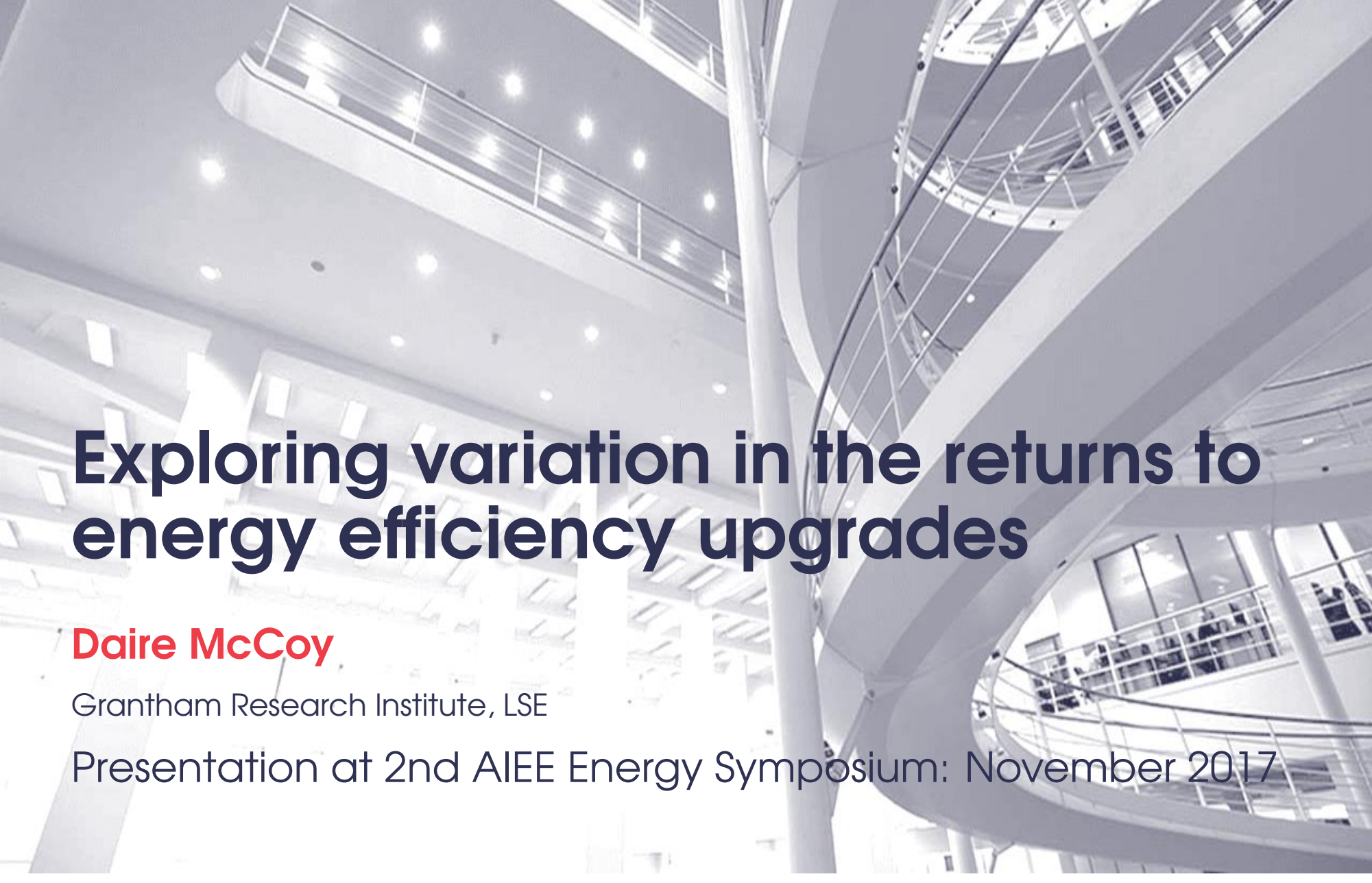

Exploring variation in the returns to energy efficiency upgrades

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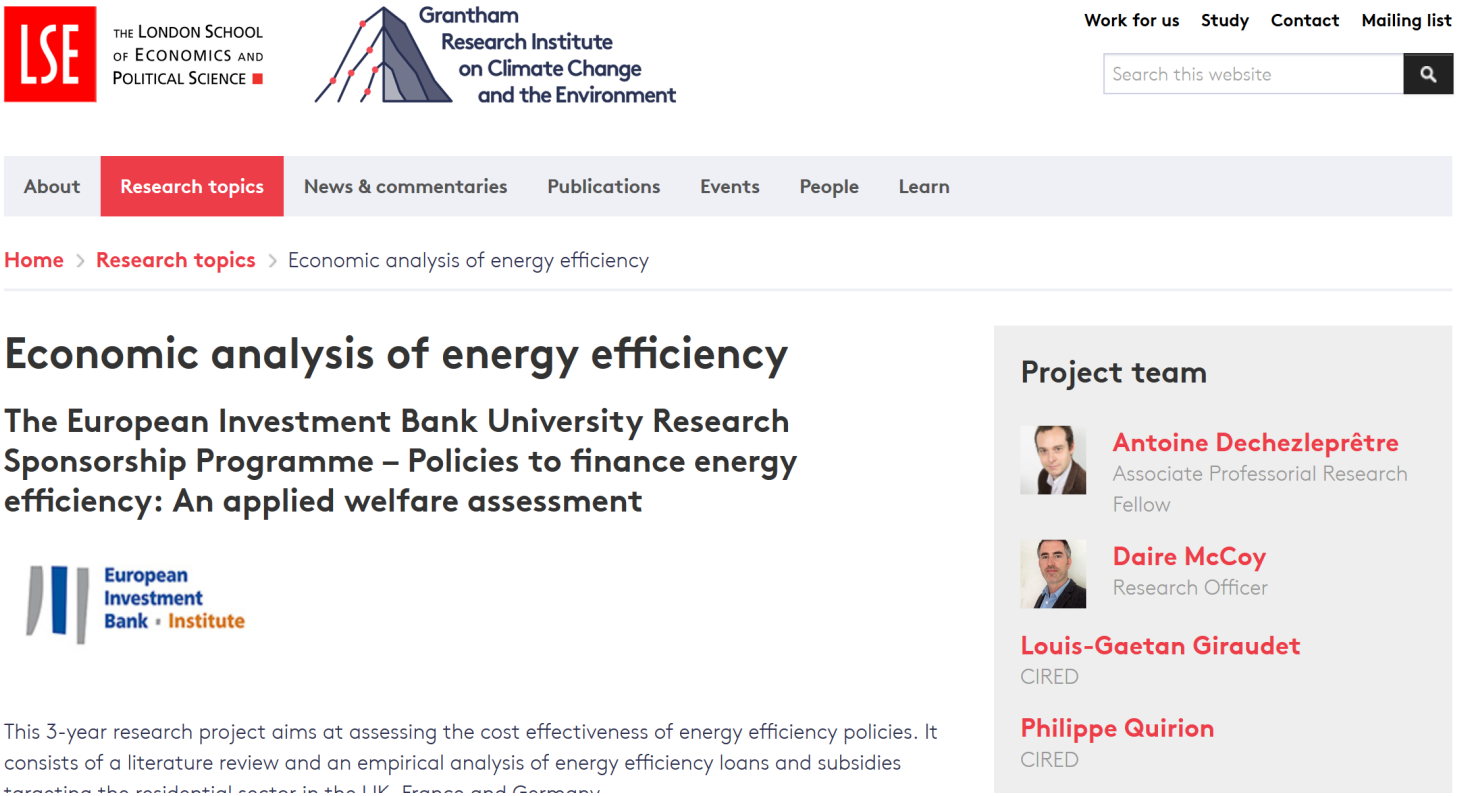
EIB funded project examining energy efficiency financing



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Introduction and motivation

- EU and UK policies to reduce emissions
  - EU 2020 Strategy
  - UK 2008 Climate Change Act
- Domestic energy consumption accounts for approx 25% of emissions
- Requires market-based or policy instruments to reduce consumption
  - Consumers can be reluctant to adopt energy saving measures - energy efficiency gap (Jaffe and Stavins, 1994; Allcott and Greenstone, 2012).
  - Policy evaluations are beset by problems - measurement error, free-riding, rebound effect (Alberini et al, 2013; Nalau, 2014; Boomhower and Davis, 2015)

Introduction and motivation

- 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
- Fowlie at al. (2015) analysis of US WAP
  - Engineering estimates can overstate the actual savings by as much as 2.5 times
- 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

What we do

Work completed so far:

- Systematically explores uncertainty and heterogeneity in returns to energy efficiency upgrades
- Characterise cross-sectional and temporal variation in the returns to energy efficiency
- Database of over four million households over an eight year period
- Statistical matching and panel econometric estimations to make a case for causality

Current work involves:

- Calculating the cost-effectiveness of installing certain measures
- Examining how the NPV of measures varies depending on other factors
- Explore distributional consequences of various policies

Background

- UK Supplier Obligations (Tradeable White Certificates)
  - Principal policy instrument for domestic energy efficiency in the UK
  - Also widely used in Europe (Italy, France)
  - Hybrid subsidy-tax instrument (Giraudet, 2012)
- Three main features:
  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

Background

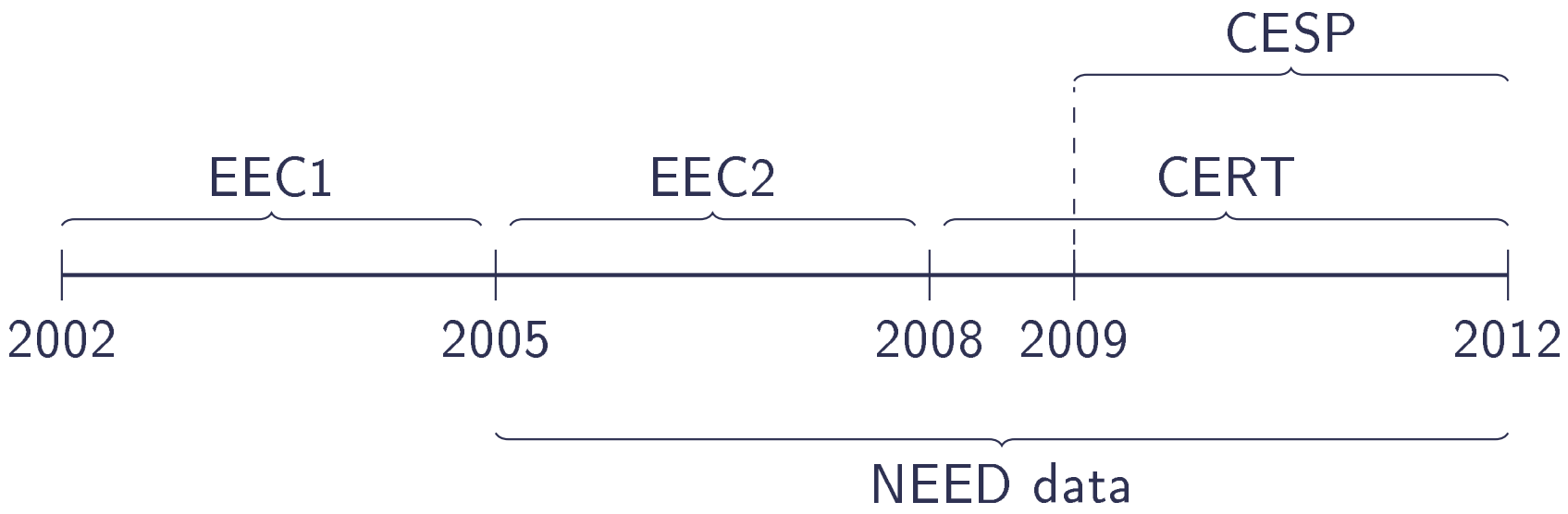

Figure: UK Energy Efficiency Programmes 2005-2012

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 (2006, 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

Measures installed

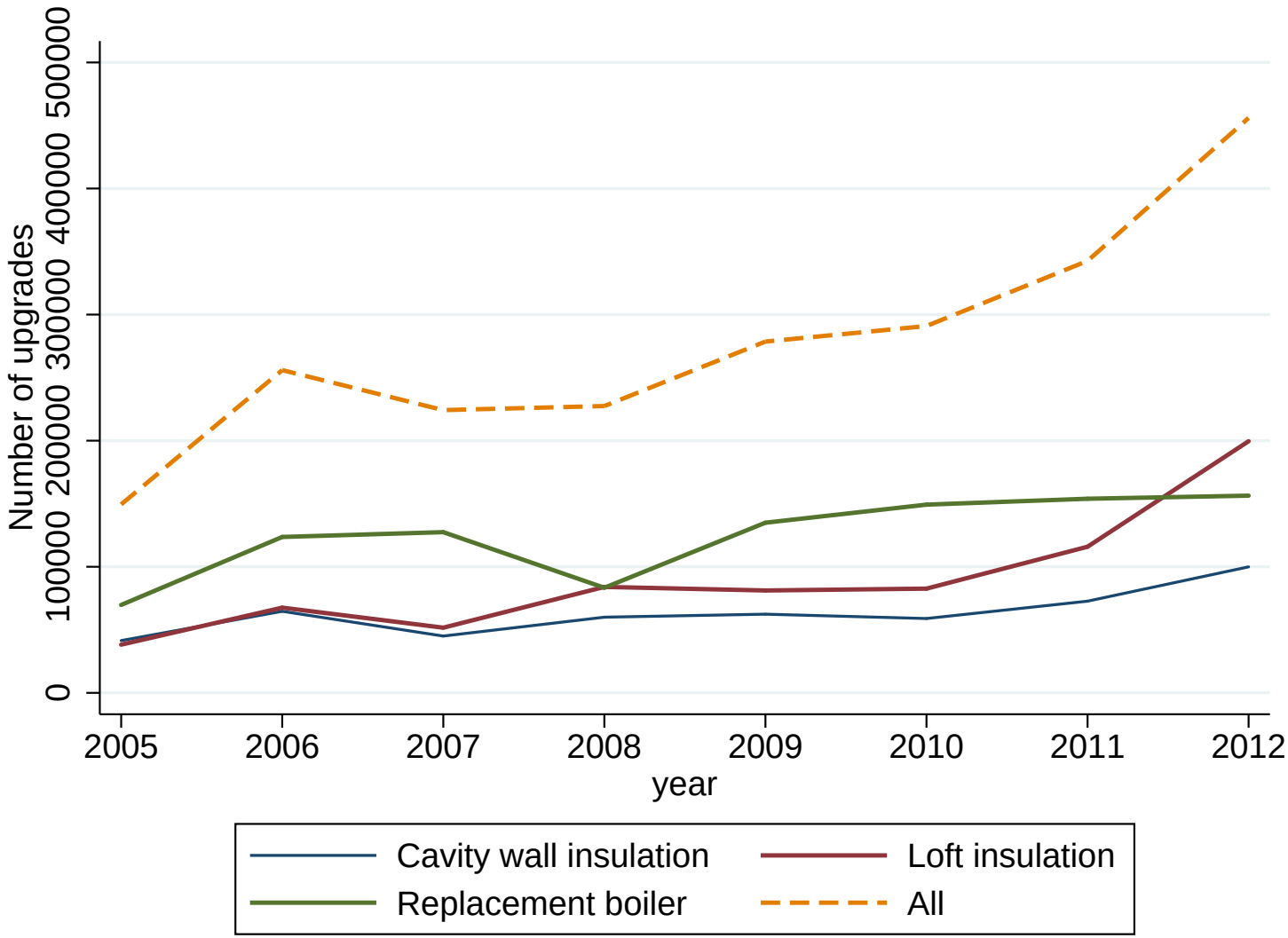

Figure: Energy efficiency measures installed, 2005-2012

Domestic energy consumption

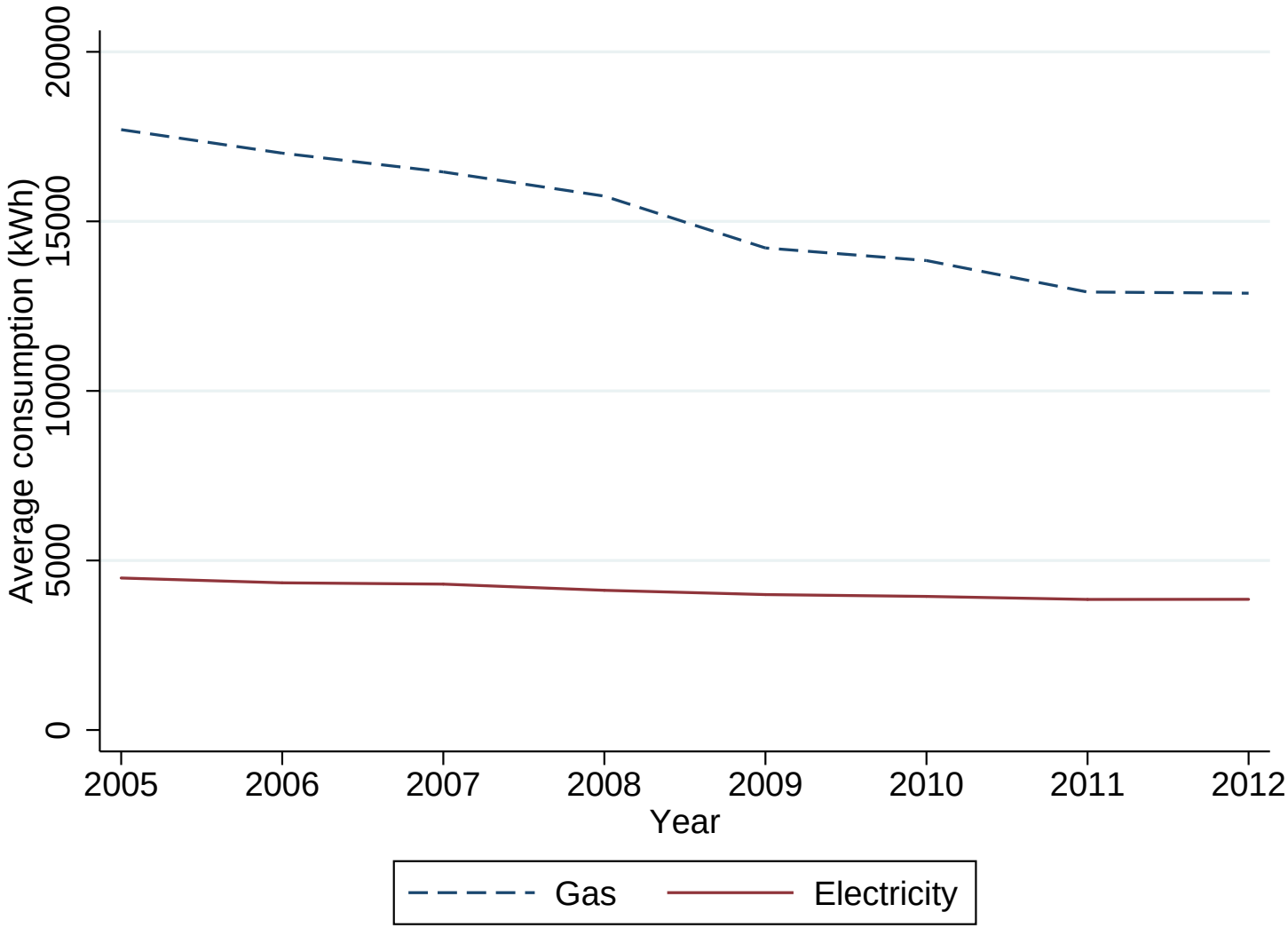

Figure: Average domestic energy consumption UK, 2005-2012

Econometric approach

First differenced panel fixed-effects estimation:

$$lnY_{it} = \alpha_i + \gamma_t + \rho_{rt} + \lambda_t + \delta D_{it} + \epsilon_{it} \quad (1)$$

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
- ϵ_{it} - error term
- D_{it} - treatment dummy
- δ - ATT

Unobserved heterogeneity

- 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 (Alberini and Towe, 2015)
- Currently comparing CEM with Nearest Neighbour, Kernel and Mahalanobis metric matching

Matching results

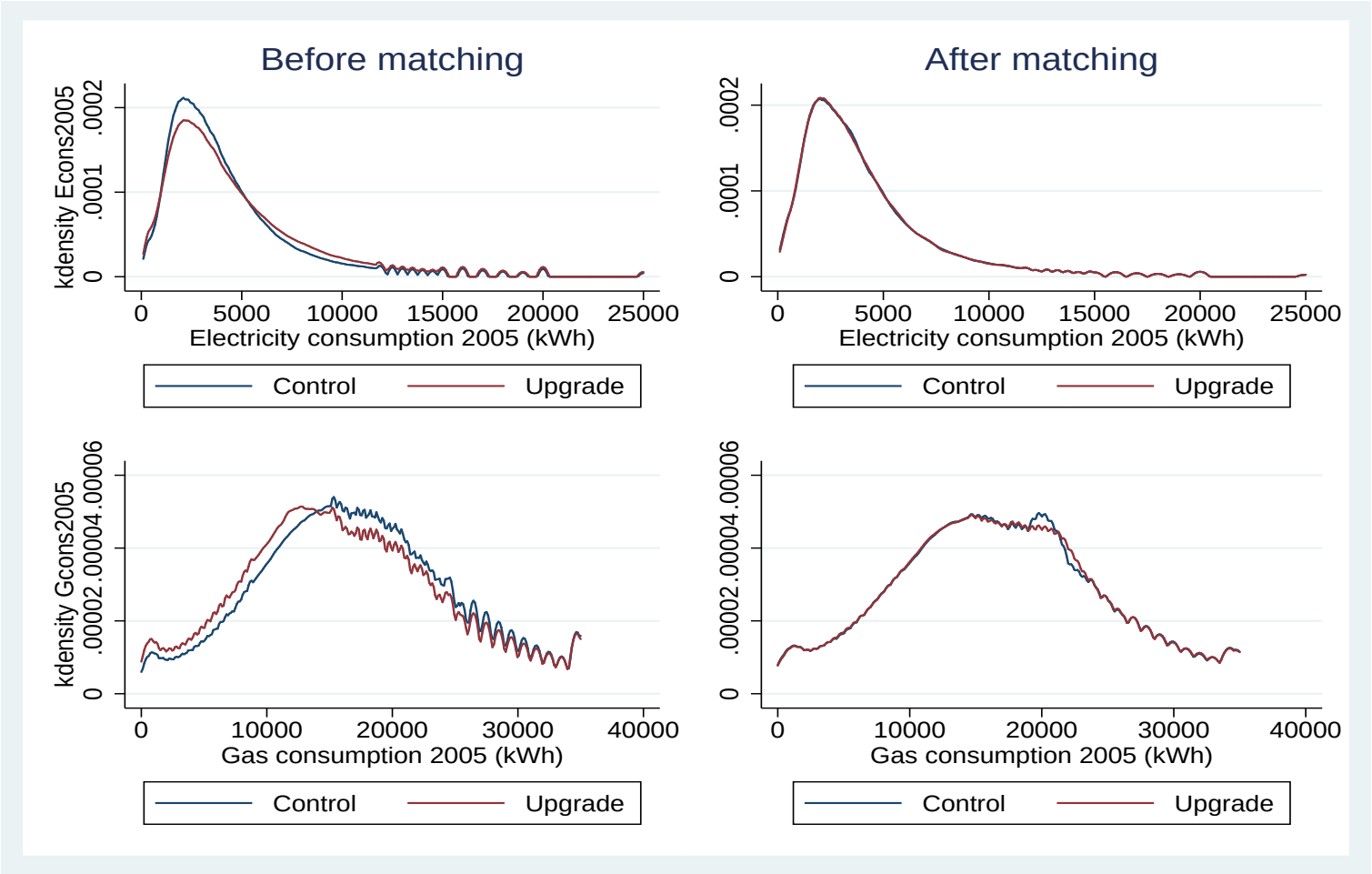

Figure: Energy consumption before and after matching

Balance table

Results 1

Table: The effect of energy efficiency upgrades on energy consumption

	(1) All (b/se)	(2) 2006 (b/se)	(3) 2007 (b/se)	(4) 2008 (b/se)	(5) 2009 (b/se)	(6) 2010 (b/se)	(7) 2011 (b/se)	(8) 2012 (b/se)
Cavity wall insulation	-0.083***	-0.091***	-0.106***	-0.094***	-0.091***	-0.085***	-0.093***	-0.092***
	(0.001)	(0.003)	(0.003)	(0.003)	(0.002)	(0.003)	(0.003)	(0.003)
Loft insulation	-0.018***	-0.023***	-0.024***	-0.026***	-0.026***	-0.029***	-0.020***	-0.019***
	(0.001)	(0.003)	(0.003)	(0.002)	(0.002)	(0.003)	(0.002)	(0.002)
Replacement boiler	-0.038***	-0.013***	-0.031***	-0.038***	-0.054***	-0.061***	-0.058***	-0.057***
	(0.001)	(0.003)	(0.003)	(0.003)	(0.002)	(0.002)	(0.002)	(0.002)
Control variables	Y	Y	Y	Y	Y	Y	Y	Y
Household fixed effects	Y	Y	Y	Y	Y	Y	Y	Y
Year fixed effects	Y	Y	Y	Y	Y	Y	Y	Y
Year*region fixed effects	Y	Y	Y	Y	Y	Y	Y	Y
Observations	14,090,155	1,581,449	1,426,137	1,402,156	1,825,972	1,919,219	2,224,096	2,220,313
Number of households	1,764,246	198,001	178,569	175,528	228,625	240,379	278,554	278,071
R squared	0.1146	0.1067	0.1123	0.1348	0.1213	0.1159	0.1131	0.117

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.

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

Results 3

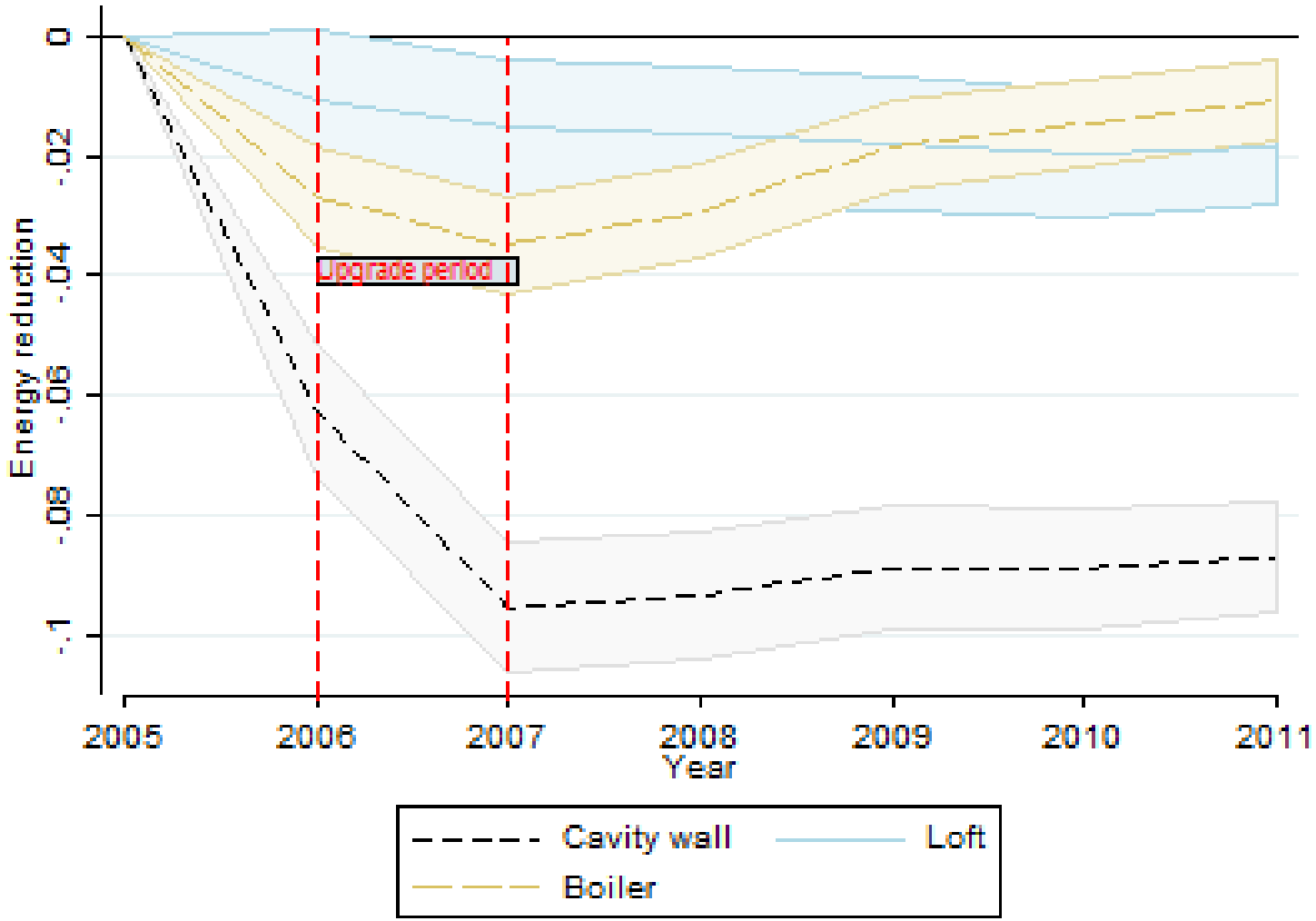

Figure: ATT gas consumption, 2005-2012

Results 3

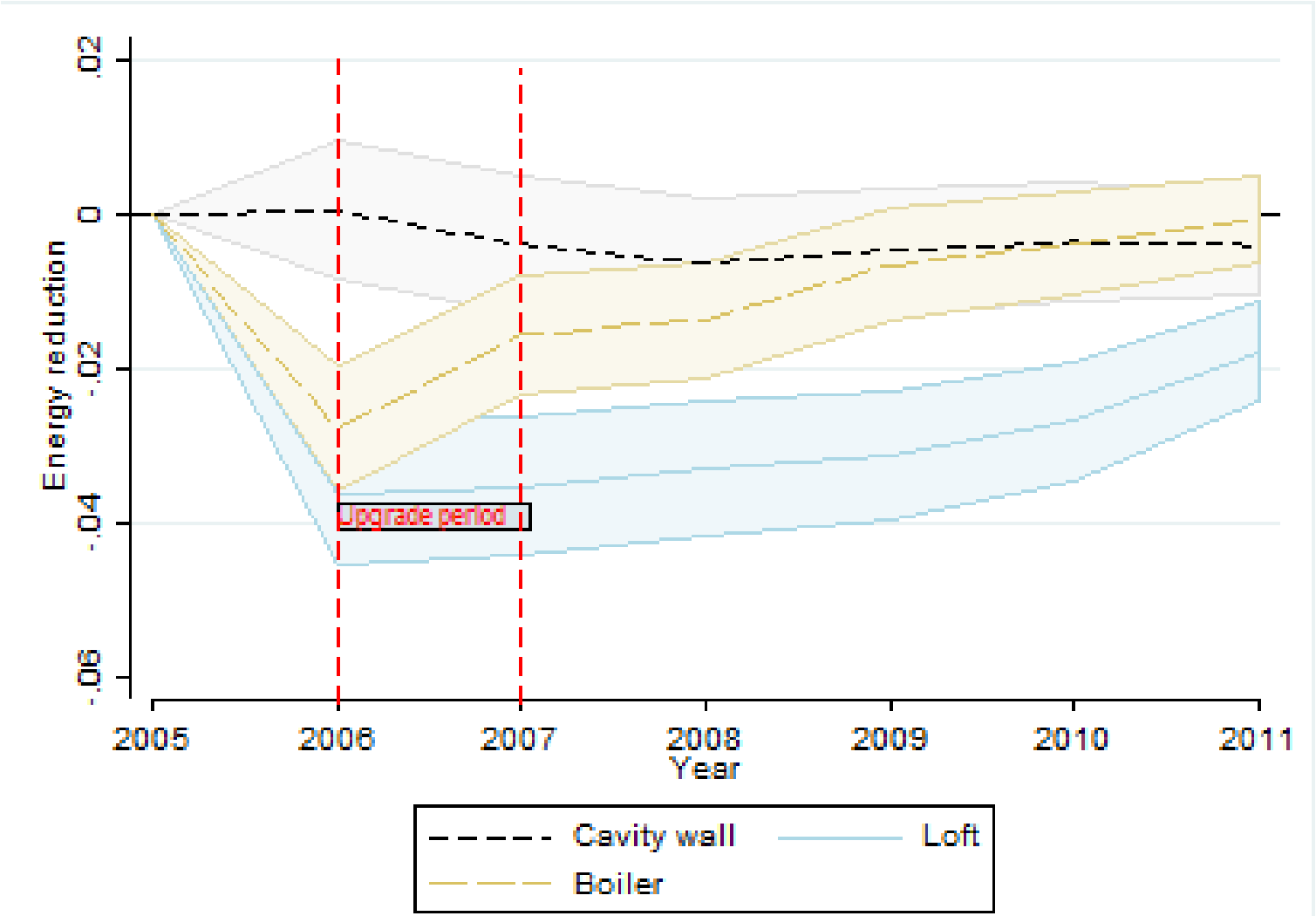

Figure: ATT electricity consumption, 2005-2012

Next steps...

- Analyse whole energy consumption
- Further explore variation by socioeconomic and dwelling characteristics - distributional consequences
- Examine cost-effectiveness of measures/policies. Cost per tonne of CO_2 removed
- Explore the extent to which observed uncertainty in savings and variation in prices explains energy efficiency gap
- Further robustness tests

Thank You!

Questions and comments greatly appreciated

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Matching results

Table: Balance tables for coarsened-exact matching

		Treated			Control			Balance	
	Variable	Mean	Variance	Skewness	Mean	Variance	Skewness	Std-diff	Var-ratio
2006 Upgrades									
Variables used in matching	prop_age	2.901	2.022	0.188	2.934	2.093	0.209	-0.022	0.966
	imd_both	2.793	2.072	0.200	2.801	2.073	0.193	-0.005	0.999
	region	5.422	7.241	-0.025	5.434	7.222	-0.031	-0.004	1.003
	fuel_type	0.988	0.012	-9.098	0.988	0.011	-9.144	-0.001	1.010
	Gcons2005	17,844	82,300,000	0.613	17,829	81,900,000	0.613	0.002	1.004
Variables not used in matching	prop_type	3.486	2.781	0.135	3.516	2.874	0.131	-0.017	0.968
	floor_area	2.168	0.426	0.806	2.184	0.433	0.794	-0.023	0.984
	loft_depth	2.055	0.361	-0.021	2.057	0.510	-0.083	-0.003	0.707
	wall_cons	0.688	0.215	-0.811	0.648	0.228	-0.621	0.084	0.942
	FP_ENG	8.510	504.478	3.765	8.501	502.775	3.772	0.000	1.003
	Econs2005	3,916	8,361,364	2.170	3,957	7,897,173	2.125	-0.015	1.059
2007 Upgrades									
Variables used in matching	prop_age	2.848	2.177	0.264	2.883	2.258	0.277	-0.023	0.964
	imd_both	2.784	2.080	0.203	2.789	2.080	0.199	-0.003	1.000
	region	5.364	7.132	-0.001	5.372	7.138	-0.006	-0.003	0.999
	fuel_type	0.990	0.010	-9.810	0.990	0.010	-9.858	-0.001	1.009
	Gcons2006	17,414	82,100,000	0.650	17,397	81,700,000	0.653	0.002	1.005
Variables not used in matching	prop_type	3.479	2.727	0.132	3.498	2.810	0.139	-0.011	0.970
	floor_area	2.186	0.430	0.823	2.195	0.435	0.807	-0.013	0.988
	loft_depth	2.060	0.376	-0.034	2.061	0.509	-0.090	-0.002	0.739
	wall_cons	0.659	0.225	-0.670	0.629	0.233	-0.535	0.062	0.964
	FP_ENG	7.777	437.916	4.110	7.771	436.075	4.119	0.000	1.004
	Econs2006	3,839	7,737,432	2.128	3,902	7,311,557	2.063	-0.023	1.058
2008 Upgrades									
Variables used in matching	prop_age	2.943	2.138	0.184	2.950	2.153	0.188	-0.005	0.993
	imd_both	3.009	2.091	-0.006	3.012	2.089	-0.008	-0.002	1.001
	region	5.315	7.269	0.059	5.316	7.270	0.056	0.000	1.000
	fuel_type	0.986	0.014	-8.370	0.986	0.013	-8.390	-0.001	1.004
	Gcons2007	17,654	80,300,000	0.696	17,646	80,200,000	0.696	0.001	1.001
Variables not used in matching	prop_type	3.294	2.692	0.199	3.379	2.843	0.206	-0.051	0.947
	floor_area	2.249	0.431	0.872	2.236	0.453	0.808	0.020	0.951
	loft_depth	2.029	0.290	0.023	2.036	0.500	-0.051	-0.011	0.581
	wall_cons	0.698	0.211	-0.863	0.661	0.224	-0.680	0.079	0.941
	FP_ENG	8.062	459.626	3.988	7.997	456.536	4.006	0.003	1.007
	Econs2007	3,724	6,866,999	2.233	3,942	7,341,078	2.014	-0.082	0.935