# Annex E: Summary of NERA Work

## Contents

# Executive Summary

This summary has been written by DECC and reflects DECC's interpretation of NERA's original report for DECC, this summary has not been reviewed by NERA.

## Introduction

This report is a summary of the econometric work carried out by NERA Economic Consulting on behalf of DECC. The work was carried out using data in the National Energy Efficiency Data-framework (NEED) before the consumption data for 2009 and 2010 had been included and further validation of the consumption data in NEED had been undertaken. The initial analysis was completed just after the 2011 NEED report was published, so the results and commentary were not available for inclusion. We are publishing this information now to aid users in understanding the various modelling approaches that have been tested on the NEED data and to encourage any further feedback from users on ideas for developing the analysis.

## Aims and objectives

The main objectives of the work were to use the data in NEED to:

1. Estimate the impact of specific household energy efficiency measures on domestic energy use.
2. Estimate a more general model of domestic energy demand (with a focus on gas consumption).

It was envisaged that the panel nature of the data, that is both among households and across years, would be exploited in the analysis to produce robust estimates.

## Methods

A variety of econometric approaches were used in order to realise these aims and identify the most reliable estimates. These methods included difference in difference, fixed effect panel regression, non-parametric techniques and two stage regression. The analysis was also extended to households with specific characteristics such as those on lower incomes and those residing in a 3 bedroom semi-detached house, the typical home in England.

## Key findings

### Impacts of measures

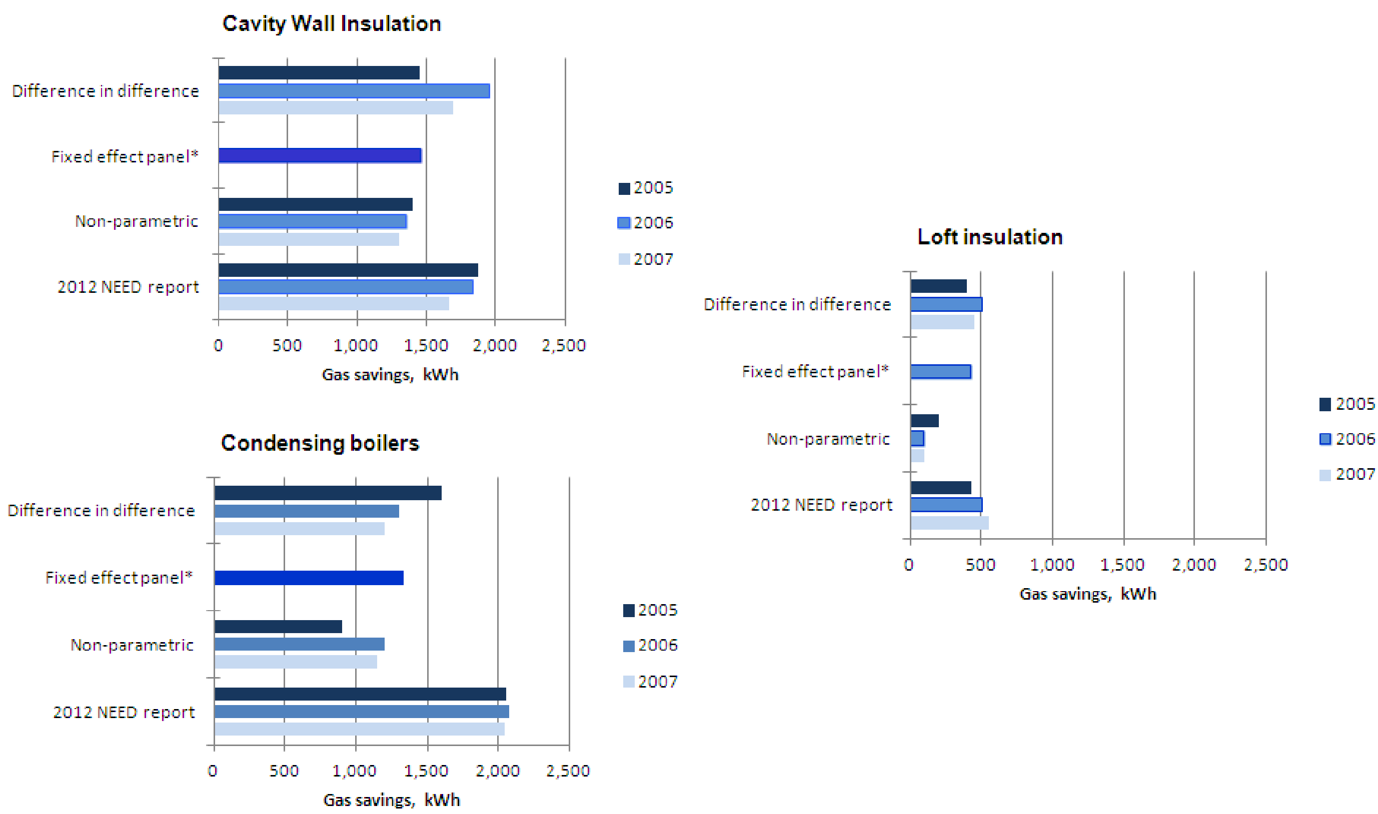
A comparison of the results for the impact of energy efficiency measures is shown in Figure 1. In each chart, the first three groups of bars are the results from this work while the set of bars at the bottom are the results from the difference in differences approach presented in the main report of which this summary is an annex.

The key findings are:

1. All the methods employed showed the measures considered led to reduced gas consumption following installation of the measures. Cavity wall insulation led to the greatest reduction in gas consumption, followed by condensing boilers and then loft insulation. This result is consistent with the results in the main report.

2. The savings from the difference in difference method were generally lower than the mean savings reported from the same method in the main report. For example, for 2005, the mean savings from cavity wall insulation was almost a quarter (23 per cent) less than the estimate in the main report. For condensing boilers, the discrepancy was much larger and almost doubled from 22 per cent in 2005 to 41 per cent in 2007. The discrepancies are due to the enhanced design of the comparator group and improved cleaning of energy data carried out by DECC in this NEED report.

**Figure 1: Impact of Energy Efficiency Measures, 2005 to 2007**




3. The results from the difference in difference method were similar on average to those from the fixed effect panel regression and slightly larger than the non parametric approach.

## Model of energy demand

The drivers of energy consumption are presented in Table 1. In this table, the factors are listed approximately in order of the size of the impact and factors with larger effects on energy demand are higher up in the list.

The factors included in the model collectively explain about one-third of the variation in gas consumption across the NEED data. The majority of the explained variation was from differences between households rather than differences in year to year consumption for the same household.

**Table 1: Model of domestic energy demand**

| Very important factors | Other less important factors | Others without significant impact |
|---|---|---|
| Area of dwelling<br>Energy efficiency measures<br>Region<br>Property type<br>Number of adults<br>Property age<br>Number of floors<br>Income<br>Female head of household<br>Number of rooms (excludes bathrooms, kitchens and conservatories)<br>Tenure[1] (rented relative to owner occupiers)<br>Number of bathrooms[2] | No conservatory<br>Age of household head[1] (age groups 26-35 and 56-65 relative to 18-25) | Conservatory characteristics (e.g. all glazed/lean to, single glazed UPVC/hardwood) |

1. Effect of this was a decrease in consumption.
2. For bathrooms, this shows that space used by bathrooms is less heated than other rooms.

This is broadly consistent with other work conducted or commissioned by DECC[1], with the best fit to date being an R-squared value of about 40 per cent. The conclusion of all this work is that the majority of variance in gas consumption comes from individuals not properties.

[1] This includes DECC local area gas model (See the special feature ‘Identifying local areas with higher than expected domestic gas use’ in Energy Trends, March 2012 available at: http://www.decc.gov.uk/assets/decc/11/stats/publications/energy-trends/4779-energy-trends-mar12.pdf) and well as the regression analysis carried out by Katalysis on behalf of DECC covered in annex F of the main NEED report.

# 1. Introduction

In order to aid development of energy efficiency policy, DECC commissioned NERA Economic Consulting to carry out econometric analysis using the data in the National Energy Efficiency Data-framework (NEED). There were two related aims of this work:

1. To estimate the impact of specific household energy efficiency measures on domestic energy use.

2. To estimate a more general model of domestic energy demand (with a focus on gas consumption).

The first aim includes estimating the average impact on gas consumption for all households that installed energy efficiency measures, as well as the impact on specific households such as those on lower incomes or those in three bedroom semi-detached houses, the typical home in England.

The second aim involved building econometric models relating household energy demand to energy prices, household and dwelling characteristics and the presence of energy efficiency measures. Such models help to predict the expected effect on energy consumption for a household randomly selected from all households with the potential to take up a specific energy efficiency measure. These methods could help to estimate the expected effect of specific energy efficiency measures on households with specific characteristics. More generally, it would allow areas to be identified which would benefit from energy efficiency measures. This is valuable to assist DECC and providers to target policies more effectively[2].

This report focuses on the impact on energy consumption of three energy efficiency measures: loft insulation, cavity wall insulation and new energy efficient gas boilers. These have played an important part in recent efforts to reduce domestic energy consumption. The effects were considered for households that only had one of these measures installed and also for those who had installed more than one of these measures.

In June 2011, DECC published the first report containing analysis using NEED. This summary is an annex to the second NEED report published in November 2012, referred to here as the "main report". The data used for the NERA analysis were a representative sample of approximately 3.5 million households in England, 15 per cent of homes in England. More detailed information on NEED is available in Annex A of the main report which is available here: http://www.decc.gov.uk/en/content/cms/statistics/energy_stats/en_effic_stats/need/need.aspx.

This summary has been written by DECC and reflects DECC's own interpretation of NERA's original report for DECC, but the summary has not been reviewed by NERA.

[2] DECC has also built a model to help with targeting 'Identifying local areas with higher than expected domestic gas use' in Energy Trends, March 2012 available at: http://www.decc.gov.uk/assets/decc/11/stats/publications/energy-trends/4779-energy-trends-mar12.pdf

# 2. Analysis Plans

In this section, the plans for analysis to achieve the aims are outlined.

## 2.1 Impacts of energy efficiency measures

The impact on energy consumption of loft insulation, cavity wall insulation and energy efficient boilers in houses (not flats) was considered.

The approaches used are outlined below:

1. Basic assessment of dataset including descriptive statistics
2. Analysis of impacts using basic treatment and comparator group
3. Analysis of impacts using treatment and comparator group with difference in difference
4. Fixed effects panel analysis
5. Non-parametric analysis

Basic assessment of NEED was designed to explore any fundamental issues with the data and identify key variables to consider for creating treatment and comparator groups. Details of the assessment and descriptive analysis carried out are available in Appendix 1.

Analysis of the impacts using basic treatment and comparator groups was considered in order to compare the average consumption of households that had been treated to those that had not. This simple approach was then enhanced with a difference in difference approach (the method used in the main report) to investigate how consumption changed across years between the treatment and the comparator. Finally these approaches were compared to more advanced techniques to explore how sensitive the findings were to different measurement approaches. Descriptions of the methods employed can be found in Appendix 2.

These approaches were also compared to the coefficients for treatment effects from models of domestic energy demand as outlined below.

## 2.2 Model of domestic energy demand (focus on gas consumption)

Based on the original descriptive analysis in the work on impacts outlined above, a number of variables were assessed for relevance to a model of energy demand.

Three approaches were considered to build a model of domestic energy demand:

1. Ordinary least squares (OLS) regression
2. Random effects panel model

3. Fixed effects panel model using 2 stage regression

The OLS regression aimed to predict consumption at a property level based on household characteristics, prices, year effects and treatment effects. However it does not attempt to account for unobserved explanatory variables (i.e. other factors which may account for variance in consumption, but we do not have data for).

Random effects and fixed effects panel regression models make different assumptions about how these unobserved explanatory variables are related to the existing or observed explanatory variables, and attempt to specifically model for these effects such that we get the best estimates of treatment effects.

It should be noted that price data was not available at household level.

More details about the methods are available in Appendix 3.

# 3. Summary of Results – Impacts of Measures

In this section, a summary of the impact of measures obtained by the different approaches is presented and compared. The results of the difference in difference approach presented here are also compared with the difference in difference results obtained in the 2012 NEED report (the “main report”).

The results of the impact of measures through the various approaches are shown in Figure 3.1. In this figure, the first four groups of bars for each chart represent outputs from the consultants project. The last set of bars at the bottom are the results from the difference in differences approach presented in the main report of which this summary is an annex.

Across all four approaches, cavity wall insulation was found to produce the greatest savings, followed by condensing boilers and then loft insulation. This is consistent with the results in the main report. However, the size of the reduction from measures depended on the approach used.

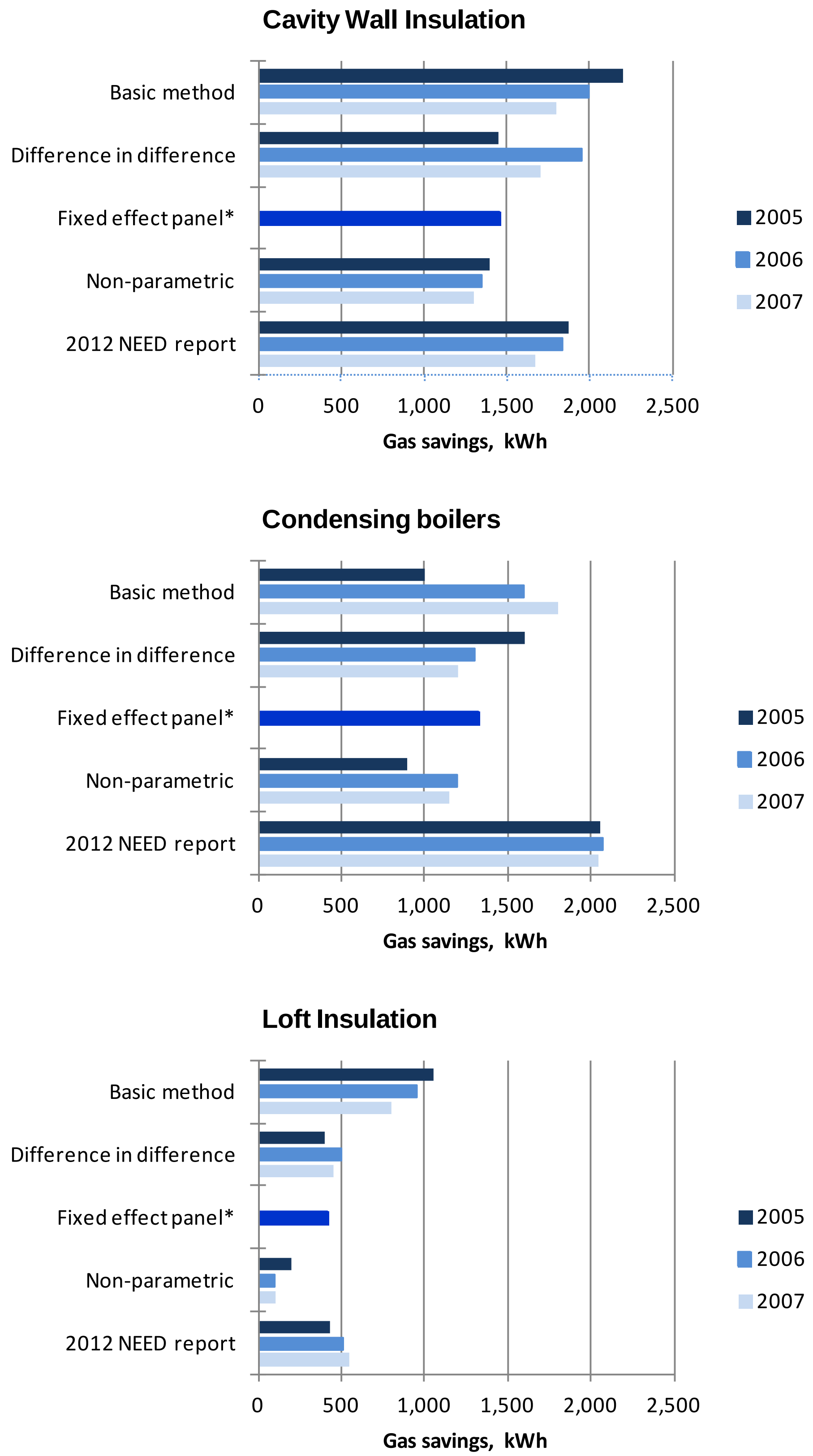
In particular, results using the basic treatment and comparator approach were generally larger, more variable and particularly for loft insulation, least consistent with other methods. The basic approach assumes that untreated households and treated households are similar in all respects, other than having energy efficiency measures installed, so direct comparisons can be made between their energy consumption to estimate impact size of measures. However, households that take up measures and are therefore in the treatment group have different characteristics to those that do not and are classed as untreated.[3] Therefore, the assumption is weak and estimates from this method are less reliable. and less emphasis should be placed on them.

The results from the difference in difference approach in this summary and those published in the main NEED report vary according to the energy efficiency measure and the installation year being considered. The most significant differences were in cavity wall insulations in 2005 and condensing boilers.

The discrepancies may be explained by the different methodology for defining the comparator group in the two reports. For this work, the comparator group was not selected in order to have similar characteristics to treated households while matching was carried out in the main report. In addition, valid consumption was defined as between 1 and 73,200 kWh and households only needed to have valid gas consumption the year before and the year after the measure was installed. In the main report, only households with gas consumption between 2,500 and 50,000 kWh in all years were included.

[3] Refer to section A2.2.3 in Appendix 2 for more details of these differences.

## Figure 3.1: Impact of Energy Efficiency Measures, 2005 to 2007




* Fixed effects panel results are not year specific and represent the average effect over the period 2004 to 2008.

More details about the methodology used by NERA are available in section A2.2 of Appendix 2. Details of the methodology used by DECC can be found in Annex D of the main report.

The results in this section are overall results for all properties in England.

## 3.1 Single measures

### Cavity wall insulation

Cavity wall insulation reduced gas consumption by around 1,300 – 2,200 kWh, depending on the estimation approach and the year considered. The panel and non-parametric methods both produced comparable estimates around the lower end of this range. The panel results were about 1,500 kWh while the non-parametric estimates were slightly lower averaging at 1,400 kWh[4]. The difference in difference estimates were on average around 1,700 kWh between 2005 and 2007, with a high of around 1,950 kWh in 2006. The basic treatment/comparator method produced the largest estimate of savings, around 2,000 kWh on average.

In the main report, the annual mean saving[5] for 2005 to 2007 was estimated to be between 1,700 and 1,900 kWh. The discrepancy between the difference in difference approaches was largest in 2005; the results in this work were almost a quarter (23 per cent) lower than the savings reported in the main report. However, in 2006 they were 6 per cent higher while in 2007 both results were comparable.

### Condensing boilers

There was more variation in the estimates for condensing boilers; gas consumption reduced by around 900 to 1,800 kWh. The lower end of this range was from the non-parametric approach and the higher end from the basic treatment/comparator estimates.

The mean savings from the difference in difference approach in the main report was fairly constant over the period at around 2,000 kWh. However, the savings were consistently lower in this work and the discrepancy depended on the year of installation. The difference was 22 per cent in 2005 compared to 41 per cent in 2007.

### Loft insulation

Loft insulation was found to have the smallest impact, reducing annual gas consumption by around 100 – 900 kWh.

The estimates were the least consistent across approaches. The panel approach suggested savings in the order of 400 kWh. While this was consistent with the difference in difference results, the non-parametric approach suggested savings of between 100 and 200 kWh. In addition, the savings from the basic treatment/comparator approach were about double those of the panel and difference in difference approaches.

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4 To aid comparison with the panel results which are not year specific, results from the other approaches have also been reported as the average amount of savings, but over the three years from 2005 to 2007 for which the data is more reliable.

5 In general, the savings in the 2012 NEED report were reported in terms of the median. However, comparisons with the mean savings are made here for consistency with the results in this report.

The mean savings here were similar on average but generally slightly lower than those in the main report, particularly in 2007 where they were 18 per cent less. The results for loft insulation were comparable in 2006.

## 3.2 Combinations of measures

In general, the results from the two advanced techniques (panel analysis and non-parametric methods) were consistent with each other in terms of the relative magnitudes of the results. For the combination of loft insulation and condensing boilers, the non-parametric results were less consistent, particularly for 2005 and 2006, due to the relatively small number of observations of households with combinations of treatments.

## 3.3 Dependency of treatment effects on household characteristics

The treatment effects themselves differ by household type. The non-parametric analysis provides treatment effect estimates for 216 different categories of household (outlined in section A2.4 of Appendix 2). Households that adopt energy efficiency measures have differed significantly from the overall population (see Section 5 of the main report). For example, they tend to be from lower income bands because of the targeting of CERT. As more households adopt energy efficiency measures, it will become increasingly important to take into account the differences between the average household and those that have not yet taken up measures, because they may have characteristics very different from the average.

# 4. Summary of Results – Model of Domestic Energy Demand

In this section, the results of the estimate for a general model of domestic energy demand are presented. The results from the fixed effects panel model using 2 stage regression are presented and then compared with results from other approaches.

Most demand models include a price variable. NEED was therefore supplemented with annual price data compiled in DECC's quarterly energy statistics[6] . However, it should be noted that the price data is not available at household level.

The results focus on gas demand. This is because the model for electricity demand was less successful since there was not a reliable way of identifying homes that were heated electrically. The results are presented for all households and separately for those on incomes of £20,000 or less.

## 4.1 Fixed effects panel model using 2 stage regression

### 4.1.1 Time varying factors

The results from the first stage of the regression are generally the same as the panel regression results for impact of measures as presented in section 4.

The results indicated that there was a significant underlying trend showing reduced energy consumption that is not explained by the observed adoption of energy efficiency measures. These trends may reflect both higher prices over the period, other energy efficiency improvements that are not observed, or differences in behaviour, etc.

The results from the second stage of the regression give the impact of individual building and demographic characteristics, assuming all other factors are held fixed. These results are presented in the sections below. Detailed model estimates for both stages are presented in Appendix 3.

### 4.1.2 Building characteristics

#### Floor area

This was found to be the most important factor affecting gas consumption. For example, a typical home with a floor area of around 90m$^2$ might consume around 17,000 kWh of gas per year, 10,000 kWh, or over half, of the consumption was attributed to floor area.

[6] http://www.decc.gov.uk/en/content/cms/statistics/publications/prices/prices.aspx

### Building form

Bungalows have the highest consumption, followed by detached, semi-detached and terraces. This can be explained by the fact that properties with large external surface area to volume ratios consume more gas. The difference between bungalows and terraces is around 5,000 kWh.

### Rooms

Gas consumption increases with the number of rooms (excluding bathrooms, kitchens and conservatories), even when the floor area remains the same. The increase was slightly more than 450 kWh per room for all households, and 380 kWh for those on low incomes. However, the increase for each additional bedroom was less than the increase for other rooms. Interestingly, consumption decreased with the number of bathrooms, so extra bathrooms may not be heated as much as the living area. Properties without conservatories have lower consumption compared with those that do, with constant floor area.

### Property age

As expected, older properties consume more gas than newer ones, although the oldest properties (pre-1900) appeared to have lower consumption than those built between 1900 and 1930. The newest properties built since the 1980s consume over 4,000 kWh less than similar properties built earlier. The differences are generally smaller for the lower income group than for the full sample.

### Geography

Properties in the North have a higher consumption than similar properties in the South, except for London which has higher consumption levels, even for households on low incomes.

### Number of floors

Properties with more floors have higher consumption, even controlling for floor area. This is not what would intuitively be expected as a property with more floors is likely to have less exposed roof area and therefore retain heat better than a property with the same floor area but fewer floors. However, it would generally have more external wall area resulting in greater heat loss and therefore require more heating than a property on fewer floors.

## 4.1.3 Demographic characteristics

This work uses household characteristics that were obtained from Experian modelled estimates and are therefore less accurate, particularly at the property level, than the other data sources, such as Valuation Office Agency property attribute data.

### Income

If all other variables remain the same, for every increase in income of £10,000, gas consumption increased on average by around 380 kWh.

### Occupants

Consumption increases with the number of adults in the household by around 875 kWh per adult for all households, or around 750 kWh for low income households.

Households with a female head generally had slightly higher consumption compared with those with a male head of household. This was found to be around 300 kWh higher for all households and 500 kWh for those on low income.

Households with children are also associated with higher levels of gas consumption, but only by around 200-300 kWh.

The age of head of household does appear to have some effect on the consumption of the household, although these effects were among the weakest. Significantly, lower income households with older residents (above age 56) appear to have the most significantly lower consumption relative to typical consumption levels (500 to 800 kWh lower).

**Tenure**

Households in rented accommodation tend to use less gas than owner occupiers, even accounting for other factors. Tenants in privately rented accommodation use around 800 kWh less gas than owner-occupiers and local authority residents use nearly 1,000 kWh less than owner occupiers. The lower consumption probably reflects both lower comfort levels and possibly the presence of unobserved energy efficiency installations[7].

The full model specification, including coefficient estimates, is set out in Appendix 3.

### 4.1.3 Unexplained variation

The model explains approximately one third of the variation in gas consumption across the NEED data. This is broadly consistent with the regression results obtained by Katalysis[8] and from DECCs local area gas model[9]. The bulk of this variation occurs because of differences from one household to another ("between household variation"), rather than differences in year to year consumption for the same household ("within household variation").

Within the same home, demographic factors such as household income and number of occupants would probably change more than building characteristics. Since the model suggests that the within household variation is less, it means that annual changes in demographic factors for a particular household are unlikely to have a dramatic impact on gas consumption.

## 4.2 Alternative approaches

Ordinary least squares (OLS) and random effects estimations were also carried out. Except for loft insulation, the estimated coefficients were very similar, with the differences between the alternative approaches being almost always less than 20 per cent, and often close to zero. The random effects results were closer to the two stage estimation than the OLS.

Cavity wall insulation and boilers were the most robustly estimated treatment effects; the differences between the estimates in the three methods did not exceed 4 percentage points.

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[7] Note that a lot of measures delivered through government schemes are installed in the social sector.

[8] Refer to annex E for a summary of this work.

[9] Refer to the special feature 'Identifying local areas with higher than expected domestic gas use' in Energy Trends, March 2012 available at: http://www.decc.gov.uk/assets/decc/11/stats/publications/energy-trends/4779-energy-trends-mar12.pdf).

For loft insulation, the treatment effect was significantly lower in OLS and less so for random effects. This is likely to be a result of the presence of unobserved loft insulation.

However, the two stage fixed effects method, avoids some of the problems of the alternative approaches, and yields treatment effect estimates that are most robust to selection bias.

# 5. Issues Raised and Improvements

This section highlights some of the main issues from this work, the improvements that were made to the DECC 2012 NEED report as a result of insights from this work and some recommendations for further research.

## 5.1 Issues raised

Most of the issues raised are regarding limitations of the data. NEED is an extremely rich source of consumption and energy efficiency data. However, as with any data source, it has limitations and it is important to understand these in order to apply NEED most effectively. A summary of the limitations of applying NEED in this study is below.

### Comparing gas and electricity consumption

Gas and electricity are reported on different annual basis. The gas year runs from 1 October of the previous calendar year to 30 September of the named year. In contrast, the electricity year is reported for the 12 months to end of January. This makes comparisons between gas and electricity consumption more complicated.

In addition, gas consumption is weather-corrected, whereas electricity consumption is not. They cannot therefore be compared directly, and their relationship (e.g. as substitutes or complements in a cold winter) cannot be investigated very well. DECC are exploring how to get access to gas data which is not weather corrected.

### Information on building fabric

NEED does not include information about the nature of a property's building fabric. For example, it does not include information about whether a property has cavity walls or solid walls, which makes it difficult to use it to get a clear picture of how much potential remains for the appropriate insulation technologies. It also complicates the definition of the relevant comparator group for different treatments. Looking ahead DECC will explore making better use of other available administrative sources and potential to produce modelled data to improve understanding of the building fabric.

### Estimating the effect of unobserved or "hidden" measures

In general, the presence of measures which have not been recorded in HEED makes the estimated treatment effect lower than the actual treatment effect (see section A1.3 in Appendix 1 for more details of the effect of unobserved measures). Information on the share of properties with "hidden" measures that are not reflected in NEED would make it possible to account for more of the currently unexplained annual reductions in average energy demand. However, this has limited potential to help with the accuracy of any model of energy consumption and further work will be required on this.

### Impact of measures in flats

It has not been possible to analyse treatment effects in flats because the address information in HEED meant that flats could not be accurately matched to the correct property within a building and therefore to the correct consumption or other variables in NEED. It is hoped that the move to use of AddressBase as the unique reference for HEED and NEED will help to resolve this issue so that future analysis can be extended to include flats.

### Identification and analysis of electric heating

NEED does not currently contain information that makes it possible to identify which properties are electrically heated without making a number of assumptions. This makes it difficult to model electricity demand. To a lesser extent, it also complicates the estimation of the gas demand model as we cannot confidently identify those households totally heated by gas or those that also have electric heating. DECC is currently investigating how NEED can be enhanced in order to improve understanding of electric heating. For example, making greater use of the detailed geographical data to develop a variable that would indicate whether a dwelling is on the gas grid.

### Price data

It should be noted that data on prices is not available within NEED and it had to be augmented with regional price data which is not at household level. This means that effect of price on households cannot be accurately estimated or predicted.

## 5.2 Improvements made in DECC report

A number of improvements have been made in the DECC 2012 NEED report. The results from NERA work were very helpful in developing these improvements. Some of these are highlighted below. More information is available in the main report.

### Additional data filtering

Some improvements have been made to the consumption data to eliminate outliers and suspect values. For example, valid gas consumption for heating has been limited to between 2,500 and 50,000 kWh rather than 1 to 72,800 kWh used previously. A maximum change in annual consumption in the year before and after a measure has been installed was applied to try and eliminate properties that may have been or become empty or had a significant change in their circumstances. The maximum decrease in consumption over the three years was 80 per cent and the maximum increase was 50 per cent.

### Comparator group construction

More reliable estimates of treatment effects are obtained when the untreated households used in the comparison group are most similar to the treated group.

In this work and also in the DECC 2011 NEED Report, the characteristics of the treatment group were not considered when constructing the comparator group. We have since improved the comparator group by creating a comparator group with the same characteristics as the treatment group in terms of gas consumption, region, property age, number of bedrooms and property type.

### Quality and value of Experian data

The quality of the Experian data currently used in NEED is in the process of being reviewed. Initial results show that the overall agreement between the VOA and Experian property data was nearly 70 per cent. A similar assessment of the household characteristics variables has not been possible, but Experian estimates 32 per cent of properties are within the correct income band and 54 per cent are within 1 band of the correct band.

In addition, DECC is investigating using the detailed geographical information present in NEED to develop additional variables, based on other existing datasets in order to supplement or even replace some of the Experian data. After this review, it may be possible to develop data that better relates to the households living in the property at each year rather than data that corresponds to a particular point in time. We expect to complete this review in 2013.

## 5.3 Future research areas

There is a wide range of possible future research areas that could be explored using NEED. Some of these areas would require NEED to be enhanced, augmented or improved in order to improve its power to provide meaningful input to policy questions. Others relate to further econometric analysis. And others would take the data and results and apply them to other policy questions.

### Development of household simulation tool

Based on the current work (or refinements described above) it may be possible to develop a tool that would take individual household input characteristics (or sets of characteristics) and calculate the estimated demand and/or estimated treatment effects for the household.

### Aggregate demand simulation model

The underlying demand equations developed here could be built up into a simulation model that would calculate the household energy demand in England under different assumptions about the development of the housing stock – including energy efficiency measures – and other underlying household demographic characteristics such as income and family size.

# 6. Summary and Conclusions

Looking across a range of methods for estimating the treatment effect of different energy efficiency measures, and allowing for the variety of data issues the difference in difference approach provides similar results to more complex and time consuming methods, and a significant improvement over more basic methods. This provides assurance in the method that we use in the main analysis of NEED data.

The modelling of energy consumption remains a very complex problem, with R squared values of greater than 30 to 40 per cent seemingly impossible to obtain with the data available. This suggests there is a significant portion of variability which relates to behaviours which we do not have the data to represent/model at a property level.

# Appendix 1. Basic Assessment and Descriptive analysis of NEED

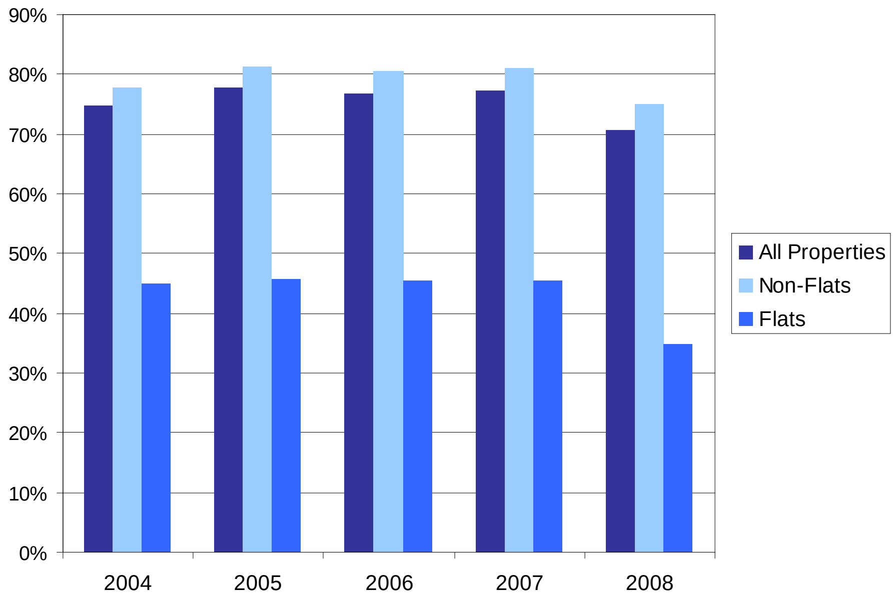
**A range of descriptive analysis were carried out with NEED to identify any issues with the data that could affect results and also to identify key variables to consider for modelling. Some of these results are presented in this appendix.**

## A1.1 Quality of gas consumption data

Energy consumption data was available for 2004 to 2008. However, data concerns with 2004 and 2008 gas consumption had been highlighted before this analysis was carried out – these were addressed before the 2011 NEED report was published.

Figure A1.1 shows the share of properties with gas consumption data in each year, relative to those with electricity.

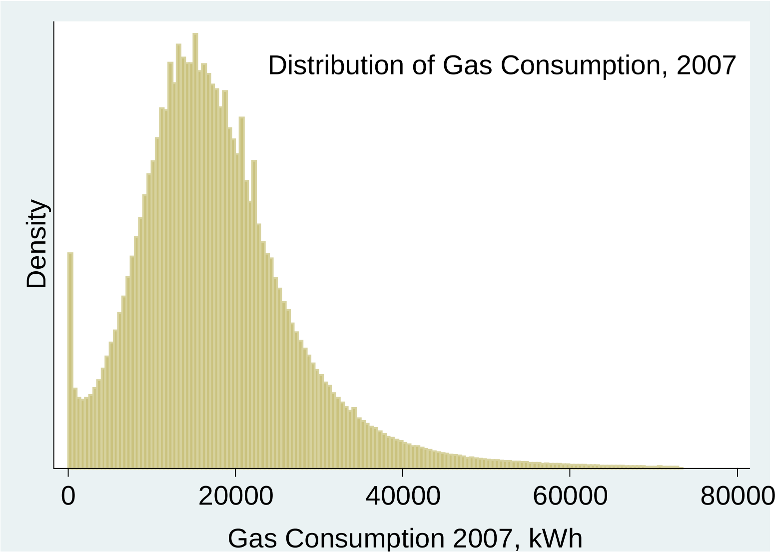
**Figure A1.1: Share of Properties with Gas Consumption, 2004 to 2008**




The figure shows that in the years 2005 to 2007, there were 77 to 78 per cent of properties with gas. This compares well with the expected share of 80 per cent. However, the share was only 75 per cent in 2004, and 70 per cent in 2008. The shortfall in 2008 was even more for flats. Because of these shortfalls in 2004 and 2008, results for impacts of measures were restricted to 2005 to 2007.

Figure A1.2 shows basic summary information for valid gas consumption between 1 and 73,200 kWh in 2007. It is shown for 2007 because of the missing consumption data in 2008.

**Figure A1.2: Summary statistics, gas consumption 2007**




The figure shows that the distribution of gas consumption is not smooth and has a number of spikes, with the most significant one at around 1 kWh. These spikes are likely to be estimated readings. In the 2012 NEED report, we have applied data filters in an attempt to remove these readings. For more information, please refer to the section on quality assurance in the main report.

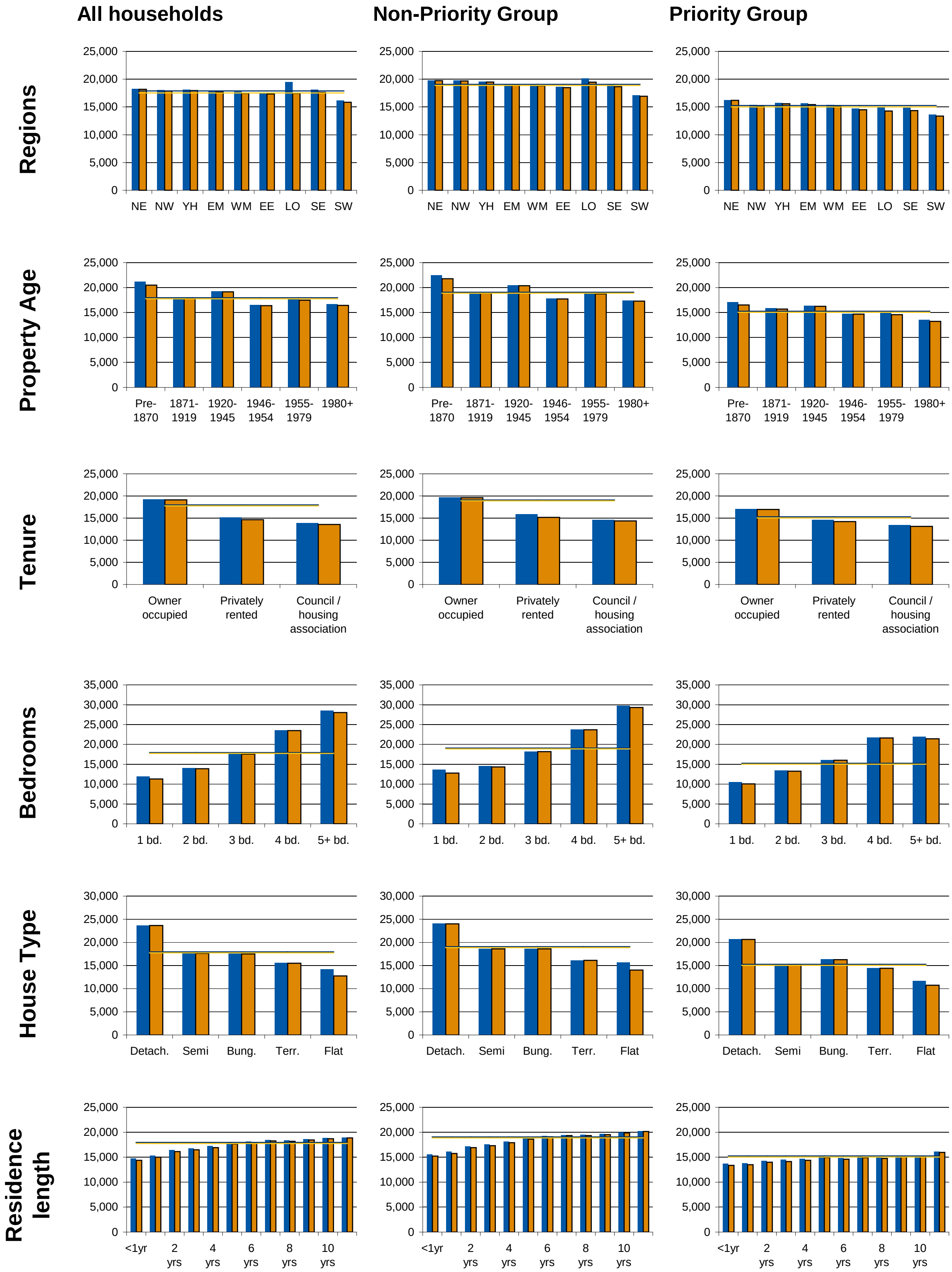
## A1.2 Variation in consumption by household characteristics

Figure A1.3 shows average gas consumption by various household characteristics. The full dataset including flats is represented by the orange bars and the sample excluding flats in blue. The averages are for factors considered one at a time and do not capture correlations and interactions between various household characteristics. It is therefore not as informative as the comparisons from multivariate methods presented in appendix 2. However, it does provide useful insights to the key variables to be considered for modelling.

Each row of charts shows the information for the full NEED sample, for households on incomes greater than £20,000 or the "non-priority group" and for households on incomes below £20,000 per year or the "priority group".

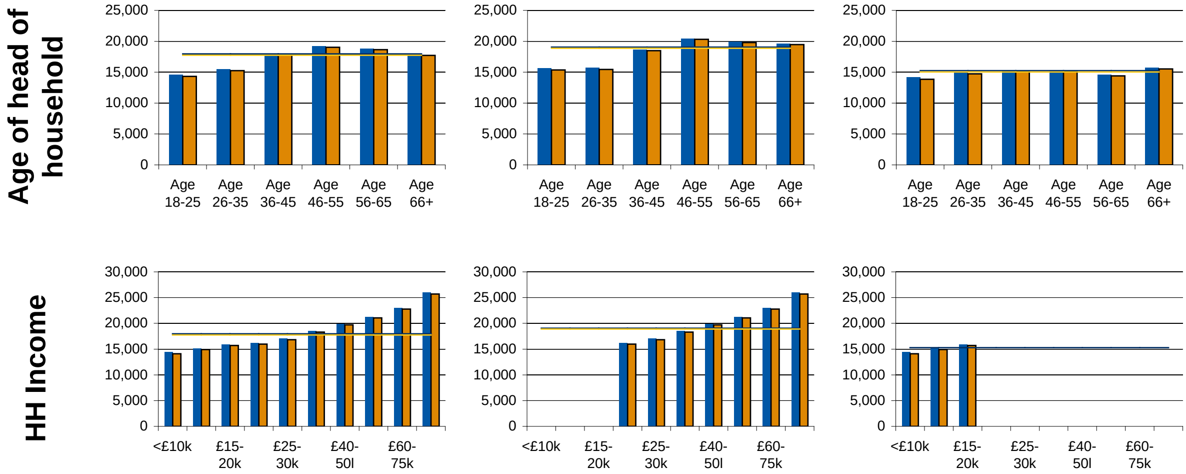
With a few exceptions, there is very little difference between the consumption including flats and that excluding flats. Mean consumption in the priority group is significantly lower than that in the non-priority group.

## Figure A1.3: Average gas consumption by type of household, 2007[1,2,3,4,5]




1. Household characteristics are based on Experian data.
2. The blue series show data for households excluding flats. The orange series includes flats.
3. The lines indicate the averages across all properties.
4. House types are as follows: Detach. = Detached, Semi = Semi-detached, Bung. = Bungalow, Terr. = Terraced.
5. The Priority Group is defined as having household income below £20,000.

**Figure A1.3 continued**




1. Household characteristics are based on Experian data.
2. The blue series show data for households excluding flats. The orange series includes flats.
3. The lines indicate the averages across all properties.
4. House types are as follows: Detach. = Detached, Semi = Semi-detached, Bung. = Bungalow, Terr. = Terraced.
5. The Priority Group is defined as having household income below £20,000.

In summary, gas consumption is very slightly higher in the North, with consumption in London, excluding flats, significantly higher than in the rest of the country. However, when flats are added, average consumption in London is the same as the overall average. Older properties appear to consume more, as expected. Owner occupiers consume the most gas, with tenanted properties having similar consumption levels, though council tenants consume slightly less than private ones. Consumption increases with number of bedrooms. Consumption is positively correlated with residence length, income and age of head of household, although it stabilizes and in some cases declines in the oldest age groups.

## A1.3 Effect of Unobserved or "hidden" energy efficiency measures

Over the period covered by NEED, cavity wall insulation was largely driven by the Energy Efficiency Commitment (EEC) and the Carbon Emissions Reductions Target (CERT) which require energy suppliers to deliver energy efficiency measures to consumers.

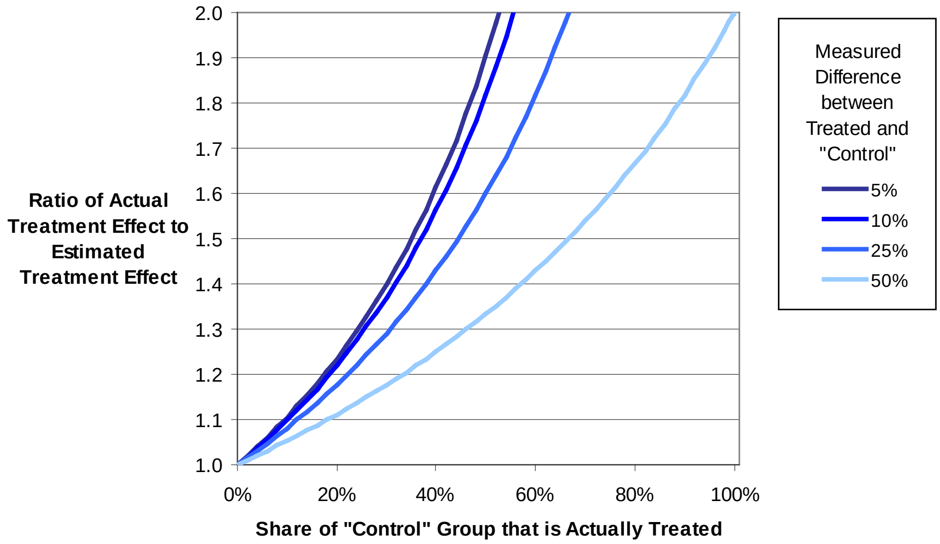
Cavity wall insulation requires special equipment and is more likely to be done by professional installers. They have to record their installations in order to receive the subsidy from energy suppliers. It is therefore likely that the majority of cavity wall insulation installations, particularly those through CERT have been recorded in the Homes Energy Efficiency Database, HEED the source of energy efficiency information in NEED.

Loft insulation is also driven by these commitments, but can be carried out by householders themselves. It is likely that the majority of DIY loft installations have not been recorded in HEED. Therefore, when the loft insulation comparator group is constructed, it is likely to include many properties that actually have loft insulation. The inclusion of these unobserved or "hidden" measures will make the comparator group have a lower average energy than it should, and this will result in estimates of the impact of loft insulation being biased downwards or lower than the actual impact.

Though installation of new condensing boilers must be carried out by certified installers,  it is not driven by energy efficiency commitments. Since 2005, building regulations required all new boilers to be condensing (with some limited exceptions) and as a result they no longer qualified for energy supplier subsidy. Therefore, not all new boilers installed are being reported in HEED.

Figure A1.4 illustrates the effect that unobserved measures have on estimates of the treatment effect for the simple case where there is only a single treatment. It assumes there are accurate estimates of average consumption for both treated households and untreated households which include unobserved installations.

**Figure A1.4: Biased Estimates of Treatment Effect when Treatment is not Observed**




The figure shows that the bias increases with the share of the comparator group that is actually treated, but it also depends on the size of the difference between the consumption of the treated and the comparator groups.

For measures that have a large difference between treated and comparator consumption (as illustrated in the bottom light blue curve), when the share of unobserved installations in the comparator group is low, say 20 per cent, the bias is relatively small; the estimated treatment effect is biased downward by only 10 per cent.  For measures that have a smaller effect on consumption, the bias is greater; for a measure that appears to deliver a 5 per cent reduction relative to the comparator group, a 20 per cent share of unobserved treatments in the comparator will bias the estimated treatment results by around 20 per cent.

The impact of hidden measures also depends on the analysis approach used. The example in the chart is based on just a simple comparison between treated and untreated groups where the hidden measure would affect the results no matter how recently it was installed. When using methods such as difference in difference, the impact of the hidden measure is only felt if it is installed in the treatment period (i.e. the year before, during or after the treatment group received its installation).

# Appendix 2. Impact of Measures, Detailed Results by Different Methods

**This appendix presents detailed results of the approaches used to estimate the impact of measures. An overview of the methodologies used as well as the reasons for using the methods are also included.**

## A2.1 Basic treatment and comparator group

### A2.1.1 Methodology

In this approach, the gas consumption in each year for treated households was compared to that of the comparator group.

Treated households were those that had installed the energy efficiency measure of interest any time *before* the year being considered. However, there was no restriction on the presence or absence of other measures and so the treatment group could therefore include households that had installed another energy efficiency measure identified in NEED.[10] The comparator group were households that had not installed the measure of interest *by the end of that year*.[11]

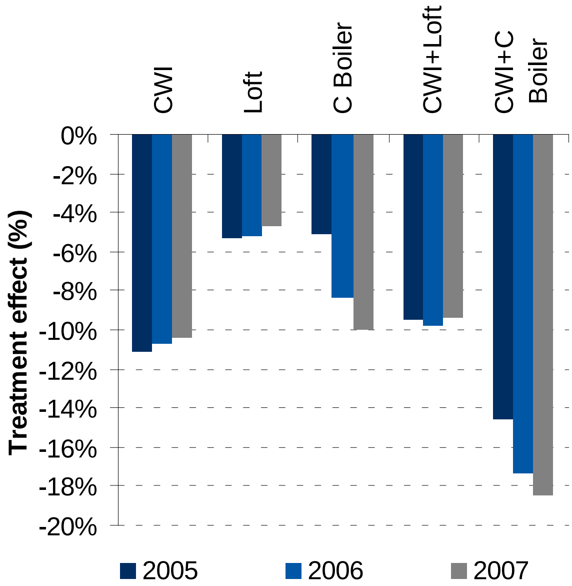
### A2.1.2 Results for overall treatment effects

The results of basic analysis are shown in figure A2.1. The results have been presented for 2005 to 2007 only. This is due to data concerns for consumption figures in 2004 and 2008 which are highlighted in section A1.1 of appendix 1.

[10] In the other approaches, there was a restriction on the presence of other minor energy efficiency measures. This specification was not followed in this approach because the number of observations in the treatment group was too small and led to unreliable estimates.

[11] For example, results for 2005 represent a comparison of the 2005 gas consumption of households who installed a particular measure in 2004 or earlier to those who have not (yet, in 2005) installed the measure.

**Figure A2.1: Average observed treatment effect, 2005 to 2007**




The figure shows that the average treatment effect varies with time. Between 2005 and 2007, households that installed cavity wall insulation consumed between 11 and 12 per cent less gas (1,900 – 2,200 kWh) than the comparator group. For loft insulation, households used 5 per cent less gas (800 – 1,000 kWh). The results for condensing boilers were more variable, reducing by between 5 and 10 per cent. The combination of condensing boilers and cavity wall insulation also showed variability with a 15 to 18 per cent reduction. For the combination of cavity wall and loft insulation, the reduction was 10 per cent which was significantly lower than the sum of savings for the individual measures. The combinations were found to reduce consumption by 1,800 to 3,400 kWh.

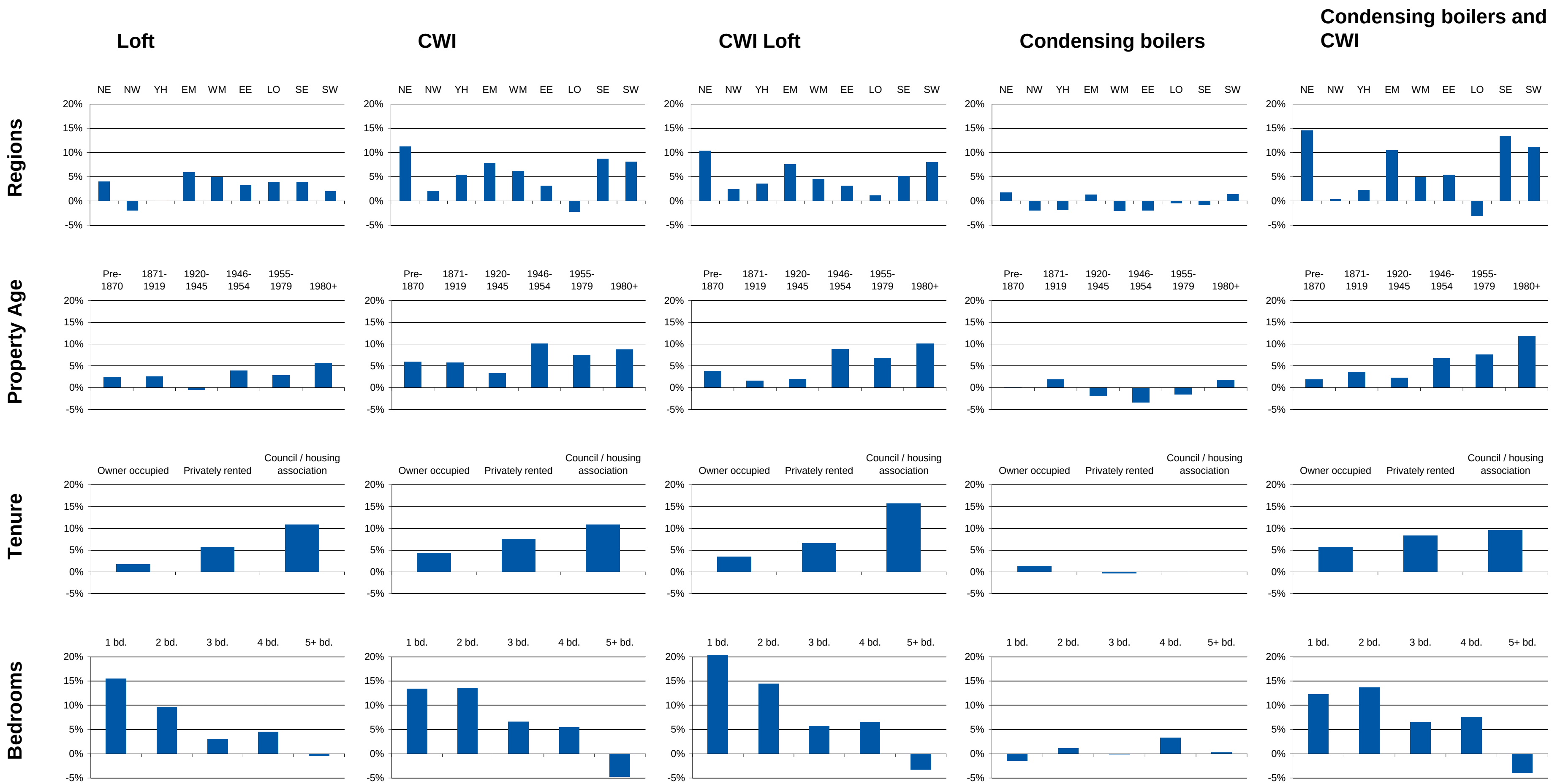
### A2.1.3 Assessment of the approach

The basic approach assumes that untreated households can be used to obtain the effect of treated households assuming they had not actually been treated. However, households that take up measures and are therefore in the treatment group have different characteristics to those that do not and are classed as untreated. This is demonstrated in Figure A2.2 in which gas consumption in 2005 in households who will take up a measure in 2006 or later up to the end of 2008 is compared to those households who according to NEED have never been treated.

The figure shows that in general, households that installed energy efficiency measures had higher initial gas consumption that those that did not install any measure. For example, initial consumption was on average 3 per cent higher for homes that subsequently installed loft insulation compared to those that never installed the measure and 6 per cent higher for those that subsequently installed cavity wall installation.

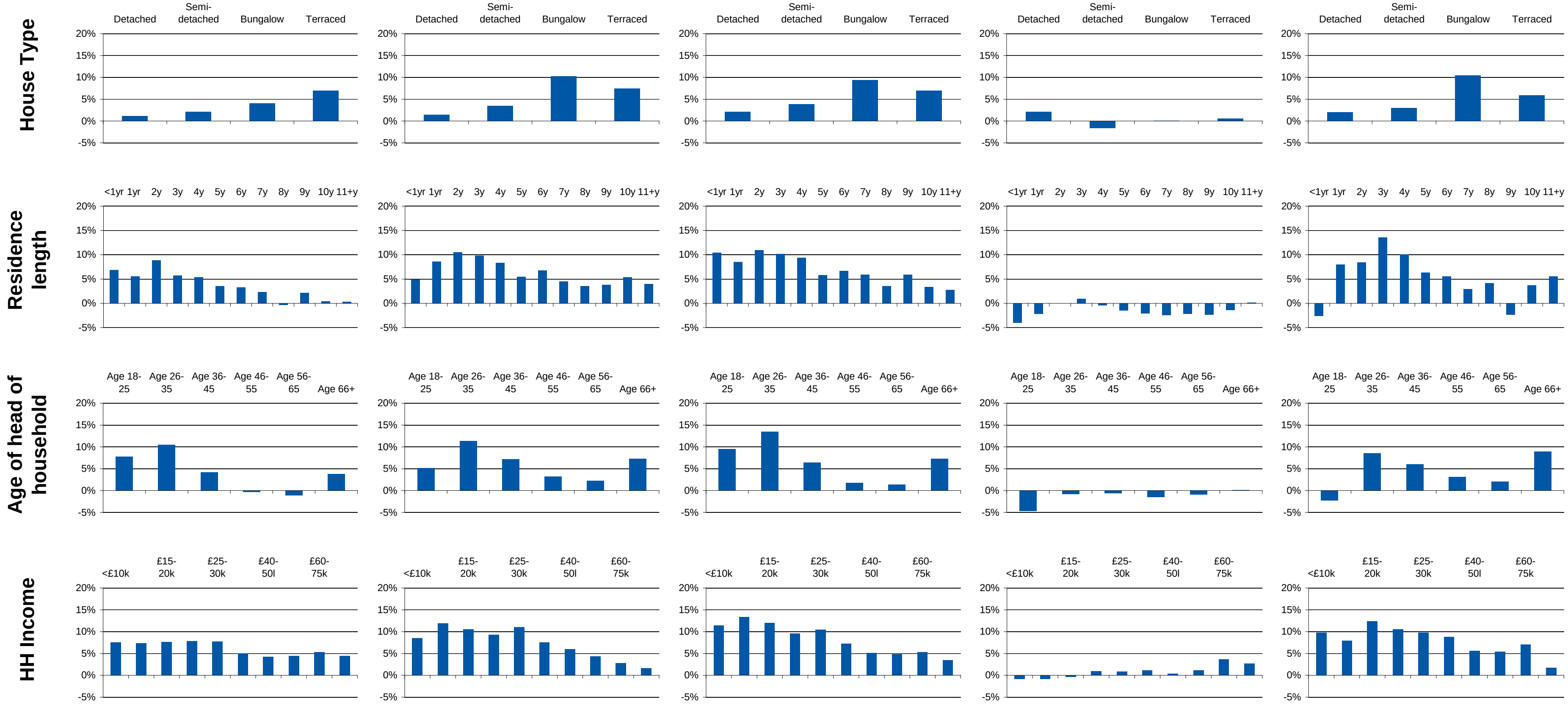
This higher initial consumption could be explained by the fact that households with high consumption and therefore higher bills, might be more likely to install energy efficiency measures. Also, local authorities and housing associations may have targeted installations in properties that were in more need of energy efficiency measures because of their higher consumption.

## Figure A2.2: Comparison of initial gas consumption of treated households relative to untreated households, 2005[1]




1. Household characteristics are based on Experian data.

## Figure A2.2 Continued




1. Household characteristics are based on Experian data.

Condensing boilers were the exception. Initial gas consumption of households that subsequently installed this measure was not noticeably different from households that did not. This could be explained by the fact that new boiler installations are driven by the mandatory requirement to install energy efficient condensing boilers.

This observation where households taking up efficiency measures have higher consumption prior to installation compared to households that do not install the measure can result in underestimated treatment effects. For these reasons, estimates from this approach are not very reliable. The method is therefore enhanced using the difference in difference approach which seeks to address this issue.

## A2.2 Difference in difference

### A2.2.1 Methodology

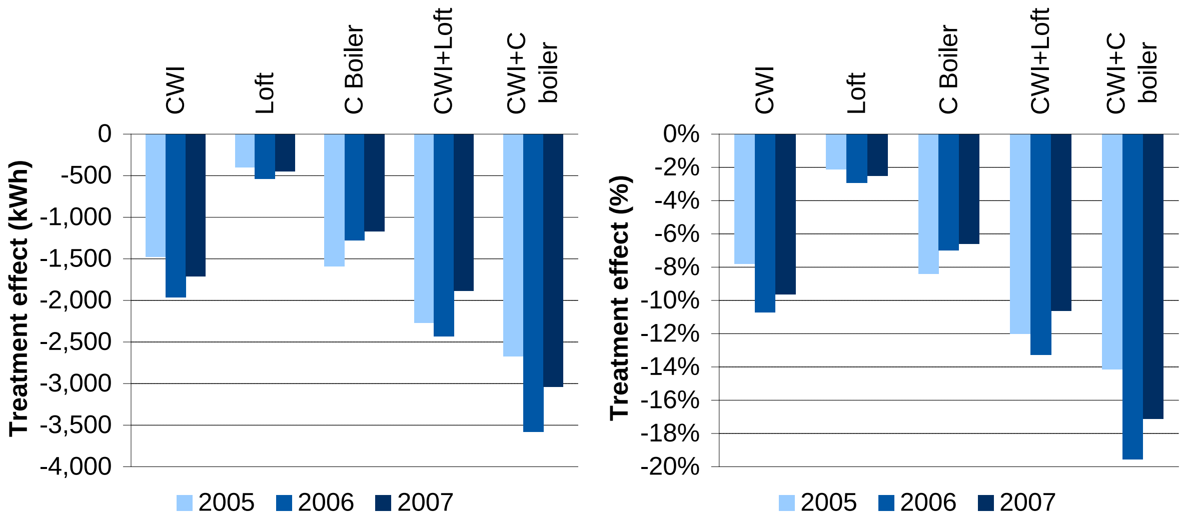
In this approach, the change in energy consumption across two years, for the treatment group and the comparator was compared. For example, in homes where energy efficiency measures were installed in 2006, the method compares the change in consumption between 2005 and 2007, to that of the comparator group. The two years considered were those immediately surrounding the year of interest.

The treatment group was defined as households that had installed the major measure of interest in a specific year and excludes households that installed any of the other major measures, before 2008 (the final year for which data was available). The comparator group therefore includes only households that have not installed any of the three major measures before 2008. This specification attempts to isolate the effect of the specific measure or combination of interest.

### A2.2.2 Overall treatment effects

Figure A2.3 shows the energy savings in kWh and in per cent, from installing major measures and selected combinations. The treatment effects indicate how much the consumption in treated households changed relative to the comparator. The percentages represent this change as a proportion of the consumption for the comparator group in the year following installation.

**Figure A2.3 Difference in Difference Treatment Effects, 2005-2007, Full Sample**




The savings varied according to the treatment year. In general, except for condensing boilers, the savings in 2006 were the largest.

**Impact of single major measures**

- Of the three major measures considered, cavity wall insulation had the largest impact. This is consistent with the findings in the main report. Between 2005 and 2007, cavity wall insulation reduced gas consumption by around 1,500 – 2,000 kWh (8 – 11 per cent total).

- The mean saving in 2005 from the difference in difference approach reported here was 1,450 kWh. This was around 23 per cent less than the saving of 1,900 kWh in the main report. In 2006, the mean saving of 1,950 kWh was 6 per cent (120 kWh) more than the savings in the main report. In 2007, both results were comparable and these results were only 2 per cent more than those in the main report.

- Loft insulation had the smallest impact, reducing gas consumption by 400 – 550 kWh (2 – 3 per cent of total consumption) between 2005 and 2007.

- In 2005 and 2007, the mean savings were lower than those in the main report, particularly in 2007 where they were 18 per cent less. In 2006 the results from both sources were comparable (only 1 per cent less).

- Condensing boilers reduce gas consumption by around 1,200 – 1,600 kWh (7 - 8 per cent of total). In the main report, condensing boilers consistently saved around 2,000 kWh of gas across the 3 years. However, the savings were considerably lower and declined from 1,600 kWh in 2005 to 1,200 in 2007. The discrepancy almost doubled from 22 per cent in 2005 to 41 per cent in 2007.

**Combinations of major measures**

- Cavity wall and loft insulation combined reduced gas consumption by between 1,900 and 2,400 kWh (11 – 13 total consumption). For 2006 and 2007, this was lower than the sum of the savings from the individual measures. This may indicate that the measures interact with each other; if one measure had already been installed, the installation of the other may have a lower incremental reduction.

- Of the measures and combinations considered, cavity wall insulation and boiler replacement reduce gas consumption by the largest amount, 2,700 – 3,600 kWh (14 – 20 per cent of total consumption). The savings from the measures combined are approximately equal to the sum of the two treatment effects, however in 2006 and 2007, the sum of the measures was lower than the combination.

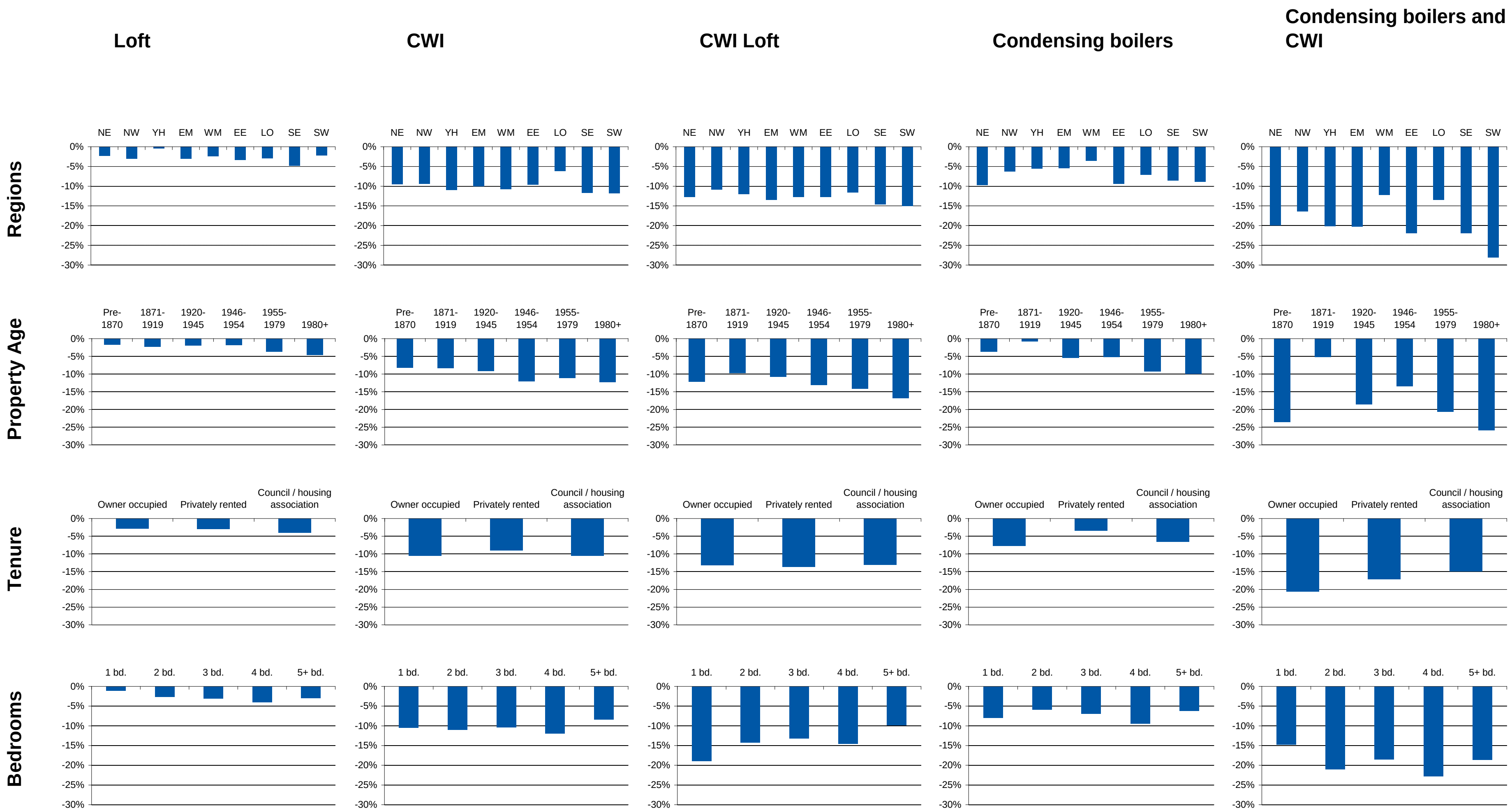
Compared to the results from the basic approach, the estimates appear more robust with less variation over time and more plausible combination effects.

### A2.2.3 Treatment effects by household characteristics

The reductions realised depended on certain household characteristics.

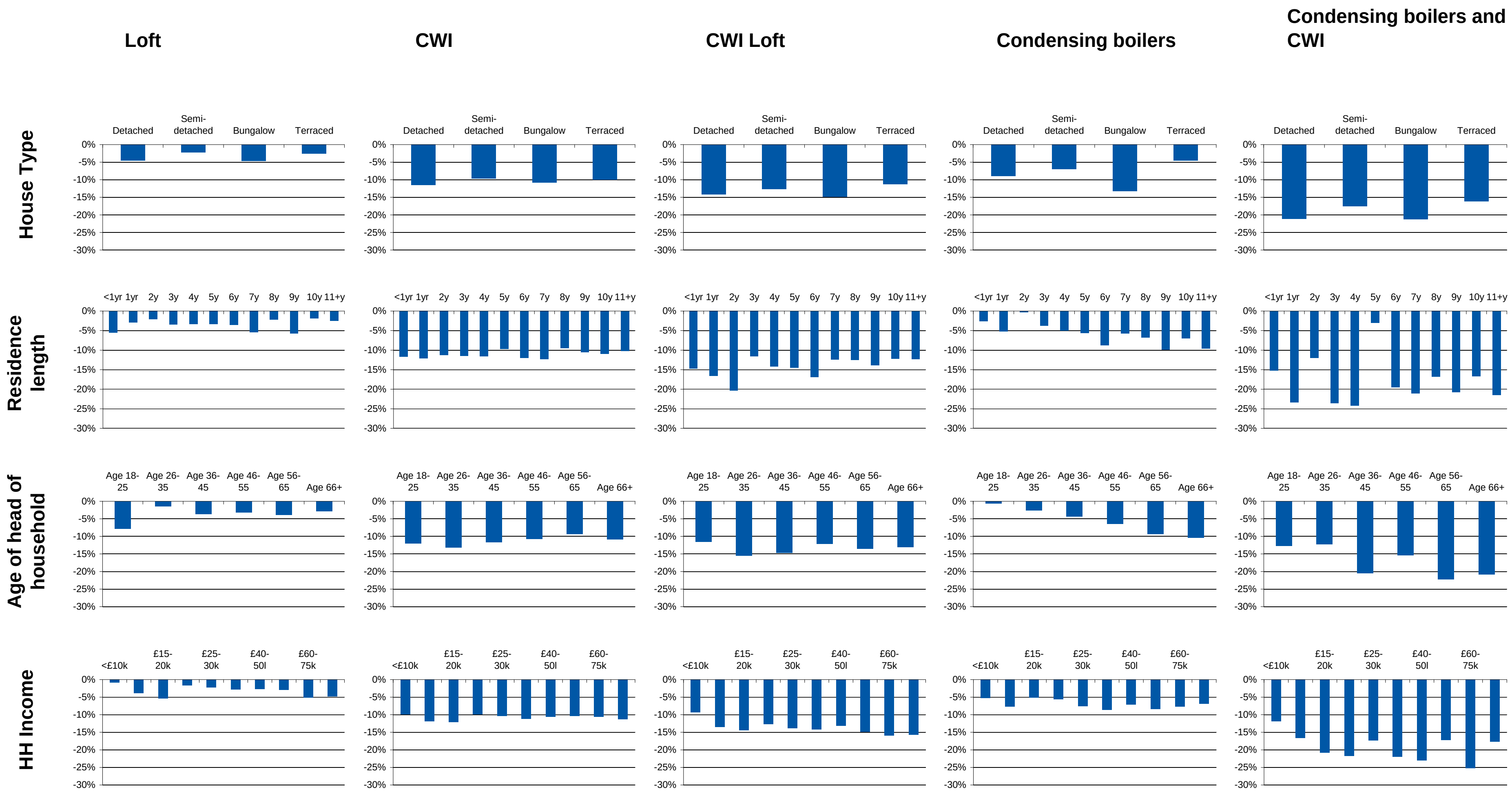
Figure A2.4 shows the variation in the treatment effect for measures installed in 2006 relative to non treated ones, by several key characteristics.

## Figure A2.4 Treatment effects – Impact on Gas Consumption, 2006[1,2]




1.The series compare the change in consumption between 2005 and 2007 for two groups of households: those that took up a given measure in 2006 vs. those that, according to NEED, did not have that measure installed prior to the end of *2007*.
2. Household characteristics are based on Experian data.

## Figure A2.4 Continued




1.The bars compare the change in consumption between 2005 and 2007 for two groups of households: those that took up a given measure in 2006 to those that, according to NEED, did not have that measure installed prior to the end of *2007*.
2. Household characteristics are based on Experian data.

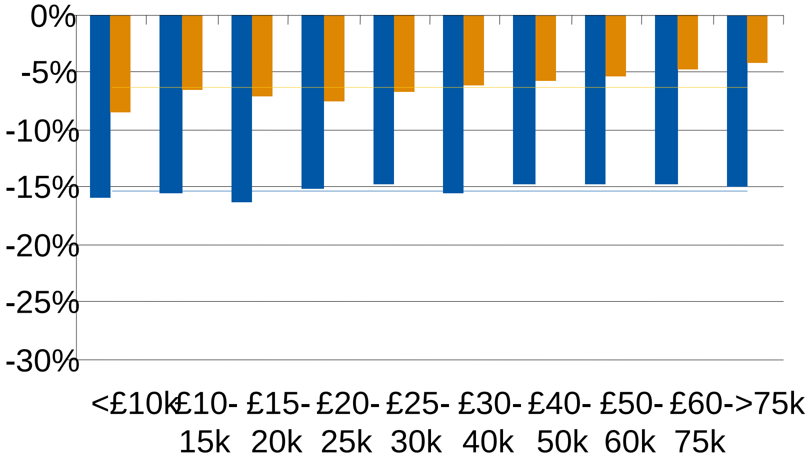
The figure shows that there was no clear relationship with savings for some characteristics, such as tenure, number of bedrooms, residence length and age of head of household.

Energy savings tended to vary by property type. Properties with more external walls and larger exposed surface area had larger savings following installation of the measure, compared with homes that did not install. Bungalows having the most, followed by detached, then semi-detached and then terraced.

Another interesting result was that savings were higher in newer properties, which was not consistent with the expectation that newer properties were already more energy efficient.

There were slightly larger *absolute* savings in higher income households that installed energy efficiency measures relative to their lower income counterparts. This could be seen as evidence of comfort taking in lower income households; the installation of energy efficiency measures would allow them to attain higher temperatures with similar levels of consumption. However, the *percentage* of savings showed a different pattern which is illustrated in figure A2.5. In the figure, the orange bars show the reduction in gas consumption between 2005 and 2007 for the comparator group and the blue bars the reduction for households that installed cavity wall insulation in 2006.

**Figure A2.5 Treatment effect of Cavity Wall Insulation installed in 2006, by income and treatment status[1]**




1. The blue bars show the reduction in gas consumption between 2005 and 2007 for the treated group and the orange bars for the untreated group.

The figure shows that the percentage of savings was the same irrespective of income for homes installing cavity wall insulation. However, for households that did not install cavity wall insulation, higher income households reduced their percentage consumption by less than lower income households.

It is possible that this pattern is due to a general decline in consumption resulting from higher prices. Higher prices would have a larger impact on poorer households, who would reduce their consumption more than households with higher incomes. However, this effect would be offset by households that installed energy efficiency measures, so the net impact for treated lower income households is the same as their higher income counterparts.

### A2.2.4 Assessment of the approach

The difference in difference approach is better than the in-year analysis in that it corrects for the higher initial consumption between treated and untreated households.

However, it does not provide an unbiased estimate of the effect of installation on a household selected at random from the population. This is because of the differences between the characteristics for households that have and those that have not been treated.

The problem of inadequate comparators affects both the basic and difference in difference approaches. The comparator group is not representative of untreated groups because they contain households that have installed energy efficiency measures, for example DIY loft insulations. In addition, the comparator group for cavity wall insulation, includes properties with solid walls which cannot have cavity wall insulation and also typically have higher than average energy consumption.

## A2.3 Panel regression

### A2.3.1 Methodology

This approach can control for any factors affecting both take up of energy efficiency measures and energy use that are not captured in the data available in NEED, provided these factors do not change with time. It does this by assuming that household consumption is the sum of

- a unobserved household effect or household fixed effect representing all factors affecting household consumption that do not change over time, or at least are constant over the time period being considered
- the effect of the treatments, and in some regressions,
- year-specific effects

The household characteristics from Experian data were not used in the panel regression because they remain the same over time and their effects are therefore covered within the household fixed effect.

The effect of the three major measures and their various combinations were considered. As in the difference in difference approach, the presence of minor energy efficiency measures, such as glazing, draught-proofing and new non-condensing boilers was not taken into account. Each of the treated groups would therefore include households that had taken any of the minor measures recorded in HEED.

Four model specifications were carried out, absolute consumption both with and without year effects and logarithmic consumption with and without year effects. For specifications with year effects, the year coefficients represent any change in consumption that is not captured by variables in the model.

### A2.3.2 Treatment effects

Detailed results for the parameter estimates from the panel regression including their statistical significance are given in Tables A2.1 and A2.2. In these tables, the reported R-squared value is the proportion of variation within each household and across years. The values are all small however, as we are interested in estimating the treatement effects it is more appropriate to focus on the significance levels of the estimated coefficients, which tend to be greater than 99 per cent.

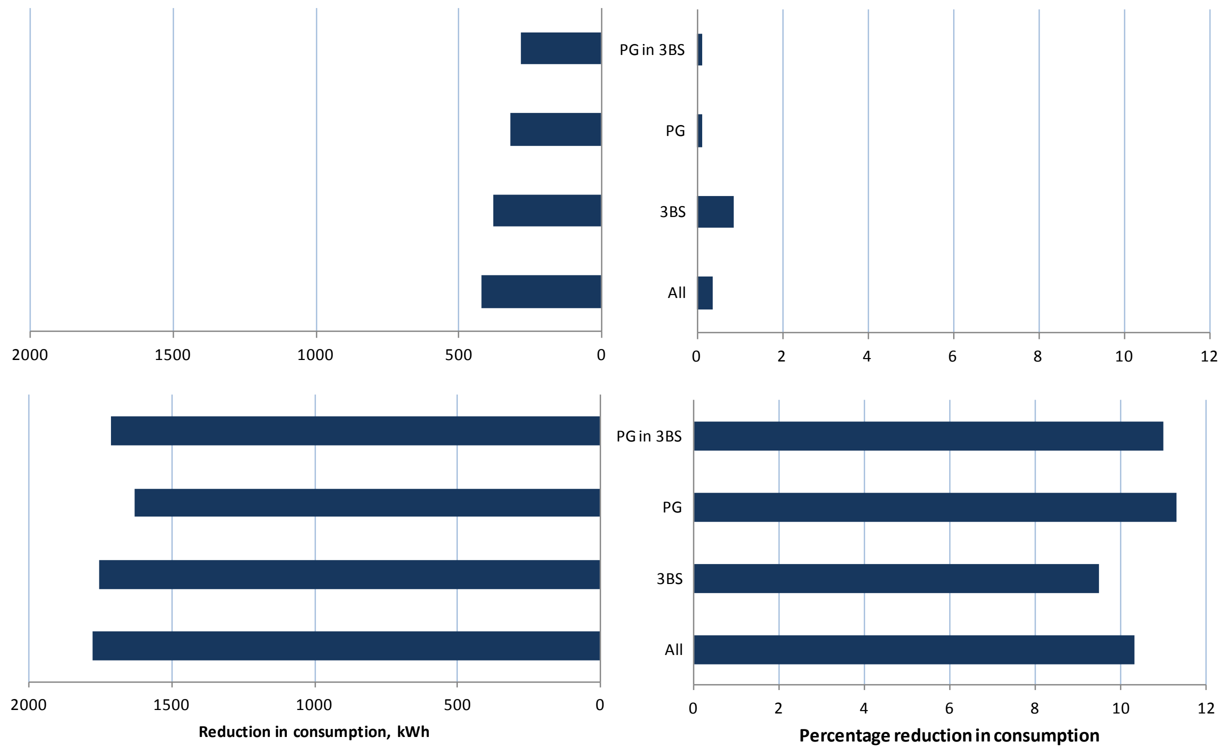
For each specification, the parameter estimates are relative to a “base group”, whose definition depends on whether year effects were included or not. For models without year effects, the base group was households that did not install any of the major energy efficiency measures. For models with year effects, the base group was those that did not install a major measure in 2004, the default year. The estimates are averaged over the five year time period considered, and are not specific to a particular year.

Some of the parameter estimates for single measures have been interpreted in the sections below. They are presented for four groups: All properties, 3 bedroom semi detached properties only (3BS), Priority group only (PG), and Priority group in 3 bed semis (PG in 3BS).

**Loft insulation**

Figure A2.6 gives a graphical representation of the results in tables A2.1 and A2.2 for loft insulation. The absolute effect in kWh is shown in the two charts on the left while the effect in percentage terms is shown on the right. The results when year effects are included are shown in the two charts on top, while the results when year effects are excluded is shown in the two bottom charts.

**Figure A2.6 Panel Regression results for Loft Insulation**



## Table A2.1: Panel Regression Results for Gas Consumption in Logarithms[1,2,3]

| | (1) | (2) | (3) | (4) | (5) | (6) | (7) | (8) |
|---|---|---|---|---|---|---|---|---|
| | (with annual dummy variables) | | | | (without annual dummy variables) | | | |
| VARIABLES | Three-bedroom semis | All residence types and sizes | Three-bedroom semis, PG | All residence types and sizes, PG | Three-bedroom semis | All residence types and sizes | Three-bedroom semis, PG | All residence types and sizes, PG |
| Loft only | -0.00871 | -0.00379 | 0.00117 | 0.00121 | -0.0947*** | -0.103*** | -0.110*** | -0.113*** |
| Cavity wall only | -0.0699*** | -0.0629*** | -0.0634*** | -0.0582*** | -0.138*** | -0.139*** | -0.142*** | -0.139*** |
| Condensing boiler only | -0.0127*** | 0.00332 | 0.0142 | 0.0252*** | -0.106*** | -0.104*** | -0.106*** | -0.0985*** |
| Loft and cavity wall | -0.102*** | -0.0959*** | -0.0796*** | -0.0798*** | -0.208*** | -0.219*** | -0.219*** | -0.223*** |
| Loft and Condensing boiler | -0.0269* | -0.0129* | 0.0184 | 0.0136 | -0.165*** | -0.171*** | -0.161*** | -0.169*** |
| Cavity wall and Condensing boiler | -0.0978*** | -0.0843*** | -0.0589*** | -0.0700*** | -0.237*** | -0.243*** | -0.237*** | -0.253*** |
| Loft, Cavity wall, and Condensing boiler | -0.129*** | -0.143*** | -0.0697*** | -0.108*** | -0.296*** | -0.333*** | -0.288*** | -0.330*** |
| Year dummy (2005) | -0.0125*** | -0.0150*** | -0.0160*** | -0.0167*** | | | | |
| Year dummy (2006) | -0.0642*** | -0.0731*** | -0.0873*** | -0.0910*** | | | | |
| Year dummy (2007) | -0.0994*** | -0.112*** | -0.126*** | -0.130*** | | | | |
| Year dummy (2008) | -0.143*** | -0.167*** | -0.187*** | -0.192*** | | | | |
| Constant | 9.748*** | 9.675*** | 9.624*** | 9.508*** | 9.701*** | 9.618*** | 9.567*** | 9.446*** |
| Observations | 2973718 | 12395959 | 771325 | 3146558 | 2973718 | 12395959 | 771325 | 3146558 |
| R-squared | 0.015 | 0.014 | 0.017 | 0.015 | 0.003 | 0.002 | 0.003 | 0.002 |
| Number of households | 610568 | 2567984 | 158116 | 646101 | 610568 | 2567984 | 158116 | 646101 |

1. Household characteristics are based on Experian data.
2. Parameter estimates are average *percentage* savings relative to the “base group”.
3. The *exponential* of the constant term, gives the estimated consumption for the base group.

## Table A2.2 Panel Regression Results for Gas Consumption in Levels[1,2,3]

| | With annual dummy variables | | | | Without annual dummy variables | | | |
|---|---|---|---|---|---|---|---|---|
| VARIABLES | Three-bedroom semis | All residence types and sizes | Three-bedroom semis, PG only | All residence types and sizes, PG only | Three-bedroom semis | All residence types and sizes | Three-bedroom semis, PG only | All residence types and sizes, PG only |
| Loft only | -380.3*** | -418.1*** | -282.0*** | -320.2*** | -1755*** | -1779*** | -1712*** | -1630*** |
| Cavity wall only | -1426*** | -1460*** | -1225*** | -1199*** | -2517*** | -2509*** | -2240*** | -2129*** |
| Condensing boiler only | -1365*** | -1322*** | -1080*** | -994.1*** | -2848*** | -2788*** | -2614*** | -2406*** |
| Loft and cavity wall | -2100*** | -2179*** | -1852*** | -1853*** | -3795*** | -3868*** | -3636*** | -3488*** |
| Loft and Condensing boiler | -1717*** | -1659*** | -1245*** | -1270*** | -3914*** | -3823*** | -3530*** | -3356*** |
| Cavity wall and Condensing boiler | -2774*** | -2786*** | -2430*** | -2427*** | -4995*** | -4968*** | -4708*** | -4516*** |
| Loft, Cavity wall, and Condensing boiler | -3603*** | -3766*** | -3102*** | -3225*** | -6261*** | -6373*** | -5895*** | -5769*** |
| Year dummy (2005) | -316.5*** | -316.2*** | -327.0*** | -297.7*** | | | | |
| Year dummy (2006) | -1051*** | -1043*** | -1123*** | -1035*** | | | | |
| Year dummy (2007) | -1640*** | -1590*** | -1679*** | -1534*** | | | | |
| Year dummy (2008) | -2321*** | -2324*** | -2426*** | -2238*** | | | | |
| Constant | 19951*** | 19834*** | 18234*** | 17135*** | 19150*** | 19006*** | 17464*** | 16392*** |
| Observations | 2973718 | 12395959 | 771325 | 3146558 | 2973718 | 12395959 | 771325 | 3146558 |
| R-squared | 0.063 | 0.054 | 0.063 | 0.051 | 0.02 | 0.015 | 0.019 | 0.015 |
| Number of households | 610568 | 2567984 | 158116 | 646101 | 610568 | 2567984 | 158116 | 646101 |

1. Household characteristics are based on Experian data.
2. Parameter estimates are average *absolute* savings relative to the “base group”.
3. The constant term gives the estimated consumption for the base group.

The effect of loft insulation was very small and was found not to be important or ‘statistically significant’. For all house types, there was a reduction of just 0.4 per cent relative to the base group. Three-bedroom semi’s had a larger reduction of just under 1 per cent (0.9%) relative to the base group. The savings were even smaller when considering households with incomes below £20,000 (0.1%).

When year effects were removed, the reductions rose substantially to around 10 per cent for all household types, and 11 per cent for households on low incomes.

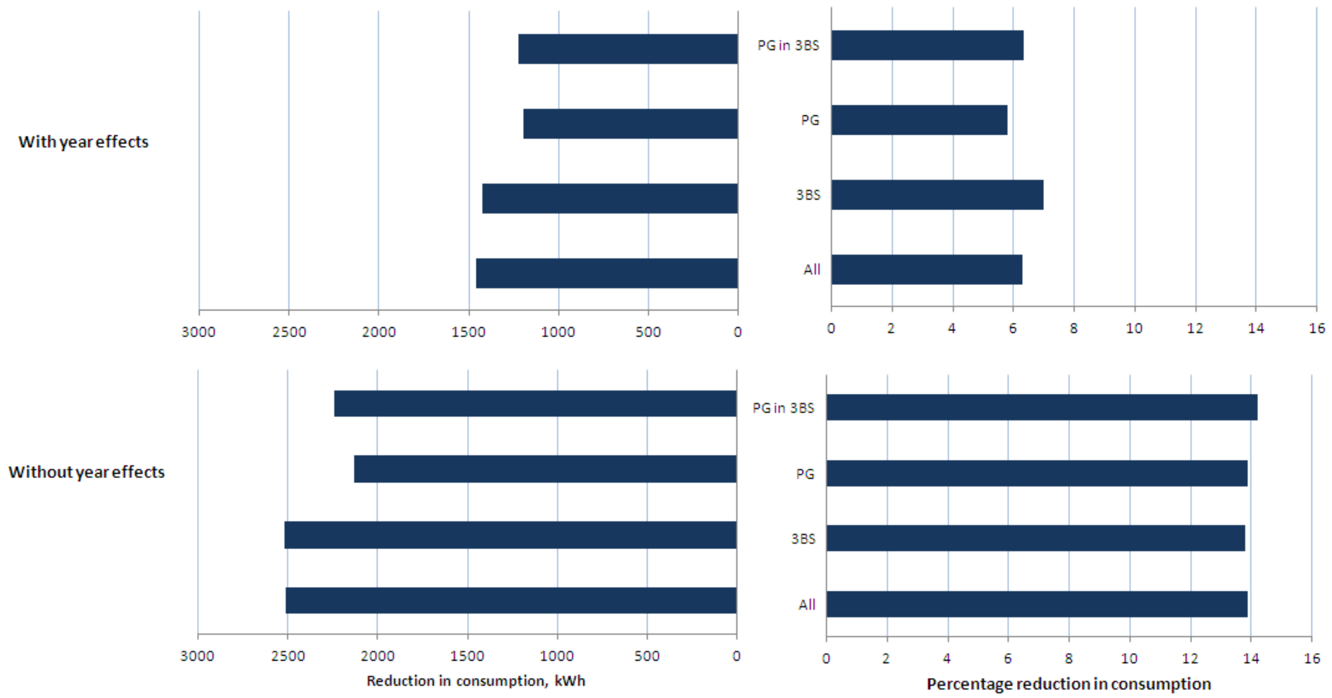
The year effects themselves were very significant statistically, accounting for average annual reductions of around 8 per cent. Putting this in perspective, this is as large as the individual impact of any of the main measures observed.

Unlike in the percentage specification, the absolute reduction in consumption from loft insulation was statistically significant, but still much smaller than those from other measures. For the full housing stock, the reduction was highest at 420 kWh/year. The reductions rose to almost 1,800 kWh/year when year dummies were excluded. For 3 bed semis, reductions of 380 kWh/year were realized which also rose to 1,800kWh/year when year dummies were excluded.

### Cavity wall insulation only

Figure A2.7 shows the estimated effect of cavity wall insulation, following the layout of Figure A2.6.

**Figure A2.7 Panel regression results for Cavity Wall Insulation**



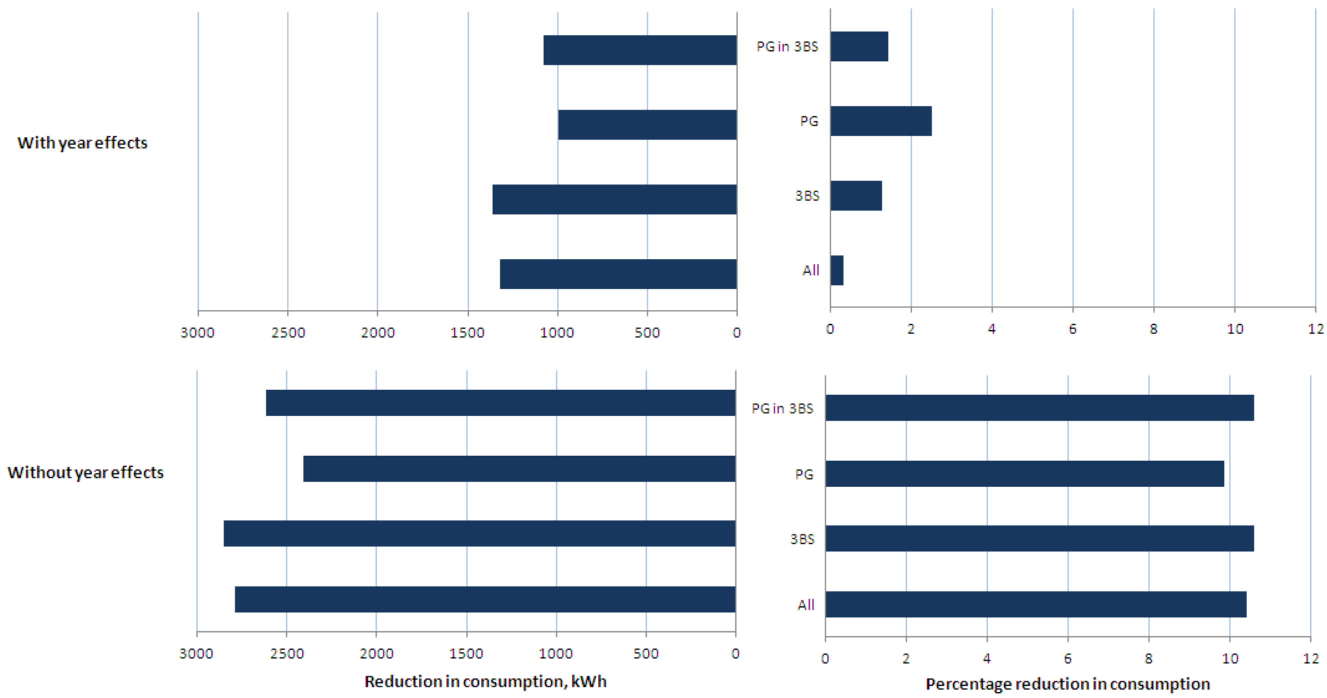
The actual savings from cavity wall insulation was just under 1,500 kWh/year. It was slightly lower for 3 bed semis at about 1,400 kWh/year while households on incomes below £20,000 saved 1,200 kWh/year. However, when the year dummies were removed, the estimated savings rose to around 2,500 kWh for all household types including the typical 3 bed semi and between 2,100 and 2,200 kWh for lower income households.

In percentage terms, the estimated savings were around 6 per cent, with households in 3 bed semis, both overall and for those on lower incomes saving slightly more (7 per cent). When year dummies were removed, the savings were about twice as large at 14 per cent for the overall sample, 3 bed semis and lower income households.

**Condensing boilers only**

Figure A2.8 shows the estimated effect of condensing boilers.

**Figure A2.8: Panel regression results for Condensing Boilers**




The estimated savings across the population were 1,300 kWh/year. Savings were highest for 3 bed semis at around 1,400 kWh/year and slightly less at around 1,000 kWh/year for lower income households. However, the magnitudes of the savings were not consistent with the low estimates from the log specification, which were between 0.3 and 1.4 per cent.

When the year dummies were removed, the savings rose again to around 2,800 kWh/year for the full housing stock. Using the log specification without the year dummies, the savings increased to around 10 per cent.

Unlike in the other cases, the absolute and percentage estimates appear consistent in this case.

### A2.3.3 Year effects

For the panel regressions with year effects, the year dummies represent any change in consumption that is not captured by variables in the model. These would include changes in consumption that are common across all households, such as those due to price changes. It would also include the effects of other energy efficiency improvements, including the uptake of hidden loft insulation and condensing boilers.

In general, when the year dummies were removed, the estimates increased substantially. The increased savings over this period is not surprising because of higher prices and correspondingly lower consumption. Removing the dummies gives some indication of the potential magnitude of these effects. The increase in coefficients for each of the individual measures is generally in excess of 1,000kWh, but the increase for cavity wall insulation, which of the three measures is expected to have the lowest amount of unobserved installations is the smallest.

### A2.3.4 Confidence intervals

Confidence intervals need to be considered alongside the point estimates given in tables A2.1 and A2.2 so as to determine their preciseness. A confidence interval provides a range between which the estimate is likely to lie within, the degree of likeliness usually taken as 95 per cent.

The confidence intervals surrounding the panel estimates for the full sample, 3 bed semis and households on lower incomes are shown in figure A2.9. The results are for the specification including year effects only. Figure A2.9(a) shows the confidence intervals for the specification in levels, while A2.9(b) shows them for the log specification. The intervals for a distance of 2 standard errors around the estimate are approximate 95% confidence intervals.

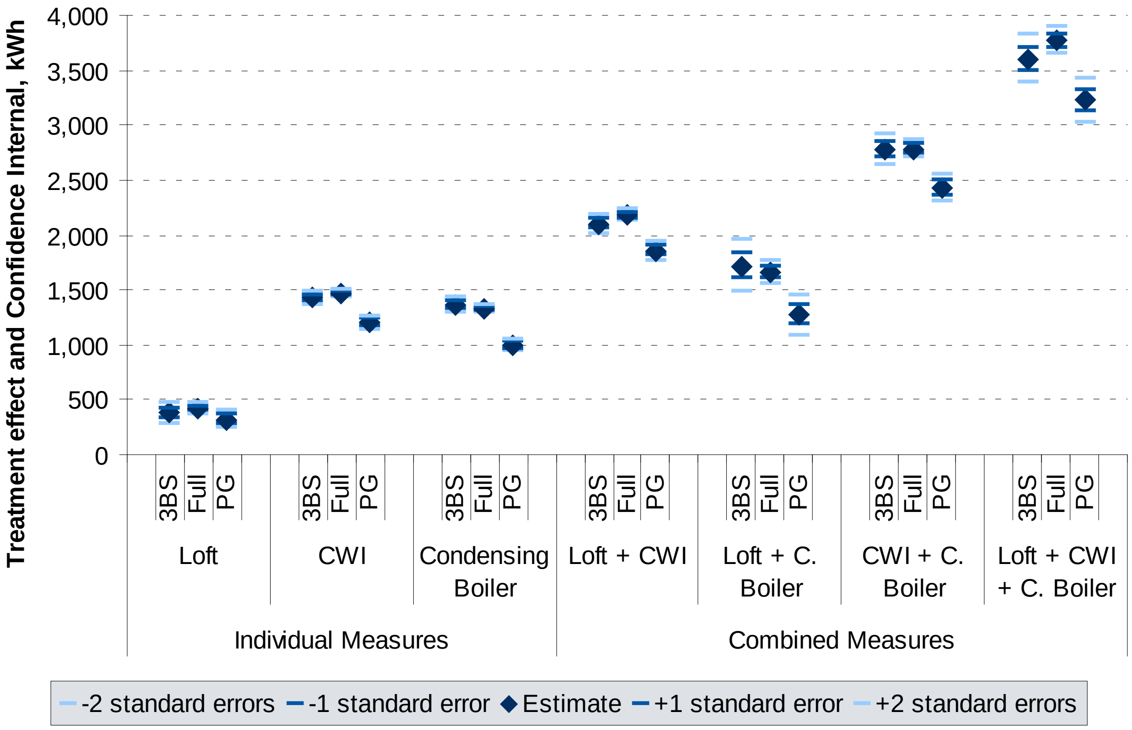
The figure shows that the confidence intervals are narrowest for the full sample. The estimates are less precise for the smaller samples representing 3 bed semi's and households on lower incomes. The estimates are also more precise for the treatment effects of individual measures than combinations.

The estimates for the log specifications are less precise, which is more apparent for the combinations. When a confidence interval includes zero, it means that estimates are not statistically different from zero. This is the case for loft insulation and boilers, where in many cases the estimates in logs are close to and including zero. However, their estimates in levels are significantly different from zero. These qualitative differences are most apparent for condensing boilers and the combination of boilers and loft insulation.

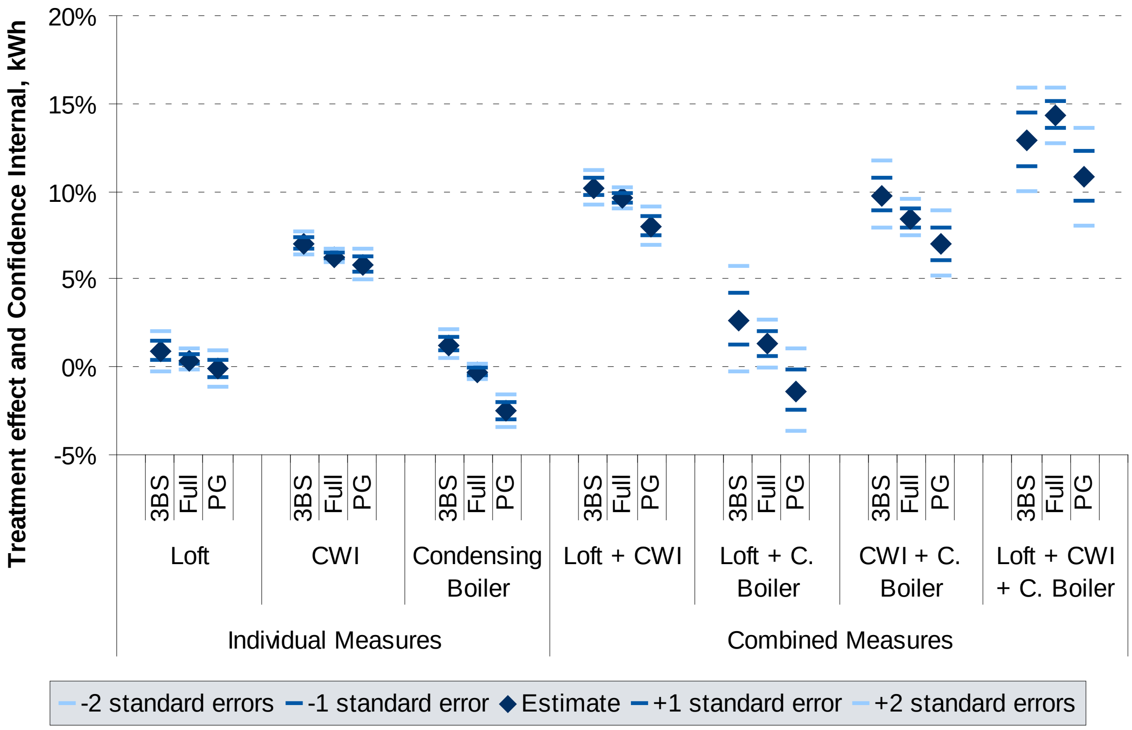
It should be noted that there are significant differences between treatment estimates based on levels and on logs.

**Figure A2.9: Confidence Interval for Treatment Effects**

**(a) Treatment effects in kWh**




**(b) Treatment effects in percentages**



### A2.3.5 Interactions with income

To determine if savings realised varied with income, the regression was repeated using interactions between each of the treatment categories and household income. The income of the household was based on the midpoint of the Experian categories[12].

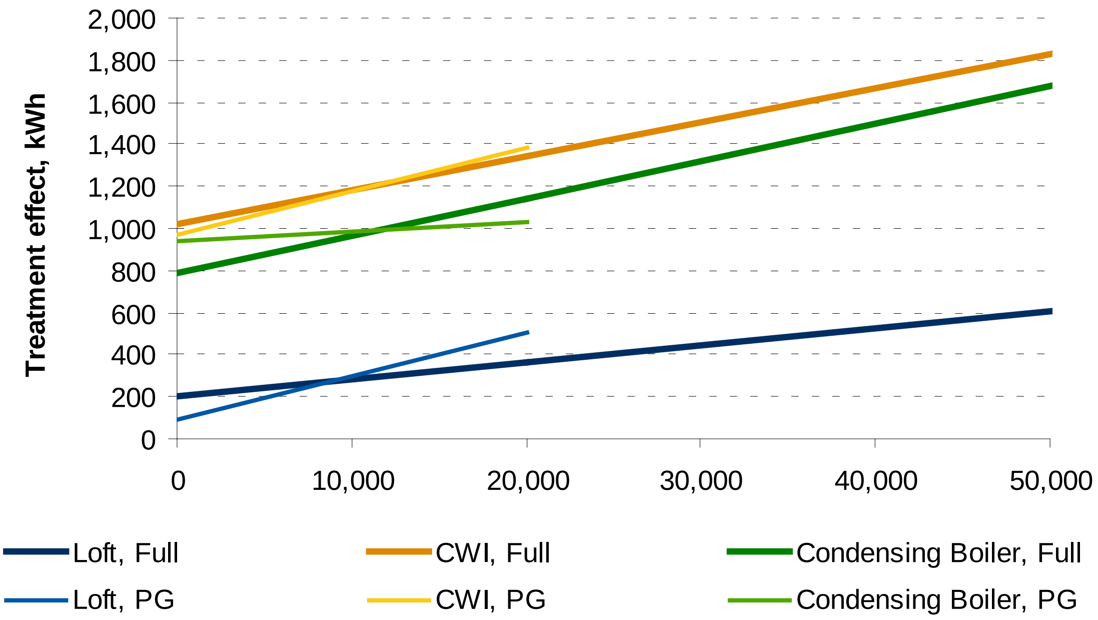
In summary, the estimates based on logs did not appear to change with income for the full sample. But the sample of lower income households that installed cavity wall insulation, appeared to have a larger percentage effect for those with higher income. For example, the effect of installing only cavity wall insulation increases by about 2 per cent for each additional £10,000 of household income.

However, the estimates based on levels were virtually all statistically significant indicating that higher income is associated with greater reductions in energy use. Households with all three major measures had the largest interaction effect, saving 200-350 kWh/year with each additional £10,000 of household income.

Figure A2.10 compares the income effect across all income groups to that for incomes below £20,000 (a) for the full sample and (b) for 3 bedroom semis.

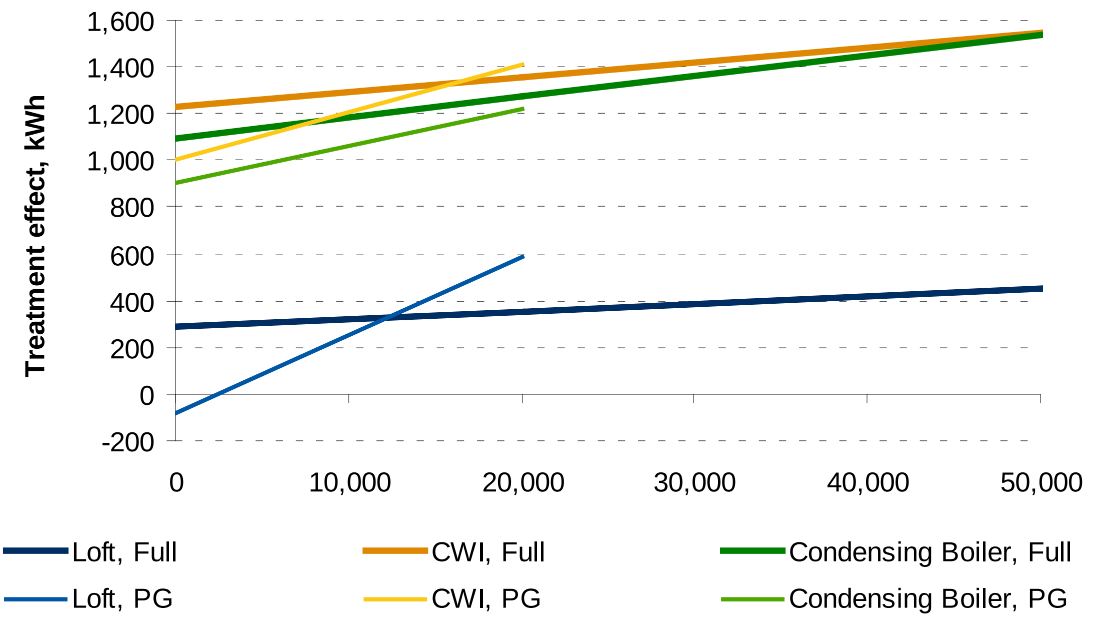
**Figure A2.10: Relationship of Income to Treatment Effect, 2004-2008**

**(a) Full sample**




[12] Households in the highest income category of £75,000+ were assigned an income of £82,500 which was based on the width of the second highest income category (£60,000-74,999)

**(b)Three bedroom semis**




The slope or steepness of the lines gives an indication of the level of relationship between income and treatment effect. Figure A2.10(b) shows that in the typical 3 bed semi, there is a larger income effect for households on incomes below £20,000 than for the population as a whole. However, in figure A2.10(a) for the full set of house sizes, there appears to be less difference between lower income households and all households. This may be due to correlations between the different household characteristic variables that are better controlled for as we limit the sample.

### A2.3.6 Assessment of the approach

The panel approach makes better use of the panel nature of the data than the difference in difference approach by using all years, rather than selecting two years to compare. In fact, the panel analysis is like difference in difference but uses all combinations of pre- and post- treatment year comparisons rather than just two.

The panel approach controls for any omitted variables not captured in NEED, that affect both take up of energy efficiency measures and energy use, provided these factors to not change with time. However, the approach cannot control for unobserved characteristics that vary with time. In addition, the methods are unsuitable if the interest is in the effect of characteristics that do not change with time.

## A2.4 Non parametric analysis

### A2.4.1 Methodology

Unlike the other approaches, the non-parametric analysis does not impose a particular functional form on the relationship between household characteristics and energy use.

The data were divided into 216 categories or “bins”. Each bin represented households with a particular set of Experian characteristics. Six variables were used to define the bins: region, property age, number of bedroom,  tenure, household income, and house type. Each of the variables were split into two or three categories as follows:

- Regions – North (East and West Midlands, North East, North West, Yorkshire and Humber)and South (East of England, South West, London, South East)

- Property age – pre 1955 and post 1955

- Number of bedrooms – less than 3 bedrooms and 3 or more bedrooms

- Tenure – owner occupied, privately rented and council/housing association

- Household income – less than £20,000, between £20,000 and £40,000, and more than £40,000

- House type – stand alone (detached and bungalow), semi detached and terraced

For example, one of the bins would comprise of owner occupiers living in a terraced house in the north that was built pre-1955 and has less than 3 bedrooms, and who have household income of less than £20,000.

The energy efficiency savings in each bin was then estimated. These bin estimates were used to gain insight into how the savings varied in different household types. As well as ensuring that the estimates were appropriate for the specific subsets of the population, the method also provided appropriate estimates for the entire population. The uptake of energy efficiency measures was not uniform across the population so to ensure the estimate for the energy savings for the overall population is accurate, it was weighted to correct for selection bias.

### A2.4.2 Distribution of households in bins

Figure A2.11 shows the number of households in the NEED sample represented in each bin. Green cells have the highest number of observations, yellow a moderate amount and red the least.

The bin with the largest number of households is an owner-occupied semi-detached house with three or more bedrooms, in the North of England, built prior to 1955, where the annual household income is between £20,000 and £40,000. The bin with the least number of observations is a detached council or housing association property with less than three bedrooms in the South of England, built before 1955, and home to residents with annual income above £40,000.

### Figure A2.11: Number of observations

| Tenure | Beds | Age | Detached / Bungalow <£20k N | <£20k S | £20k<x<£40k N | £20k<x<£40k S | >£40k N | >£40k S | Semi-Detached <£20k N | <£20k S | £20k<x<£40k N | £20k<x<£40k S | >£40k N | >£40k S | Terraced / Flat <£20k N | <£20k S | £20k<x<£40k N | £20k<x<£40k S | >£40k N | >£40k S |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Owner-Occupied | <3 beds | <'55 | 3479 | 2269 | 3617 | 2970 | 1463 | 2082 | 6278 | 1902 | 12956 | 4809 | 3974 | 3123 | 26448 | 5128 | 46643 | 14300 | 12922 | 9546 |
| | | 55+ | 10174 | 5604 | 10148 | 6075 | 3604 | 3308 | 7003 | 3551 | 16292 | 9296 | 5584 | 4822 | 7713 | 7032 | 16257 | 22748 | 6394 | 14614 |
| | 3+ beds | <'55 | 12398 | 6227 | 23765 | 15722 | 29642 | 32281 | 36444 | 11982 | 97027 | 41707 | 48898 | 41515 | 36369 | 10430 | 75631 | 38129 | 26284 | 29082 |
| | | 55+ | 28482 | 16128 | 69975 | 37939 | 96248 | 79963 | 28683 | 14449 | 93307 | 50591 | 46640 | 41140 | 11985 | 8001 | 29698 | 29735 | 13495 | 23569 |
| Privately Rented | <3 beds | <'55 | 887 | 203 | 362 | 182 | 78 | 75 | 3111 | 562 | 1864 | 580 | 195 | 176 | 16507 | 4690 | 7437 | 5235 | 845 | 1246 |
| | | 55+ | 1072 | 281 | 625 | 234 | 126 | 99 | 2769 | 839 | 2055 | 751 | 255 | 219 | 5668 | 4442 | 3494 | 4999 | 478 | 1271 |
| | 3+ beds | <'55 | 677 | 477 | 529 | 428 | 266 | 383 | 5924 | 1803 | 3654 | 2018 | 672 | 826 | 11833 | 3890 | 5506 | 3764 | 670 | 987 |
| | | 55+ | 840 | 510 | 941 | 825 | 866 | 935 | 3708 | 1294 | 2893 | 1710 | 639 | 834 | 2908 | 1732 | 1858 | 2075 | 318 | 825 |
| Council/Housing Association | <3 beds | <'55 | 5141 | 1282 | 1965 | 559 | 130 | 60 | 19036 | 3206 | 5455 | 1851 | 439 | 307 | 19300 | 13312 | 7270 | 9074 | 599 | 1528 |
| | | 55+ | 6813 | 1768 | 2837 | 833 | 213 | 126 | 20049 | 4365 | 5348 | 2221 | 374 | 314 | 18218 | 17221 | 6811 | 10925 | 545 | 1654 |
| | 3+ beds | <'55 | 1898 | 537 | 869 | 454 | 115 | 112 | 34437 | 6451 | 12815 | 6162 | 1390 | 1311 | 30853 | 14744 | 14996 | 12538 | 1481 | 2567 |
| | | 55+ | 1373 | 573 | 704 | 502 | 185 | 174 | 18423 | 4556 | 6471 | 3985 | 698 | 861 | 17205 | 12482 | 8498 | 11270 | 940 | 2397 |

The chart brings out very clearly some aspects of the NEED sample. There are relatively few rented properties, stand alone properties are rarely rented, higher income households are unlikely to rent and are most likely to be found in relatively large semi-detached houses, middle income households are also most likely to be owner-occupiers and to be found in three-bedroom semi-detached households.

## A2.4.3 Distribution of gas consumption in bins

Figure A2.12 shows the distribution by bins with valid gas consumption between 1 and 73,200 kWh in 2007. The matrix has been rearranged to better highlight some of the relationships.

### Figure A2.12: Gas Consumption by Bin, 2007 (kWh)

| Beds | Income | Age | Detached / Bungalow O-O N | O-O S | PR N | PR S | CH N | CH S | Semi-Detached O-O N | O-O S | PR N | PR S | CH N | CH S | Terraced / Flat O-O N | O-O S | PR N | PR S | CH N | CH S |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| <3 beds | <£20k | <'55 | 18368 | 16766 | 14325 | 16021 | 13238 | 10971 | 16393 | 15319 | 14797 | 14369 | 13168 | 11461 | 14370 | 12785 | 13186 | 11621 | 12958 | 11205 |
| | | 55+ | 16769 | 15367 | 13002 | 12766 | 11967 | 10827 | 13475 | 12603 | 11471 | 10897 | 10466 | 9783 | 12143 | 10713 | 10595 | 9488 | 10257 | 9493 |
| | £20k<x<£40k | <'55 | 19828 | 18480 | 15904 | 16813 | 14008 | 12408 | 17658 | 16550 | 15342 | 16413 | 14305 | 13564 | 15178 | 13705 | 13549 | 12274 | 14005 | 12568 |
| | | 55+ | 17802 | 16605 | 13879 | 14839 | 12377 | 11356 | 13822 | 12851 | 11881 | 11780 | 11514 | 11000 | 12446 | 10668 | 10529 | 9649 | 10968 | 10335 |
| | >£40k | | 23942 | 23448 | 19843 | 20824 | 15357 | 16071 | 19883 | 19782 | 17625 | 17669 | 15988 | 15798 | 16445 | 15289 | 14478 | 12963 | 15409 | 14121 |
| | | | 20719 | 19837 | 20386 | 19823 | 14431 | 15443 | 15136 | 14389 | 13289 | 13507 | 12310 | 12081 | 13303 | 11922 | 11487 | 10555 | 12596 | 11718 |
| 3+ beds | <£20k | <'55 | 22743 | 22360 | 20621 | 23207 | 15872 | 15787 | 19295 | 18192 | 17662 | 18440 | 15872 | 15557 | 17437 | 15741 | 16974 | 15866 | 15867 | 14448 |
| | | 55+ | 20616 | 19735 | 19538 | 18997 | 15400 | 15456 | 17148 | 15983 | 15260 | 15282 | 13726 | 13843 | 15750 | 14350 | 15033 | 14061 | 13946 | 13010 |
| | £20k<x<£40k | <'55 | 25233 | 24088 | 22843 | 23453 | 17129 | 17139 | 20709 | 19732 | 18730 | 18652 | 17067 | 16751 | 18763 | 17661 | 17298 | 16757 | 16690 | 15770 |
| | | 55+ | 21261 | 20395 | 20938 | 19710 | 16778 | 16621 | 18047 | 16644 | 16115 | 16144 | 14812 | 14995 | 16422 | 14783 | 15294 | 14475 | 14662 | 14400 |
| | >£40k | | 30643 | 29317 | 29297 | 28138 | 20964 | 24555 | 23921 | 23057 | 21167 | 20974 | 18332 | 18011 | 21060 | 19912 | 19222 | 18034 | 17347 | 16962 |
| | | | 24137 | 23611 | 24519 | 23797 | 20784 | 20943 | 19750 | 18698 | 17319 | 17151 | 16147 | 15759 | 18693 | 17174 | 17238 | 15456 | 15335 | 14890 |

The figure shows a clear trend from high consumption to low consumption when moving from the bottom left to the upper right which reflects the size of property being heated. It confirms that households renting from the council or housing associations use less gas than those renting privately, who use less than owner-occupiers. It also confirms that wealthier households, households in the North and those in older properties consume more gas.

### A2.4.4 Treatment effects

The treatment effects were estimated by comparing the average consumption in each bin of those who have installed a major energy efficiency measure or combination to the consumption of those who have not installed any of the major measures.

The output for cavity wall insulation is shown in Figure A2.13. Here, red is used to indicate an increase in consumption and green a reduction and the colours graduating in between. Bins where there were less than ten households that had installed the energy efficiency measure or the combination were excluded from the analysis. This was to ensure that undue weight was not given to bins with very few households, or outliers. Such bins are represented in white.

**Figure A2.13: Treatment Effect of Cavity Wall Insulation Only, by Bin, 2007 (kWh)**

| | | | Owner-Occupied | | | | | | Privately Rented | | | | | | Council / Housing Association | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | Det. / Bung. | | Semi | | Terrace | | Det. / Bung. | | Semi | | Terrace | | Det. / Bung. | | Semi | | Terrace | |
| | | | N | S | N | S | N | S | N | S | N | S | N | S | N | S | N | S | N | S |
| <3 beds | <£20k | <'55 | 739 | 1582 | 647 | 2294 | -674 | 741 | 1138 | 3127 | 503 | 2665 | -881 | 451 | -465 | -171 | -487 | 530 | -227 | -118 |
| | | 55+ | 469 | 1339 | -614 | -214 | -880 | 196 | -38 | -3020 | -977 | 82 | -750 | 1066 | 60 | 1013 | -806 | 139 | -711 | 380 |
| | £20k<x<£40k | <'55 | 895 | 1854 | 1331 | 2327 | -588 | 984 | 1462 | 284 | -578 | 2421 | -245 | 2189 | -769 | -727 | -342 | 1012 | -813 | 419 |
| | | 55+ | 216 | 1274 | -912 | 204 | -1003 | 2 | -340 | 722 | -796 | -1305 | -1492 | -711 | -595 | -522 | -903 | -216 | -905 | -47 |
| | >£40k | <'55 | 1832 | 5082 | 1953 | 3362 | 188 | 1677 | . | . | 1933 | . | -3125 | 2517 | 916 | . | 172 | -1388 | -1241 | 987 |
| | | 55+ | 1818 | 2231 | -774 | 191 | -1046 | -119 | 4583 | . | -2476 | . | -1154 | -2066 | -252 | 529 | -2317 | -744 | -1921 | -700 |
| 3+ beds | <£20k | <'55 | 2145 | 4269 | 2083 | 2575 | 660 | 1797 | 1955 | 6925 | 1692 | 3905 | 1529 | 2443 | -9 | 661 | 204 | 935 | 447 | 800 |
| | | 55+ | 2106 | 2613 | 1062 | 1734 | 9 | 734 | 2748 | 2734 | -132 | 1588 | 403 | 1181 | -373 | 1367 | -523 | 529 | -219 | 240 |
| | £20k<x<£40k | <'55 | 3748 | 4609 | 2423 | 3526 | 975 | 2382 | 3228 | 325 | 2155 | 2001 | 1692 | 1351 | -1662 | 1784 | 559 | 1349 | 548 | 1516 |
| | | 55+ | 1724 | 2057 | 1079 | 1344 | 569 | 997 | 1228 | 1520 | 255 | 1040 | 20 | 1176 | -735 | 509 | -831 | 699 | -143 | 423 |
| | >£40k | <'55 | 4444 | 5244 | 3517 | 4815 | 2321 | 2684 | 2194 | 2240 | 1169 | 4109 | 2295 | 2910 | -303 | . | 1182 | 2582 | 482 | 639 |
| | | 55+ | 1794 | 2622 | 1457 | 1842 | 1578 | 1135 | 1150 | 2329 | -593 | -278 | 1309 | -729 | 1331 | 4740 | 1593 | 492 | -310 | 422 |

The figure shows that there were some bins, particularly rental properties, where the effect of cavity wall insulation was in the opposite direction as expected[13]. These bins have higher average energy consumption when the measure had been installed compared to where it had not been. What was expected was lower energy consumption in households that have installed CWI.

The figure also shows that newer properties seem to have lower energy savings than older properties and properties in the South appeared to enjoy greater benefit than properties further North. For the well-populated owner occupied section, stand alone properties (detached and

[13] This was still observed when the threshold for number of treatments within each bin was raised from 10 to 100 in an attempt to remove the effect of any remaining outliers in sparsely populated treatment groups.

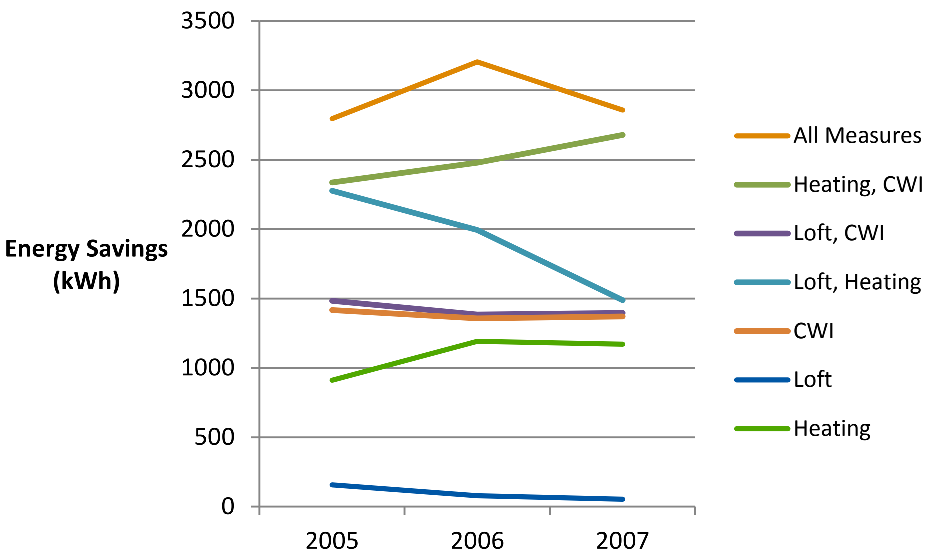
bungalow) have the most significant energy saving benefit, followed by semi-detached. This is consistent with the difference in difference result that the greater the exposed surface area of a property, the greater the benefit of insulation; larger properties generally show greater benefit.

These relationships were still found to hold when starting consumption was controlled for by calculating the *relative* treatment effect; there is a greater relative impact in larger properties, and in the South, and across incomes.

### A2.4.5 Average treatment effect for overall population

The treatment effect for the overall population was obtained by calculating the weighted average using the household bin size for the NEED sample. The average treatment effects for the population for properties that installed a measure or combination of measures by the end of each year is shown in Figure A2.14. As with the basic approach, the results have been presented for 2005 to 2007 only. This is due to data concerns for consumption figures in 2004 and 2008 which are highlighted in section A1.1 of appendix 1.

**Figure A2.14: Saving by Measures, population average, 2005 – 2007, kWh[1]**




1. The results shown are not independent data points. Once a household has taken up a measure, it persists in that state until the time when they add another measure. In addition, the pair-wise comparisons make use of the same data points.

The figure compares the average consumption of households that have measures installed as of the end of the gas year shown. The figure shows that the impact of some measures vary for households taking up the measure in successive years.

Loft insulation shows a very slight impact on energy use, and this impact declines to almost nothing in subsequent years. This negligible effect is confirmed when the effect of loft and cavity wall insulation is compared to the effect of cavity wall insulation alone; the two curves are nearly indistinguishable. However, loft insulation does appear to have significant benefit when added to properties that already have a condensing boiler, but the trend over time does not seem plausible. In 2005, there was 1,400 kWh additional savings when loft insulation was added to homes that already had a boiler replacement compared with the savings realised when there was only a replacement boiler, but this increase dropped to around 300-400 kWh by 2007. Adding loft insulation to a household that already had CWI and a new condensing boiler also showed a declining pattern with time, but this was less pronounced. The savings in 2005 were about 400kWh which declined to around 200 kWh by 2007.

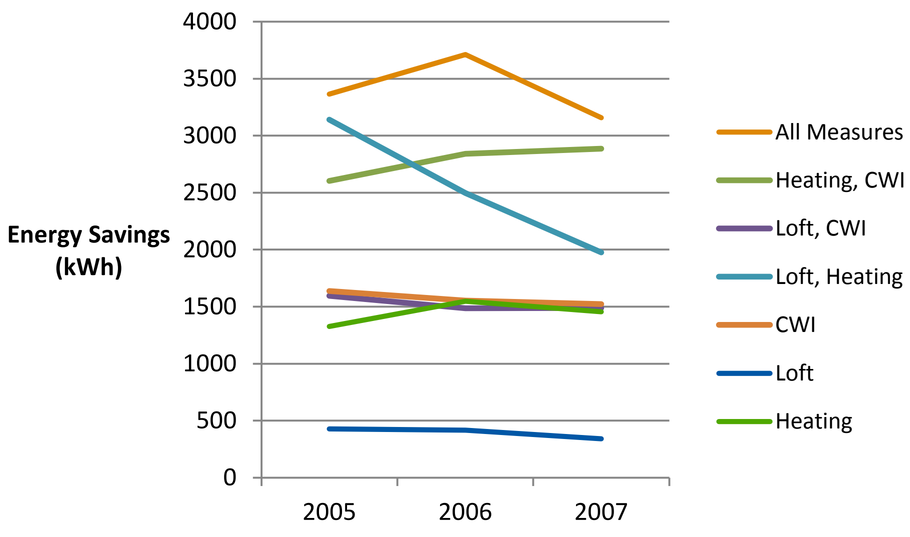
Installing a new condensing boiler alone results in savings of between 900 and 1,200kWh. As discussed above, this saving is increased when it is combined with loft insulation but it declines dramatically over the period. In 2007, there were 1,400kWh additional savings when a new boiler was combined with loft insulation compared to loft insulation alone. This is very close to the additional savings observed in 2007 when a new boiler was combined with cavity wall insulation, compared with the savings from cavity wall insulation alone. Finally, the benefit of adding a boiler to properties that already have the other two measures also fluctuates over time, but by 2007, it is around 1,400 kWh, similar to the values for the additional benefit from the other combinations.

Of the single measures considered, CWI appears to have the greatest impact, saving around 1,400 kWh of energy. When added to loft insulation, it increases savings by about 1,300 kWh compared to loft insulation alone, which hardly has an impact. The additional savings are higher when it is combined with a new boiler, saving between 1,300 and 1,500 kWh over and above the savings from a new boiler alone. When it is added to homes that already have both of the other measures, the savings are only 500 kWh in 2005, but this rises considerably to 1,300 kWh by 2007.

### A2.4.6 Average treatment effect for three-bedroom semi-detached houses

Figure A2.15 shows the average treatment effects for three-bedroom semi-detached houses (classed using Experian data).

**Figure A2.15: Energy Savings by Measures, 3-Bed Semis (Experian data), 2005 – 2007 (kWh)**

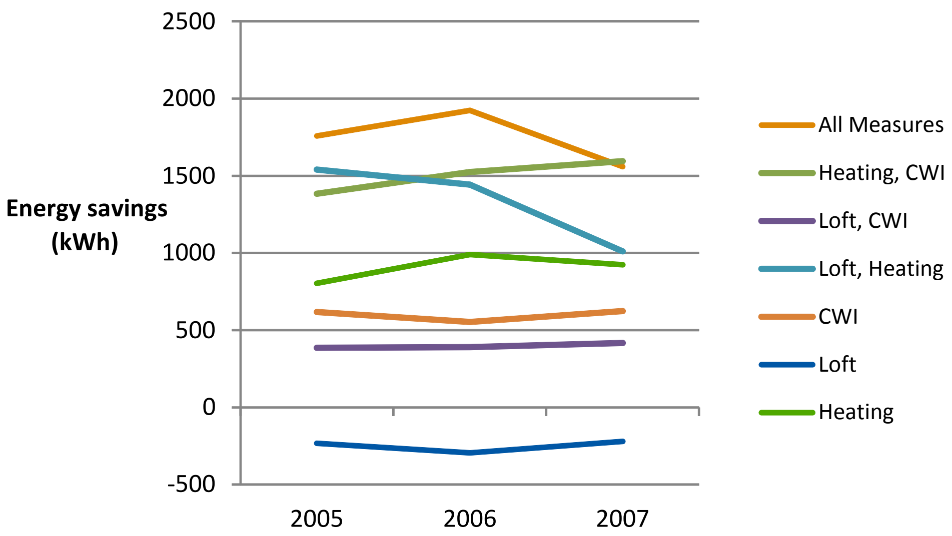



The figure show similar relative impacts and trends to the results for the overall population. However, results in 2005 indicate that properties with all measures had the same energy consumption as those with condensing boilers and loft insulation. This suggested that the addition of cavity wall insulation had no impact.

### A2.4.7 Average treatment effect for households with incomes of £20,000 or less

Figure A2.16 shows the average treatment effects for the lower income households.

**Figure A2.16: Energy Savings by Measures, Lower Income Households, 2005 to 2007, kWh**




The figure shows that the estimated treatment effects are substantially lower than the effects for the overall population. Strangely, there appeared to be an *increase* in consumption for loft insulation.

The average consumption for the overall population is 16,600 kWh, whereas for this income group it is around 12 per cent lower, at 14,600 kWh. The treatment effects appear to be 20 per cent lower for boilers and less than half that for cavity wall insulation. The reduced impact of the efficiency measures cannot therefore be solely explained by lower income households using less energy in the first place. The most likely explanation is that this income group have a significant amount of comfort taking.

### A2.4.8 Assessment of the approach

The approach has some similarities with  the univariate method, but it simultaneously considers household characteristics on multiple dimensions to better understand the effects on the overall population.

The non-parametric approach is superior to both difference in difference and panel approaches in the respect that it provides a more accurate view of the likely treatment effects for the entire population (or the residual untreated population), by correcting for observed selection bias in treatment frequency.  On the other hand, it does not control for unobserved dwelling or household-specific differences, which the panel and difference in difference approaches account for.

# Appendix 3. Modelling Domestic Energy Demand

**In this section, detailed results of the estimate for the domestic model for energy demand is presented. An overview of the methodologies used as well as the reasons for using the methods are also included.**

## A3.1 Methodology

The original NEED dataset was augmented with regional price data and property attribute data from the Valuation Office Agency, VOA. However, due to computing resources, the demand models were estimated using sub-samples, representing 10 per cent of the full NEED dataset.

### A3.1.1 OLS regression

In this approach, the panel nature of the data is ignored and the information on energy consumption and treatment levels across years and households is pooled together to estimate the relationship between consumption and treatments.

The OLS regression aimed to predict consumption at a property level based on household characteristics, prices, year effects and treatment effects. However it does not attempt to account for unobserved explanatory variables (i.e. other factors which may account for variance in consumption, but we do not have data for).

### A3.1.2 Random effects and fixed effects panel regression model

These methods control for any factors affecting both take up of energy efficiency measures and energy use that are not captured in the data available in NEED, provided these factors do not change with time.

Random effects and fixed effects panel regression models make different assumptions about how these unobserved explanatory variables are related to the existing or observed explanatory variables, and attempt to specifically model for these effects such that we get the best estimates of treatment effects.

The fixed effects panel model assumes the unobserved explanatory variables are correlated to an observed characteristic and have a fixed value (i.e. is not randomly distributed over the population).

The random effects panel model tries to account for unobserved explanatory variables, by treating the impact of the unobserved variables as being randomly distributed across properties and not correlated with any of the observed characteristics or with treatment status. For example, properties which occupants with varying degrees of energy efficiency awareness (where this awareness is not related to the characteristics we are already measuring, such as property size, household income, age of head of household, gender of head of household etc).

### A3.1.3 Two stage regression

In the first stage, a fixed effects panel regression was carried out. The results of the regression were the estimated savings for a particular household which represent the “baseline” consumption level for that household, prior to treatments and any time-dependent effects. These results were used in a second regression to estimate the extent to which various observed household characteristics affected a households baseline level of consumption.

The 2 stage regression approach is an attempt to move the impact of the time invariant fixed effects onto the other known time invariant household characteristics, rather than on the estimates of the treatment effects. So whilst some of the estimated coefficients will still be biased by these unobserved variables, we get a cleaner estimate of the effects of the treatments in question. This is desirable, because it is the uptake of energy efficiency measures are directly affected by the relevant energy policies, whereas other household characteristics are not

## A3.2 Results

The results of the two-stage demand models for the full sample and for low income households is shown in table A3.1.

For each model, coefficient values are shown in the first column and the standard errors in the second column. Coefficient values in bold indicate significance at the 5 per cent level, and coefficients in bold italic blue indicate significance at the 0.01 *per cent* level – i.e. $p < 0.0001$. In general, the majority of coefficients are estimated very precisely, with the exception of some of the dummy variables indicating the age of the head of household, some others related to the material used for the construction of any conservatory, and the gas price.

The value “Rho” at the bottom of the table indicates the proportion of the variation in energy consumption that is explained by the household-specific constant. This gives an indication of the extent to which sample variance is due to differences between different households as opposed to year to year variation within each household. In general, the value of Rho are relatively high, indicating that most of the variation is energy consumption in NEED is as a result of differences between households, rather than changes in each household’s consumption from one year to the next.

The R-squared value refers to the variation in the household-specific constant that can be accounted for by the observed household characteristics in the model. Note that this excludes the reduction in consumption that can be explained by the efficiency measures. So, for example, in the first model, which estimates consumption on the full sample, the household specific constants account for 81 per cent of all variation in energy consumption and therefore only 19 per cent is down to annual variation. The observed household characteristics explain 38 per cent of the variation in the value of household specific constants across households. The overall explanatory power of the model is then equal to the product of these two values (81% x 38% = 31%) *plus* the *additional* explanatory power of efficiency treatments over and above what would already been explained by other characteristics.

## Table A3.1 Results of Two-Stage Demand Estimation Regression[1]

| Household Characteristic | Full Sample | | Priority Group | |
|---|---|---|---|---|
| | Coefficient | Std. error | Coefficient | Std. error |
| **First Stage Regression Results** | | | | |
| **Average HH baseline level, 1st stage** | *20,628* | 379 | *16,194* | 920 |
| **Gas Price** | -51 | 221 | 811 | 536 |
| **Treatment Effects** | | | | |
| Loft only | *-410* | 75 | -267 | 152 |
| CWI only | *-1,464* | 56 | *-1,082* | 137 |
| New condensing gas boiler only | *-1,397* | 55 | *-953* | 128 |
| Loft + CWI | *-2,213* | 79 | *-1,738* | 169 |
| Loft + boiler | *-1,679* | 177 | **-1,087** | 314 |
| CWI + boiler | *-2,765* | 127 | *-2,320* | 268 |
| Loft + CWI + boiler | *-3,588* | 205 | *-2,939* | 397 |
| **Year Dummies** | | | | |
| Year dummy for 2005 | *-319* | 55 | **-501** | 132 |
| Year dummy for 2006 | *-1,043* | 144 | **-1,561** | 347 |
| Year dummy for 2007 | *-1,579* | 234 | **-2,411** | 570 |
| Year dummy for 2008 | *-2,315* | 271 | **-3,251** | 658 |
| **Second Stage Regression Results** | | | | |
| **Constant, 2nd stage** | *-13,098* | 306 | *-9,927* | 896 |
| **General household characteristics** | | | | |
| Income | *382* | 10 | 203 | 111 |
| Female head of HH (Y<=>1) | *316* | 32 | *507* | 76 |
| Have children (Y<=>1) | *199* | 40 | **278** | 102 |
| Number of Adults in HH | *871* | 16 | *757* | 43 |
| **Tenure** | | | | |
| Privately rented | *-809* | 73 | *-799* | 128 |
| Council / housing association | *-968* | 48 | *-993* | 87 |
| **Age of head of household** | | | | |
| 26-35 | **-399** | 106 | 232 | 167 |
| 36-45 | 41 | 103 | 356 | 163 |
| 46-55 | 189 | 103 | -229 | 153 |
| 56-65 | **-365** | 104 | **-776** | 179 |
| 66+ | -214 | 103 | **-528** | 151 |
| **Number and size of rooms** | | | | |
| Number of bedrooms | -94 | 42 | -148 | 104 |
| Number of rooms[1] | *464* | 30 | **382** | 77 |
| Number of bathrooms[2] | *-1,087* | 55 | **-605** | 200 |
| Number of floors | *546* | 75 | 368 | 192 |
| Area of conservatory | 12 | 13 | 46 | 40 |
| Area of dwelling | *109* | 1 | *115* | 2 |
| **Type of dwelling** | | | | |
| Semi-detached | *-2,214* | 54 | *-2,472* | 182 |
| Bungalow | *1,258* | 89 | 464 | 257 |
| Mid- or end-terraced | *-4,044* | 59 | *-3,868* | 186 |
| Flats and others | (omitted) | | (omitted) | |
| **Additional dwelling characteristics** | | | | |
| All glazed/lean to | 638 | 331 | 636 | 983 |
| No conservatory | **-709** | 256 | -453 | 795 |
| Single glazed UPVC/hardwood | 80 | 368 | 154 | 1,035 |
| Conservatory exists but type unknown | 63 | 204 | -307 | 667 |
| Existence of conservatory not known | -235 | 224 | -270 | 721 |
| **Dwelling age** | | | | |
| 1900-1918 | *552* | 79 | 384 | 174 |
| 1919-1939 | *639* | 63 | *714* | 140 |
| 1945-1954 | *-549* | 75 | -187 | 158 |
| 1955-1982 | *-1,141* | 60 | **-544** | 133 |
| 1983-2011 | *-4,093* | 69 | *-2,615* | 163 |
| **Region** | | | | |
| South West | *-2,021* | 66 | *-1,784* | 167 |
| South East | *-494* | 64 | **-651** | 181 |
| London | *1,625* | 91 | *2,377* | 346 |
| East Midlands | *398* | 65 | **728** | 152 |
| West Midlands | *691* | 62 | **688** | 147 |
| Yorkshire and Humber | *1,401* | 62 | *1,297* | 145 |
| North East | *1,965* | 74 | *2,179* | 160 |
| North West | *1,092* | 58 | *815* | 136 |
| **Rho** | 81% | | 75% | |
| **R-squared** | 38% | | 24% | |

1. Physical building characteristics are based on VOA data and demographic characteristics are based on Experian data.

The results in the first stage represent time varying factors such as treatment effects. The results here are very similar to the panel results in appendix 2. This is expected as this stage is also a fixed effect panel regression. The parameter estimates are slightly different because here the model is based on a slightly different dataset. VOA sub-samples were used instead of the full NEED dataset and it also includes an additional variable, gas price. However, the gas price variable was not significant.[14]

There was a significant underlying time trend showing reduced energy consumption that is not explained by the observed adoption of energy efficiency measures. These trends reflect both higher prices over the period as well as other energy efficiency improvements that are not observed – including the uptake of "hidden" loft insulation and condensing boilers. The effect of other energy efficiency improvements accounts for more of the declining trend than does price: changes in price account for average annual reductions of around 100 kWh over the period, whereas the residual time trend is closer to a reduction of 500 kWh per year. The interpretation of coefficient values has been given in Section 5.

In general, the models of lower income groups consumption are less successful at explaining variation in consumption than the model of the full sample, and the models in absolute levels of consumption provide a better fit of the data than the models in logs.

## A3.3 Unexplained variation

The model explains approximately one third of the variation in gas consumption across the NEED data. This is broadly consistent with the regression results obtained by Katalysis. The results also compare well to other attempts to estimate gas consumption (see, for example Meier & Rehdanz (2010), who achieved R-squared values of around 20 per cent for their full sample, for energy or gas expenditure, using a significantly smaller panel data set that contains much more detailed household information).

The bulk of this variation occurs because of differences from one household to another ("between household variation"), rather than differences in year to year consumption for the same household ("within household variation").

From one year to the next, demographic factors such as income and number of occupants would probably change more for the same household than building characteristics. Since the model suggests that the variation from year to year changes for a particular household is less, this has some implications for the measurement error in Experian demographic variables. It means that any annual changes in demographic factors for a particular household would not have a dramatic impact on gas consumption, although they could still account for up to a third of the variation.

[14] However, when the full dataset was used instead of the sub-sample, the coefficient was found to be significant at around -350 kWh/pence.

## A3.4 Alternative approaches

Ordinary least squares (OLS) and random effects estimations were also carried out. Except for loft insulation, the estimated coefficients were very similar, with the differences between the alternative approaches being almost always less than 20 per cent, and often close to zero. The random effects results were closer to the two stage estimation than the OLS.

Cavity wall insulation and boilers were the most robustly estimated treatment effects; the differences between the estimates in the three methods did not exceed 4 percentage points.

For loft insulation, the treatment effect was significantly lower in OLS and less so for random effects. This is likely to be a result of the measurement error in recording the uptake of loft insulation.

However, the 2 stage fixed effects method, avoids some of the problems of the alternative approaches, and yields treatment effect estimates that are most robust to selection bias.