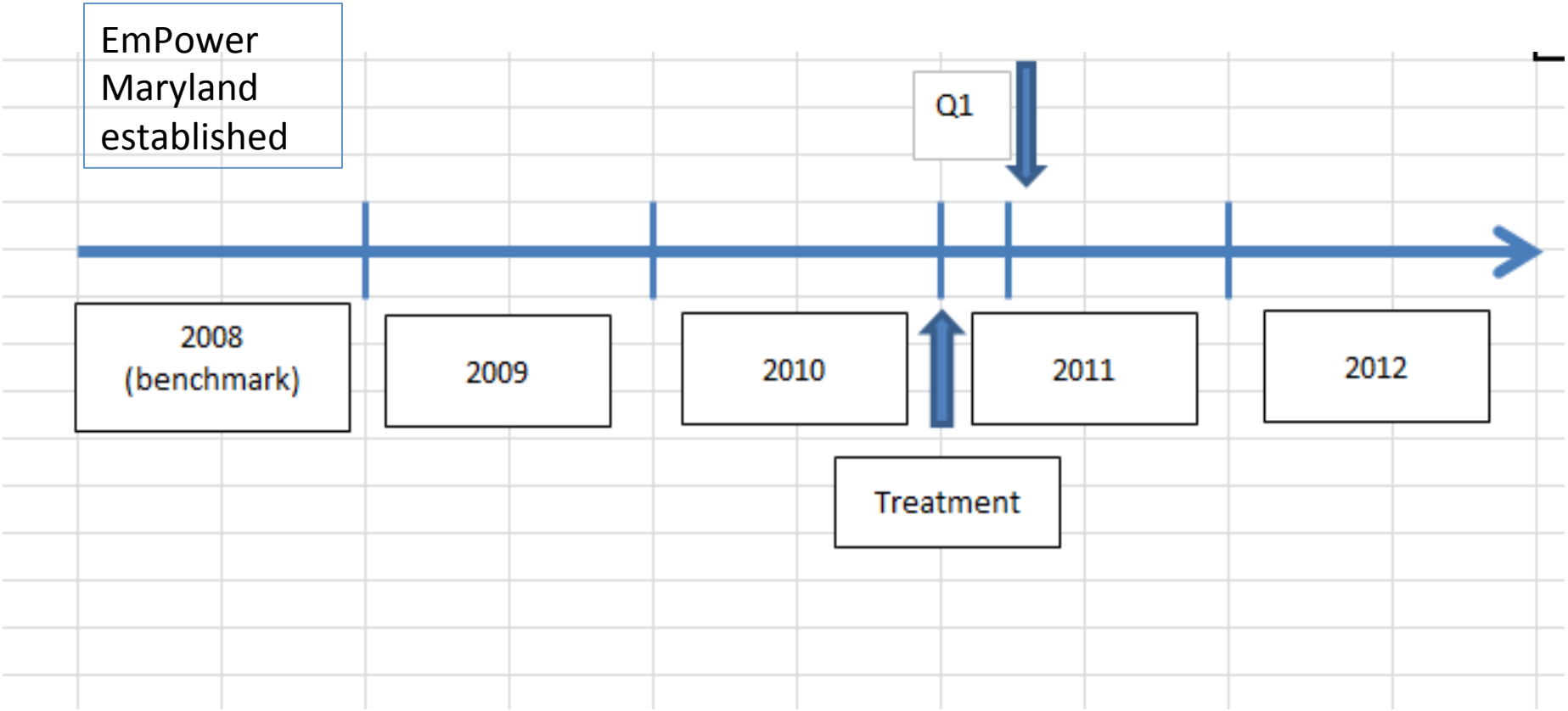
This paper

- Treatment = program offered by a MD utility to residential customer to help meet EmPower MD goals
- Two treatments:
  - Energy Audit (Quick Home Energy Check-up)
  - Rebate on the purchase of a high-efficiency heat pump
- Treatments take place in Q1 2011
- Have electricity usage before and after for treated households and controls
- Participation is voluntary…

Research Questions

1. What are the effects of energy audits and incentives on high-efficiency heat pumps on residential electricity usage?
2. Are these cost-effective ways to reduce CO2 emissions associated with generation?
3. Which works best to address selection bias…?
   - fixed effects
   - Matching on pre-program usage
   - Matching on pre-program usage and housing characteristics

Timeline


EmPower Maryland established
Q1
2008 (benchmark)
2009
2010
2011
2012
Treatment

Quick Home Energy Check-up

- Professional assesses…
  - Insulation
  - Heating and cooling systems
  - Windows and doors
  - Lighting
  - Appliances
  - Water heater

…and offers advice

- One hour
- Cost:
  - to the household: $0
  - To the utility: $200
- Products (CFLs, pipe insulation) may be offered to the household
- We don't know what the household does after the QHEC

Heat Pump Rebate

- $200 - $400 on the purchase of a heat pump with SEER of 14.5 or better

Data Sources

- Usage and billing records from the electric utility (2008 – 2012)
- Utility program participation records
- MDPropertyView
  - Issued every year since 1996 by the State of Maryland
  - Lists and describes all homes in MD
- US Census: neighborhood characteristics
- Weather data from NOAA

Where


HARRISBURG
Philadelphia
Raystown Lake
PENNSYLVANIA
Susquehanna
Delaware
NEW JERSEY
Cumberland
Potomac
Baltimore
DOVER
Delaware Bay
MARYLAND
DELAWARE
Deep Creek Lake
Potomac
ANNAPOLIS, MD
WASHINGTON, DC
Alexandria
Potomac
Shenandoah
WEST VIRGINIA
Chesapeake Bay
VIRGINIA
Potomac
Lake Anna
Survey Area
Charlottesville
0 km 20 40 60 km
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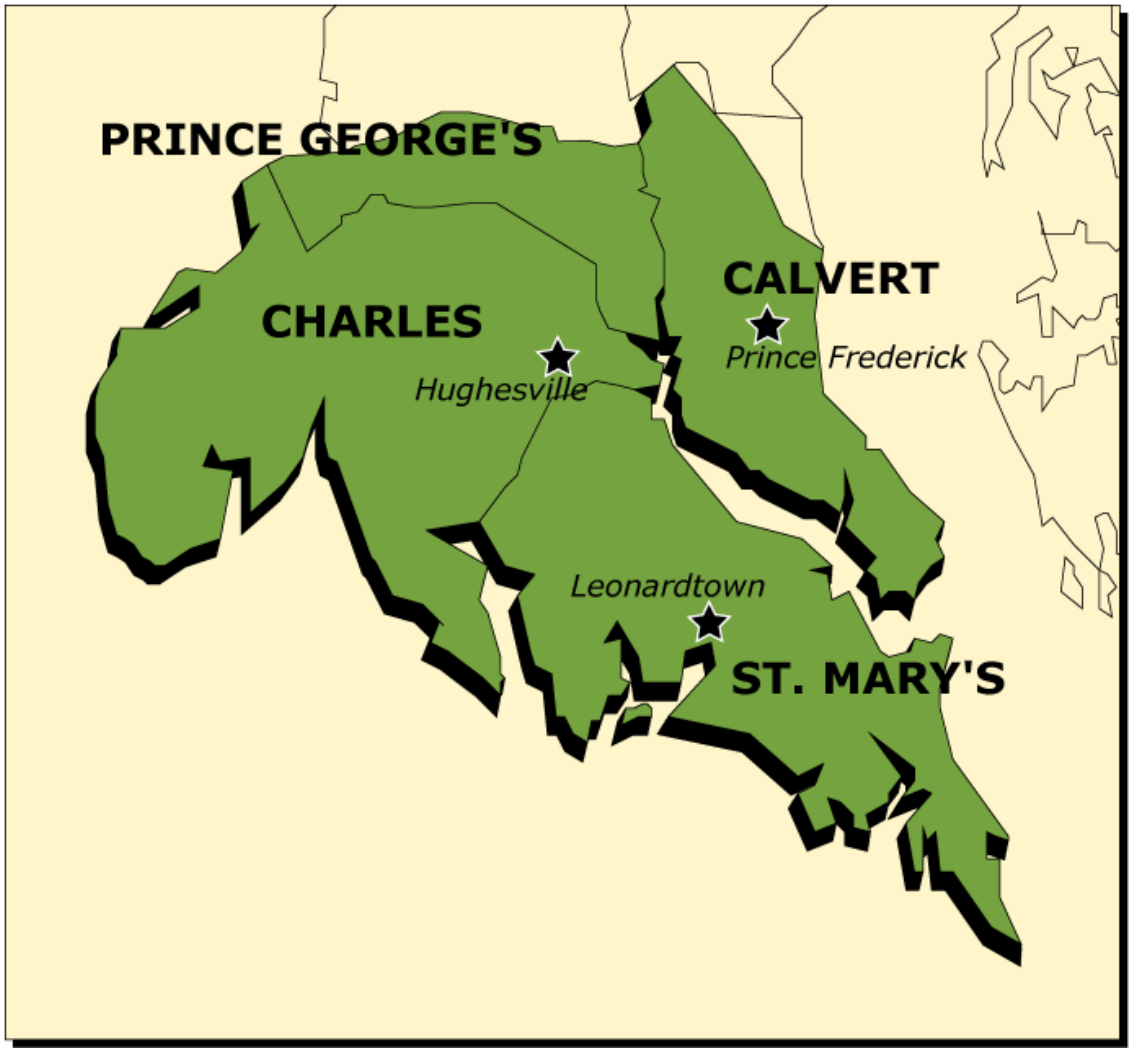
Why—SMECO Service Area



Study Design

- Difference-in-difference approach
  - i.e., retrospective case-control study
  - Treatment and control groups
  - Have electricity usage records before and after treatment
- Outcome variable: ln electricity usage
- Average treatment effect on the treated (ATT)

Basic Model
(in the absence of programs)

$$\ln E_{ist} = \alpha_{is} + \tau_{st} + \mathbf{W}_{ist}\boldsymbol{\beta} + \varepsilon_{ist}$$

Household × season fixed effects

Season × year fixed effects

Weather and billing period controls

Basic Model - 2

$$\ln E_{ist} - \ln E_{is(t-1)} = \alpha_{st} + (\mathbf{W}_{ist} - \mathbf{W}_{is(t-1)})\boldsymbol{\beta} + (\varepsilon_{ist} - \varepsilon_{is(t-1)})$$

FD, fourth-lag differences, and within estimator give different results if household-by-season effects are present.

Assess the Effect of Treatment

$$\ln E_{ist} - \ln E_{is(t-1)} = \alpha_{st} + (\mathbf{W}_{ist} - \mathbf{W}_{is(t-1)})\boldsymbol{\beta} +$$

$$+ \mathbf{X}_i\boldsymbol{\gamma} + (TGroup_i \times Post_{ist}) \cdot \delta + e_{ist}$$

Characteristics of the dwelling and pre-program usage

ATT

Alternatively…

$$\ln E_{ist} - \ln E_{is(t-1)} = \alpha_{st} + (\mathbf{W}_{ist} - \mathbf{W}_{is(t-1)})\boldsymbol{\beta} +$$

$$+ \mathbf{X}_i\boldsymbol{\gamma} + (TGroup_i \times (Post_{ist} - Post_{is(t-1)})) \cdot \delta + e_{ist}$$

Characteristics of the dwelling and pre-program usage

ATT

Matching

- Seeks to create a situation where the treatment is as good as randomly assigned
- For each treated unit, look for a control unit with identical **X**s
- Compute Δy between treated and control unit
- Average the Δy across all pairs, conditionally on the distribution of **X** in the treated units

Difficulties with Matching

- Exact matching v. matching with continuous variables (Abadie and Imbens, 2006, 2011)
- Usually done with cross sections
  - With panel data, what if someone is matched with himself pre-treatment?
- Match observations (i.e., electricity usage records) or units (i.e., households)?
  - We do both
  - Both trim the sample

Coarsened Exact Matching (CEM)

- The units to be matched are the households
- Convert continuous variables into discrete categories
- Do exact matching
- Compute CEM weights
- WLS regression that includes original matching variable to control for any residual imbalance
- Use full panel of electricity usage observations in the regression

What are our Matching Variables?

- 2008 summer and winter usage
- House characteristics:
  - Square footage
  - Heat pump
  - Floors
  - Vintage
  - Basement
  - Construction quality
  - Construction materials

Construction of the Sample

Start:

- QHEC households +
- Heat Pump rebate households +
- Households in homes as similar as possible to the above

Data cleaning:

- Exclude mobile homes
- Exclude households in multiple programs
- Exclude households in utility programs after Q1 2011
- Only accounts active since Jan 2008

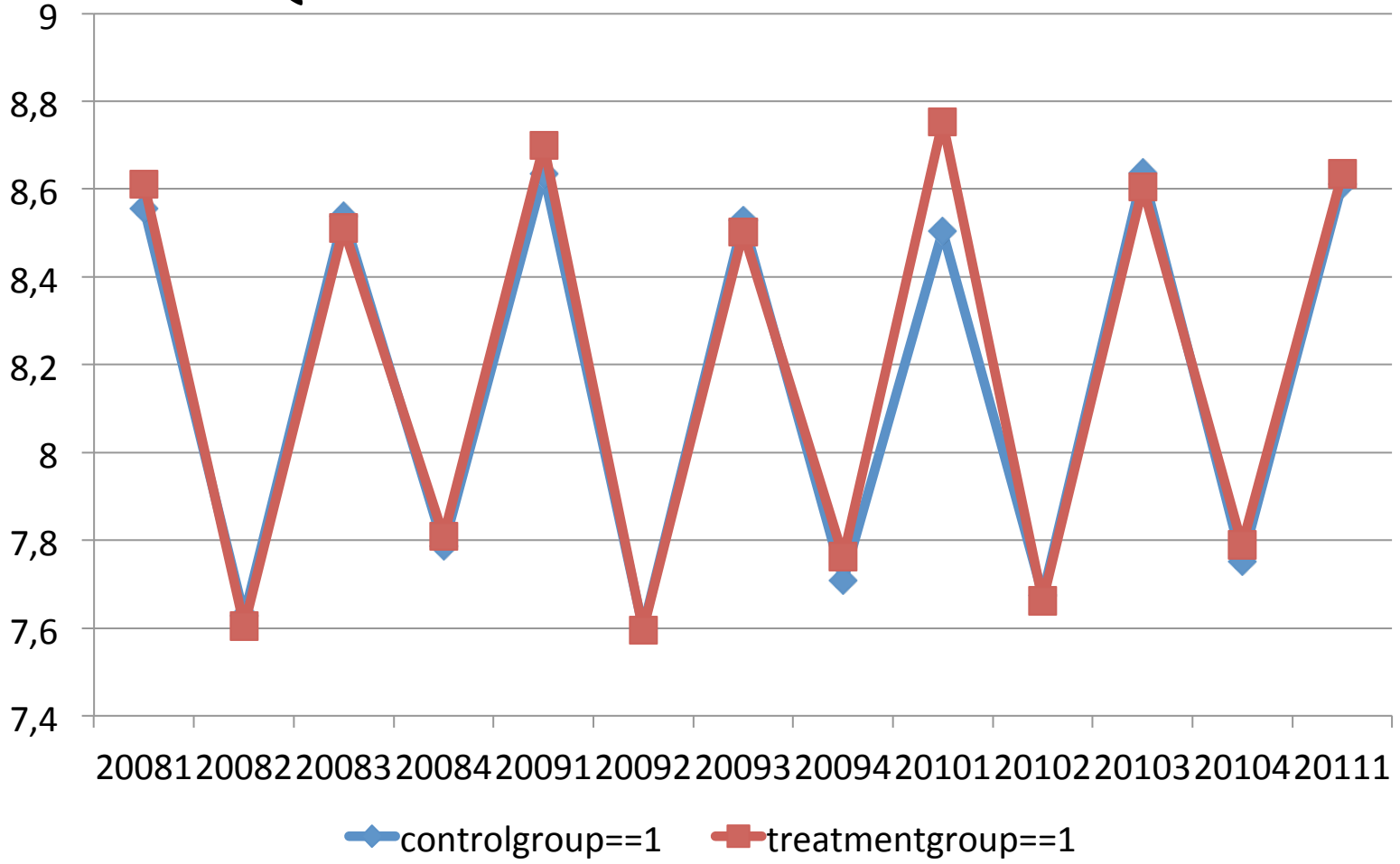
The Sample

- QHEC: 378 hholds
- HP rebate: 430 hholds
- Controls: 10,676 hholds
- Panel dataset:
  - For each hhold, seasonal total usage (4 obs. per hhold per year)
  - Up to 13 seasons per hhold
- Sample for econometric analysis has over 100,000 obs.

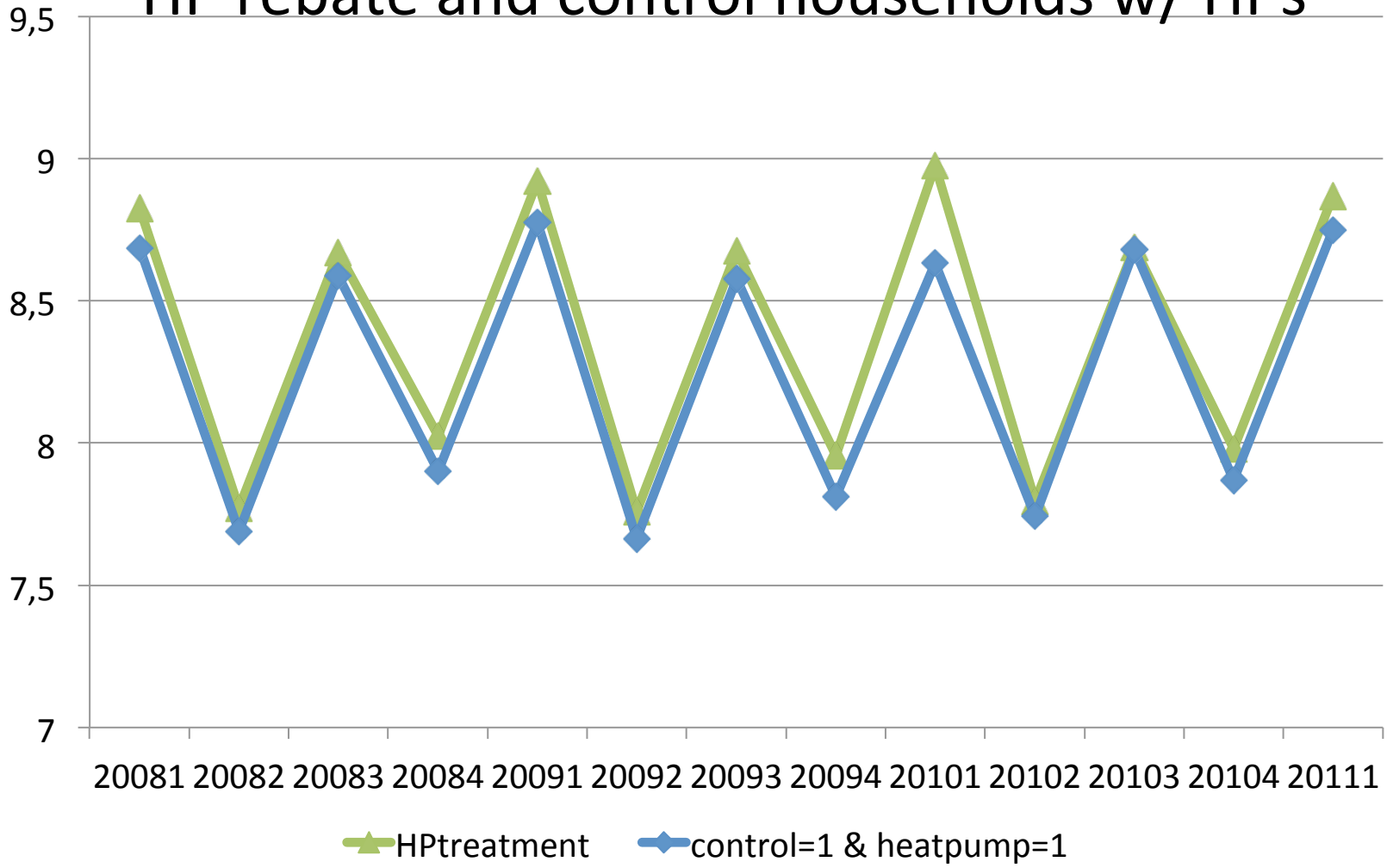
Selected Descriptive Statistics

Variable	Sample mean
Sqft feet	Mean 1928.19 Median 1808
Heat pump present	0.6225
Built before 1960	0.0594
Built 1960-69	0.0649
Built 1970-79	0.1572
Built 1980-89	0.2170
Built 1990-99	0.3921
Built 2000 and later	0.1094
1 floor	0.3198
2 floors	0.5583
Fair construction quality	0.3544
Average construction quality	0.5414
Good construction quality	0.0776

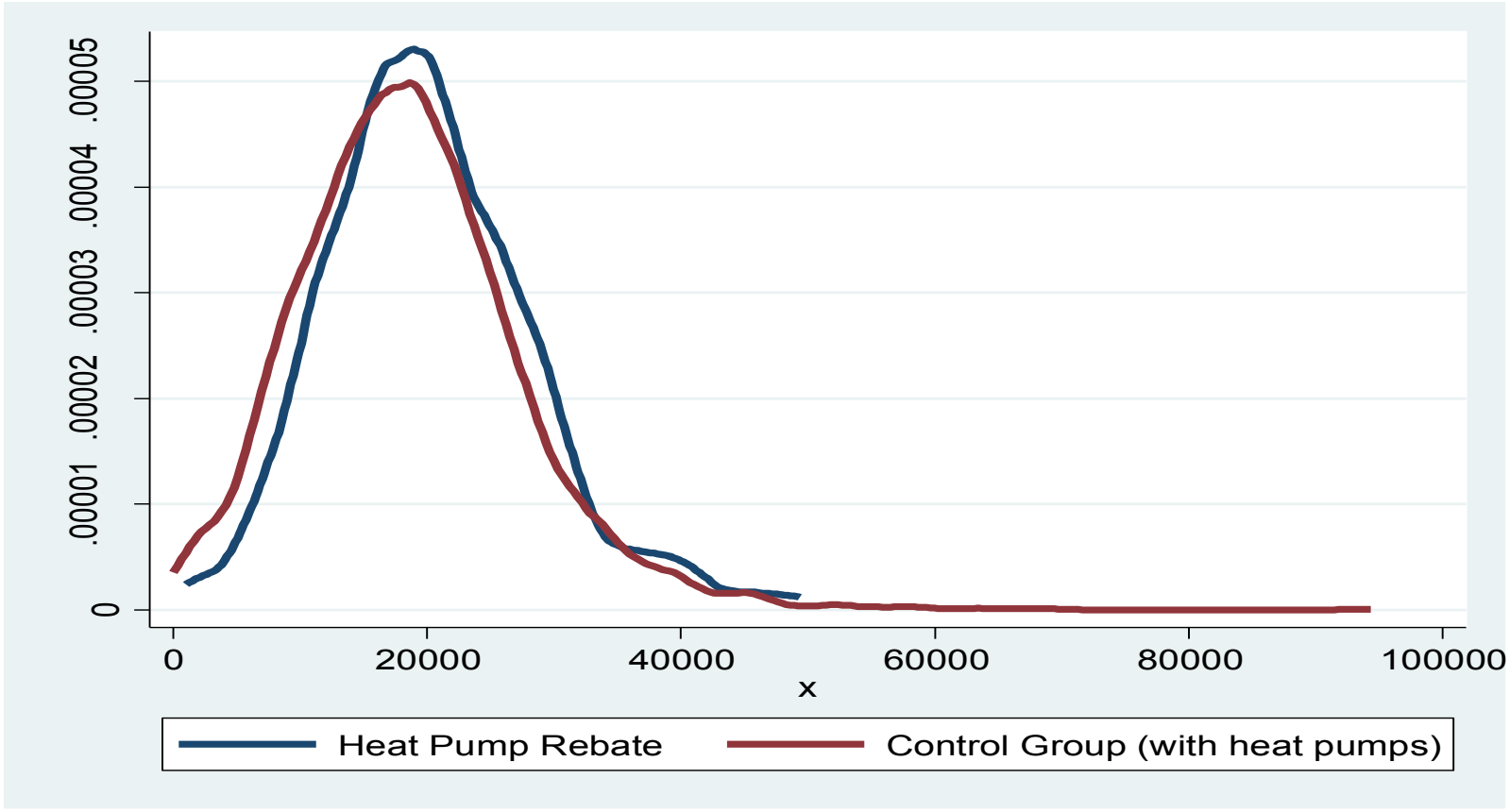
Average log usage by season: QHEC and control households



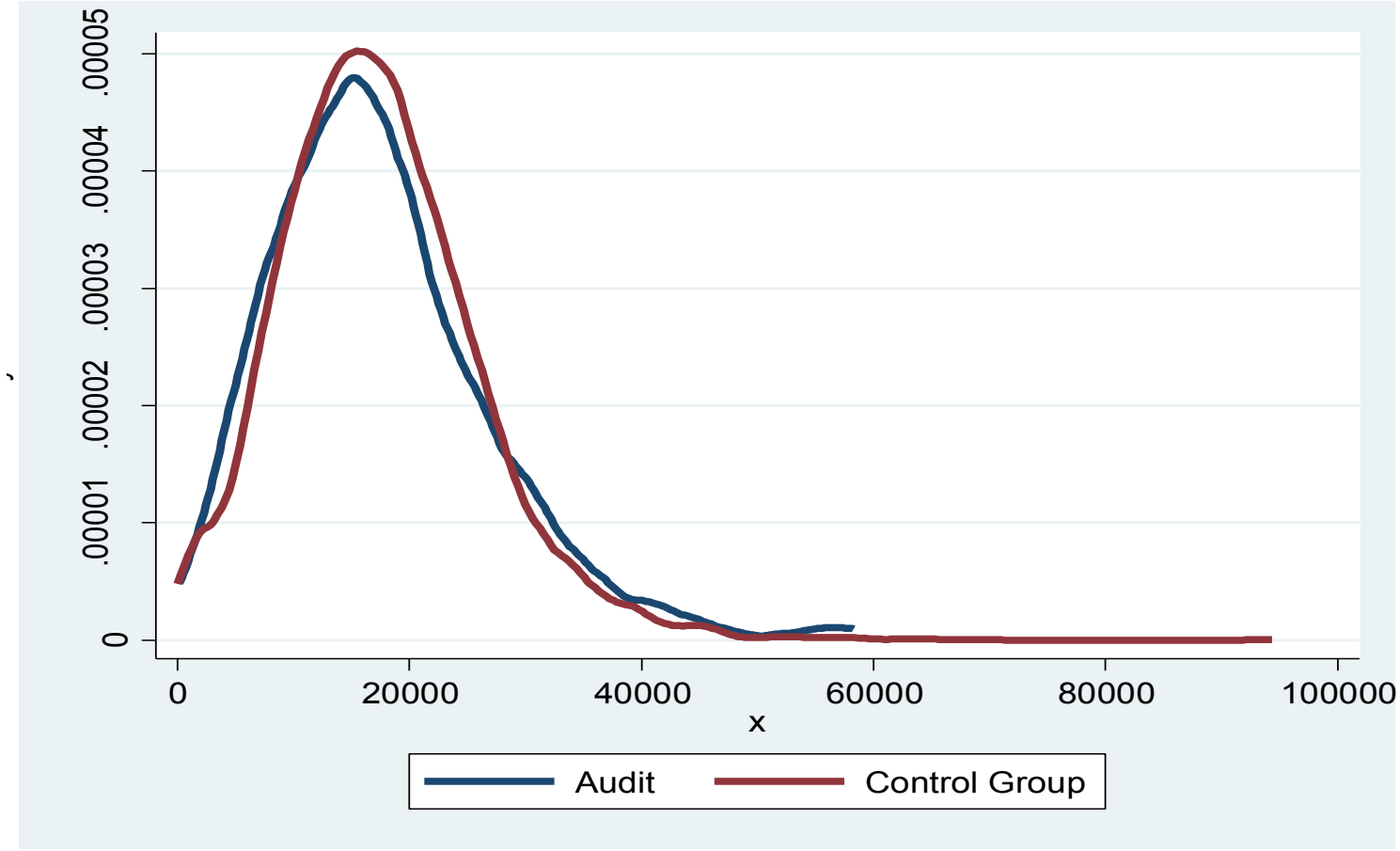
Average log usage by season: HP rebate and control households w/ HPs



2008 electricity usage
HP rebate and controls w/ HPs



2008 electricity usage
QHEC and controls



Comparison of dwelling characteristics across groups

	Audit	Control Group	HP Rebate	Controls w/ HPs
Sqft	1917.95	1931.22	2072.4	2029.01
heat pump	0.6085	0.6224	1.0000	1.0000
Built Pre 1960	0.0763	0.0612	0.0059	0.0104
Built 1960-69	0.0518	0.0665	0.0059	0.0051
Built 1970-79	0.2071	0.1565	0.0356	0.0508
Built 1980-89	0.2507	0.2124	0.3145	0.2735
Built 1990-2000	0.3787	0.3879	0.5964	0.5117
Built 2000+	0.0354	0.1155	0.0415	0.1485
1 floor	0.3578	0.3540	0.2614	0.2461
2 floors	0.6147	0.6236	0.732	0.7205
Average quality	0.4796	0.5404	0.6291	0.6113
Fair	0.4142	0.3559	0.2463	0.2721
Good	0.0899	0.0770	0.1128	0.1011

Preliminary Regressions: Audit

	OLS in the levels	FE (conventional hhold effects)	OLS in the fourth-lag differences
treatment group dummy	0.0003 (0.04)	--	0.0058 (1.042)
treatment × post dummy	-0.0405 (-2.74)	-0.0457 (-4.83)	-0.0186 (-1.92)
Benchmark year usage	Yes	--	Yes
Season × year	Yes	Yes	Yes
weather controls	Yes	Yes	Yes
house characteristics	Yes	--	Yes

CEM for Audit v. Control Group

	CEM 1	CEM 2
Matching variables	- 2008 usage	- 2008 usage - House characteristics
Matched households	10,580 (97.85%)	3603 (33.33%)
Nobs used in the final regression	177,550 (97.88%)	60,763 (33.50%)

Audit Regressions – WLS w/ CEM 1

	Levels	Fourth-lag-differences	Fourth-lag-differences	Fourth-lag-differences (summers 2011 and 2010)	Fourth-lag-differences (summers only)
Treatment group	0.0228 (2.32)	0.0049 (0.84)	0.0058 (1.06)		
Treatment group × post	-0.0370 (-2.33)	-0.0201 (-1.90)			
Treatment × Δpost			-0.0300 (-2.73)	-0.0414 (-2.51)	-0.0303 (-1.88)
Benchmark year usage	Yes	Yes	Yes	Yes	Yes
Season × year	Yes	Yes	Yes	n/a	Yes
weather controls	Yes	Yes	Yes	Yes	Yes
house characteristics	No	No	No	No	No

Audit Regressions – WLS w/ CEM 2

	Levels	Fourth-lag-differences	Fourth-lag-differences	Fourth-lag-differences (summers 2011 and 2010)	Fourth-lag-differences (summers only)
Treatment group	0.0075 (0.81)	0.0058 (0.92)	0.0101 (1.70)	--	-0.0021 (0.09)
treatment × post	-0.0382 (-2.53)	-0.031 (-2.82)			
Treatment × Δpost			-0.0576 (-5.75)	-0.0464 (-2.63)	-0.0473 (-2.30)
Benchmark year usage	Yes	Yes	Yes	Yes	Yes
Season × year	Yes	Yes	Yes	--	Yes
weather controls	Yes	Yes	Yes	Yes	Yes
house characteristics	Yes	Yes	Yes	Yes	Yes

CEM for Heat Pump Rebate v. Control Group w/ Heat Pump

	CEM 2
Matching variables	- 2008 usage - House characteristics
Matched households	3603 (33.33%)
Nobs used in the final regression	60,763 (33.50%)

Preliminary Regressions: HP Rebate

	OLS in the levels	FE (conventional hhold effects)	OLS in the fourth-lag differences
Treatment group	0.0456 (5.60)	--	-0.0044 (-0.881)
Treatment group × post	-0.072 (-5.47)	-0.0682 (-7.74)	-0.00006 (-0.006)
Benchmark year usage	Yes	Yes	Yes
season × year	Yes	Yes	Yes
weather controls	Yes	Yes	Yes
house characteristics	Yes	--	Yes

HP Rebate Regressions: CEM 2

	Levels	Fourth-lag-difference	Fourth-lag-difference	Fourth-lag-difference (summer 2011 and 2010)	Fourth-lag-difference (summers only)
Treatment group	0.0072 (1.02)	-0.0039 (-0.81)	-0.00020 (-0.04)	-	-0.0300 (-3.55)
Treatment group × post	-0.04936 (-4.24)	0.0071 (0.83)			
Treatment group × Δ4 post			-0.0056 (-0.609)	-0.0220 (-1.53)	0.0098 (0.65)
Benchmark	Yes	Yes	Yes	Yes	Yes
season × year	Yes	Yes	Yes	Yes	Yes
weather controls	Yes	Yes	Yes	Yes	Yes
house characteristics	Yes	Yes	Yes	Yes	Yes

Summary

- Heat pump rebate brings no reduction in energy use (see Alberini et al., 2014)
- Audits seem more promising (5% reduction), but
  - We don't know what households do to reduce usage
  - And so we don't know for how long the electricity use reductions will remain in place

CO2 Emissions Reduction: What is the Cost-Effectiveness of the Programs?

- Audit only
- But how long will the usage reductions be in place for? Assume 7 years.
- Cost of audit to the utility: $200 + $60 (avg. cost of products)

- **Utility calc 1**: 4800 KWh/lifecyle × 0.608 kg CO2/kWh = 2.918 tons CO2 avoided
- Cost per CO2 ton: $89
- **Our calc**: 18,000 kWh/ yr × 0.05 × 7 yrs × 0.608 = 3.830 tons CO2
- Cost per CO2 ton: $68

Conclusions

- Energy audit more promising at reducing electricity usage than heat pump rebate
- Difficult to compute CO2 emissions reductions and cost-effectiveness because we don't know the horizon
- Used all possible, flexible fixed effects to accommodate unobserved heterogeneity
- Further used matching
- Recommend matching/controlling for past usage AND dwelling characteristics

Thank you!

Definition of ATT

$$E(y_{i1} \mid D_i = 1) - E(y_{i0} \mid D_i = 1)$$

Table 6. Coarsened exact matching (CEM) results. QHEC households v. control households.				
	CEM 1		CEM 2	
Matching variables	2008 winter usage 2008 summer usage		2008 winter usage 2008 summer usage Dwelling characteristics	
Number of strata	101		3290	
Number of matched strata	43		235	
	Control households	Treated households	Control households	Treated households
Matched	10215	365	3309	294
Unmatched	233	2	7139	73
Multivariate L1 distribution	0.4888		0.9661	
Nobs on usage in the regression	177550 (from matched households)	3780 (from unmatched households)	60763 (from matched households)	120567 (from unmatched households)

CEM 2 for HP rebate

	CEM 2	
Matching variables	2008 winter usage 2008 summer usage Dwelling characteristics	
Number of strata	1510	
Number of matched strata	166	
	Control households	Treated households
All	6519	337
Matched	2880	293
Unmatched	3639	44
Multivariate L1 distribution	0.9604	
Nobs on usage in the regression	53624 (from matched households)	61401 (from unmatched households)