How well do energy efficiency measures actually perform?

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Introduction and motivation

Expections vs

“There is no realistic, or affordable, energy development strategy that is not led by energy efficiency. For the IEA, it is the first fuel" - Fatih Birol, 2016

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Why Government Energy-Efficiency Programs Sound Great–But Often Don't Work

By Sam Ori

Nov 13, 2017 10:00 pm ET

Introduction and motivation

Fowlie at al. (2015), Allcott and Greenstone (2017)

- Actual energy savings 40-60 percent of predicted

Gerarden at al. (2015) energy efficiency gap

- Market failures, behavioural failures, model/measurement error
- Unobserved costs, overstated savings from adoption, consumer heterogeneity, inappropriate discount rates and uncertainty contribute to low adoption rate not being as "*paradoxical as it first appears.*"

Kotchen (2017) long-run effects of building regulations

- Effects of code change on electricity consumption diminish over time
- Effects on gas consumption increase over time

Introduction and motivation

What we do:

- Examine how well measures perform, how this varies over time, by measure, by household type
- How this effects cost-effectiveness of measures, distributional impacts of policies
- Provide some evidence on the relative cost-effectiveness of different types of EE policies

How we do it:

- Analyse a database of over four million households over an eight year period to systematically explore EE
- Statistical matching and panel econometric estimations to control for unobserved heterogeneity and selection
- Population of supplier TWC schemes - mitigate against “site selection bias" (Allcott, 2015)

Presentation overview

- Background
- Data
- Methods
- Results

Background

- UK Supplier Obligations (Tradeable White Certificates)
    - Principal policy instrument in UK
    - Also widely used in Europe (Italy, France)
    - Hybrid subsidy-tax instrument (Giraudet, 2012)
- Three main features (Bertoldi and Rezessy, 2008):
    1. An obligation is placed on energy companies to achieve a quantified target of energy savings
    2. Savings are based on standardised ex-ante calculations
    3. The obligations can be traded with other obligated parties
- Market-based flexibility aims to encourage cost-effectiveness
- Suppliers bear the cost and then pass through to their customers
- Widely considered to have been a cost effective measure

Background

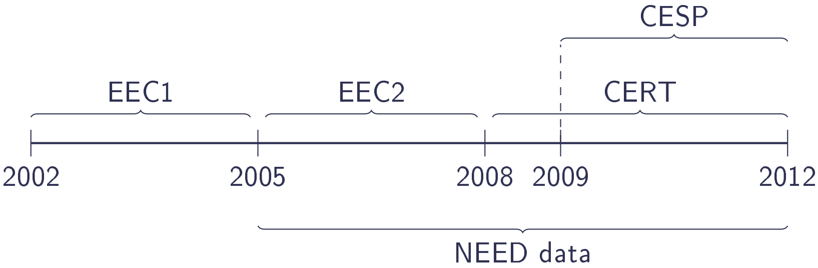


Figure: UK Energy Efficiency Programmes 2005-2012

SO Details

Background

Table: Energy savings by scheme and measure

	EEC1 2002-2005	EEC2 2005-2008	CERT 2008-2012
Insulation	56%	75%	66.20%
Heating	9%	8%	8.20%
Lighting	24%	12%	17.30%
Appliances	11%	5%	5.90%
Other	-	-	2.40%

Source: Lees (2005, 2008), Ofgem (2013)

NEED database

National Energy Efficiency Data-Framework (NEED)

Table: Data sources combined in NEED

Type of variable	Source
Energy efficiency measures	HEED/Ofgem/DECC
Energy consumption	Energy Suppliers
Property attributes	VOA
Household characteristics	Experian

Source: DECC/BEIS

IMD

Measures installed

Measures installed

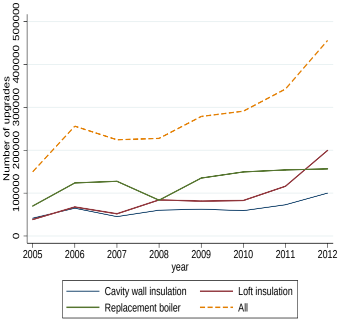


Figure: Energy efficiency measures installed, 2005-2012

Energy consumption

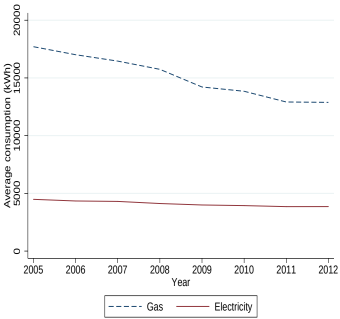


Figure: Average domestic energy consumption (kWh) UK, 2005-2012

Non-random assignment

- Households are not randomly assigned measures. They chose to avail of supplier offers
- Selection into scheme is likely correlated with energy consumption, income, location and other factors...
- Not taking this into account would bias results
- Pre-process data using coarsened-exact matching to reduce imbalance in observed variables (Iacus, King, and Porro, 2008; Alberini and Towe, 2015)
- Match on variables most likely to (i)predict selection into scheme, (ii) energy consumption (iii) level and trend of prior year's energy consumption

Identification: Matching

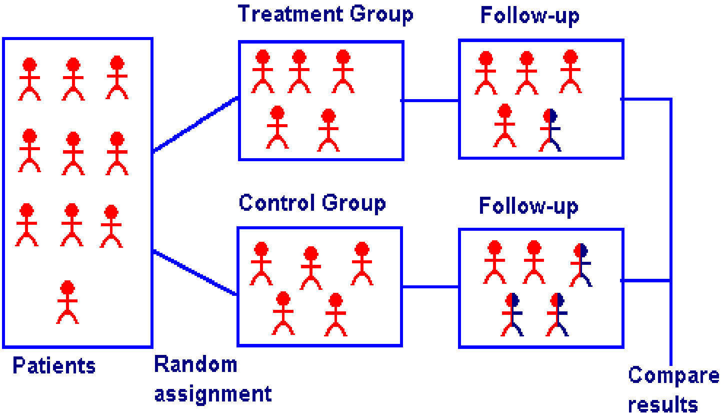


Figure: Assignment to treatment and control

Matching results: energy consumption

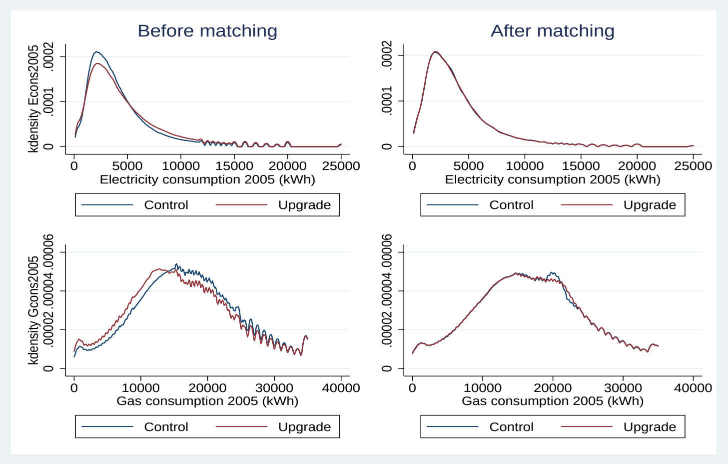


Figure: Energy consumption before and after matching

Balance tables

Matching results: parallel paths

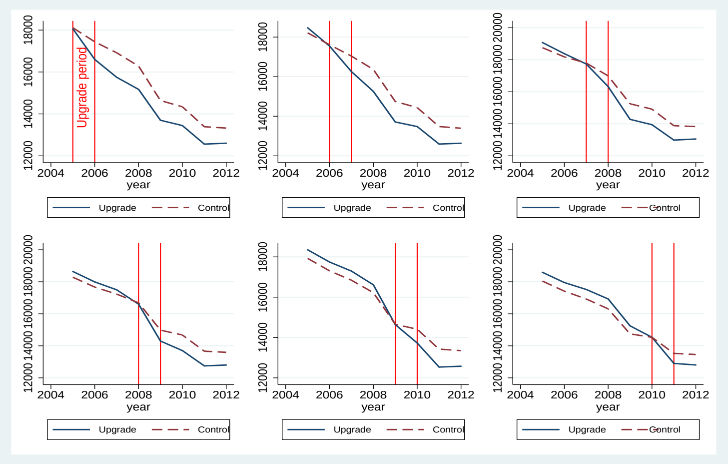


Figure: Consumption trend: Treatment and control group

Econometric approach

First-differenced fixed-effects panel estimation:

$$ln(y_{it}) = \alpha_i + \gamma_t + \rho_{rt} + \delta \sum_{j=1}^{J} D_{ijt} + \epsilon_{it} \tag{1}$$

Where:

- y_{it} - energy consumption by household i in year t
- α_i - household fixed effect
- γ_t - year dummy
- ρ_{rt} - year*region interaction
- D_{it} - treatment dummy
- δ - ATT
- ϵ_{it} - error term

Results overview

- R1: Main results
- R2: Heterogeneity in returns
- R3: Comparison with ex-ante predictions
- R4: Cost effectiveness

R1: Main results

Table: The effect of energy efficiency upgrades on energy consumption

	(1) Full sample	(2) 2006 upgrades	(3) 2007 upgrades	(4) 2008 upgrades	(5) 2009 upgrades	(6) 2010 upgrades	(7) 2011 upgrades
Cavity wall insulation	-0.094***	-0.097***	-0.111***	-0.099***	-0.098***	-0.097***	-0.101***
	(0.001)	(0.002)	(0.003)	(0.002)	(0.002)	(0.002)	(0.002)
Loft insulation	-0.030***	-0.026***	-0.031***	-0.028***	-0.027***	-0.039***	-0.035***
	(0.001)	(0.003)	(0.003)	(0.002)	(0.002)	(0.002)	(0.002)
Replacement boiler	-0.092***	-0.080***	-0.093***	-0.087***	-0.102***	-0.109***	-0.099***
	(0.001)	(0.002)	(0.002)	(0.002)	(0.002)	(0.002)	(0.002)
Control variables	Y	Y	Y	Y	Y	Y	Y
Household fixed effects	Y	Y	Y	Y	Y	Y	Y
Year fixed effects	Y	Y	Y	Y	Y	Y	Y
Year*region fixed effects	Y	Y	Y	Y	Y	Y	Y
Observations	5502936	617022	545627	564756	730447	746573	871379
Number of households	687925	77128	68203	70595	91306	93322	108922
R squared	0.349	0.327	0.353	0.370	0.369	0.386	0.367

Notes: This table reports coefficient estimates and standard errors from eight separate regressions. The dependent variable in all regressions is the logarithm of annual gas consumption in kilowatt hours. Column(1) "All" denotes efficiency upgrades occurring at any time during the sample period. Columns (2-8) relate to upgrades occurring only in the relevant year. Each individual year denotes upgrades occurring solely in that year. For each upgrade group a matched control group is created using coarsened-exact matching. The sample includes billing records from 2005 to 2012. Standard errors are clustered at the household level. Triple asterisks denote statistical significance at the 1% level; double asterisks at the 1% level; single asterisks at the 10% level.

R2: Heterogeneity in returns

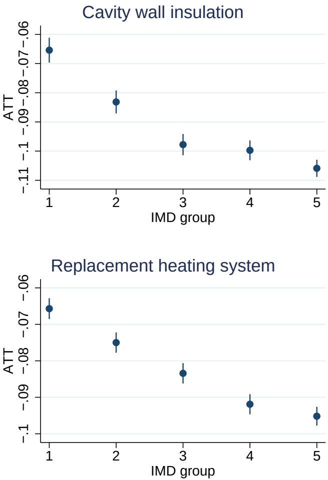


Figure: ATT by IMD group, all periods

R2: Heterogeneity in returns

Figure: ATT over time for measure installed in 2006

R2: Heterogeneity in returns

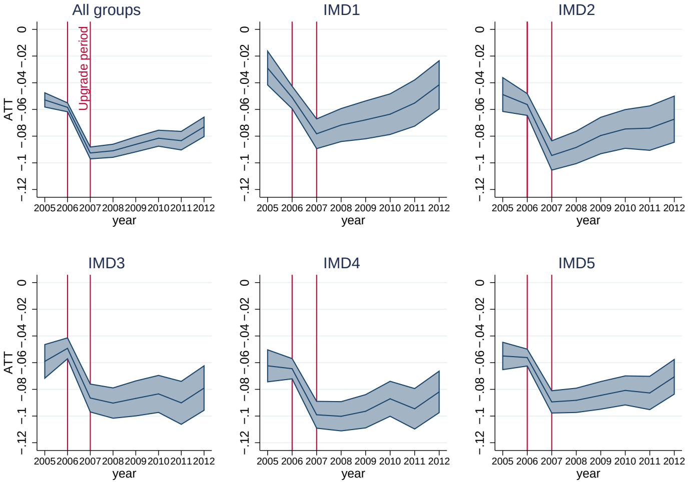
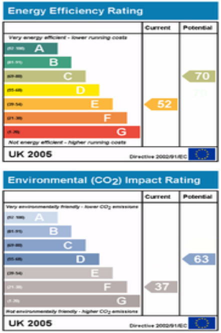


Figure: ATT over time for replacement heating system installed in 2006, by IMD

R3: Comparison with ex-ante SAP predictions

- The Standard Assessment Procedure (SAP)
- Bottom-up engineering model developed by BRE



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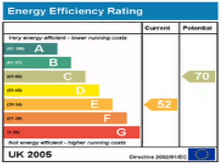

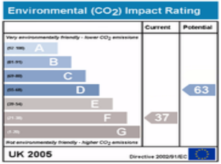

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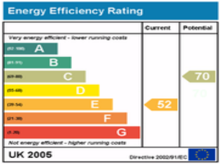

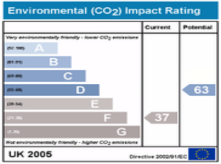

Measures installed	SAP predicted (kWh)	Empirical estimates (kWh)	Percentage of predicted
Cavity wall insulation	2724	1278	47%
Loft insulation	671	384	57%
Replacement heating system	3588	1328	37%

Source of SAP predicted savings: Adapted from Dowson (2012) Shorrock (2005)

Results summary

- Cavity wall insulation and replacement heating systems - approx 9%. Loft insulation - approx 3%
- Savings are greater for less deprived households
- Savings are more stable over time for less deprived households
- Bottom-up engineering model overstate savings by 43-63%

Results summary

- Cavity wall insulation and replacement heating systems - approx 9%. Loft insulation - approx 3%
- Savings are greater for less deprived households
- Savings are more stable over time for less deprived households
- Bottom-up engineering model overstate savings by 43-63%

- What does this mean in terms of cost-effectiveness?
- As measured by IRR, cost per kWh off energy saved, cost per tonne of CO2 removed

Some assumptions required

About (i) energy prices

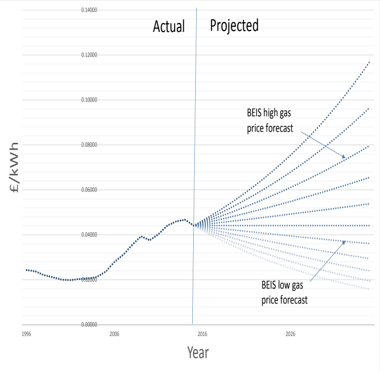

Figure: Gas prices ±5%

(ii) estimated cost of measures

Table: Cost estimates

Measure	Cost assumptions (£)
Cavity wall insulation	350
Loft insulation	285
Replacement boiler (policy cost)	200
Replacement boiler (private cost)	2000

Source: Authors calculations based on Lees (2005, 2008) Shorrock (2005) EST (2013)

(iii) estimated lifespan of measures...

Internal Rate of Return (IRR)

Table: IRR of measures

	IRR 10	IRR 20	IRR 30
Cavity wall insulation	3%	12%	13%
Loft insulation	-13%	0%	3%
Replacement heating (200)	17%	22%	23%
Replacement heating (2000)	-22%	-6%	-1%

Cost effectiveness

Table: Cost per tonne of CO2 removed and per kWh of energy saved

	£ per tonne of CO2	£ per kWh
Cavity wall insulation	36	0.0072
Loft insulation	90	0.0171
Replacement heating (200)	60	0.0141
Replacement heating (2000)	600	0.1412

Note: Calculated using Carbon Trust estimates
of CO2 per kWh of electricity and gas

Cost effectiveness

Table: How does this compare?

Intervention type	Reference	Evaluation type	Relevant subset	Percent reduction in energy usage	Engineering estimates of percent reduction in energy usage	Cost effectiveness (cents per kWh saved, 2015 USD)
Behavioral programs	Allcott (2011)	RCT	NA	2		3.6
	Allcott & Rogers (2014)	RCT	One-shot intervention			4.4
			Two-year intervention			1.1 to 1.8
			Four-year intervention			1.2 to 1.8
	Ayres et al. (2012)	RCT	Sacramento, California	2		5.5
			Puget Sound, Washington	1.2		2
Building codes	Novan et al. (2017)	RD analysis	NA	1.3	20	24.4
Efficient equipment or energy savings subsidy	Alberini & Towe (2015)	Matching	NA	5.3		3.9
	Alberini et al. (2016)	DID	Rebate of $1,000 or more	0		
			Rebate of $450	5.5		47.9
			Rebate of $300	6.2		28.2
	Burlig et al. (2017)	Machine learning	NA	2.9 to 4.5	11.6 to 18	
	Davis et al. (2014)	DID regression	Refrigerators	8		27.2
			Air conditioners	plus 1.7		4.5
Information provision	Alberini & Towe (2015)	Matching		5.5		
UK Supplier Obligation (TWC)	McCoy & Kotsch (2018)	Matching, FE regression	Cavity wall insulation	9.4	20.0	1.54 to 2.31
			Loft insulation	3	5.2	3.65 to 5.47
			Replacement heating system	9.2	24.9	3.02 to 30.19
Previous estimate						1.92
Adapted from Gillingham et al (2018)						

Conclusions

Key findings:

- Measures funded by UK Supplier Obligations delivered significant savings for households
- Considerable variation by measure, household type and over time
- Considerably less than engineering model estimates
- Despite this they were cost-effective and compare favourable with other schemes
- Distributional concerns despite explicit targets for deprived households

Policy implications:

- Underlines need to use actual rather than estimated savings
- Evaluations need to better quantify non-financial savings. Particularly comfort and health benefits of EE
- Variation in returns has implications for policy prescription: Low interest loans may need to be **very** low interest for some households

Summary of EIBURS project

Key findings:

- WP 1: Characterised and presented an overview of the key information asymmetries which effect adoption of energy efficiency measures
- WP 2: Provides an empirical analysis of whether banks are pricing energy efficiency projects efficiently. Evidence suggests they are not
- WP 3.1: Outlines the key empirical challenges in performing robust energy efficiency project evaluations
- WP 3.2: Examines how well energy efficiency measures actually perform. UK measures have been largely cost effective, but need to better quantify all costs and benefits, and some distributional concerns.
- Next steps: Finalise results, submit report to EIB and submit papers to peer-review journals.

Summary of EIBURS project

Where to go next:

- Help banks to price EE projects efficiently. Mobilise finance through "Green Tagging" and better quantification the associated risks of "green" vs other portfolios

- "Energy Epidemiology" - leverage more data, smart meters, randomised-controlled trials to better measure energy performance

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Overview of Supplier Obligations

Table: Overview of Supplier Obligations

	ECC1	ECC2	CERT	CESP
Target	62 TWh	130 TWh	293 million t CO2 =494TWh	19.25 Mt CO2
Costs	167 million	400 million	1,158 million	unknown
% savings in priority group	50%	50%	40%	lowest 10-15% of areas ranked by IMD
# cavity wall insulations	791,524	1,336,374	2,568,870	3,000
# loft insulations	528,496 (loft top up, 15,979,367 DIY in m^2)	1,980,445	3,897,324 (professional), 112,850,996 (DIY in m^2)	23,503
# replacement boilers	195,832 (Hot water tank)	2,082,812	31,986	42,898

Source: Lees 2005, 2008; Rosenow, 2012; Ofgem, 2013

Background

IMD

Table: Composition of IMD in %

	England 2010	Wales 2011
Income	22.5	23.5
Employment	22.5	23.5
Health	13.5	14
Education	13.5	14
Access/barriers to services	9.3	10
Living environment/ housing	9.3	5
Physical environment	0	5
Crime [Wales: Community Safety]	9.3	5

NEED Overview

Matching

- FE estimator assumes D_{it} is strictly exogenous and randomly assigned
- Its likely that selection into upgrade is correlated with energy consumption
- Leading to biased estimates
- Pre-process data using CEM to reduce imbalance in observed variables (Iacus, King, and Porro, 2008; Alberini and Towe, 2015)
- Match on variables most likely to predict (i)selection into scheme, (ii) energy consumption; prior year's energy consumption
- Excellent balance on matched, needs improvement on unmatched
- Currently comparing CEM with Nearest Neighbour, Kernel and Mahalanobis metric matching

Matching results

Table: Percentage matched

Dwellings receiving upgrades	Count
Full database	1,869,372
2005 or unknown upgrade date	416,994
Remaining sample	1,452,378
Matched sample	1,286,419
Unmatched	165,959
Matched as a percentage of eligible	89%

Standardised difference:

$$d = \frac{\overline{\mathrm{x}}_{treatment} - \overline{\mathrm{x}}_{control}}{\sqrt{\frac{s^2_{treatment} + s^2_{control}}{2}}} \tag{2}$$

Variance ratio:

$$F = \frac{s^2_{treatment}}{s^2_{control}} \tag{3}$$

Matching results

Table: Balance table for full database

Unmatched sample	Treated			Control			Balance	
Variable	Mean	Variance	Skewness	Mean	Variance	Skewness	Std-diff	Var-ratio
prop_age	2.96	1.98	0.16	3.00	3.00	0.31	-0.03	0.66
imd_both	2.85	2.11	0.15	2.96	2.01	0.05	-0.08	1.05
region	5.34	7.33	0.03	5.81	6.31	-0.29	-0.18	1.16
fuel_type	0.98	0.02	-7.43	0.98	0.02	-6.33	0.04	0.74
Gcons2005	18124	78900000	0.65	17394	86200000	0.73	0.08	0.92
prop_type	3.33	2.63	0.22	3.56	2.92	0.08	-0.14	0.90
floor_area	2.20	0.40	0.89	2.20	0.46	0.77	-0.01	0.86
loft_depth	2.03	0.28	0.04	2.08	0.53	-0.13	-0.08	0.52
wall_cons	0.73	0.20	-1.02	0.59	0.24	-0.36	0.29	0.82
FP_ENG	2.95	1.97	0.06	2.89	2.12	0.10	0.04	0.93
Econs2005	3903	7653561.00	2.16	3998.54	8374713	2.14	-0.03	0.91

Elec/gas matched

Matching results

Table: Balance table for full matched sample

All years matched	Treated			Control			Balance	
Variable	Mean	Variance	Skewness	Mean	Variance	Skewness	Std-diff	Var-ratio
prop_age	2.91	2.32	0.24	2.91	2.31	0.24	0.00	1.00
imd_both	2.92	2.07	0.09	2.92	2.07	0.09	0.00	1.00
region	5.62	6.83	-0.15	5.62	6.82	-0.15	0.00	1.00
fuel_type	0.98	0.02	-7.45	0.98	0.02	-7.47	0.00	1.01
Gcons2005	18020	84200000	0.67	18017	84300000	0.67	0.00	1.00
prop_type	3.36	2.68	0.19	3.48	2.87	0.14	-0.07	0.93
floor_area	2.21	0.42	0.86	2.21	0.45	0.80	0.00	0.93
loft_depth	2.04	0.30	0.03	2.05	0.52	-0.08	-0.02	0.57
wall_cons	0.67	0.22	-0.71	0.63	0.23	-0.52	0.09	0.95
FP_ENG	2.95	2.04	0.06	2.96	2.09	0.05	-0.01	0.98
Econs2005	3945.89	7999389.00	2.15	4028.94	8182317.00	2.09	-0.03	0.98

Elec/gas matched

Matching results

Table: Balance table for 2006 matched sample

2006 Matched	Treated			Control			Balance	
Variable	Mean	Variance	Skewness	Mean	Variance	Skewness	Std-diff	Var-ratio
prop_age	2.90	2.02	0.19	2.93	2.09	0.21	-0.02	0.97
imd_both	2.79	2.07	0.20	2.80	2.07	0.19	-0.01	1.00
region	5.42	7.24	-0.03	5.43	7.22	-0.03	0.00	1.00
fuel_type	0.99	0.01	-9.10	0.99	0.01	-9.14	0.00	1.01
Gcons2005	17844	82300000	0.61	17829	81900000	0.61	0.00	1.00
prop_type	3.49	2.78	0.14	3.52	2.87	0.13	-0.02	0.97
floor_area	2.17	0.43	0.81	2.18	0.43	0.79	-0.02	0.98
loft_depth	2.05	0.36	-0.02	2.06	0.51	-0.08	0.00	0.71
wall_cons	0.69	0.21	-0.81	0.65	0.23	-0.62	0.08	0.94
FP_ENG	2.95	2.01	0.05	2.96	2.06	0.05	0.00	0.97
Econs2005	3915.91	8361364.00	2.17	3957.42	7897173.00	2.13	-0.01	1.06

Elec/gas matched

Matching results

Table: Balance table for 2011 matched sample

2011 Matched	Treated			Control			Balance	
Variable	Mean	Variance	Skewness	Mean	Variance	Skewness	Std-diff	Var-ratio
prop_age	2.97	2.30	0.22	2.97	2.30	0.22	0.00	1.00
imd_both	2.94	2.10	0.06	2.94	2.10	0.06	0.00	1.00
region	5.55	6.95	-0.11	5.55	6.95	-0.11	0.00	1.00
fuel_type	0.98	0.02	-6.92	0.98	0.02	-6.87	0.00	0.99
Gcons2010	14490	67800000	0.91	14410	68300000	0.91	0.01	0.99
prop_type	3.29	2.70	0.24	3.46	2.91	0.15	-0.10	0.93
floor_area	2.24	0.43	0.87	2.22	0.46	0.80	0.03	0.94
loft_depth	2.03	0.31	0.01	2.06	0.51	-0.08	-0.03	0.61
wall_cons	0.67	0.22	-0.74	0.64	0.23	-0.59	0.07	0.95
FP_ENG	2.95	2.02	0.06	2.97	2.06	0.04	-0.02	0.98
Econs2010	3508.37	6440704.00	2.14	3615.08	6580746.00	2.17	-0.04	0.98

Elec/gas matched

Cost assumptions

Table: Assumptions for costs of measures

	Low (£)	High (£)
Cavity wall (pre 1976)	300	325
Cavity wall (post 1976)	300	325
Loft 300mm (currently none)	138	273
Loft 300mm (currently 100mm)	86	211
Loft 300mm (currently 200mm)	35	170
Condensing boiler	100	300

Source: Shorrock (2005)

Table: Assumptions for costs of measures

	(1994) EESOP1	EESOP2	EESOP3	(2005) EEC1
Cavity wall insulation	223	219	261	261
Condensing boiler	450	270	165	114

Source: Lees (2005)

Cost effectiveness

Table: Assumptions for costs of measures

	Defra EEC1	Defra EEC2	Defra CERT	Lees 2005	Lees 2008
Cavity wall insulation	268	313	380	274	350
Loft insulation (top up)	213	260	286	217	275
Loft insulation (virgin)	213	260	286	252	295
A and B boiler	145			120	
A and B boiler and heating control	217			190	
All boilers			50		45

Source: Lees (2005, 2008)

R3: Comparison with ex-ante SAP predictions

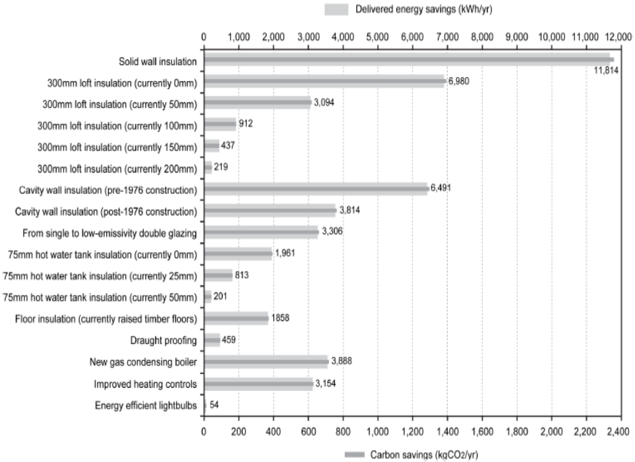

Figure: Predicted savings for typical semi-detached dwelling. Source: Shorrock (2005); Dowson (2012)

Results 2

Table: The effect of energy efficiency upgrades on energy consumption for varying levels of area-level deprivation in England and Wales

	(1) All (b/se)	(2) IMD_BOTH=1 (b/se)	(3) IMD_BOTH=2 (b/se)	(4) IMD_BOTH=3 (b/se)	(5) IMD_BOTH=4 (b/se)	(6) IMD_BOTH=5 (b/se)
Cavity wall insulation	-0.083***	-0.063***	-0.078***	-0.090***	-0.092***	-0.098***
	(0.001)	(0.003)	(0.002)	(0.002)	(0.002)	(0.002)
Loft insulation	-0.018***	0.009***	-0.013***	-0.020***	-0.030***	-0.037***
	(0.001)	(0.002)	(0.002)	(0.002)	(0.002)	(0.002)
Replacement boiler	-0.038***	-0.021***	-0.029***	-0.035***	-0.048***	-0.057***
	(0.001)	(0.002)	(0.002)	(0.002)	(0.002)	(0.001)
Control variables	Y	Y	Y	Y	Y	Y
Household fixed effects	Y	Y	Y	Y	Y	Y
Year fixed effects	Y	Y	Y	Y	Y	Y
Year*region fixed effects	Y	Y	Y	Y	Y	Y
Observations	14,090,155	3,003,248	2,889,623	2,687,038	2,611,884	2,898,362
Number of households	1,764,246	376,494	361,945	336,373	326,837	362,597
R squared	0.1146	0.1002	0.1077	0.1172	0.1306	0.1424

Notes: This table reports coefficient estimates and standard errors from six separate regressions. The dependent variable in all regressions is annual gas consumption in kilowatt hours. Column(1) "All" denotes efficiency upgrades occurring for all matched households in the sample. Columns (2-6) report segmented results for households allocated to the Incidence of Multiple Deprivation (IMD) of the area in which they reside, where 1=most deprived and 5=least deprived. For each upgrade group a matched control group is created using coarsened-exact matching. The sample includes billing records from 2005 to 2012. Standard errors are clustered at the household level. Triple asterisks denote statistical significance at the 1% level; double asterisks at the 1% level; single asterisks at the 10% level.

Results 2

Table: Additional estimation results

The effect of energy efficiency upgrades on energy consumption

	(1) Full sample	(2) Only gas	(3) Matched sample	(4) Only gas and matched	(5) Only gas, matched and elec	(6) 50 drop	(7) 60 drop	(8) 70 drop	(9) 70 drop, elec
Cavity wall insulation	-0.092***	-0.092***	-0.083***	-0.084***	-0.083***	-0.095***	-0.096***	-0.094***	-0.092***
	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)
Loft insulation	-0.025***	-0.026***	-0.018***	-0.019***	-0.020***	-0.029***	-0.030***	-0.030***	-0.029***
	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)
Replacement boiler	-0.055***	-0.062***	-0.038***	-0.045***	-0.049***	-0.090***	-0.092***	-0.092***	-0.091***
	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)
					0.179***				0.138***
					(0.000)				(0.001)
Control variables	Y	Y	Y	Y	Y	Y	Y	Y	Y
Household fixed effects	Y	Y	Y	Y	Y	Y	Y	Y	Y
Year fixed effects	Y	Y	Y	Y	Y	Y	Y	Y	Y
Year*region fixed effects	Y	Y	Y	Y	Y	Y	Y	Y	Y
Observations									
Number of households									
R squared	0.115	0.118	0.115	0.167	0.118	0.398	0.375	0.349	0.369