DISTRIBUTIONAL IMPACT OF TIME OF USE TARIFFS

OFFICE OF GAS AND ELECTRICITY MARKETS (OFGEM)

2 MAY 2017

FINAL REPORT

Prepared by:

Cambridge Economic Policy Associates Ltd

DISCLAIMER

EXECUTIVE SUMMARY

Background and objective

The purpose of this study is to assess the distributional impacts of time of use (ToU) tariffs. Such tariffs may become more widespread if a decision is taken to mandate half-hourly settlement (HHS) in the domestic electricity market.

Since smart meters record consumption for every half hour period, it will be possible for suppliers to offer customers tariffs which reflect their consumption on a half-hourly basis. HHS would mean that suppliers would face the true cost of their customers' consumption each half hour. Thus, HHS puts incentives on suppliers to offer more cost-reflective tariffs, which in practice will mean ToU tariffs.

In this study, we assess the impact of ToU tariffs on customers, differentiated according to sociodemographic group. CEPA was asked to examine the following points:

- the potential incidence of different tariffs on consumer bills for different sociodemographic groups;
- the impact of different levels of consumer behaviour in response to those tariffs for different sociodemographic groups; and
- the potential mitigation and support measures.

Study methodology

CEPA developed an Excel model to assess the distributional impact of specific ToU tariffs on household bills in comparison to a flat tariff. The model includes functionality to:

- assess what proportion of households in each sociodemographic category (or however categorised) are likely to take up a specified tariff;
- assess what change in consumption (behavioural response) the households are likely to make in response to the tariff they have selected; and
- calculate the bills that result by household.

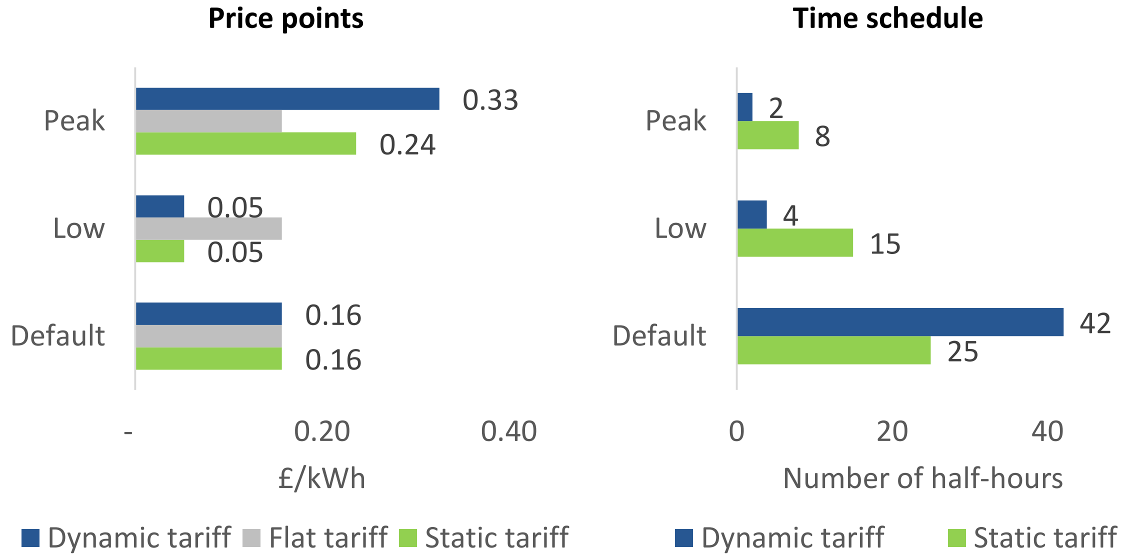
Consumption data

We apply our model to datasets of household half-hourly consumption, associated with sociodemographic data. The best available datasets for this purpose we could locate came from the two largest smart metering trials in the UK, the Energy Demand Research Project (EDRP) and the Low Carbon London (LCL) trials. These datasets are associated with sociodemographic data using the ACORN classification, which was used to relate impacts to social characteristics.

Tariff scenarios

Our tariff scenarios were chosen to facilitate a useful assessment of distributional effects. To identify distributional effects, we designed the tariff scenarios so that **if consumers do not change their consumption, the bill of the average customer will remain unchanged relative to what they would have paid under an existing flat tariff**. Our tariff scenarios were also designed to be commercially realistic from the perspective of both supplier and customer. We compare a flat tariff with a static tariff (price always changes in the same way each day) and a dynamic tariff (prices may change at short notice). Figure E1 shows the tariffs in our main 'Reference' scenario. The chart on the left displays prices under the three tariffs during peak, low and default periods; and the chart on the right shows the number of half hour periods in a day for which the given tariff applies (on average in the case of the dynamic tariff).

Figure E1: ToU tariff pricing profile in £/kWh and by number of half hours per day

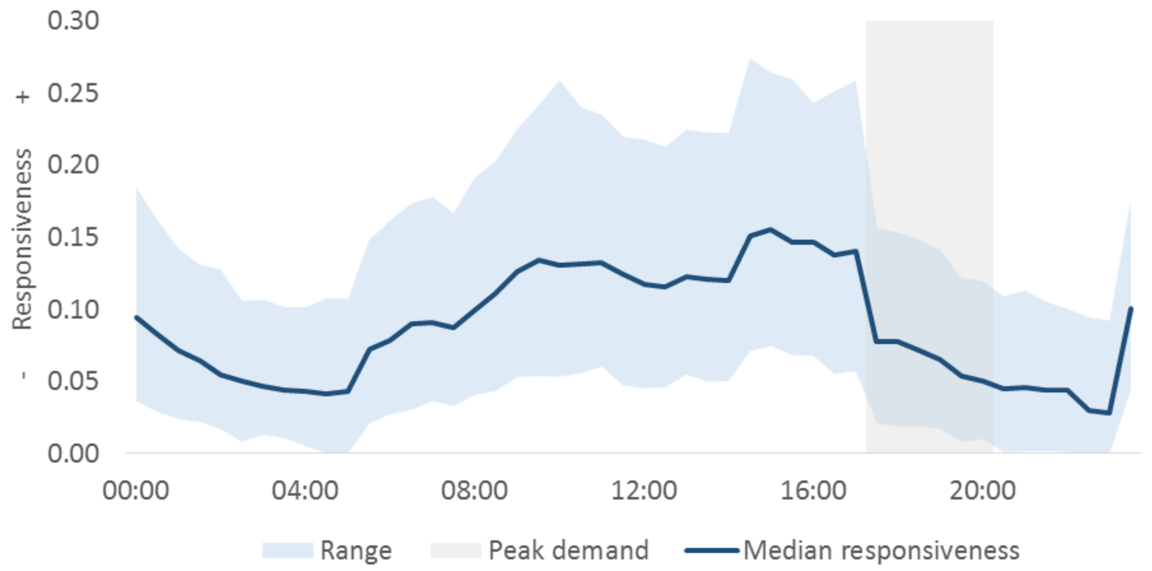


Note: Under the static tariff, the time periods of the different prices are fixed each day, whereas under the dynamic tariff the times vary according to market conditions.

Consumer response

We determined the responsiveness of customers to pricing, by time of day and by sociodemographic category, through statistical analysis of data from the LCL trial. We show price responsiveness by time of day in Figure E2. As can be seen, customers are less responsive to price at night and during the evening, which partly coincides with the peak demand period for domestic customers.

Figure E2: Price responsiveness of customers by time of day



Note: The peak consumption period for the dataset is highlighted. This may differ from the market peak. Responsiveness is measured as price elasticity of demand as a positive number.

We assessed scenarios for take-up of tariffs from existing literature, which mainly encompassed customer survey evidence rather than trials. We also carried out a small survey of former trial customers. We found that customers tend to think about 'high price' and 'low price' rather than detailed price levels. Almost all respondents agreed or strongly agreed that if they were on a smart ToU tariff they would like to receive monthly feedback on amount of savings compared to a flat tariff. There was strong agreement that they would be willing to share smart meter data to get good advice on tariffs.

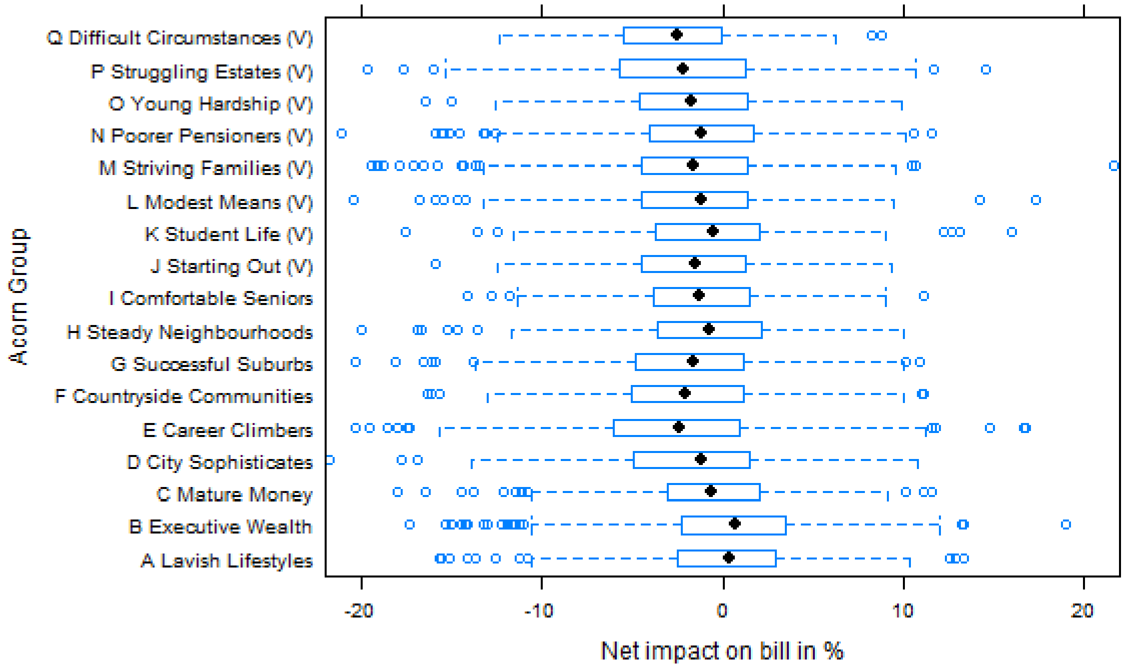
Findings: Impact of ToU tariffs on households' bills

Figure E3 shows the impact of a static ToU tariff on bills as a percentage change in comparison to the flat tariff bill, disaggregated by ACORN sociodemographic group, including the effect of consumers' predicted demand response. It shows the median impact as well as the spread of impact.[1] It shows that almost all sociodemographic groups save on their annual bills on average, except some of the most well-off groups.

We find that there are households in all groups that would be worse off under ToU tariffs to some modest degree, even though on average they would be expected to adjust consumption in response to prices. Currently customers must make an explicit choice to be put on a ToU tariff. They would not be likely to make that choice if they expected a higher bill. So they are unlikely to suffer this loss as long as it remains an explicit choice.

[1] Due to methodological issues, the spread is underestimated by a small proportion.

Figure E3. Impact on bill in relative terms under static ToU reference tariff (% net impact on bill compared to a flat tariff), assuming customers adjust consumption to tariff

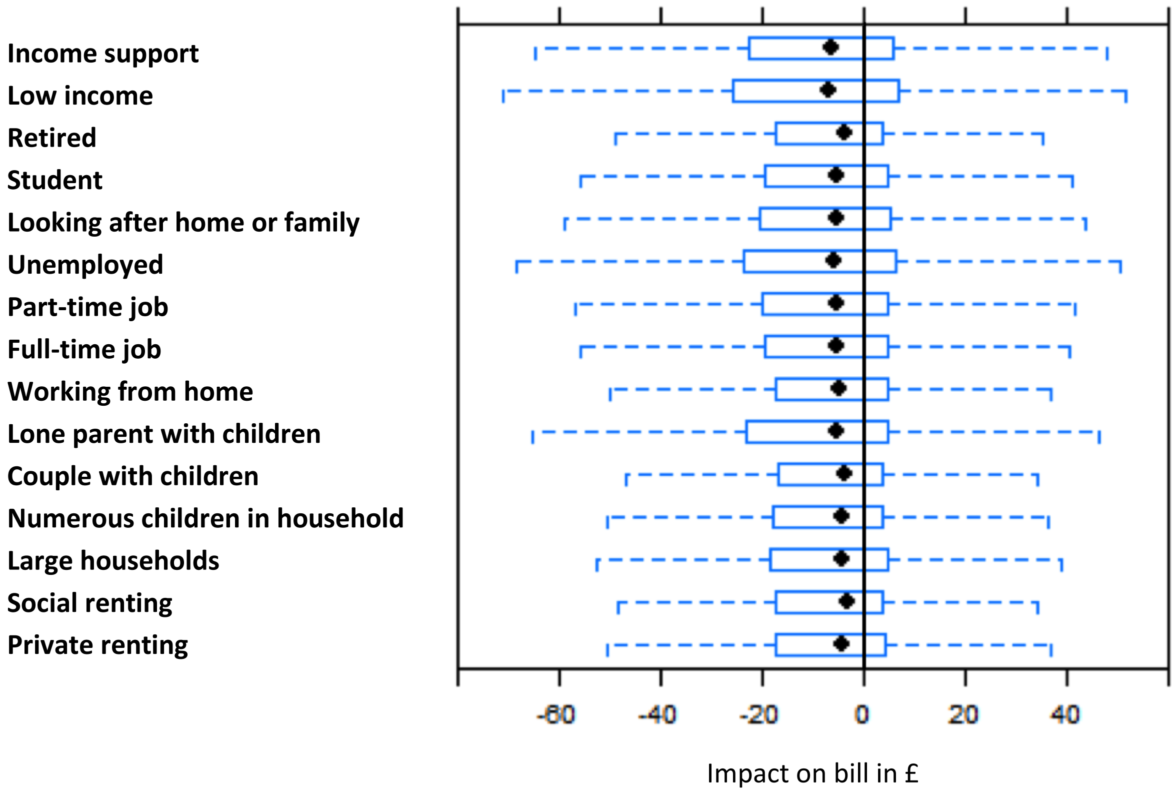


Key: Black Dot shows median, Box shows interquartile, Bars show 2nd to 98th percentiles, circles are outliers[2]

Figure E4 shows the distribution of bill impacts under the static ToU reference tariff for a number of socio-economic groups containing a high proportion of vulnerable consumers. The figures here are shown under the assumption that customers adjust their consumption to the prices they face, according to the responsiveness parameters we have assessed. Some small differences in median bill can be seen, but the main conclusion is that there is a broad distribution of impact within each group. In other words, within each vulnerable group, there is potentially an ill-defined subset that would experience a bill increase if they were to take up a ToU tariff. At the same time, a slight majority of such customers would benefit from a ToU tariff. On average these lower income groups experience bill reductions of about £8.60 (about 2% for them) but the variation from individual to individual is much larger.

[2] It is likely that the outliers are mostly not genuine outliers in their class. This is both because postcode-level social classification is being used, and because of the presence of other data difficulties. Rather the outliers are likely mostly are made up of, in part, consumers unrepresentative of the social category attributed to the postcode, and, in part, data difficulties such as meter faults, theft, non-domestic use of electricity, etc. We would not recommend any policy conclusions be based on an examination of outliers.

Figure E4: Distribution of bill impact under static ToU reference tariff for household categories with a high proportion of vulnerable customers, assuming customers adjust consumption to tariff



Key: Dot shows median, Box shows interquartile, Bars show 2nd to 98th percentiles

Under the Reference scenario, (shown in Figure E1), the average customer, with a £615 annual bill under uniform charging methods, would on average save about £8 (1.3%) under the static ToU tariff and save about £7 (1.1%) under the dynamic ToU tariff. These modest figures can be increased somewhat if the peak to off-peak price ratio is increased, but that also increases the losses to those who would lose out. Smart appliances allow some modest increase in savings. A storage battery adequate to cover all peak consumption would increase potential savings to £96 for the static tariff and £32 for the dynamic tariff.

We find only a slight association between sociodemographic characteristics and the effect on bills under ToU tariffs. The small associations we found may be distorted by data shortcomings. Nevertheless, the conclusion that there is a wide range of impacts in every sociodemographic group is so pervasive that it seems likely to be broadly true, despite the data shortcomings. There may be some characteristics which the data does not report on that would be more strongly associated with electricity consumption habits, but (if so) they have not been clearly identified.

We would therefore encourage future research to assess the causal relationship between ToU tariff incidence on bill and the characteristics and circumstances associated with vulnerability presented in this report.

Findings: Uptake of ToU tariffs and supportive technologies

The conclusions presented above are predicated on the assumption that the customer takes a ToU tariff. Those whose bills might rise in practice will tend not to choose a ToU tariff, as long as a sensible alternative remains. Using the survey data we have, and taking account of the savings expected and consumers' stated preferences, we found only about 8% of customers would adopt ToU tariffs, even though many more would enjoy savings. Many are simply not engaged, and others will not be interested in modest prospective savings. Static ToU tariffs are consistently found to be favoured over dynamic ToU tariffs.

Across sociodemographic groups, the empirical evidence suggests that the distribution of uptake closely follows the distribution of impact. Middle income consumers are expected to be the most likely to take up ToU tariffs as they are set to gain the most from them. Both vulnerable households and wealthy households are less likely to adopt ToU tariffs. Vulnerable customers are generally less engaged in energy purchase, which means they are less likely to make explicit choices but rather remain with their existing arrangements.

The data underpinning these findings on choice are based on customer preference survey data, which is less reliable than observed choices. Evidence suggests that customers are suspicious of unfamiliar products, and their willingness to switch may be likely to increase with increasing familiarity or positive experience of others. So willingness to switch to a ToU tariff might eventually increase.

Surveys indicate that there are currently low levels of interest in adopting smart appliances although clearly this would depend on the cost and degree to which such appliances became industry standard. Battery storage is of interest to customers. In our own small survey of former trial participants, 70% agreed or strongly agreed (8% disagreed/strongly disagreed) with the statement, *"I would be more interested in a ToU tariff if my supplier also offered me a home battery"*. Currently, batteries are far too expensive to justify such usage, but their price is falling rapidly.

Recommendations: protecting vulnerable consumers

Many vulnerable customers would be better off on ToU tariffs, but they may need targeted support to make that choice. Others would be worse off, and thus may need protecting from making that choice. But as long as being on a ToU tariff requires an explicit choice, many will be protected by not making that choice. In time, complications may arise since flat tariffs may rise, and/or ToU tariffs may become default tariffs.[3] The inevitable effect of more cost-related charging is to unwind existing cross-subsidies. While many consumers would experience bill reductions, a minority of vulnerable or fuel poor customers would experience bill increases.

[3] Ofgem's view is that this would be unlikely under the current regulatory arrangements.

We do not find a case for regulating the structure of ToU tariffs in general. It does not protect against these potential detriments, and the effect is likely to be perverse. There are some more detailed matters of regulation that Ofgem may wish to consider. In particular, the wider availability of ToU tariffs may present new opportunities for supplier conduct that might be to the detriment of consumers. Ofgem should monitor such behaviour closely and consider whether any remedies are required.

Ofgem or central government (particularly BEIS) may wish to consider other initiatives which could support vulnerable consumers, which would help protect them as cross-subsidies unwind. Examples include:

- support for energy efficiency measures;
- information and awareness;
- supporting the customer's tariff decision by facilitating the use of smart meter data for bill projections;[4] and
- if or when such technologies become cheap enough, assistance with supportive technologies such as domestic electricity storage.

[4] It is already the case that access to smart meter data for marketing purposes is subject to the consent of the consumer and we are not suggesting that this should change. What we are suggesting is that the institutions through which customer data may be used for bill projections should be designed both to make it easy for the customer to obtain the comparisons they desire, and also to give them confidence in the projections made and the data security.

Contents

1. **Introduction** ... **11**
   - 1.1. Background ... 11
   - 1.2. Objective and scope of this study ... 11
   - 1.3. Structure of this document ... 12
2. **Approach To Assessing the Distributional Consequences of Time of Use Tariffs** ... **13**
   - 2.1. Introduction ... 13
   - 2.2. Consumption profiles ... 14
   - 2.3. Sociodemographic groups and characteristics ... 15
   - 2.4. Designing tariffs suitable for distributional assessment ... 21
3. **Assessing the Likely Response to Time of Use Tariffs** ... **29**
   - 3.1. Introduction ... 29
   - 3.2. Consumer response to price signals ... 29
   - 3.3. Consumer decision to adopt tariffs and technologies ... 33
4. **Assessment of the Distributional Consequences of Time of Use Tariffs** ... **39**
   - 4.1. Introduction ... 39
   - 4.2. Net impact on bills ... 40
   - 4.3. Impact on bills across sociodemographic groups ... 45
   - 4.4. Impact on bills across sociodemographic characteristics ... 52
   - 4.5. Tariff uptake ... 55
5. **Discussion and Recommendations** ... **58**
   - 5.1. Introduction ... 58
   - 5.2. Incidence of ToU tariffs on vulnerable groups ... 59
   - 5.3. Policy implications ... 62
   - 5.4. Limitations and influence of trial design ... 65

ANNEX A Smart meter data ... **68**

ANNEX B ACORN segmentation ... **74**

ANNEX C Technology assumptions ... **78**

ANNEX D Elasticity calculations and impact on bills ... **80**

ANNEX E Tariff and technology uptake: supporting evidence ... **88**

ANNEX H Table of figures ... **122**

ANNEX I Bibliography ... **123**

1. INTRODUCTION

1.1. Background

The purpose of this study is to assess the distributional impacts of time of use (ToU) tariffs. Such tariffs may become more widespread if a decision is taken to mandate half-hourly settlement (HHS) in the domestic electricity market.

The widespread introduction of smart meters provides more detailed data, to charge electricity to suppliers based on their customers' actual half-hourly consumption. Since smart meters record consumption for every half hour period, it will be possible for suppliers to offer customers tariffs which reflect their consumption on a half-hourly basis. For example, this may enable different prices at several different times of day: an example of a time of use (ToU) tariff.

Currently suppliers do not face the precise costs of their domestic customer's consumption each half hour, rather it is estimated using models populated with data on domestic consumption profiles. HHS would mean that suppliers face the true cost of their customers' consumption each half hour. Thus HHS puts incentives on suppliers to offer more cost-reflective tariffs, which in practice will mean ToU tariffs.

It is likely that customers will have a choice between the present 'flat' tariffs and ToU tariffs. Flat tariffs are tariffs which do not vary by time. The term covers both the currently offered Standard Variable Tariffs and fixed tariffs. It is also likely that flat tariffs, in particular Standard Variable Tariffs, will remain the default tariff, at least for the time being. Default tariffs are the tariffs applied to customers who do not make a choice to change tariff, or who do not make a choice when a time-limited tariff expires. In time, subject to the regulatory framework, it is possible that default tariffs may evolve towards more cost-reflective ToU tariffs[5].

1.2. Objective and scope of this study

Ofgem contracted CEPA to assess the distributional consequences of time of use (ToU) tariffs for domestic customers. CEPA was asked to examine the following points:

- **The potential incidence of different tariffs on consumer bills for different sociodemographic groups:** This involves producing a quantitative assessment of the impact of smart tariffs on the bills of different sociodemographic groups, assuming both no change in their consumption and changes in their consumption in response to the price variations. This analysis is forward looking to take into account the phased introduction of smart tariffs and future technologies.

[5] Ofgem's view is that this would be unlikely under the current regulatory arrangements

- **The impact of different levels of consumer behaviour in response to modelled tariffs for different sociodemographic groups**: We make an estimate of the most likely behavioural response of different sociodemographic groups to different types of smart tariffs. This is an input to the task above. Our estimate is based on what we could discover about consumers' willingness to respond to price and/or incentive signals, depending on their sociodemographic group, from the best available datasets of customer smart meter data available for this purpose. Our analysis also took into account the effects of different smart tariffs (e.g. tariffs with varying peak to off-peak price differentials) on consumers' willingness to change their behaviour.
- **Potential mitigation and support measures:** Having identified the likely effect of smart tariffs for different sociodemographic groups, we consider measures to protect customers who might lose out, particularly those customers who are vulnerable.. We also consider measures to help customers who might benefit from smart tariffs to take them up.

1.3. Structure of this document

This document is structured as follows:

- Section 2 sets out how we will determine the distributional consequences of half-hourly settlement;
- Section 3 describes our approach to estimating what behavioural response consumers are likely to have to the tariffs they might be faced with given half-hourly settlement;
- Section 4 presents our findings on the distributional consequences of time of use tariffs;
- Section 5 sets out our discussion on the finding and related mitigation measures; and
- Annexes A to I provide detail of the data, calculations and other useful complementary information used for this analysis.

2. Approach To Assessing the Distributional Consequences of Time of Use Tariffs

CEPA developed a model to assess the distributional impact of specific ToU tariffs on household bills in comparison to a flat tariff. The main functionality of the model is to calculate household bills under a variety of scenarios.

We apply the model to datasets of half hourly household consumption, which are matched to household sociodemographic data. This Section explains the tariff scenarios we use to explore the distributional effects of likely variations.

2.1. Introduction

CEPA has developed an Excel model to assess the distributional impact of specific ToU tariffs on household bills in comparison to a flat tariff. The functionality of the model is as follows:

- It is applied to a database of households showing their half-hourly consumption profile over the year, and contains data to classify those households by social category.
- It assesses what proportion of households in each category are likely to take up a specified tariff.
- It assesses what change in consumption (behavioural response) households are likely to make in response to the modelled tariffs.
- It calculates the bills that result by household.
- It assesses the distributional impact of those bills against households' social characteristics.

There are three key inputs to the model:

- a database of households containing their consumption profiles and social characteristics;
- parameters which describe the choice of and response to those tariffs (behavioural factors) – these are described in Chapter 3; and
- tariff scenarios used to demonstrate distributional effects.

In this section, we first describe our datasets.[6] We prepared the data using database tools prior to modelling, since Excel cannot handle such large datasets directly.

There are two key aspects to that data, which we describe in this section:

- household consumption profiles (section 2.2); and

---

[6] Our model can also be used to analyse metering data which may become available in future, as well as other tariffs, and has been supplied to Ofgem for that purpose.

- household social characteristics (section 2.3).

This section also sets out the classification methods used to define households' social characteristics.

To achieve a useful assessment of distributional effects, the tariffs we input into the model have to be carefully chosen. For example, an unrealistically low tariff would be beneficial to nearly all customers but no supplier would offer such a tariff. We have designed the structure and level of the tariff to be realistic and capable of separating distributional effects from responses arising from a change in the level of tariff. We describe the tariffs we use in the model in section 2.4.

Here we give only an overview of the data used. Further detail is presented in Annex A.

2.2. Consumption profiles

To carry out the modelling, we required data on the half-hourly consumption of a sample of domestic customers, which is matched, or capable of matching, to sociodemographic data on those households. We believe that the best available data for that purpose comes from two past smart meter trials run in the UK. These are the Energy Demand Research Project (EDRP) and the Low Carbon London (LCL) smart meter trials. A further advantage of these datasets is that they allow an analysis of household response to the two kinds of smart tariff of interest, static and dynamic time of use.

- **EDRP** was a major set of trials across the UK incorporating smart meter readings along with sociodemographic information. The publicly available anonymised sample[7] contains half-hourly smart electricity data between January 2008 and September 2010 for 14,621 households.
- The **LCL** trial involved 5,567 households from the London area, of which 1,122 experienced an experimental dynamic time-of-use (dToU) tariff, which was in effect for the duration of 2013.

The EDRP trial provides the most complete source of smart meter data across a reasonably representative sample of the UK population. It was also an experimental study of behavioural responses to static ToU tariffs. The LCL trial, while focused solely on the London area, provides a unique opportunity to study the behavioural response of households under a dynamic ToU tariff.

We believe that these are currently the best available sources of data for this study. Numerous other studies using smart meters have been carried out, both in the UK and abroad. Many are unsuitable because they do not represent UK consumption patterns or demographics, and others are too small.

[7] The non-anonymised sample, which was in the past available to selected researchers subject to confidentiality restrictions, is no longer available.

Table 2.1 sets out the main features of these datasets. Additional information regarding the EDRP and LCL datasets is provided in Annex A.

Table 2.1: Features of the EDRP and LCL datasets

	EDRP (static ToU trial)	LCL (dynamic ToU trial)
Number of household	14,621	5,567
Treatment group (ToU tariff)	3,268	1,025
Control group (Flat tariff)	11,044	3,580
Time period	Jan 2008 – Sep 2010	Jan 2013 – Dec 2013
Trial	Static tariff	Dynamic tariff
Geographic coverage	UK	London
Household characteristics	ACORN	ACORN Appliance and attitude survey

2.3. Sociodemographic groups and characteristics

One of the key objectives of this study is to assess the impact of ToU pricing on vulnerable groups. We first define what is implied by vulnerability and the characteristics associated with it. We then present the data available to conduct this assessment.

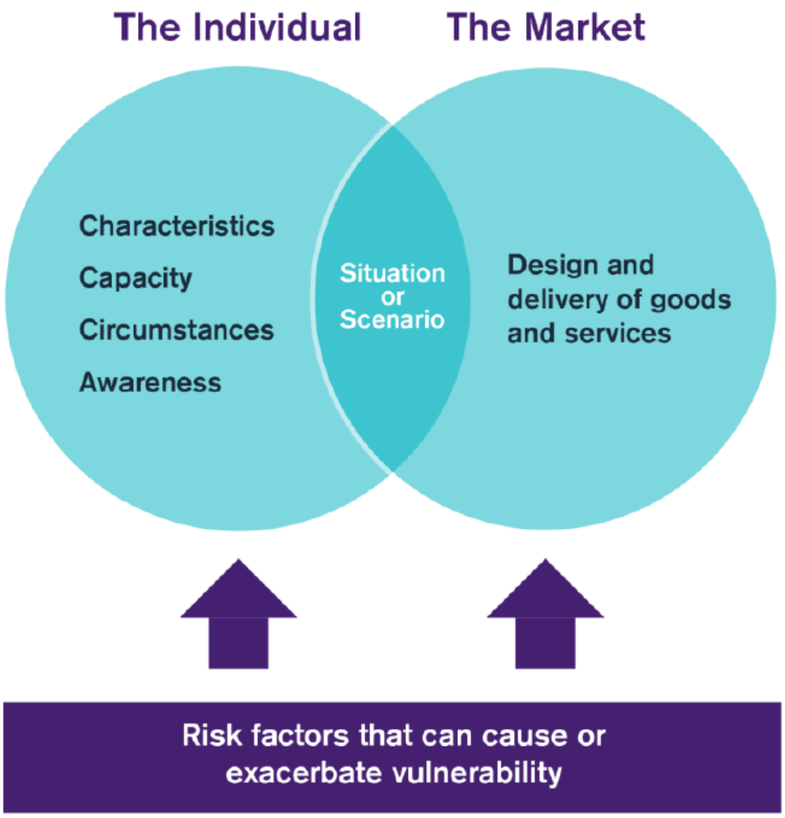
2.3.1. Defining vulnerability

Ofgem defines a vulnerable household in the energy market as one which is:

- significantly less able than a typical consumer to protect or represent their own interest; and/or
- significantly more likely to experience detriment, or for that detriment to be more substantial.

Consumer vulnerability depends not only on personal characteristics but also on the situation or scenario they are in and how the market responds to their needs, as illustrated in Figure 2.1.

Figure 2.1: Schematic representation of vulnerability



Source: Ofgem

In practice there is a range of **characteristics** and **circumstances** that can lead customers to experience greater risk of detriment. The table below provides a summary of the key characteristics and circumstances associated with vulnerability.

Table 2.2: Shortlist of risk factors

High risk characteristics	How the characteristic might affect ability to respond behaviourally
Vulnerable characteristics - risk factors	
Disability or impairment	Living with physical health issues or mental illness. Cognitive or speech impairment.
Literacy	Literacy or numeracy difficulties. Not speaking English as a first language.
Age	Number of children in household decreases capacity to respond behaviourally. Senior consumers may be less confident engaging with technology.
Individual circumstances - risk factors	
Dwelling size	Large homes consume more electricity and have a greater peak load.
Family structure	We expect single parent families with dependent children, student and pensioner households to be more vulnerable, as well as those living alone or with full-time carers.

Economic activity	The part-time employed are more sensitive to bill impacts due to low income but also potentially more flexible due to more hours of occupancy compared to say full-time employed.
Income	Level of income is highly correlated with vulnerability. Income includes receipt of job seeker's allowance, disability living allowance and other forms of income support.
Technology usage	Not having internet access, low technology ownership.
Behavioural constraints	Concern about excessive noise, etc, from using appliances flexibly at night, e.g. washing machine. Working from home should allow more flexibility but at the same time more opportunity to experience high bills. Less flexible if working outside home 9-5.
Wider circumstances - risk factors	
Electric Appliances	Electric hobs, ovens and showers – all these loads are typically not easy to shift.
Heater fuel	Electric central heating and portable electric heating.
Tenure	Principal agent problem for privately and socially rented dwellings.
Location	Living in a rural area.
Metering	Prepayment meter.

2.3.2. Sociodemographic data used

The EDRP and LCL trial data is available publicly alongside the ACORN sociodemographic segmentation. There are potentially other segmentations available, but ACORN allows us to compare and contrast analysis across the two largest UK smart meter trials and across both a static and dynamic trial.

ACORN is a sociodemographic segmentation of residential neighbourhoods in the UK. Two levels of segmentation are available: postcode and household. The postcode level classifies each postcode in the country into one of 6 Categories, 17 Groups and 62 Types. Household level segmentation does this for each household.

ACORN offers us three levels of sociodemographic granularity, according to whether we analyse by Category, Group or Type. There is a trade-off between analysing an impact on bills at a more granular level and confidence in the results: the more granular the sociodemographic group, the smaller the number of households per group and therefore the less confident we can be that those households are representative of the underlying population. To proceed with any kind of analysis at all, we have to assume that the sample is representative. Unfortunately, there is good reason to suspect it is not. Participation in the trials was voluntary, and exclusion criteria were used, some of which tended to exclude vulnerable customers. Thus there is a risk that the sample population in any given ACORN segment might differ systematically from the general population in that segment. We can neither quantify nor remove this potential bias.

Throughout this paper, we use ACORN Group (17 Groups) as the main level of aggregation as it strikes the best balance between granular results and statistically significant estimates. As demonstrated in Annex B, this is the level of grouping that provides the highest level of disaggregation while retaining external validity, ie, sufficient data points within each group to give us a statistically good estimate of the mean for each sample, if in fact the sample were representative. ACORN Groups are tagged by letters A to Q but are also given memorable names to help explain how each of those Groups are composed.

Table 2.3 shows some key household characteristics by ACORN Group. It demonstrates that vulnerable households are more prevalent amongst Groups J to Q. The Categories, Groups and Types are more fully detailed in Annex B.[8]

Table 2.3: Characteristic prevalence within demographic group, relative to the national median

ACORN group code	ACORN group name	Job Seekers Allowance	Aged 75+	Social Renting	Couples with Dependent Children
A	**Lavish Lifestyles**	Very Low	High	Very Low	High
B	**Executive Wealth**	Low	UK Median	Very Low	High
C	**Mature Money**	Low	Higher	Lower	UK Median
D	**City Sophisticates**	Marginally Lower	Low	Marginally Higher	Low
E	**Career Climbers**	Marginally Lower	Lower	Low	Marginally Higher
F	**Countryside Communities**	Low	High	Low	Marginally Lower
G	**Successful Suburbs**	Low	UK Median	Lower	Marginally Higher
H	**Steady Neighbourhoods**	Marginally Lower	UK Median	Lower	Marginally Higher
I	**Comfortable Seniors**	Low	Very High	Lower	Low
J	**Starting Out (V)**	Marginally Higher	Low	Low	Marginally Lower
K	**Student Life (V)**	High	Lower	Lower	Low
L	**Modest Means (V)**	High	Marginally Lower	Marginally Higher	Marginally Higher
M	**Striving Families (V)**	High	Marginally Higher	Very High	Marginally Higher
N	**Poorer Pensioners (V)**	High	Higher	Very High	Low
O	**Young Hardship (V)**	Higher	Low	High	Low
P	**Struggling Estates (V)**	Higher	Low	Extremely High	Marginally Lower

[8] An ACORN user guide is available for more information about the specifics of each Group.

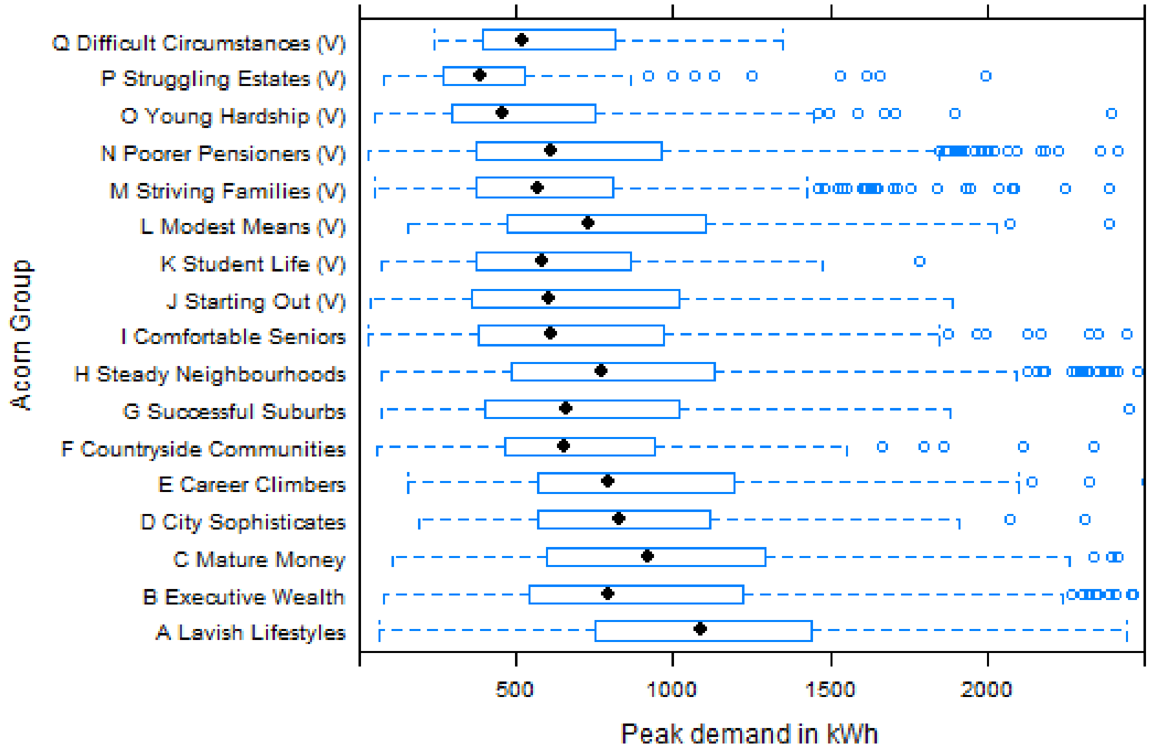
ACORN group code	ACORN group name	Job Seekers Allowance	Aged 75+	Social Renting	Couples with Dependent Children
Q	**Difficult Circumstances (V)**	Higher	Low	Extremely High	Low

Key: (V) indicates a Group likely to contain a material proportion of vulnerable households

Figure 2.2 shows the level of peak time consumption for the EDRP trial across sociodemographic groups. Groups containing a material proportion of vulnerable households are tagged with the letter (V). Peak consumption provides an indicator of how consumers might be impacted by ToU tariffs since peak consumption is expected to be more expensive under ToU tariffs than under flat tariffs. Overall, we find that the groups containing more vulnerable customers generally have a lower level of peak demand than the others. As a result, those groups are, as a whole, less likely to be negatively impacted if they switch to ToU tariffs and tend not to curtail their peak consumption in response. But it is also worth noticing the wide range of consumption across nearly all groups.

We show a "whisker diagram" below to indicate the variation of consumption pattern within groups. We find that certain groups containing a higher proportion of vulnerable customers, such as Group N 'Poorer Pensioners' and Group L 'Modest Means' (the characteristics of these groups will be examined more closely below), have more variation in their level of peak demand than some other groups. Thus these groups include important subgroups with higher peak demand who are therefore are potentially more at risk from the higher level of peak prices which may arise under ToU tariffs.

Figure 2.2: Whisker diagram of peak** time consumption (in kWh) across sociodemographic groups*



Note (*): Whisker Diagrams illustrate the distribution of observations. The black dot shows the median; the blue box shows the interquartile range containing 50% of observations; the "whiskers" - dotted lines with vertical endpoints – show the 2nd to 98th percentiles; circles show outlying points beyond these.

Note (**): Peak time is defined here as actual aggregate peak period of consumption in the dataset, which may differ from the wider market peak.

2.3.3. Strengths

The main advantage of using the ACORN classification is the diversity and range of characteristics it reports on. In addition to the characteristics that define the ACORN categories, ACORN brings together information on hundreds of additional household characteristics covering consumer lifestyle, behaviour and attitudes, and reports how these characteristics are distributed within its categories. This allows us to examine the impact on bill according to these characteristics, recognising that they are distributed within, rather than defining, the ACORN categories. In particular, it allows us to examine most of the characteristics that define vulnerable groups.

2.3.4. Limitations

The ACORN classification has two levels of granularity: postcode level and household level. The EDRP data includes only postcode-level ACORN grouping, while the LCL uses household-level grouping.

- **Postcode segmentation**: *"ACORN is the segmentation of residential neighbourhoods in the UK. It classifies each postcode in the country into one of 62 types that give a distinctive picture of the kinds of people who live in an area."*[9]
- **Household segmentation**: *"Household ACORN is a geodemographic segmentation of the UK's population at household level which segments households into 6 categories and 62 types."*

The ACORN postcode-level categories describe only group characteristics – i.e. for all the households in a postcode – as opposed to the individual characteristics of each household. As a result, the correlations between impact and households' characteristics should be treated with more caution when the postcode-level classification is in use. Therefore the characteristic of households in the EDRP data are not their direct characteristics but those of their neighbourhood, where there is greater diversity than at household level. The precision of the results using EDRP data will therefore be weaker than with the LCL data.

Despite this limitation, the EDRP data is still useful as it allows us to gain some insight of behavioural response to static ToU tariffs, since LCL only uses dynamic tariffs. Moreover, the EDRP data also benefits from materially more data points, which helps offset the less accurate classification in terms of statistical identification.

Finally, the selection process for admitting individual households to the meter trials means that there is a risk that the datasets are not representative of the individual ACORN segments.

2.4. Designing tariffs suitable for distributional assessment

The base tariff, against which we compare all ToU tariffs, is a 'flat' tariff with the same unit price at all times. To draw effective conclusions on distributional effects of ToU tariffs, the tariffs which are used for comparison against the base tariff must be carefully designed to illuminate the distributional effect. In particular:

- the tariffs used for comparison need to be realistic in structure to represent tariffs likely to emerge in the market; and
- the pricing levels of tariffs being compared need to be carefully matched, so that the comparison does indeed draw out distributional effects, not effects arising from what would amount to changes in overall price levels.

Suppliers might offer tariffs priced at markedly different levels, just as they do today, even though those tariffs are mostly otherwise very similar. There are many reasons tariffs in the market may be at different levels, which have nothing to do with their structure. In this study, we wish to elucidate distributional effects which arise specifically from the tariffs' structures. Therefore we avoid comparing tariffs of different levels. It would be appropriate to compare tariffs of different levels only if we had some good reason to suppose that a tariff must be at

[9] http://acorn.caci.co.uk/downloads/ACORN-User-guide.pdf

a materially different level as a result of its structure, and we could size that difference. That is not the case here. Thus the tariffs we study in this report are all carefully matched according to level, so that what is being demonstrated is a distributional effect, not a level effect.

The tariffs we have used for this study have at most three different pricing levels. Clearly tariffs might in principle be more complex. We believe that tariffs with three levels have sufficient complexity to demonstrate the key distributional effects, and we believe that this is borne out by the results of this study.

There is little direct evidence on what tariffs will be offered in a future market where the smart meter rollout is complete and consumers are settled half-hourly. But we can try to anticipate the dynamics of a competitive electricity market. Most tariffs which have been the focus of past study, and which have been implemented in markets with present time of use metering, fall into the categories of static and dynamic ToU tariffs. Thus it seems appropriate that this study should encompass those two tariff types.[10]

2.4.1. Approach to tariff design

Our approach is to compare tariffs that are of the same level, so that we can identify distributional effects. There are potentially a number of ways this could be defined. For practical reasons, the criterion we have chosen is that **if consumers do not change their consumption, the bill of the average customer will remain unchanged relative to what they would have paid under an existing flat tariff**.

For this to be a useful criterion, we need to demonstrate that the criterion generates realistic tariffs. Suppliers should be willing to offer the tariff the criterion produces, and customers should be willing to choose the tariff. We are content that this is true for the following reasons:

- if consumers with average consumption patterns switch to ToU tariffs and respond, as one would expect, by reducing or transferring consumption away from high price periods, they will save on their electricity bill; and
- if the supplier sets a higher price during periods of the day or week when costs are expected to be higher, and consumers respond in the natural way, suppliers should see their costs of supply reduced.

Thus such a tariff presents mutual benefit to both supplier and consumer, and therefore it is realistic to expect to see it in the market.

We see in the present market that tariffs of essentially the same structure are offered at a variety of levels, and the same is likely to be true with ToU tariffs. It is possible that in the short run ToU tariffs might be systematically a little higher than the flat tariff which a specific customer might compare it with, because the ToU tariff can still be attractive to a subset of

[10] During finalisation of this report, the UK energy supplier 'Green Energy' offered a smart tariff for use with the new smart meters. It is a tariff with three prices of precisely the general nature of tariffs studied in this report.

customers it suits particularly well. It is possible in the longer run that ToU tariffs might typically become lower than comparable flat tariffs, because as time passes customers who cost more to serve might selectively remain on flat tariffs. Thus we have no good grounds for a difference in the level of ToU tariffs of any particular size or even direction. This tends to confirm that an assumption of equal level is appropriate.

2.4.2. Tariff features

There are three essential considerations in designing ToU tariffs: tariff schedule, price points and whether supportive technology is used alongside.

Tariff schedule

The tariff schedule includes the timing, duration and frequency of price signals. We classify tariffs into three groups: static tariffs, dynamic tariffs and load control arrangements.

- **Static tariff**: Under static ToU tariffs, residential customers typically face two or more rates for their electricity at fixed times of the day.
- **Dynamic tariff**: Under dynamic ToU tariffs, the rates paid by residential customers for electricity depends on the time of day and can vary from day to day. Dynamic tariffs suitable for domestic consumers would typically have a reasonable notice period (e.g. 24 hours) of price fluctuations, although that might be avoided if the tariff arrangements were connected to some automation of response.
- **Load control arrangements**: Customers give suppliers or other third parties some control over certain technologies in their homes. This could be for example reducing electric heating during periods of high demand, usually within agreed boundaries. In exchange, customers pay a lower rate for electricity or receive some other form of reward.

We model both static and dynamic tariffs. We were unable to locate sufficiently useful data to enable us to model load control explicitly. But the practical effect of load control is similar to the use of smart appliances in conjunction with dynamic tariffs, which we do model, under the category of supportive technology. Therefore we do not explicitly consider load control arrangements further.

Price point levels

Another key determinant of bill impacts of a ToU tariff is the relative price level at various points of the day; we refer to those as price points. We consider tariffs with three price points as sufficient to demonstrate distributional effects. We call these three price points:

- **Peak** – the highest of the three prices;
- **Low** – the lowest of the three prices; and
- **Default** – the intermediate price.

We model the time structure of price periods according to the timing of price events in the EDRP and LCL trials, as we have evidence on those. For details about the profile of the price events in the trials refer to Annex A. But our model is flexible and any possible time structure can be modelled.

Assumptions on price points and tariff design have a significant impact on the results of the distributional analysis. Therefore in our modelled ToU tariffs, we vary price points to assess their impact on consumer bills.

Supportive technologies

The introduction of supportive technologies might ultimately have important effects in supporting smart tariffs, as they can accentuate the advantage of smart tariffs or mitigate their disadvantages. A variety of technologies could be considered, but for simplicity, we have selected two technologies as demonstrating the main possibilities: smart appliances and battery storage, described in Table 2.4.

Table 2.4: Supportive technologies we consider for working alongside smart tariffs

Technologies	Rationale
Battery storage	Batteries can mitigate the impact of peak pricing on consumer bills, because they can be automated to discharge at periods of peak price and charge during low price periods. This is simple with a static tariff; under dynamic tariffs a more sophisticated controller is required to obtain best advantage from possession of the battery.
Smart appliances	Smart appliances, for these purposes, are those which have a mechanism to allow their load to be varied or time-shifted in response to changes in price. In the best case, this is automated, which is similar to direct load control. But it can also include devices where the customer can manually insert a decision (e.g. tells a freezer to avoid responding to its thermostat for a limited period of time).

Smart appliances can support consumers to reduce their peak consumption. They also illustrate an effect similar to direct load control. Battery storage has the potential to enable consumers to avoid peak consumption almost entirely. Our assumptions and calculations are detailed in Annex C. We estimate the effect of smart appliances on peak shifting to be between 3% and 14%,[11] while storage could in principle shift peak consumption by close to 100%.[12]

2.4.3. Shortlist of tariffs scenarios designed

We model the impact on consumers' bills of the two tariff types identified, i.e. the static and dynamic tariffs; and apply variations of these two tariff types across five scenarios. Our first scenario is used as the central, or reference scenario. Two further scenarios test the impact

---

[11] In practice we reduce consumption by 10%.

[12] In practice we reduce it by 99% to avoid introducing zeros and therefore errors in the model.

of changing the price level and time schedule (or timing of price events) respectively. In addition, we apply two further scenarios to examine the effect of smart appliances and electricity storage.

Scenario 1: Reference

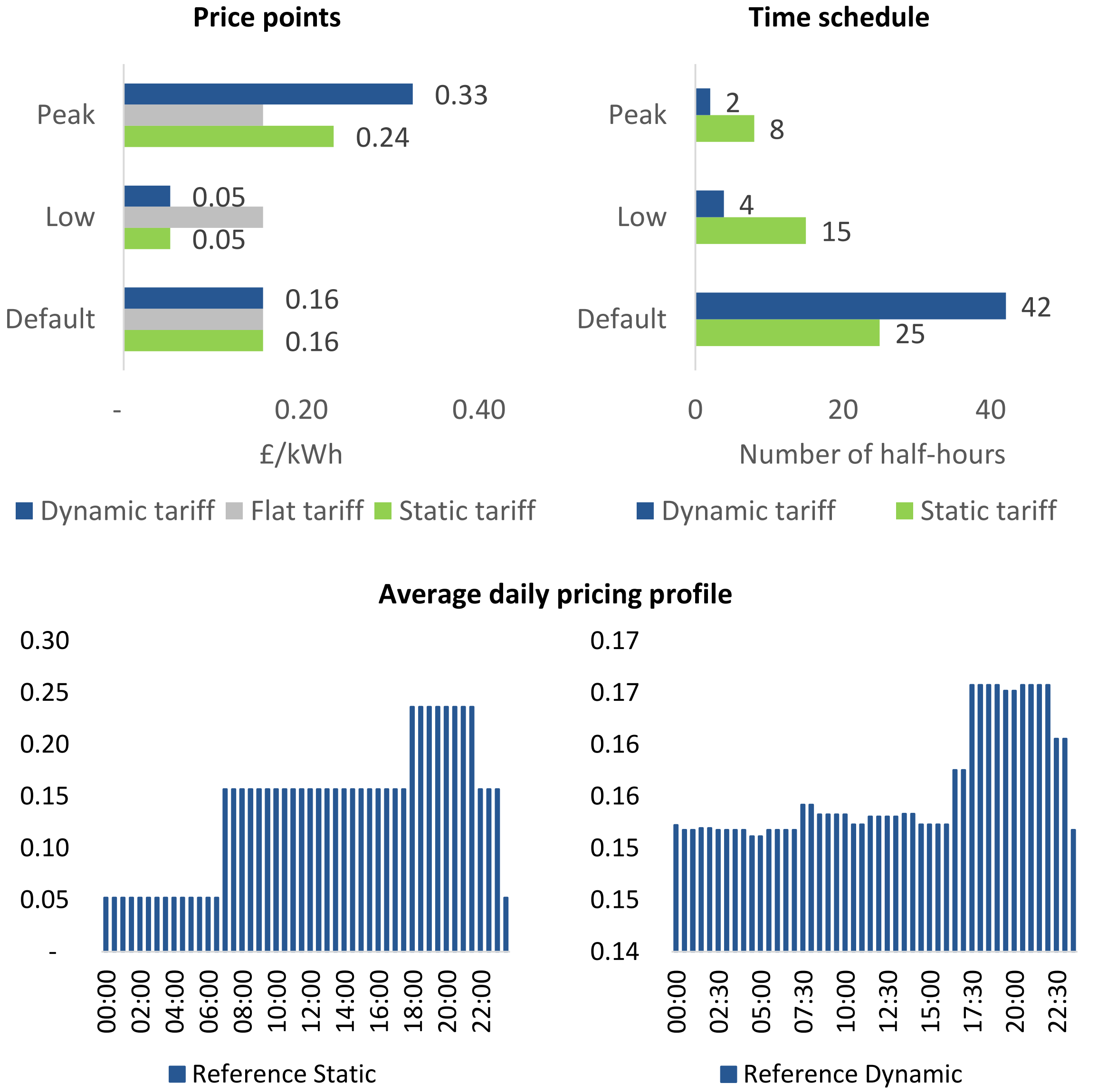
In line with our approach detailed above, the reference tariff is designed so that if consumers do not respond (referred to as the 'no response' group in this study) the bill of the average customer would remain unchanged relative to what they would have paid under an existing flat tariff.

The price ratios in this scenario (i.e. the ratios between the three price points) are 'intermediate' in magnitude, being just about sufficient to produce some useful behavioural response. In experiments with two prices, it is generally found that a price difference of a factor of about three is required to produce a material behavioural response. Here we have a somewhat different situation with three prices, and the ratio of each price to the adjacent price is in the range of two to three, and a much larger ratio from the peak to the low.

Figure 2.3 shows the resulting price points, time schedule and pricing profile to obtain this.

On the left-hand side, we show reference price points for the flat, static and dynamic tariffs during each of the three time periods; i.e. peak, low and default. The flat tariff is constant across all time periods. The right-hand side reports the frequency of price events across the peak, low and default price points, on average in the case of the dynamic tariff. That is, it shows the number of half-hour periods during each day for which peak, low or default price points are applied. Under the static tariff this will be the same every day, whereas dynamic tariffs introduce pricing points according to the situation in the market, which may in principle occur at any time. Peak pricing events occur less frequently with dynamic tariffs. It is typical under such tariffs to have a higher peak price than is usually seen in a static tariff, and we have reflected that in our scenario. The time profile graph for the dynamic tariff shows the average price across the year at each half hour. As can be seen from the profile, high price events mostly occur in the evening. But the average evening price is lower than under the static tariff because typically high price events are only called some evenings. This reflects the real world situation that it is only on some evenings that the wholesale price of electricity is substantially higher than during the day. Low price events also tend to be rarer under dynamic tariffs.

Figure 2.3: Reference tariff

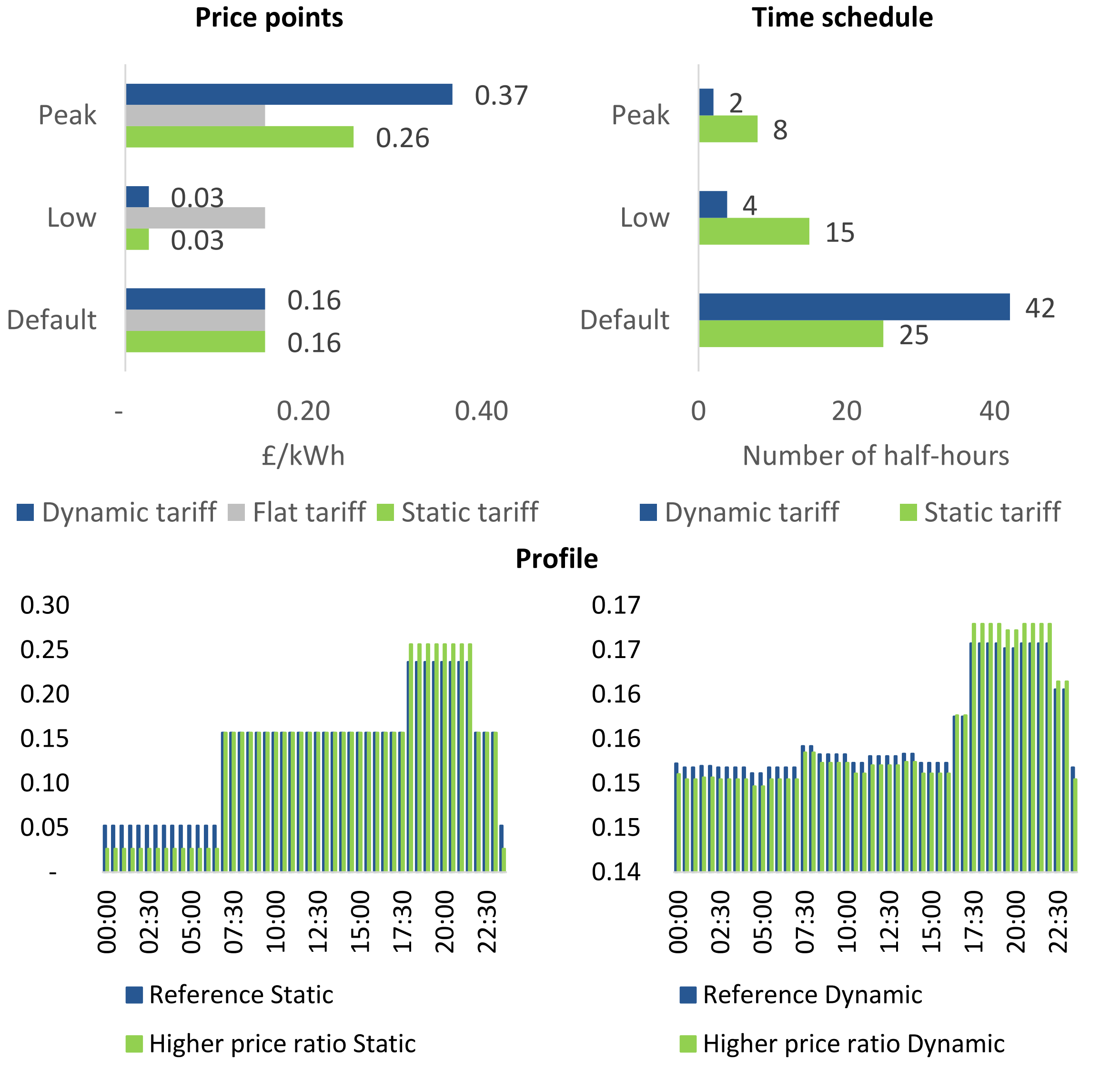


Note: the pricing profiles show the average price point at every half-hour for the static tariff (left) and dynamic tariff (right) during both weekdays and weekends. In the case of the static tariff, the peak, off-peak and default time periods take place at the same half-hours every day of the year. The average daily pricing profile is the same as the price points shown above, since each half-hour is either peak, off-peak or daily. As for the dynamic tariff, the price event for each half-hour may vary from one day to the next.

Scenario 2: Higher price point than reference tariff

Next, we test the impact of price points giving higher incentives for consumers to switch to the ToU tariff. Like the reference scenario the pricing is set at a level so that the 'no change in behaviour' group experiences no change in ToU bill relative to the flat tariff.

Figure 2.4: Higher price point than reference tariff



Scenario 3: More frequent price signals than reference tariff

Under this scenario, the frequency of peak and off-peak periods is increased.[13] Again, the pricing is set at a level so that the 'no response' group on average experiences no change in ToU bill relative to the flat tariff.

[13] Note: the pricing of the dynamic tariff has to be adjusted slightly to keep the same level of price. This issue does not affect the static tariff.

Figure 2.5: More frequent price signals than reference tariff

Scenario 4: Reference tariff with smart appliances

In this scenario we use the same inputs as for the reference scenario, but alter the consumption profile of all households equally to simulate the use of smart appliances to shift demand away from peak price periods.

Scenario 5: Reference tariff with battery storage

In this scenario we use the same inputs as for the reference scenario, but alter the consumption profile of all households equally to simulate the use of battery storage to avoid using electricity during peak price events.

These scenarios are passed through the distributional impact model to assess their impact on consumer bills. In the next section we provide details of how we model behavioural response to those tariffs.

3. ASSESSING THE LIKELY RESPONSE TO TIME OF USE TARIFFS

An important factor in determining the likely distributional consequences of ToU tariffs is how customers respond. Our model attempts to account for the choices that customers make. This section describes the evidence on which we base our assumptions in relation to two behavioural factors:

- **Customer consumption choices in response to different prices and time schedules within the tariff**: We address this primarily by calculating elasticities of demand from meter trial data.
- **Customer decisions to take up the various tariffs and supportive technologies that may be offered**: We address this primarily through findings from a literature review of consumer surveys, given lack of direct evidence. Our choice of scenarios was informed by our own small survey of former metering trial participants.

3.1. Introduction

This section sets out relevant evidence relating to consumer decision-making in this context, and explains our choice of values used to populate the model.

An important factor in determining the likely distributional consequences of ToU tariffs is consumers' ability and willingness to respond to varying energy prices, which we call their 'behavioural response'. Our model takes account of what we believe to be the two key aspects of consumer behaviour.

The two key aspects of consumer behaviour are:

- **the response of a customer to varying prices at different times under a ToU tariff**: We address this primarily by calculating elasticities of demand from meter trial data.
- **the customer's decision to take up a tariff / supportive technologies**: We expect that customers will be able to choose from several tariff types, and whether to take up a ToU tariff at all. We also expect that consumers will be able to adopt supportive technologies. In the absence of much suitable experimental data, we address this primarily through a literature survey of market research, and secondarily through a small survey of our own.

We consider these in turn in the following two sections.

3.2. Consumer response to price signals

In this section we explain how the model accounts for consumer response to price signals.

3.2.1. Approach

From the trial data collected, we use econometric techniques to ascertain the effect on demand of a change in price. We summarise this numerically as the price elasticity of demand.[14]

In practice, we find that elasticity varies materially by hour of the day, according to households' needs and availability.

Since the demand profile data we input to our model shows only the total demand for each of three pricing periods, in practice a suitable average elasticity must be calculated which is applicable to each pricing period, and will change according to the time structure of the tariff under examination.

3.2.2. Methodology

Both the EDRP and LCL trials contained a control and treatment group, where the former experienced a flat tariff and the latter a ToU tariff. This potentially presents a number of methods for estimating elasticities:

- **Before and after approach**. This is a common method but not possible on this occasion because data before the start of the trials was not collected[15] for either the EDRP or the LCL trials.
- **Control group and treatment group approach**. This would seem to be an obvious approach, but it depends upon the difference between the control and treatment group being the only relevant factor being tested. In practice, this approach produces implausible (often positive) elasticities, suggesting that allocation to the treatment group is not 'as good as random'.[16] We therefore reject this approach.
- **Variations within the treatment group**. We can assess change in demand as a result of a change in price between pairs of half-hours. For example, for a half-hour on a given day, the price level of the ToU tariff may be different from the same half-hour a day or a week later. If so, we can examine the change in demand as a result of a change in price between these two half-hours.

[14] Price elasticity of demand is the ratio of the change in demand to the change in price which produces that demand change. Both changes are reported proportionately or in percentage terms. Accordingly, elasticities are a pure number independent of the units of measure used for price or quantity. So, for example, if a 1% increase in price produces a 2% reduction in demand, the elasticity is properly –2 (calculated as –2%/1%). In nearly all cases an increase in price reduces demand, so demand elasticities are nearly always negative. Because of this, it is common to omit the minus sign. In line with that convention, we may sometimes omit the minus sign, in which case we may describe it as a "responsiveness".

[15] Or has not survived.

[16] There are several plausible reasons why the difference might be more than just the price. For example, merely being on a smart tariff with an IHD tends to make people aware of their consumption and reduce it even if the price reduces.

We used the third method as the two alternatives were unavailable or unusable. The disadvantage of this third approach is that it can only be applied to the LCL trial data, since the price points under the EDRP trial were the same throughout the sampling period. The econometric analysis used to derive elasticities under this approach is presented in Annex D.

Calculating elasticities by this approach requires two simplifying assumptions:

- Since we are able to derive elasticities from the LCL trial only, and still wish to apply those results to the EDRP data, we have to assume that the values derived from the LCL trial, which took place in London, are applicable to the wider population; and also are valid in wider circumstances than dynamic tariffs.
- Since the LCL trial took place for only a year, we can only assess short-term elasticities. Long-term elasticities may differ. There are various considerations, some tending to increase responsiveness and some tending to reduce responsiveness, in the longer term.[17]

3.2.3. Elasticities during a typical day

Elasticities estimated from the LCL trial are shown in Figure 3.1, which displays the level of responsiveness across a typical day of the year for all households in the sample. Elasticity values close to zero indicate a low level of responsiveness while larger numbers show higher level of responsiveness to prices. We note that even the largest elasticities indicate relatively modest price responsiveness.

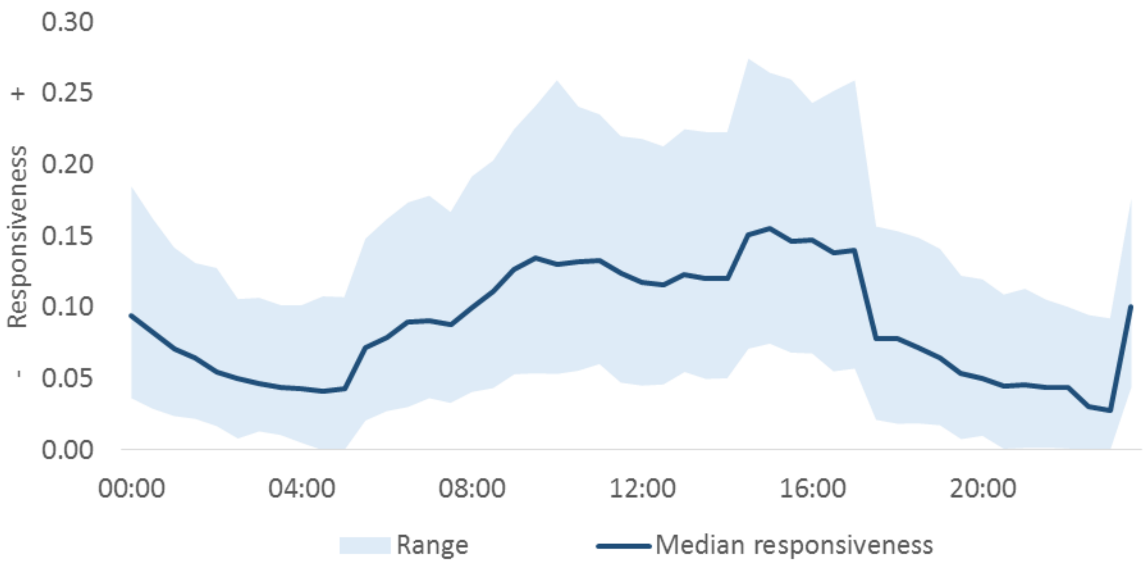
On a typical day, the level of responsiveness is quite low throughout the night, then increases sharply in the morning to reach its highest in the afternoon. It then drops suddenly in the early evening hours to levels comparable to night-time levels. In the late evening, elasticities become small, suggesting that households stop paying attention to prices in the late evening. There is, however a very sudden increase in elasticity in the night after the late evening. There is a level of statistical uncertainty around these estimates of elasticity, and one should concentrate on the broad shape rather than specific values. The apparently positive (but small) elasticities at the end of the evening are likely due to estimation uncertainty. In practice we have aggregated elasticities for use in the model.

The elasticity values calculated for a typical day are used in the distributional impact model. We also calculate values for each ACORN Group at different hours of the day.[18]

[17] For example, if prices change in the long term, it makes it more worthwhile for people to replace their appliances with more energy-efficient appliances, or devices that enable time-shifting. Conversely, if consumers do not succeed in building persistent habits, price responsiveness may weaken over time: there is some international evidence that the efficiency interest initially awakened by the installation of a smart meter and IHD tends to reduce later. We cannot predict which is likely to be the larger effect.

[18] With over 500 data points, these averages would be statistically robust, if the sample was representative of the wider population. However there are grounds for concern that it is not representative.

Figure 3.1: Elasticity in the LCL trial



3.2.4. Elasticities across sociodemographic groups

Figure 3.2 shows the elasticities observed across ACORN groups. The differences are not large, but some distinctions do emerge.[19] For example, the following figure illustrates that the level of responsiveness is higher among middle-income consumers: from 'Comfortable Seniors' to 'Mature Money'.

We see that groups showing a lower degree of responsiveness include both wealthy households and lower income groups, which are more likely to include higher numbers of vulnerable consumers. In the latter case, we can in particular observe the groups 'Struggling Estate', 'Young Hardship' and 'Difficult Circumstances'.[20]

There are several possible reasons to think that responsiveness might vary with income and vulnerability, and indeed differently for different subsets of the vulnerable. Those on low incomes should in principle be more concerned about the price they pay for electricity than the wealthy, given their lower disposable income, and thus try harder to reduce their electricity use in response to a high price. But there may be factors that in practice inhibit them from responding to price. For example:

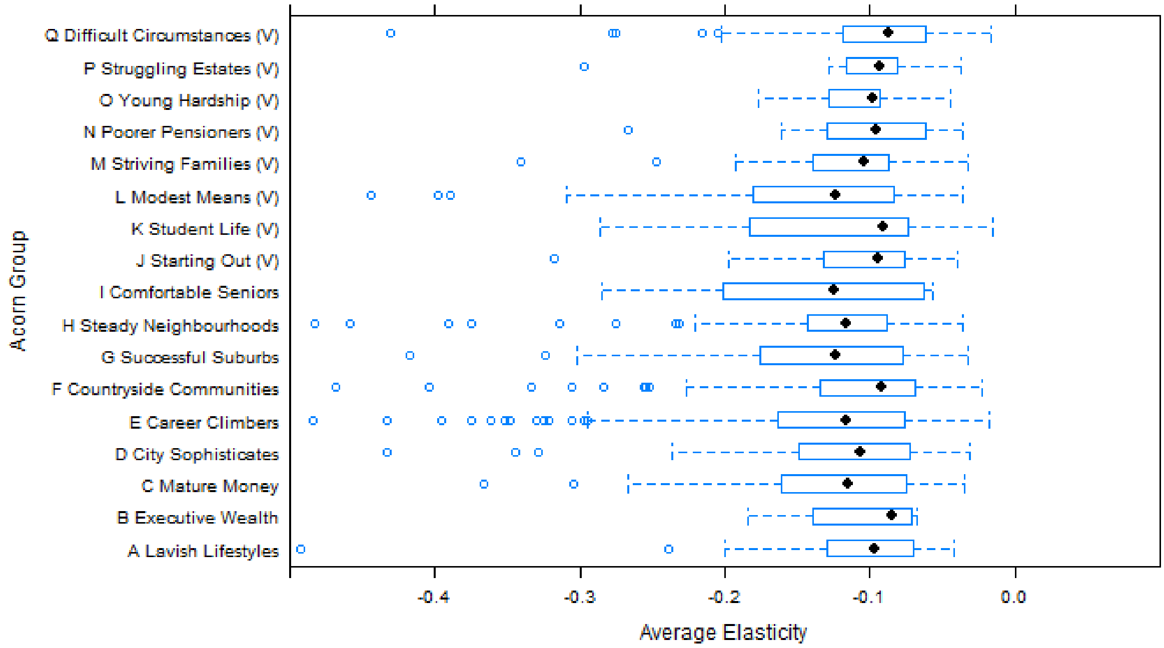
- Vulnerable consumers may be less able to engage with their electricity tariff, and thus respond to specific price signals. We examine later on whether there is some correlation between price responsiveness and willingness to take up ToU tariffs.
- Some consumers in the lower income groups have already, for budgetary reasons, reduced their consumption to the minimum tolerable, or have relatively little

[19] Many of the sociodemographic groups do not have sufficient data points in the LCL dataset for it to be a statistically robust average. However this is a lesser concern than the lack of representativeness of the sample.
[20] Moreover the spread is relatively narrow in these categories, so they are relatively consistent in their behaviour.

discretionary consumption remaining. Thus they may be relatively unresponsive to price since there is little opportunity for them to reduce consumption from present levels.

- Consumers in lower income groups are likely to be subject to cash flow constraints which make them less able to choose more efficient appliances in the first place, or to replace them with more efficient appliances.

Figure 3.2: Average peak elasticities across ACORN groups



Key: Black Dot shows median, Box shows interquartile, Bars show 2nd to 98th percentiles, circles are outliers

3.3. Consumer decision to adopt tariffs and technologies

In this section we detail how we modelled tariff and technology uptake. There is little experimental evidence available on this. We therefore reviewed a literature which mainly reports attitude surveys and data on situations that might be considered to have some similar features. From this review, we use our judgement to select appropriate values to populate the model. Attitude surveys are not always reliable, so these parameters are uncertain and should be subject to scenario analyses.

Importantly, it is likely that certain classes of consumer may find it more desirable than others to take up ToU tariffs. Some groups are likely to remain unengaged with the market and simply remain on their current tariff due to that lack of engagement rather than conscious choice. Similarly for technology we can expect some selection effects as some consumers, possibly from wealthier households, are more likely to take up certain technologies.

3.3.1. Approach

We gathered evidence on tariff and technology uptake through the BEIS Consumer Panel Survey, a literature review, and a small survey of our own. The full results of the literature review and the BEIS Consumer Panel Survey are summarised in Annex E.

Most of the relevant literature on tariff choice is drawn from consumer surveys rather than experiments in actual tariff choice. We find a small amount of literature reporting trials where customers were allowed a choice of tariff, but it is difficult to use such evidence because it typically arose in small trials carried out under conditions hard to compare to Great Britain. Surveys concerning choices that a customer might make if offered it, a kind of data known in general as 'stated preference' or 'market research', are unreliable predictors of future market take-up, especially when they relate to products or services where the customer has no direct experience on which to base their forecast choice. As such, results should be treated with appropriate caution.

We also carried out a small survey on attitudes towards smart ToU tariffs with some of the previous LCL trial participants to supplement this research. We carried out this survey because it enables us to ask questions of customers who have experienced smart tariffs, whereas most surveys do not have access to such a population.

77 households who were previously part of the LCL trial responded to our survey. Although a small sample, the value of the data is increased by the fact that these households have had first-hand experience of a dynamic ToU tariff for twelve months during 2013.

These respondents' attitudes towards smart ToU tariffs can therefore be considered much better informed than that of consumers with no exposure to smart ToU tariffs. Their responses also give a better indication of customer satisfaction after signing up to a ToU tariff.

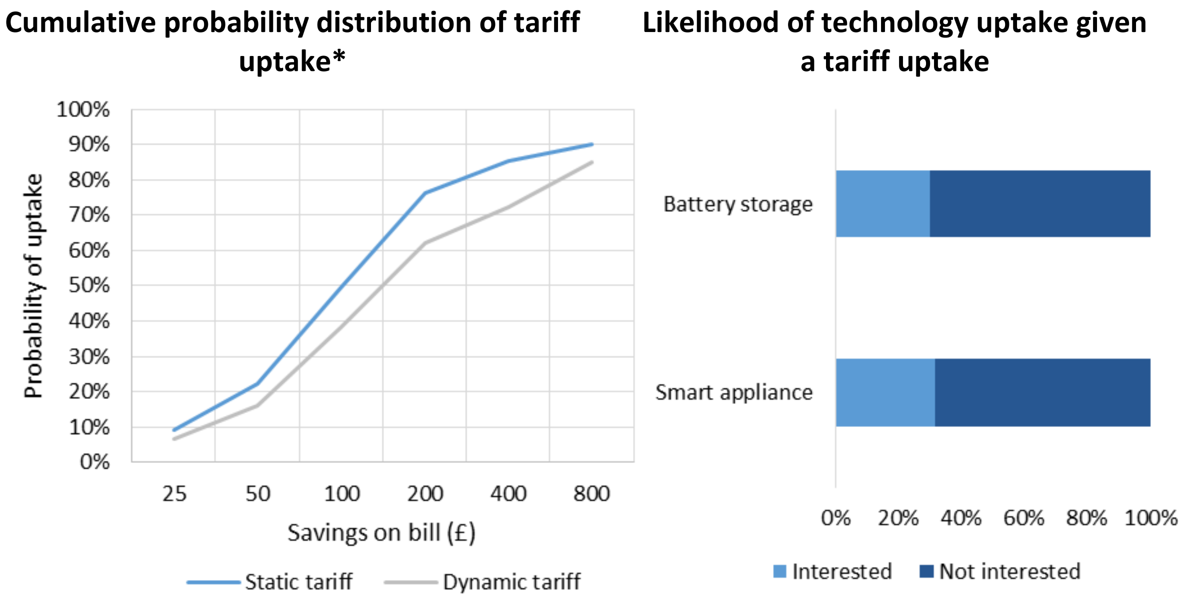
3.3.2. Overview of literature review and the BEIS Consumer Panel Survey

The literature review is reported in Annex E. This review and analysis of secondary data tends to show that in general domestic customers tend to prefer a static ToU tariff over a dynamic ToU tariff. This is unsurprising since domestic customers cannot really envisage responding to tariffs varying in real time, and it presents a risk to them. It also shows that battery storage and smart appliances are equally attractive to them. Income and household size are positively associated with high potential uptake across both tariffs and technologies. Age is mildly negatively correlated with likelihood of uptake across both tariffs. These findings were incorporated in our modelling and inform the likelihood of tariff uptake given its impact on groups of consumers.

The BEIS Consumer Panel Survey, taken together with assumptions emerging from the literature review, allows us to estimate uptake probabilities for both the static and dynamic tariffs, according to the expected level of savings from switching. We show this distribution in the left hand part of Figure 3.3. This shows that if a consumer could expect only a small level of savings (around £25), they will only have around 10% probability of switching. At a savings level of around £100, the take-up likelihood has risen to 50%. Increasing the uptake likelihood much above 50% requires implausibly large savings. Overall this data indicates an openness to ToU tariff, but achieving the kind of bill savings that might attract a substantial proportion of customers will be challenging.

We also estimated from the survey the probability that consumers would buy smart appliances or battery storage given that they switched to a dynamic tariff. As the right-hand part of Figure 3.3 shows, this probability is broadly similar across technologies with a slight preference for smart appliances. This data should be again treated with caution as consumers in the survey were not informed as to the cost of obtaining and maintaining such technologies or what the potential savings would be. Currently, the cost of domestic batteries is prohibitive, and some customers may find the physical size of batteries an impediment to adoption.

Figure 3.3: Cumulative probability distribution of tariff uptake



Note (*): Probabilities are the likelihood of taking up that particular tariff if the only alternative is a flat tariff. We do not have data addressing the choice between static and dynamic tariffs.

3.3.3. Findings from our survey of LCL former participants

This section summarises findings from our survey of 77 former participants in the LCL trial. We also refer to findings from the original larger[21] survey of LCL participants, to which our survey is a supplement. We refer on occasion to the original survey. For a full list of results, refer to Annex F.

[21] 708 responses from 1044 participants.

ToU tariff attitudes among ToU trial

A survey conducted during the LCL trial with participants in the dynamic ToU pricing trial, and followed up for this report, found high levels of support for such tariffs. The LCL trial tested a day-ahead dynamic tariff on 1,044 householders in London and 77% of the 708 people who completed the survey said that they would stay on the tariff if they had the chance and 81% agreed or strongly agreed that it should be the standard tariff for everyone (Carmichael *et al* 2014).[22]

This 'familiarity breeds consent effect'[23] suggests a note of caution with regard to the findings on household attitudes to smart ToU tariffs that are based on respondents with no experience or exposure to these kinds of tariffs. In other words, while a static ToU tariff is preferred by survey participants at first sight, nothing indicates that this dynamic will hold. And over time dynamic ToU could be preferred as more households try it.

The survey responses in Fell *et al* (2015) indicated slightly greater reported willingness to sign-up to a Static ToU tariff (30%) than a dynamic ToU tariff (25%). Combine dynamic tariff with smart appliances and the difference disappears. Direct Load Control was the most popular offering (37% interested in signing up). For former LCL dynamic ToU trial participants responding to the present survey, their reported interest in signing up to the tariffs options are shown in the table below. These survey results are quite different to those of Fell *et al* and show much greater levels of interest in smart ToU tariffs and much less interest in direct load control, although the way in which these demand-side response (DSR) offerings were presented was not identical.

Table 3.1: Interest across DSR arrangements

	Slightly interested, interested, or very interested	Not interested at all	It is hard to say how interested I would be in this tariff without having a better idea of what being on this tariff would be like and how much I would save
Dynamic ToU tariff	53%	11%	12%
Fixed/Static ToU tariff	57%	12%	12%
Direct Load control	42%	53%	5%

Source: CEPA survey

[22] This is the report of the LCL trial. A potential self-selection bias towards initially pro-smart meter and pro-dynamic ToU initial dispositions among the households participating in the study is an issue to some degree but should have been somewhat reduced by incentives offered during trial recruitment and for survey responses.

[23] Some possible reasons for this 'familiarity breeds consent' effect emerged in the LCL trial analysis which found that, financial savings aside, a majority of survey respondents (n=708) reported the tariff gave them a greater sense of control (71%), motivated them to get chores done (80%), was useful for planning/remembering activities (77%), helped them reduce overall consumption (63%) and was enjoyable in some ways (55%) (Carmichael *et al* 2014).

Another point of difference when comparing between the larger survey conducted by Fell *et al* 2015 and the survey results reported here is that Fell *et al*'s respondents included Economy 7 customers and all were specifically requested to imagine having electric heating and to factor this in when considering the appeal of the DSR options presented.

Technology uptake alongside smart tariffs

This issue of heating raises another point concerning a present-bound versus forward-looking perspective on ToU take-up. Availability of smart ToU tariffs will be limited by the pace of smart meter rollout and half-hourly settlement and it may be at least 2020 before the majority of households have access to these tariffs. By this time there could be changes in the context for smart ToU tariffs such as a steep fall in the cost of batteries and PV. A greater share of renewables generation and movement towards the electrification of both transport and heating may eventually also increase the consumer demand for storage of cheap-rate electricity, though this is more likely on a longer timescale. Such changes – and accompanying technology uptake – could drive demand for and ability to manage smart tariffs. Automated appliances could also help households maximise flexibility on smart ToU. Our survey asked about how home battery storage and automation by smart appliances might affect interest in smart ToU tariffs.

- 70% agreed or strongly agreed (8% disagreed/strongly disagreed) with the statement, *"I would be more interested in a ToU tariff if my supplier also offered me a home battery"* with 45% willing to be tied into a 3-year contract if their supplier offered them a home battery at no upfront cost.
- 66% agreed or strongly agreed (10% disagreed/strongly disagreed) with the statement, *"If I had a ToU tariff I would be interested in having a battery in my home to help save money on my energy bills"*.

Expected bill saving

While consumers' principal interest in smart ToU is to save money, understanding behavioural response is not as simple as considering price points in isolation: 74% of our survey respondents either agreed or strongly agreed with the statement, "*While on Economy Alert, I mostly thought about the electricity rates as being simply 'High' or 'Low' rather than thinking about the exact cost in pence per unit of electricity*".

Information provision

The information consumers would like to receive while on a DSR tariff is also good indicator of what information they would like for deciding on adopting that tariff. 96% of our respondents agreed or strongly agreed that if they were on a smart ToU tariff they would like to receive monthly feedback on savings in absolute terms (pounds sterling) compared to a flat tariff, with a lower figure (63%) wanting savings in percentage terms.[24] This suggests that consumers considering signing up to smart ToU tariffs would value tailored advice in the form of estimates of bill impacts compared to their present tariff and relevant alternatives. Regulatory direction on such comparisons may be required. He *et al* (2013) have also argued that there is a need to establish price comparison tools to support customers in making informed choices among a range of contracts.

Data sharing

The importance of tailored advice on bill impacts based on smart meter data and household data (e.g., appliance ownership, occupants etc.) raises the issue of the willingness of consumers to share this data with those providing the advice. Our survey findings indicate that a large majority of respondents would be willing to share data with a third party for this purpose as shown in Table 3.2. This suggests that data sharing concerns will not be a significant barrier for offering these services to support informed choice.

Table 3.2: Willingness to share smart meter data and household information with third parties offering tailored advice on tariff choice.

	Agree or Strongly agree	Disagree or Strongly disagree
I would be willing to share my smart meter data (showing how much electricity you consume and at what times) with third parties of my choosing to get tailored advice on tariffs (data shared would be for your past, say, 6 months consumption and would not give them access to ongoing or future consumption)	68%	14%
I would be willing to share information about my household (e.g. which appliances I use, number of occupants) with third parties of my choosing to get tailored advice on tariffs	58%	23%

[24] 73 respondents answered this question.

4. Assessment of the Distributional Consequences of Time of Use Tariffs

This section sets out our key modelling results. We find that:

- Under our Reference scenario ToU tariffs, the average customer, having a £615 bill under uniform charging methods, would on average save about £8 under the static ToU tariff and about £7 under the dynamic ToU tariff.
- Smart appliances allow some increase in savings, but a battery would increase savings to £96 for the static tariff and £32 for the dynamic tariff.

Comparing impacts across sociodemographic groups:

- The spread of impacts within each ACORN Group is large. Whilst we do find systematic differences between ACORN Groups in terms of impact, the spread of outcomes within each group is much larger than the differences between Groups.
- On average, customers in all but two (wealthy) groups experience some reduction in bill.
- Whilst differences between groups are small, some of the social groups with a higher proportion of vulnerable customers, 'Modest Means' and 'Student Life' are on average at more risk of some increase in bill than other groups and savings are small for 'Poorer Pensioners'.

We also compared impacts across the sociodemographic characteristics of interest among those that ACORN reports on.

- We find that the characteristics 'Working at home', 'Student', 'Privately rented', 'Large household', and 'Retired' are all associated with slightly lower bill savings.
- The spread of bill impact within each characteristic is wider than the spread within ACORN Groups.

The key conclusion is that while a modest majority of consumers would experience a small decrease in their bill on a TOU tariff, there appear to be significant subsets of all social groups liable to experience a material increase in bill if they were to move to a ToU tariff.

It is unlikely that households liable to lose from ToU tariffs would voluntarily choose to switch to one. Many who would gain from ToU are also likely to be reluctant to choose them.

4.1. Introduction

In this section we summarise our modelling results to assess the distributional consequences of ToU tariffs. A complete presentation of results is provided in Annex G. This section is set out as follows:

- section two shows the effect of ToU on the average consumer's bill for each of our five tariff scenarios. We show the effect of the tariff with no change in consumption, and then the predicted effect if consumers change their consumption in response to the tariff;
- section three shows the distribution of impact on bills across sociodemographic groups (defined by the 17 ACORN Groups);
- section four examines differences in bills related to specific sociodemographic characteristics of interest; and
- section five calculates the likely take-up of tariffs across sociodemographic groups and by characteristics of interest.

A detailed discussion and interpretation of these results is delayed to Section 5.

4.2. Net impact on bills

In this section we report the effect on the average bill for customers under our five scenarios in turn.

4.2.1. Reference scenario

As we described in Section 2, the pricing of the ToU tariffs in the Reference scenario is designed so that the bill of the average consumer, assuming no change in consumption, remains unchanged relative to the flat tariff.

To compute the net impact on bill, we first estimate (1) what the bill of each consumer would have been under a flat tariff, then calculate (2) the bill under the ToU tariff and (3) subtract (1) from (2) to find the net impact on bill. We do this for both static and dynamic ToU tariffs.

These calculations are performed four times to account for differences in tariff schedule and behaviour. Each calculation produces four results, labelled as follows:

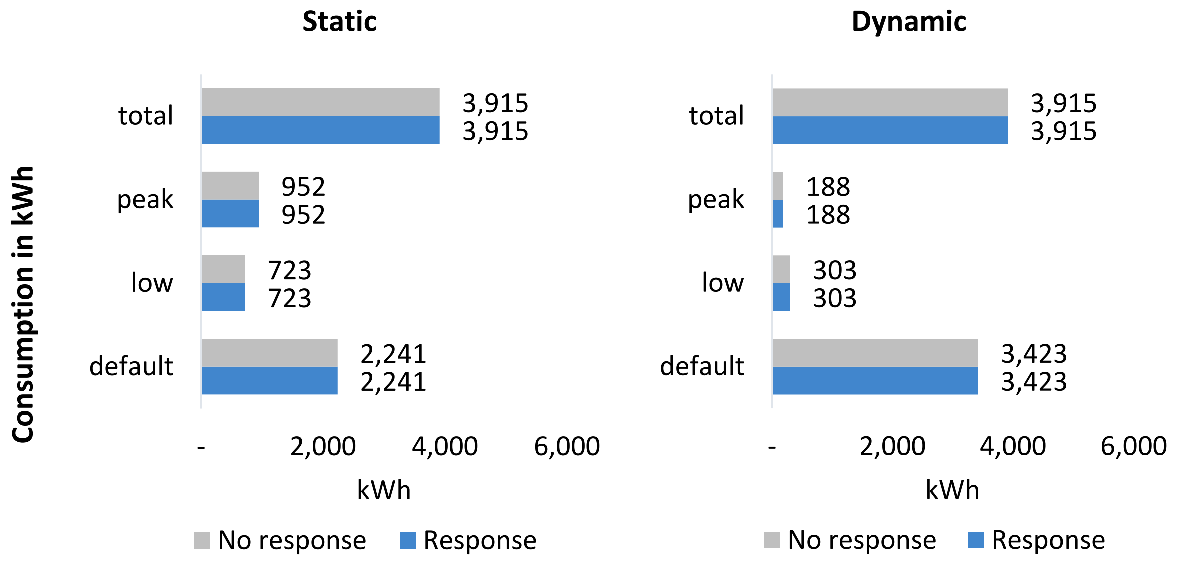
- **Static no response:** All consumers adopt a static ToU tariff but *do not* change their consumption in response to it;
- **Static response:** All consumers adopt a static ToU tariff and change their consumption in response to it in the expected manner – i.e. they move their consumption away from high price periods and towards low price periods: for reasons of practicality, we do this by applying the average group response to each individual in the dataset;[25]

[25] In practice each individual will have their own individual response, but we do not know this. We therefore apply to each individual the group average response which we have established in Section 3. This simplification does not affect the average, but it will tend somewhat to narrow the estimated spread of outcomes for the individuals. The reduction in spread is likely to be small because, in general, the elasticities are small and the spread around them small in proportion. In principle a more accurate spread of outcomes could be estimated by a simulation incorporating a Monte Carlo element. But that would be more computationally demanding task than the present scope of modelling facilitates.

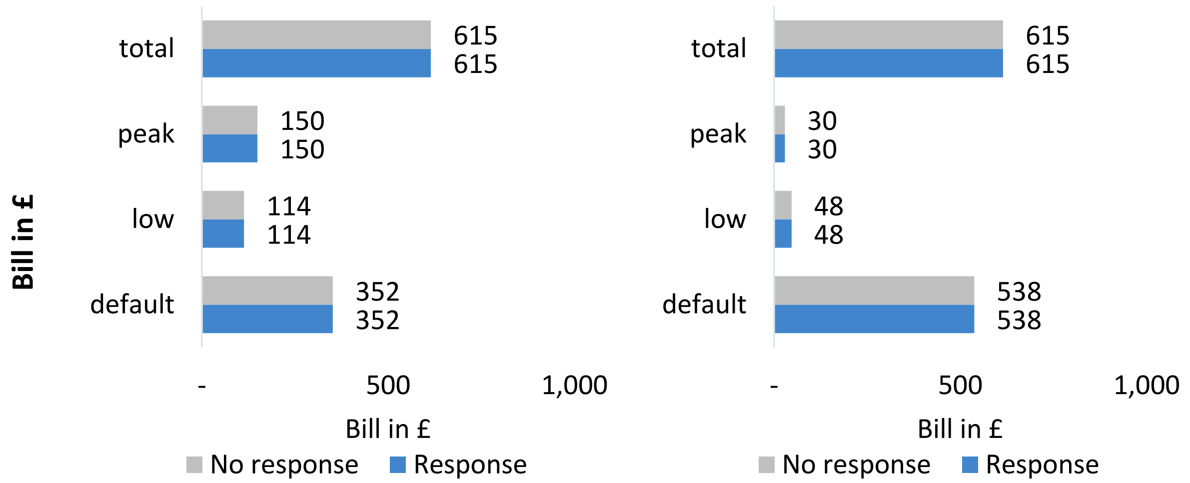
- **Dynamic no response:** All consumers adopt a dynamic ToU tariff but do not change their consumption in response to it;
- **Dynamic response:** All consumers adopt a dynamic ToU tariff and change their consumption in response to it in the expected manner – i.e. they move their consumption away from high price periods.

Figure 4.1 shows the bill of the average consumer in the sample under a standard flat tariff, which is £615.[26] To allow comparison with the later figures, we break down the bill into the time periods that apply for the static and dynamic tariffs we later model. However, in this case, since the tariff displayed is a flat tariff, pricing is uniform across those periods. The left side of the figure shows the distribution of the bill between these three price periods that will apply under the static tariff we study, and the right hand side the dynamic tariff. The peak and low pricing periods are less frequent under a dynamic tariff, since the dynamic tariff is assumed to respond to occasional strong events, rather than the typical ups and downs of a day under the static tariff. Since the tariff shown in the diagram is uniform, there is no behavioural response or difference in total bill between the static and dynamic tariffs.

*Figure 4.1: Flat tariff consumption and bill (£)**



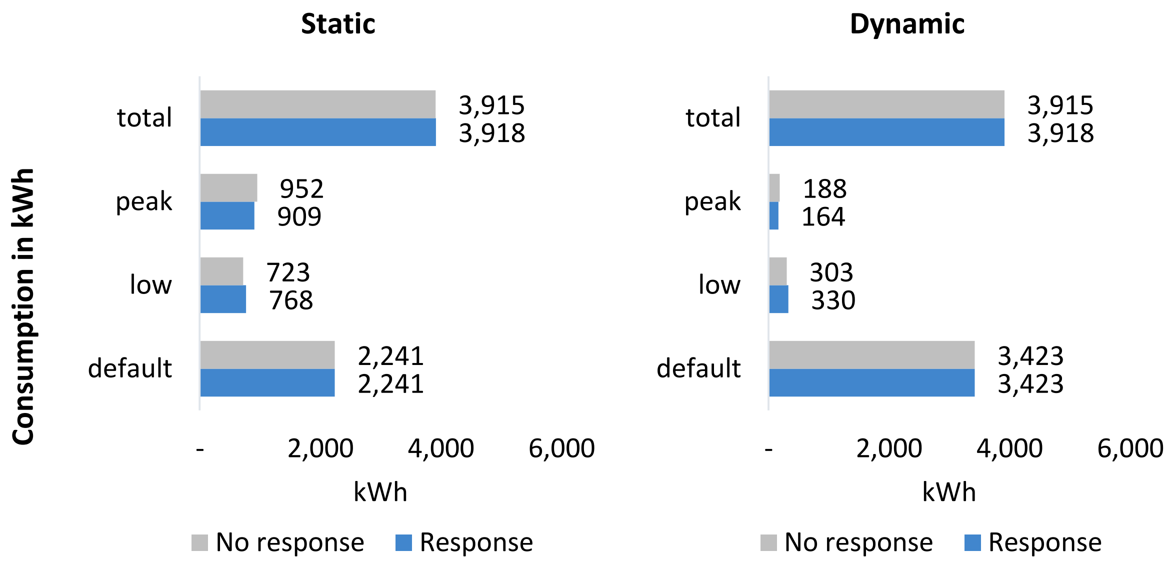
[26] In a sense this is an arbitrary figure which can be adjusted to any convenient level without changing the essential nature or conclusions of the report. It corresponds roughly to the bill under typical standard variable tariffs available at the time of the trials.



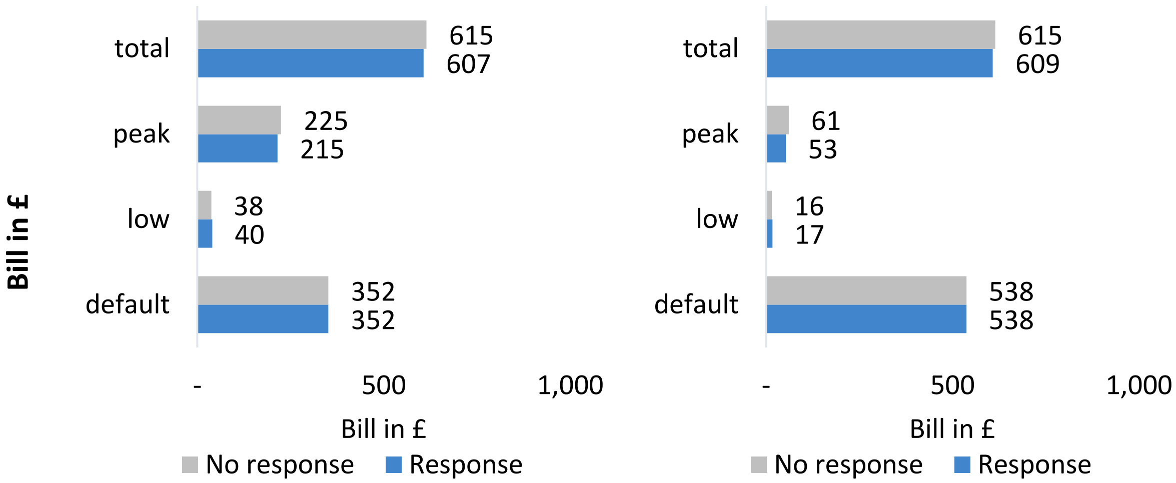
*Note: *This figure shows a flat tariff, so the pricing in all periods is the same.*

Next we examine the average annual bill under the ToU pricing defined by our Reference Scenario. This is shown in Figure 4.2. By virtue of the design of the Reference Scenario, the total average bill without response to the tariff is not affected: it is still at £615 on average for both the static and dynamic tariff. However, the distribution of the bill across the three price points changes. The bill increases at peak time, while it decreases at the low and default time. The average bill decreases when customers respond to the tariff.[27] To aid understanding, in Figure 4.3 we present the same results in terms of net impact on the bill.

Figure 4.2: ToU tariff consumption and bill (£) under the Reference Scenario

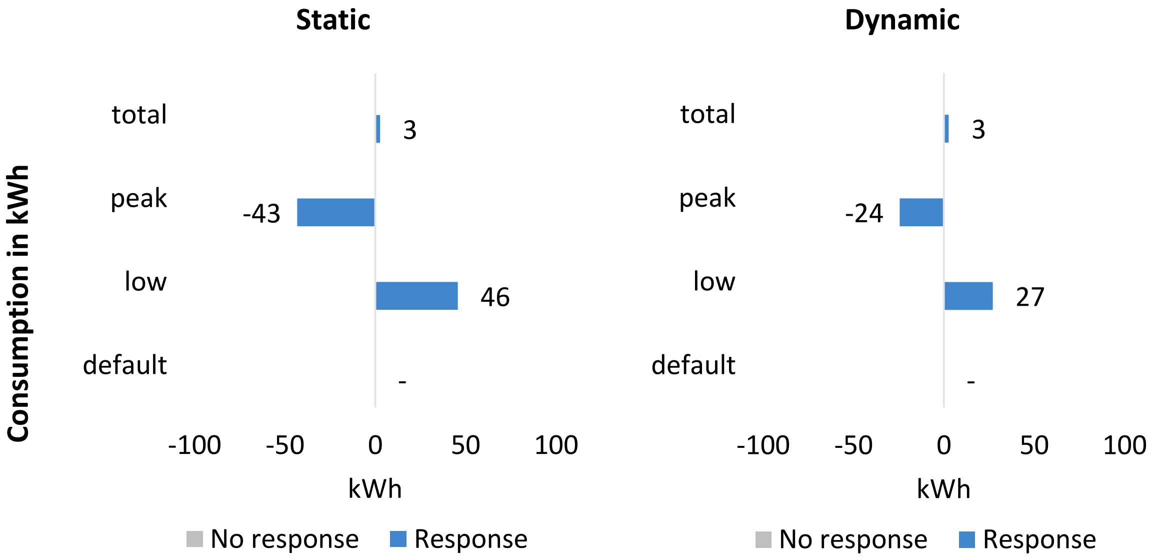


[27] This is not a foregone conclusion. It depends upon the net effect of the varying prices of the ToU tariff.

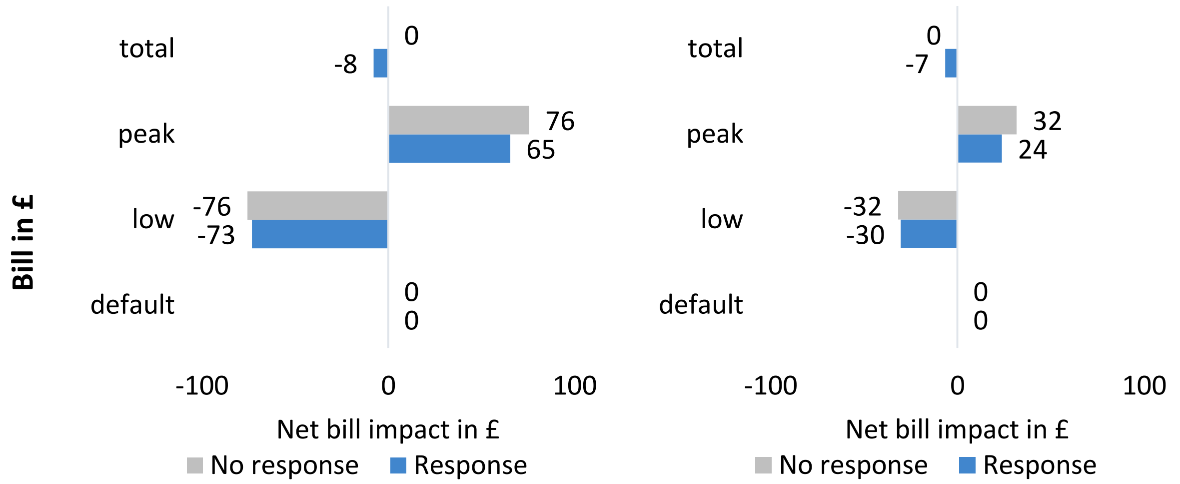


In summary, the net impact on the bill is, by design, nil when consumers do not change their demand. Taking into account the average response of consumers to price differences, we find an annual saving on average of £8 under the static tariff and £7 under the dynamic tariff. Moreover, given there are more frequent low price events under the static tariff[28] compared to the dynamic tariff, there are also more opportunities for consumers to respond. But £8 is only 1.3% of a £615 bill, so the effect is small.

Figure 4.3: Net ToU consumption and bill under the Reference Scenario



[28] This analysis compares specific static and dynamic ToU products, where there are more price events in the static ToU tariff, rather than providing findings about static and dynamic products in general.



4.2.2. Other scenarios

Table 4.1 provides a summary of differences between the five scenarios modelled, which we discussed in full in Section 2.

Table 4.1: Tariff pricing and schedule across all 5 scenarios

Scenario	Pricing and schedule	Technology
1) Reference	Neutral impact on the average consumer who does not change their demand	None
2) Higher price ratio	Neutral impact on the average consumer who does not change their demand, but higher peak off-peak price ratio than (1)	None
3) More price signals	Neutral impact on the average consumer who does not change their demand, but a more frequent occurrence of peak and off-peak prices than (1)	None
4) Appliances	Same as scenario 1	Smart appliance
5) Battery	Same as scenario 1	Battery storage

Table 4.2 shows the net impact on bill across all five scenarios, and Table 4.3 shows the interquartile range of the net impacts.

Table 4.2: Average impact on bill across all 5 scenarios

Scenario	Static		Dynamic	
	No response	Response	No response	Response
1) Reference	£0	-£8	£0	-£7
2) Higher price ratio	£0	-£12	£0	-£11
3) More price signals	£0	-£9	£0	-£22
4) Appliances	£0	-£17	£0	-£10
5) Battery	£0	-£96	£0	-£32

Table 4.3 Interquartile range of impact on bill across all five scenarios

Scenario	Static		Dynamic	
	No response	Response*	No response	Response*
1) Reference	-£19 ¦ £21	-£25 ¦ £12	-£2 ¦ £2	-£9 ¦ -£5
2) Higher price ratio	-£23 ¦ £26	-£35 ¦ £12	-£3 ¦ £2	-£14 ¦ -£9
3) More price signals	-£21 ¦ £23	-£29 ¦ £12	-£2 ¦ £2	-£16 ¦ -£12
4) Appliances	-£19 ¦ £21	-£34 ¦ £2	-£2 ¦ £2	-£11 ¦ -£8
5) Battery	-£19 ¦ £21	-£111 ¦ -£78	-£2 ¦ £2	-£32 ¦ -£31

Note (*): The interquartile range reported here is likely to be slightly narrower than the true interquartile range. This is because the model applies the average response to each individual consumer, rather than the spread of responses that will occur in practice.

We find that a higher peak to off-peak price ratio (Scenario 2) enables consumers to make higher savings if they change their consumption in response to the larger price differential. That is, for the same level of effort (i.e. same level of response to prices), consumers are able to save more.

Similarly, more frequent price signals (Scenario 3) allow consumers to save more since they are provided with more opportunity to make savings by responding to price incentives.

Smart appliances (Scenario 4) help consumers with an additional £9 saving under the static tariff, and an additional £3 under the dynamic tariff, relative to the Reference scenario. Savings are higher than the 'Higher price' and 'More frequent signals' scenarios.

Battery storage (Scenario 5) has the single most beneficial impact on consumer bills. But, simply by inspection, it is clear that the savings do not come near justifying investment in domestic battery storage, if this is the only use of the device. Therefore, despite the level of projected savings, we do not expect battery technology to be viable for the typical household simply trying to arbitrage likely domestic smart tariffs at current high battery prices. Only with a substantial reduction in battery prices, or other major changes in the market and domestic use of electricity, will battery storage become viable for households.

4.3. Impact on bills across sociodemographic groups

This section examines how ToU tariffs affect different sociodemographic groups. We use the 17 ACORN Groups we described in Section 2. We first consider the Reference Tariff, and then move on to the other four tariff scenarios.

We discuss limitations of the study arising from data quality in more detail in Section 5, but for the purposes of interpreting the results we briefly summarise the most important limitations here.

- Participation in the meter trials was voluntary, and many participants were excluded by detailed selection criteria, suggesting that they are probably not a representative sample of all households.

- In particular, selection criteria tended to exclude vulnerable customers, so the datasets may be especially unrepresentative in those ACORN segments that would be expected to have higher proportions of vulnerable customers.
- Our elasticities are calculated from the LCL dataset, which may not be representative because it is confined to London, and does not contain sufficient data points to calculate separate statistically robust averages for each ACORN group.
- ACORN is at postcode level for most of the data we use, which means that not all data points will reflect the ACORN group to which they are assigned.
- ACORN reports on additional characteristics by reporting their occurrence in each group, which means we can only probabilistically associate it with any data point.

There are also some limitations arising from the calculation methods we use, either because of data shortcomings, or to make it tractable, which we explain when we reach those.

4.3.1. Reference scenario

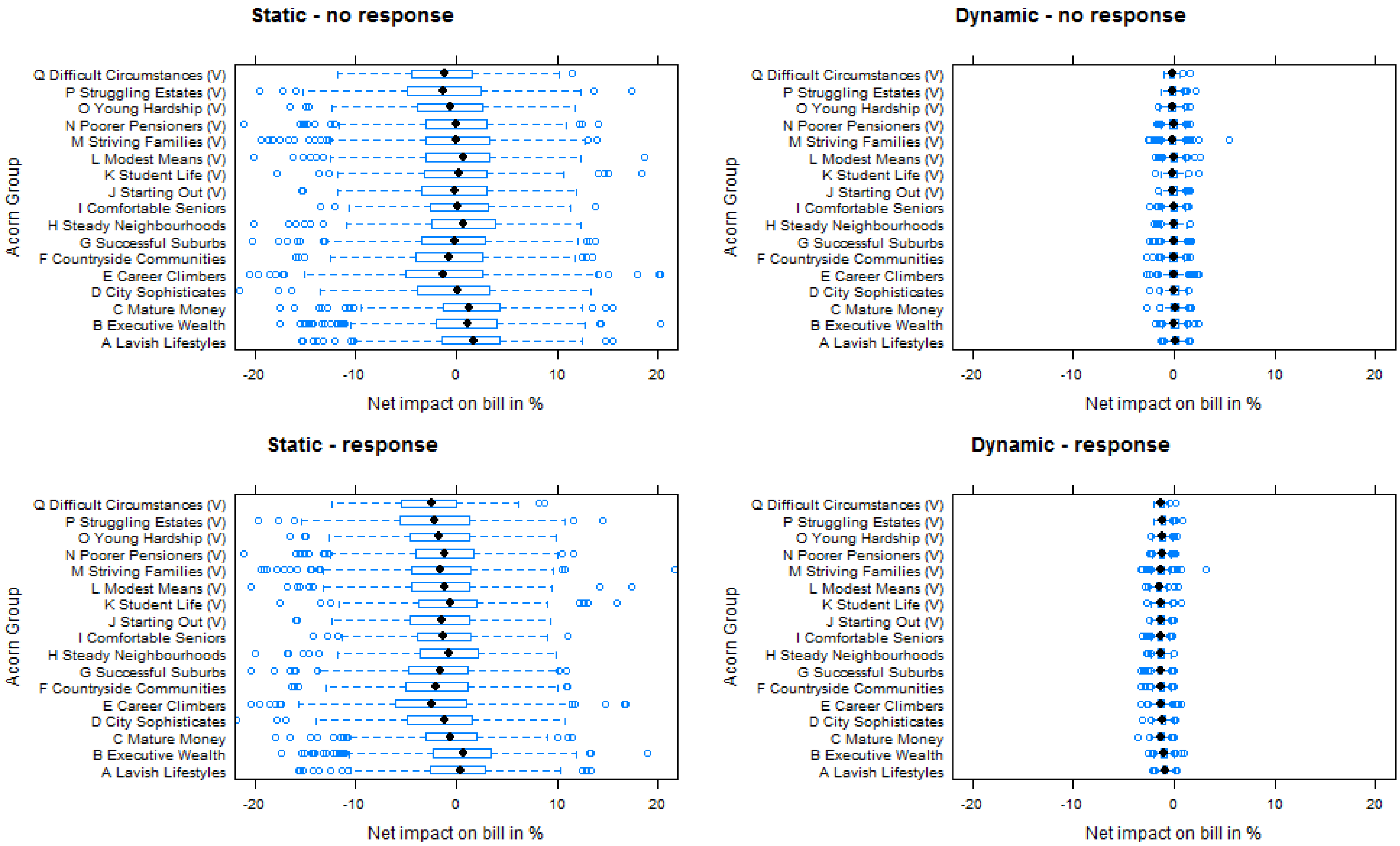
Error! Reference source not found. shows the impact on bill in relative terms (the net impact on bill in % compared to a flat tariff). We report the relative impact on bill to allow for better comparison across groups. Reporting the absolute saving (in £) would show that wealthy households consistently save more, but would ignore their baseline bill.

Impacts by sociodemographic group without behaviour change

If we examine the median impact (black dot), we find that some household groups are more likely to be negatively affected assuming they do not respond to price signals.

- The most well-off consumer groups are likely to experience a 2-3% increase in bill if they do not change their consumption in response to prices.
- Among middle-income consumers the average consumer in most groups would experience a small reduction in their bill. But the average consumer in the 'Steady Neighbourhoods' group would be expected to see a small bill increase.
- Among lower income groups, we find the average consumer in a majority of groups would experience a small reduction in their bill, particularly 'Difficult Circumstances' and 'Struggling Estates'. We find that the average consumer in 'Modest Means' and the 'Student Life' groups experiences a small bill increase. Their bill would increase by close to 1% on average. 'Poorer Pensioners' also do less well than most.

Figure 4.4: Net impact on bills (in relative term) across sociodemographic groups under the Reference tariff



Impact by sociodemographic group with behaviour change

If we allow for consumers to change their consumption in response to prices, we find that on average customers save on their annual bills for both the static and dynamic tariffs. In particular, we find that numerous middle income groups save from responding to the ToU tariff; e.g. ‘City Sophisticates’, ‘Career Climbers’, ‘Countryside Communities’, ‘Successful Suburbs’. And similarly, many vulnerable consumer groups save substantially; e.g. ‘Starting Out’, ‘Modest Means’, ‘Striving Families’, ‘Young Hardship’, ‘Struggling Estates’, ‘Difficult Circumstances’. Only the ‘Lavish Lifestyle’ and ‘Executive Wealth’ groups; i.e. one of the most better-off groups, experience an increase in bill.

Table 4.4: Net average impact of behaviour for the static reference tariff

		Static no response	Static response	Difference
A	Lavish Lifestyles	£9	£1	-£8
B	Executive Wealth	£5	£3	-£3
C	Mature Money	£8	-£5	-£12
D	City Sophisticates	-£1	-£10	-£9
E	Career Climbers	-£8	-£16	-£7
F	Countryside Communities	-£5	-£13	-£7
G	Successful Suburbs	-£2	-£12	-£9
H	Steady Neighbourhoods	£4	-£5	-£9
I	Comfortable Seniors	£1	-£8	-£9
J	Starting Out (V)	-£1	-£10	-£9
K	Student Life (V)	£0	-£5	-£5
L	Modest Means (V)	£1	-£10	-£11
M	Striving Families (V)	-£1	-£11	-£10
N	Poorer Pensioners (V)	-£1	-£8	-£7
O	Young Hardship (V)	-£5	-£11	-£6
P	Struggling Estates (V)	-£9	-£14	-£6
Q	Difficult Circumstances (V)	-£8	-£16	-£8
Average (may not match due to rounding)		£0	-£8	-£8

Legend: Figure shows change in bill in comparison to the flat tariff, so positive is an increase and negative a reduction.

Range of Impacts

Our model slightly underestimates the range of impacts because we know only the average response of the group, not each individual’s response. With this limitation in mind, when we examine **Error! Reference source not found.** - the interquartile range (the boxes) of the impact on bill - with response, ranges from -7% to 3% for the static tariff and from -2% to -1% for the dynamic tariff. It suggests that the static tariff produces greater variability in outcome than the dynamic tariff. Further details are provided in Annex G.

If we examine the whole range of impact (the horizontal distance between the 2nd and the 98th percentile, as well as any outliers), we find there are a material number of households in all groups that would be negatively affected, despite them changing consumption in response to prices. It should be noted however that given the expectation of higher bills, these consumers would be unlikely to choose to take up a ToU tariff.

- If consumers do not respond, the net impact on bill ranges from -15% to +15% for the static tariff, whereas this is contained to -2% to +6% with a dynamic tariff, even though both tariff groups yield the same average impact; i.e. zero.
- If consumers do respond, net impact ranges from -15% to +10% for the static tariff, whereas this is contained to -4% to +3% with a dynamic tariff.

Overall, it should be observed that the range of impacts within each ACORN Group is large. Whilst the average differences may be robust, nevertheless the differences between households are not very well explained by ACORN Group.

4.3.2. Other scenarios

For ease of comparison, in the diagrams which follow we only present the outcome of model runs using the static tariff, and with response in level of consumption, for the other four scenarios. Similar findings for the dynamic tariff can be also be observed. Key findings are:

- A higher peak to off-peak ratio (Scenario 2) accentuates differences across groups but on average increases the overall saving. The difference between the lowest and highest median outcome between socio-demographic groups was a 4 percentage point difference under the Reference scenario; it is 10 percentage points under scenario 2. The risk to households also increases as both the interquartile range and the min-max range[29] increase.
- Likewise, more frequent price signals (Scenario 3), while increasing the average saving, reinforce differences across sociodemographic groups, though not to the same degree as under scenario 2.
- Smart appliances (Scenario 4) do not materially increase average savings for households. But they reduce the spread of outcomes, and thus reduce the proportion of households experiencing a material negative impact. The effect of smart appliances is, according to the results of surveys used to construct the model inputs, estimated to be similar across the ACORN Groups; but in practice it is reasonable to expect that smart appliance usage may be correlated with behaviour to some extent. One might expect that those best able

[29] That is, the 2nd to 98th percentile range.

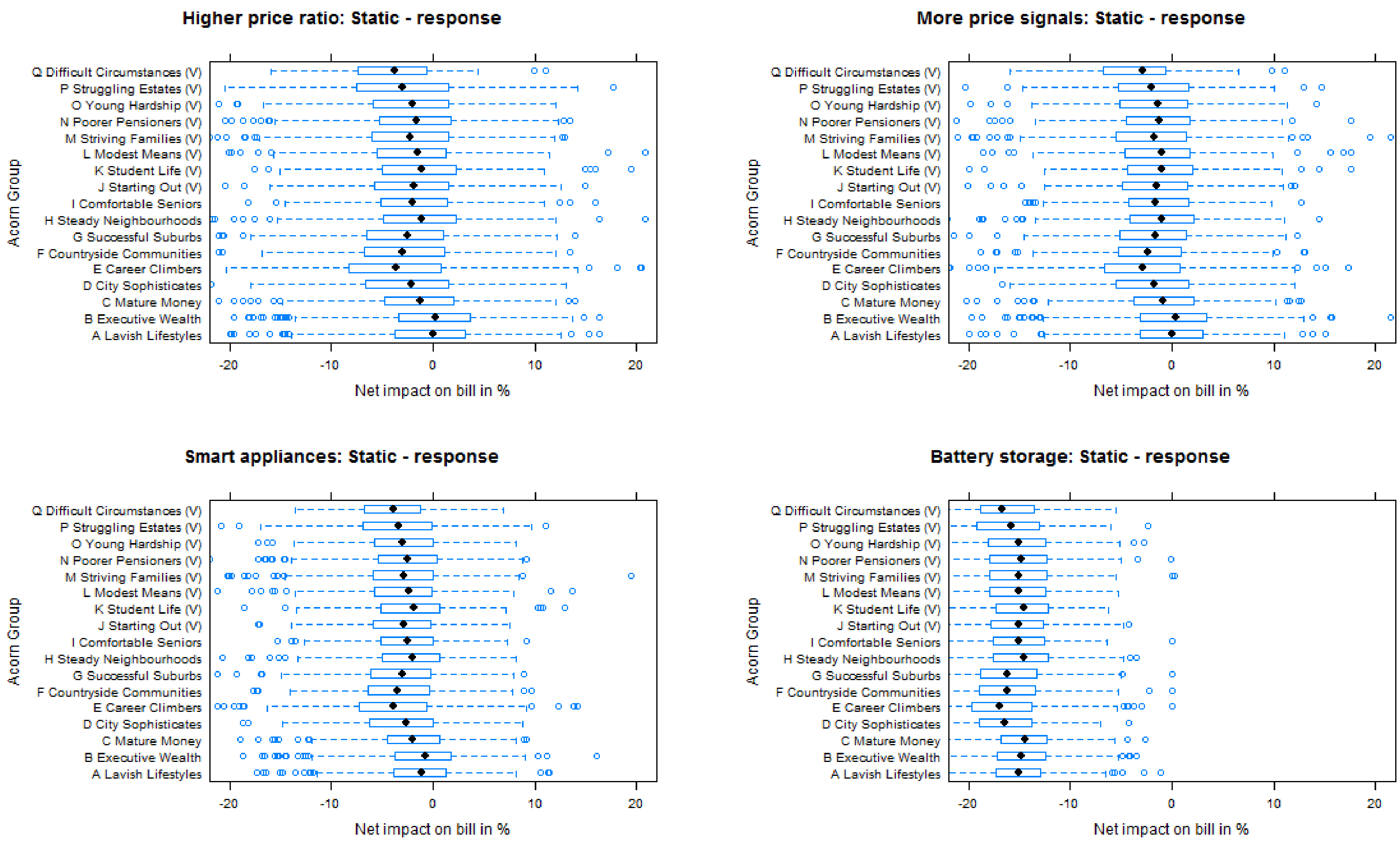
to monitor and respond to prices may also be more capable and engaged at programming and using their smart appliances. But we do not have evidence of how correlated and how variable this would be across ACORN Groups.

- Battery storage can potentially remove the risk of experiencing an increase in bill entirely.[30] It provides considerable protection for individuals with high peak consumption. A battery automates the process of demand response, thus avoiding the need for the human to do anything. Batteries are capable of removing the "hassle factor" from ToU tariffs.[31]

[30] We have made the simplifying assumption that a battery allows a household to displace their grid consumption entirely, so long as they have energy remaining in the battery, at times when it is convenient to do so (i.e. when prices are high). This can straightforwardly be automated, thus requiring no intervention by the customer to achieve it. In reality, battery output constraints may mean this is not quite true, because of the large swings in individual household consumption that occur at short timescales (minutes and seconds). Shared or interlinked batteries between several households would more nearly allow this idealised outcome. Supercapacitors, if these become practical as a substitute for domestic batteries, may also have technical characteristics that more nearly allows this outcome.

[31] Nevertheless, domestic batteries currently remain too expensive to be a viable purchase if this was the only advantage they offered a household. They are more likely to be seen in households which have some of their own generation.

Figure 4.5: Distribution of impact across all scenario – static tariff with response only



4.4. Impact on bills across sociodemographic characteristics

In this section, we examine how the impact on bills is *statistically associated* with the characteristics and circumstances which indicate a higher risk of vulnerability. ACORN reports the association between ACORN groups and numerous characteristics, and thus allows us to examine the association between bills and those characteristics, not just the ACORN groups. We have investigated the association specifically for characteristics most associated with vulnerability.

Our approach is to calculate the weighted average change in bill using the proportion of each group which ACORN reports as having the characteristic of interest. We then calculate a spread of impacts associated with each characteristic. We also calculate a weighted average level of elasticity at peak and off-peak time across characteristics.

This weighted average approach is not the ideal way to approach this. Ideally we should wish to estimate an econometric model which identifies the causal effect of each characteristic in a statistically robust manner, but the quality of available data does not allow us to do that. We are therefore only able to say that these weighted average impacts are *associated* with certain characteristics, rather than being the *causal effect* of those characteristics in the sense of an econometric model. These averages should therefore be taken as only indicative.[32]

Table 4.5 presents the results for the reference scenario. All of the characteristics we examined are associated with a saving in their bill, on average. However, several characteristics are associated with a lower saving on average. Those characteristics are:

- Those working mainly at or from home;
- Students;
- Households living in privately rented accommodations;
- Large households;
- Retired households;
- Households with full-time employees.

Other characteristics are associated with higher savings; these include:

- Consumers on income support;
- Part-time employees;
- Unemployed and looking for work;

[32] For example, a particular ACORN group has a range of outcomes, and we can anticipate that the customers with a particular characteristic might not be evenly spread across that range. The weighted average approach in effect assumes that the customers with that characteristic are in fact evenly spread across the group. An econometric approach would have a chance of identifying the extent to which a characteristic represented a distinctive subpopulation, with a different average from the group in which it was found, provided it occurred in a sufficiently regular way across groups.

- Households with individuals looking after home or family;
- Families with children, whether these are single parents or couple families.

But it is important to note that the differences identified are all small at around ±£3 per year. The average across all these characteristics is a saving of around £8. Households experiencing lower savings save around £5 and those experiencing higher savings save around £11. Furthermore, given that the weighted averages are indicative rather than a statistically correct estimate, small differences are not reliable indicators of true differences.

Table 4.5: Weighted average impact on bill and elasticities by sociodemographic characteristics - Reference scenario, with response

Characteristics	Net impact on bill	Peak elasticity	Off-peak elasticity
Average	-£8.6	-0.092	-0.096
Privately rented	-£5.0	-0.07	-0.11
Social renting	-£9.6	-0.09	-0.09
Household size : 5+ persons	-£6.9	-0.07	-0.11
Children at home : 3+	-£10.3	-0.09	-0.09
Couple with children	-£9.4	-0.11	-0.10
Lone parent with children	-£11.7	-0.09	-0.09
Work mainly at or from home	-£4.8	-0.08	-0.10
Employee Full-Time	-£7.8	-0.09	-0.09
Employee Part-Time	-£10.1	-0.11	-0.10
Unemployed and seeking work	-£11.8	-0.09	-0.09
Looking after home or family	-£11.7	-0.09	-0.09
Student	-£4.9	-0.07	-0.12
Retired	-£7.2	-0.09	-0.08
£0-£20,000	-£9.3	-0.09	-0.09
Income Support	-£10.1	-0.11	-0.10

Note: The association between low impact, off peak and peak elasticities is illustrated by highlighting lower savings, low peak elasticities and high off-peak elasticities in blue. In each case, we highlight the most extreme quarter of the column.

Table 4.5 shows an association between low bill saving, low[33] peak elasticity and high off-peak elasticity. A high off-peak elasticity implies that the customer class is inclined to increase consumption when price is low, and a low peak elasticity implies that the customer class is little inclined to reduce consumption when the price is high. Thus these are the associations one would expect. At the same time it should be understood that the actual magnitude of the impacts above, and especially the differences in impacts, is small in comparison to the spread of impacts within households with a particular characteristic, which we show in the

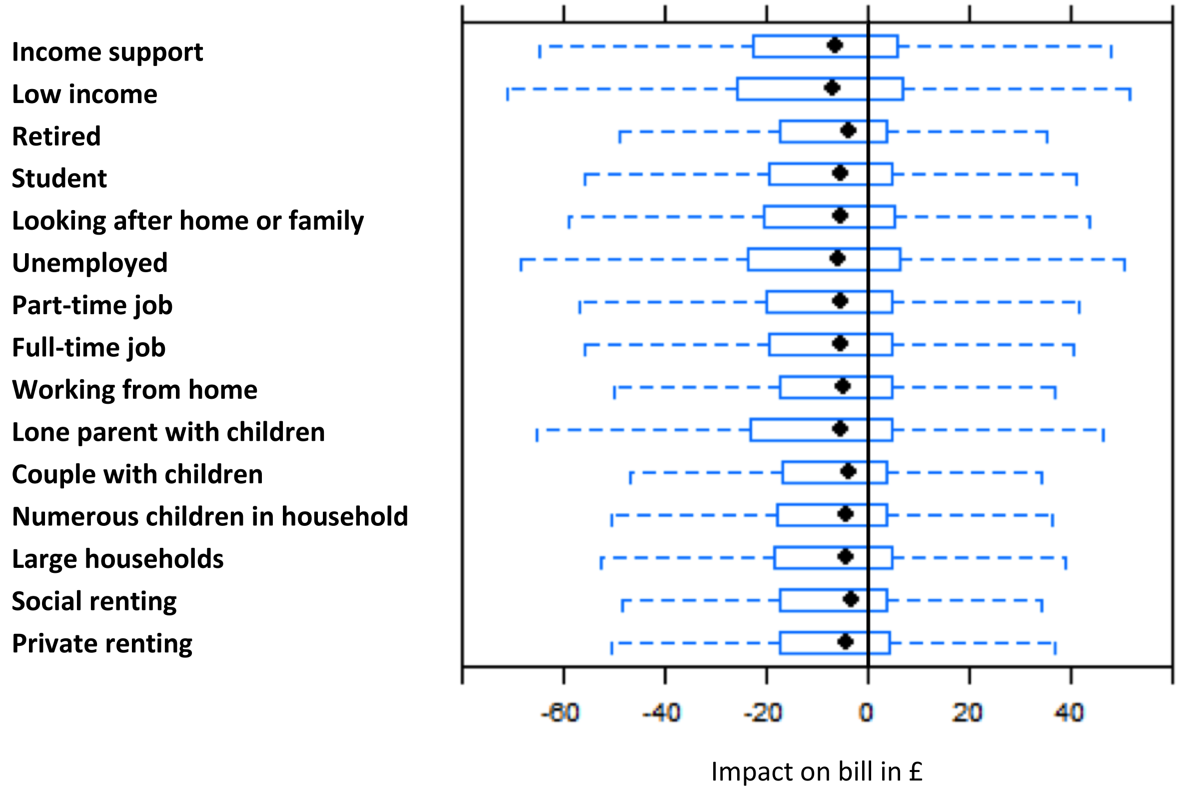
[33] "Low" here means low in absolute magnitude, i.e. closer to zero, which is consistent with colloquial usage.

figure below. Because of the limitations of the calculations underlying our estimates, these spreads should also be taken as indicative.[34]

In essence, this study has found that there are some systematic[35] differences between sociodemographic Groups and sociodemographic characteristics in terms of the effect of ToU tariffs. But there remain much larger differences between individual households within those sociodemographic or characteristic groups. In any sociodemographic group, there will be material numbers likely to experience increases in bill if they chose to move to a ToU tariff and others likely to make relatively large savings.

This finding of greater diversity *within* sociodemographic groups than *between* them is consistent with what the trials themselves reported. The pervasiveness of the finding that the distribution is wide in every category examined, including categories that the trials probably studied relatively well, tends to make us believe it is true in general. However, we cannot be sure to what extent the finding report is distorted – either exaggerated or understated – as a result of shortcomings of the data that has been available to us.

Figure 4.6: Impact on bill in £ across sociodemographic characteristics associated with vulnerability



[34] First, the spreads of outcomes in the ACORN groups we based this on are somewhat compressed for reasons set out above. On the other hand, the weighted average approach cannot pick up if customers of a particular characteristic are distributed in a distinctive way within a group, rather than being spread evenly through it. We cannot say for certain what bias that produces, but it is most likely a bias in the other direction (i.e. tending to stretch the distribution, as well as bias the mean).

[35] Albeit subject to the limitation that we suspect the samples may not be properly representative.

4.5. Tariff uptake

We have used the model to calculate tariff uptake for the various tariff scenarios, based on the analysis of evidence described in Section 3, first for the Reference tariff. We also show how it varies with sociodemographic factors. The evidence on tariff uptake only addresses the likelihood of taking up a tariff if that was the only alternative to a flat tariff. We do not have evidence on tariff take-up in more complex markets with multiple alternatives.

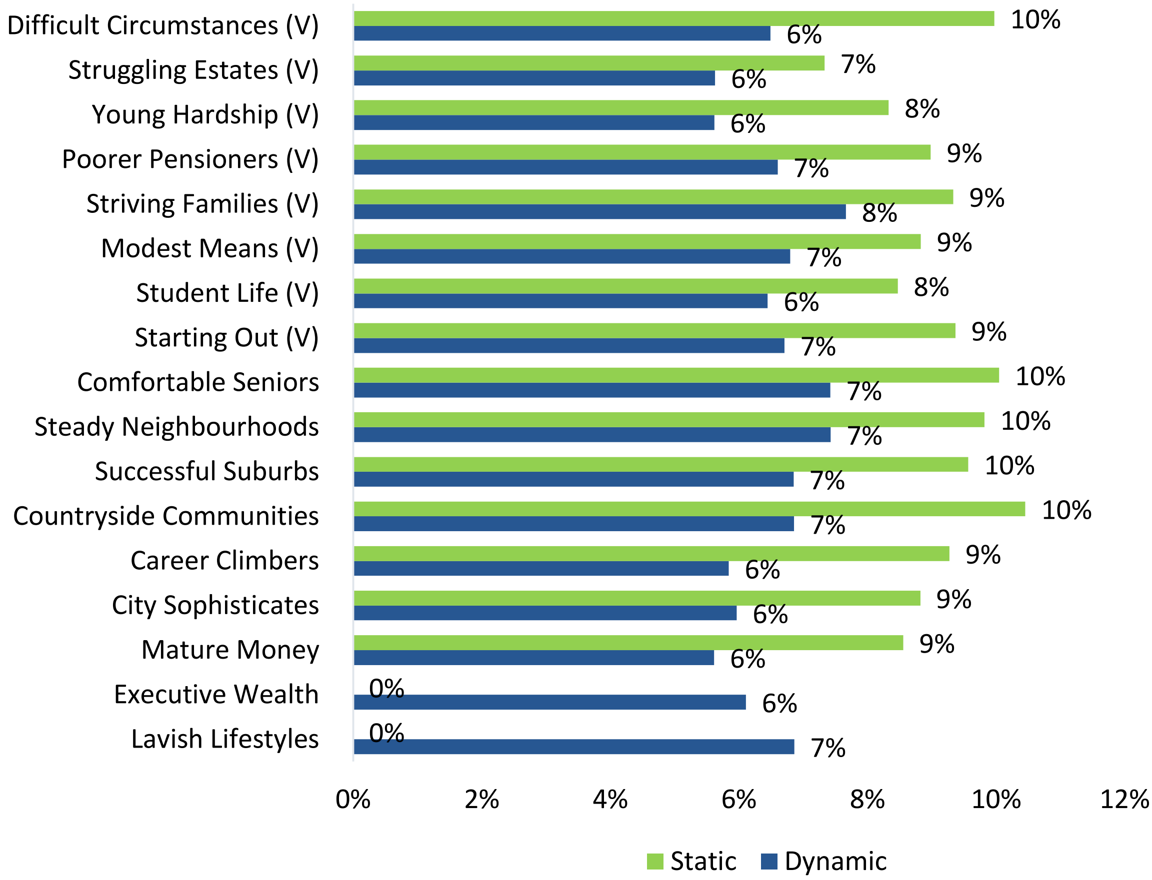
4.5.1. Reference tariff

For the ‘no response’ group, who do not change their consumption, we find an average uptake of 4% for the static tariff and 0% for the dynamic tariffs. This is because the static tariff will benefit some households even if they do not respond. The same applies for the dynamic tariff but savings are too small for households to consider switching.

For the ‘response’ group, we find an average uptake of 9% for the static tariff and 7% for the dynamic tariff.

The likelihood of uptake across groups, as shown in Figure 4.7, closely follows the distribution of impact. Some of the richest households are the least likely to take up this tariff. In fact some of the wealthiest households, which have the most inelastic demand and are expected to experience an increase in bill on average, if they were to switch to a ToU tariff, are not expected to take up ToU tariffs at all. Some of the social groups with a higher proportion of vulnerable customers are also less likely than the average to take up the tariff, but outside the wealthiest groups the differences from group to group are relatively small.

Figure 4.7: Likelihood of uptake for the reference tariff*



Note (*): These take-up likelihoods are on the assumption that each tariff is the only tariff offered as an alternative to the flat tariff. If both tariffs were offered, the uptake numbers would not be additive. We do not have evidence to address that question.

4.5.2. Other scenarios

Figure 4.8 shows the expected uptake across all scenarios. An increased price ratio (Scenario 2) and more frequent pricing periods (Scenario 3) are more attractive to the average consumers than the reference tariff although none is a game changer in terms of uptake.

Smart appliances (Scenario 4) are at present, unlikely to be taken up *en masse* alongside smart tariffs. While taking up a tariff makes supportive technology more attractive, the probability of consumers switching to ToU *and* purchasing a supportive technology is lower than the probability of each event happening separately.[36] We find that low-income households are very unlikely to take up smart appliances. This is not just a matter of being less able to afford it, or issues related to living in rented accommodation. The data also indicates that they are, regardless of cost and other impediments, less eager to try out such technology than middle-income groups. We expect that, in practice, overall uptake will at least initially, be lower and depend on drivers such as product standards.

[36] Figures from the BEIS consumer panel survey show that around 10% of consumers would be prepared to switch to ToU regardless of savings (albeit not negative).

Based on expected savings (only), the data indicates that battery storage would be taken up as consumers sign-up to ToU tariffs. Here again, this analysis does not account for the cost of purchasing, installing and maintaining battery storage. As things stand, this is not an economic proposition, and only becomes relevant when batteries become much cheaper than currently. Even assuming we have reached that point, we expect the take up to be less for low-income consumers, since they have less to gain.

The wealthiest households are more likely to adopt batteries, if they became economically viable. These households have a higher average peak consumption, which presents a greater saving opportunity from being able to time shift peak demand.

Figure 4.8: Uptake of ToU tariffs across all scenarios

Scenario	Static		Dynamic	
	No response	Response	No response	Response
1) Reference	4%	8%	0%	7%
2) Higher price ratio	4%	9%	0%	8%
3) More price signals	3%	9%	0%	7%
4) Appliances	4%	9%	0%	7%
5) Battery	4%	30%	0%	7%

Note: For scenarios 4 and 5, the %age shows the joint probability of tariff being chosen and equipment being accepted

5. Discussion and Recommendations

In this Section we discuss our key findings on the distributional consequences of ToU tariffs, and move on to discuss how policy measures might mitigate risks identified. Our main findings are:

- The wide dispersion of bill impacts of ToU tariffs within all sociodemographic groups is significantly greater than any systematic difference between groups.
- *On average and given the tariffs tested*, social groups which are most likely to be associated with vulnerability are set to make a small (e.g. 2-3%) gain from a transition to ToU tariffs. But individual circumstance vary widely around this.
- Customers liable to lose out on ToU tariffs are unlikely to take them up. Many who would benefit from them might not take them up: many will just not engage, and for some others the savings may be too small to motivate them to switch.
- In the longer term, widespread uptake of ToU tariffs may raise the prices of non-ToU offerings. Subject to the regulatory framework, suppliers may start introducing default tariffs with ToU elements (Ofgem's view is that this would be unlikely under the current regulatory arrangements). This would represent an unwinding of present cross-subsidies. Some of the losers would include some who are already fuel poor or vulnerable.
- Restricting the market by detailed regulation of the design or levels of ToU tariffs would do little to address these issues, and could reduce the ability of smart meters to deliver the benefits intended. We suggest a number of detailed areas of regulation where Ofgem may wish to do further work.
- Ofgem may wish to use new powers that require suppliers to carry out trials to develop greater understanding of ToU tariff impacts.
- More widely, policy makers including central Government may want to consider targeted support to maximise benefits and mitigate risks for vulnerable consumers. This may include energy efficiency programmes, promotion of flexible technologies and educational/awareness programmes.

It is important to note the limitations inherent in available data, which was not collected with the purposes of this study in mind.

5.1. Introduction

In this Section, we discuss the findings on the distributional consequences of ToU tariffs:

- we discuss the incidence of tariffs on social groups, and their responsiveness to those tariffs;

- we discuss mitigation measures; and
- finally, we discuss the limitations of this study arising from use of trial data not designed for this purpose.

5.2. Incidence of ToU tariffs on vulnerable groups

Here we discuss the results of our modelling to understand how ToU tariffs will affect the most vulnerable. Some smart tariffs are now present in the market, but this has not affected the range or level of other tariffs available in the market. For the customer, it is a voluntary and explicit decision to accept a ToU tariff. The customer who would lose out from a ToU tariff is unlikely to choose one. But the range of tariffs on offer may change in time. We also discuss how the market might develop, and what effect that may have for the consumer.

5.2.1. How ToU tariffs may affect the most vulnerable

Our main conclusion is that there is a broad distribution of impact within every sociodemographic group, including those with a higher proportion of vulnerable customers (Figure 4.4). We also find a similar broad distribution when examining classes of customer with social characteristics that indicate a higher risk of vulnerability (Figure 4.6). We find within each sociodemographic group and each class with a higher risk of vulnerability, an ill-defined subset that would experience a moderate bill increase if they were to take up a ToU tariff. At the same time, more than half of customers in every class with a higher risk of vulnerability, and in all socio-demographic groups except those with the highest income, would benefit from a ToU tariff. There are shortcomings in the data that might have distorted these distributions. But the conclusion that there is a wide range of impacts in every sociodemographic group is so pervasive that it seems unlikely to be wrong.

Our distributional analysis concludes that, *on average and for the tariffs tested*, social groups with a high proportion of vulnerable households will make small gains (around £9 (2%) on average in our reference case) from a transition to ToU tariffs. However, there is large variation amongst individual households within any one sociodemographic group. In particular, the 2 to 98 percentiles show a range of bill change from around -£60 (11% saving) to +£40 (7% bill increase) for individual households, assuming average demand change in response to the tariffs. Thus examining the full range of ToU tariff impacts shows that a minority of households would experience a moderate bill increase, in every sociodemographic group. This is either due to the nature of their consumption profile and/or because they are either unable or not sufficiently motivated to modify their behaviour in response to ToU prices.

There is a significant margin of error in relation to our findings regarding the impacts of households' characteristics and circumstances on consumption and responsiveness profiles. All groups show a large dispersion about the average. The following results should be considered with these limitations in mind.

Sociodemographic classifications do not specifically identify vulnerable customers, rather there are groups and characteristics where the vulnerable are more common. We know only the class average, and that may be different from the experience of the vulnerable households within the class. It may also be that trial selection methods mean that certain demographics are over- or under-represented in the dataset, and thus in the data we examine the rate of vulnerability may be different from what the ACORN classifications appear to tell us. Bearing these shortcomings in mind, our results suggest that these are some of the groups who, if they find themselves on ToU tariffs, appear to show larger savings on average:

- **Single parents with dependent children; families with numerous children**: These household types make larger savings mainly because they already consume a higher proportion of their electricity outside the peak than the average household. Their responsiveness to price is about average.
- **Two parent family with dependent children**: Although these households have among the highest level of peak consumption, they also exhibit among the highest level of responsiveness, and thus make relatively large savings by moving consumption away from the peak.
- **Households with individuals looking after home or family**: This group makes savings because they also have a lower proportion of their consumption in the peak, and about average responsiveness.
- **Those on income support:** Those on income support are found to save more than average. These households have a medium level of peak consumption and a medium level of responsiveness.
- **Those with low income:** Those in the lower income band (between £0 and £20,000) are found to save more than average. These households exhibit about average responsiveness and a medium level of peak consumption.

However, other consumer groups appear to be less well-placed to respond to price signals, and therefore may not benefit as much from smart tariffs on average. With the same caveats, especially that these are small differences, outweighed by the range of variation in each group, we noted that groups who did not save as much included:

- **Students**: The degree of responsiveness of this group is the lowest (across the characteristics of vulnerable groups examined) and their level of peak consumption is one of the highest amongst groups containing vulnerable consumers.
- **Retired**: These households have a relatively high level of peak consumption, and their responsiveness is about average.
- **Working mainly at or from home**: Households in this group have a relatively high level of peak consumption and below average responsiveness.

- **Privately rented**: Households living in privately rented dwellings have a low level of responsiveness.

Unfortunately, the data available for this study was not sufficiently granular to examine the causal influence of certain other characteristics which might have been of interest to the impact of ToU tariffs. Nor were we able to examine the effect of certain characteristics that might be strongly related to consumption (for example households with predominantly electric heating) as our data did not address such characteristics. Our results are only descriptive and, because of the imperfect nature of the sociodemographic information that ACORN provides, should be treated with care.

5.2.2. Attitudes of vulnerable consumers to ToU tariffs

Our findings suggest that those least likely to save (or most likely to experience a bill increase) by adopting ToU tariffs are also the least likely to take up these tariffs. This holds in the case that taking up such a tariff requires an explicit choice to do so. However, this assumption may not endure in future as suppliers could choose, subject to the regulatory framework,[37] to introduce ToU elements into default options, which are currently known as standard variable tariffs.

Our literature review and the data analysis suggests that the social groups with higher proportions of vulnerable customers require higher savings to be successfully encouraged to take up ToU tariffs. Further, they are generally more likely to be disengaged from their utility bills – i.e. they tend not to make explicit choices but remain with the default option.[38] Thus, many would not make a voluntary choice to take-up ToU tariffs regardless of the saving. As a result, the social groups with a higher proportion of vulnerable consumers are less likely to actually experience the effect of ToU tariffs, because they are less likely to choose them. As above, this conclusion assumes that flat tariffs remain the default.

5.2.3. How flat tariffs may evolve

We have so far taken the flat tariffs as unchanged from those presently offered,[39] so that those who remain on them are unaffected by the ToU offer, but this may not remain true in the longer term. In the longer term, sufficient consumers may take up ToU tariffs such that the cost to suppliers of offering flat tariffs may be affected, thus prompting them to change the price. For example, if sufficient numbers of responsive or low peak demand customers choose ToU tariffs, then remaining customers will include proportionately more with high peak demand who are costlier to serve. If this were to occur, we anticipate that flat rate tariff

[37] Ofgem's view is that this would be unlikely under the current regulatory arrangements.
[38] Section 9 of the Competition and Markets Authority Energy Market Investigation presents characteristics of disengaged consumers based on its consumer survey, consistent with the assertion we make. Available here.
[39] Aside from changes in the underlying cost of supply, such as the cost of energy and network costs, that affect all suppliers equally.

rates would shift upwards to reflect the higher average costs incurred by those who do not take up ToU offerings.

On the other hand, the take-up of ToU tariffs, if it is successful in modifying consumer behaviour in helpful ways, should have market-wide benefits in reducing the costs of supply across the whole market. This may wholly or partially offset increases in flat rate tariffs. But it may still be that relatively speaking, the costs of serving customers selectively remaining on flat tariffs is higher than those who are on ToU tariffs. Thus the level of flat tariffs in the market may become, on average, higher than the level of ToU tariffs.

This may have two implications:

- Since social groups with higher proportions of vulnerable customers are less likely to adopt ToU tariffs even where they may benefit from them, they may need targeted support and encouragement to adopt such tariffs to prevent consumer detriment.
- Those vulnerable customers who have a higher than average peak demand, that they cannot reduce sufficiently, will continue to be better off on a flat rate tariff, but would see bills rise relative to others as cross-subsidies unwind. There is a question surrounding whether protection measures may need to be put in place to protect this class of customer.

5.3. Policy implications

5.3.1. Possible regulatory measures

The evidence gathered under this report does not provide any clear support for the idea that there is a need for any specific regulation of ToU tariff design. Our findings suggest that the main concern is that some vulnerable consumers may have little ability to respond to price signals, and so could suffer detriment should they take up a ToU tariff. However, there is also evidence that these consumer types will be the least likely to take up ToU tariffs, so long as it remains an explicit choice.

Regulating ToU tariff design would be a significant market intervention and may have wider distortionary effects or unintended consequences. Elements of tariff regulation designed to protect one group of consumers may have negative impacts on others.[40] Some vulnerable consumers may be able to make significant savings from the use of ToU tariffs, particularly with the help of supportive technologies.

[40] A comparison can be made with bank account conditions. "Free If In Credit" bank accounts are beneficial for low income customers who have the discipline to remain in credit but maintain low account balances. This is the behaviour of many low income bank customers. Attempts to protect another set of vulnerable customers who frequently incur overdraft charges is likely to be damaging to this first vulnerable group. It is often hard to avoid difficult policy trade-offs in this area.

Regulation of supplier conduct in relation to customer switching

Ofgem already regulates supplier conduct in relation to customer switching. It is possible that the presence of ToU tariffs in the market present the opportunity for new kinds of conduct that might be detrimental to consumers, and further regulations or amendments to existing regulations may be required.[41] To make customers more confident to take up ToU tariffs to their benefit, it is also likely that Ofgem will need to consider whether any changes to the current regulatory framework or Confidence Code would be necessary. This should ensure that suppliers and third parties are able to access half-hourly data, with the customer's permission, in order to provide accurate bill comparisons under different tariffs.[42]

ToU default

In assessing the effect of ToU tariffs, the standard for comparison has been against flat tariffs. This is appropriate because customers who are not fully engaged in the market, and are therefore often paying default tariffs, are on flat tariffs. The default tariffs in the market, the standard variable tariffs, are rarely the most advantageous tariffs available to a customer. Conversely, at some point in the future energy suppliers may have incentives to put their customers on ToU tariffs as a default tariff, subject to regulatory arrangements.[43] In this case, although consumers would still have an opportunity to have a flat tariff, they would change from an opt-out to an opt-in basis.

Ofgem may therefore wish to consider explicitly the case for restrictions on the nature of default tariffs.[44] However, the pros and cons of a policy controlling the nature of a default tariff will require careful further thought and analysis. The effect of a policy requiring default tariffs to be flat, for example, would be to perpetuate the cross-subsidies implicit in flat tariffs, and to dilute the market-wide efficiency savings that smart meters and half-hourly settlement are intended to bring.

Requiring further trialling

In this report we have clearly noted the limitations of existing data which prevent us from drawing firm conclusions regarding impacts and opportunities arising from ToU tariffs for vulnerable consumers. In order to support firm policy conclusions, further evidence is required on the costs, behavioural implications and distributional characteristics of ToU

---

[41] Ofgem is already making steps in this direction It has issued a consultation *Standards of Conduct for suppliers in the retail energy market.* This includes proposed requirements on suppliers to "treat customers fairly," and a proposal to introduce "an enforceable principle into the domestic Standards of Conduct which makes it clear that suppliers have a special responsibility towards consumers in vulnerable situations".

[42] Access to data from Smart Meters is already covered by the Data Access and Privacy Framework. Suppliers or third parties seeking to access half hourly data for the purposes of tariff comparisons can only do so with the consumer's explicit consent..

[43] Ofgem's view is that this would be unlikely under the current regulatory arrangements.

[44] As noted above, Ofgem's view is that this would be unlikely under the current regulatory arrangements.

tariffs. Ofgem recently published its decision on selection criteria for requiring suppliers to test measures to promote consumer engagement.[45] This may present an opportunity to require suppliers to conduct experiments such as randomised controlled trials (supported by behavioural theories and insights) which are specifically designed to address the issues that we study here. We can note in passing the compulsory water metering trials[46] in the 1980s.

5.3.2. Wider policy considerations

In addition to the policies which Ofgem may wish to consider, it may also want to work with central government (particularly BEIS) on other initiatives which could support vulnerable consumers. Widespread uptake of ToU tariffs would unwind cross-subsidies. As there are inevitably some vulnerable customers currently benefiting from those cross-subsidies, it may be appropriate to find other ways to help them. For example, the following will all tend to protect vulnerable customers on ToU tariffs:

- **Supporting energy efficiency**: While some of the benefit of ToU tariffs may arise by shifting load away from peak periods, use of energy for activities such as lighting, cooking and entertainment may be less flexible. Policy makers may want to consider further support they can provide to encourage greater energy efficiency amongst vulnerable consumers. The main areas where such help would be useful would be in relation to loads that are hard to shift, and in the rented sector where the tenant is using landlord equipment. The justification would be similar to the reasons for supporting house insulation.
- **Education and awareness campaigns**: Consumer awareness of ToU tariffs is currently low and this has been identified as a barrier to potential take-up. An important aspect of the adoption of innovative services is that it develops and evolves by diffusing through society from early adopters to other groups. In our survey, 73% of respondents indicated that if others take up a smart tariff, this would make taking up such a product more attractive.
- **Accurate data and information**: To make informed tariff choices, consumers of all types will need accurate and clearly presented information setting out the benefits to them from switching to a ToU tariff. It is already the case that access to smart meter data for marketing purposes is subject to the consent of the consumer, and we are not suggesting that this should change. What we are suggesting is that the institutions through which customer data may be used for bill projections should be designed both to make it easy

[45] Available here.

[46] The entire Isle of Wight was the subject of the largest compulsory water metering trial, chosen because a reduction in consumption there would avoid a costly expansion of the water transfer scheme from the mainland; metered tariffs gave rise to the desired consumption reduction and the trial then became permanent. Other compulsory water metering trials were at Chorleywood and Brookmans Park, which are affluent areas, and may have been less useful for understanding sociodemographic effects.

for the customer to obtain the comparisons they desire, and also to give them confidence in the projections made and the data security. This may be particularly important for those vulnerable consumers who may otherwise be less inclined to adopt a ToU tariff, even when it is to their advantage. As well as encouraging clearer engagement and information provision by suppliers, Government's Midata programme[47] may act as a facilitator in allowing consumers to gain a better understanding of their energy use and the bill impacts[48] resulting from a switch to a ToU tariff.

- **Encouraging supportive technologies**: Supportive technologies could help vulnerable consumers to shift load away from peak periods to benefit from ToU tariffs. As with building efficiency, the government could at some point consider financial support for installing supportive technology, because of its beneficial effects. At present only battery technology has the potential to provide a comprehensive safety net to avoid peak prices. In contrast, smart appliances provide a rather small protection. But making batteries an economic option would depend upon further major reductions in the cost of batteries. How to make most effective use of domestic batteries also requires further research.

5.4. Limitations and influence of trial design

This study has made predictions of the impact, response to, and consumers' willingness to adopt ToU tariffs using the best evidence available from two UK trials. These trials were the most comprehensive ToU evidence base available. However, they were not designed with this explicit intention in mind. Therefore, any study in this area is necessarily founded on an evidence base with certain limitations. This can, ultimately, only be mitigated by carrying out trials designed specifically to elucidate the effect of a full range of customers experiencing realistic ToU tariffs. For example, compulsory trials were used to evaluate the effect of water metering across the whole of an area, charged using realistic tariffs.

Several characteristics of past trial designs limit their reliability for developing definitive conclusions in this area:

- **Trial design**: In the LCL trials the tariff schedule was designed to investigate flexibility across days and time of day but was not designed to assess impacts on bills. The timing, duration and frequency of price events heavily influenced the distributional impacts on bills, and the tariff characteristics used in the trials were not indicative of likely real world tariffs. Similar issues are present with EDRP.
- **Recruitment**: Participation in ToU aspects of the trials was voluntary, likely resulting in some self-selection and therefore a non-representative sample. Self-selection bias would have been somewhat mitigated by the incentives used to recruit participants onto the

[47] The Midata programme is designed to provide individuals with increased easily accessible information and data regarding their energy use. It was launched in 2011 as a voluntary programme. See here.

[48] Consumers may require assistance in using the data to calculate bill impacts. Third parties, such as price comparison sites, may have a role in providing that assistance.

trials. Further, certain categories of customer were deliberately excluded due to suppliers' concerns (e.g. customers with pre-payment meters, some other households assessed as vulnerable under some criteria, dual-fuel customers) or technical issues (tower block residents).

- **Understanding**: In a year-long trial, many customers will likely not have sufficient time to build responsiveness habits, and thus their reactions may not be optimised to what they might achieve with longer practice. Feedback on savings made versus a flat tariff was also only given at the end of the trial, instead of on a monthly basis, as customers would prefer.
- **Feedback**: Devices available to customers in trials differ from what will likely be available with smart metering. Thus, the feedback observed is not necessarily robust in assessing what will happen with the devices being installed in the present roll-out.
- **Trial tariff levels**: To make trials acceptable to customers, ToU tariffs were lower than is realistic in a real-world roll-out of such tariffs. These low tariffs may have distorted behaviour – customers could reduce bills without trying, and may not have taken as much action as they would in the presence of realistic tariff rates.
- **Absence of real incentives**: Consumers were also given a money-back guarantee, so if their bill had risen on the ToU tariff they would be reimbursed the extra. This likely reduced motivation to shift consumption and reduced their responsiveness.
- **Baseline data**: Baseline data for assessing responsiveness is lacking – ideally customer consumption should be monitored before the new tariffs are implemented. Long delays in smart meter installations prevented the collection of baseline data in the LCL dynamic ToU trial.
- **Duration**: Trials were time-limited. With open-ended tariffs, the financial case for householder investments in energy efficient appliances or technology to support load shifting becomes much stronger. Our survey confirms that over 50% of households would expect to invest in some more energy efficient appliance or smart appliance if the ToU tariffs had continued.
- **Supporting technology**: The nature and cost of supporting technology to facilitate energy saving and flexibility is evolving rapidly. Costs of supporting technologies have already fallen materially since the trials were done only a few years ago, and costs may fall substantially further given trends. Thus these trials did not use supportive technologies whereas in future they may be material to the advantage and use of ToU tariffs. Recently a small scale trial has been started making use of domestic storage batteries.[49]

[49] Trial at Oxspring in Yorkshire with 40 households making use of PV and batteries. Batteries are more economic in combination with embedded generation. A significant feature is that the batteries are interlinked between households which can overcome constraints and substantially increase the value of the batteries.

- **Advice**: Experimenters in the trial tried to avoid any distortional impacts on behaviour by providing no guidance. However, in a competitive market such guidance (helping customers to select tariffs which may be most suitable for them and providing advice on how to manage consumption under ToU tariffs) is more likely to be provided. The literature has shown that the provision of information has helped consumers, although marginally.

Thus, there are many reasons to expect that behaviour in the real world will be different from that demonstrated in these electricity smart metering trials. The most significant limitations come from the reimbursement for out of pocket customers, the selection of trial participants, the effect of artificially low tariffs, and the short period of the trials.

We suggest that future research facilitates truly representative customer samples, market realistic tariffs, and attempts to estimate robust elasticity values and the causal relationship between elasticity and sociodemographic characteristics.

---

http://www.northernpowergrid.com/news/home-battery-trial-aims-to-increase-electricity-network-capacity-to-enable-more-solar-homes-and-save-millions-for-customers

ANNEX A SMART METER DATA

A.1. Data preparation

The Excel model cannot accept data straight from the meter trials, as Excel is not suited to handling large datasets. Accordingly the data has to be summarised and prepared using a database program to present it in a form that the model accepts.

We made some adjustments to clean the consumption data ahead of calculating the impact on bills.

- We identified duplicate meter readings with different values (same household id, date and time, electricity consumption) and removed them accordingly.
- We removed meter readings with null or zero values on the assumption that null electricity demand can only be a result of poor data.
- We excluded 'profile 2' customers[50] from EDRP since their behavioural response prior to the trial could bias the results.
- We adjusted household annual consumption: some households did not have a full year of data. It implied that when calculating annual bills, their bills were lower than the average household. Instead of excluding them from the model, we adjusted their consumption volume to give a typical yearly consumption value for each household.
- We removed any outliers; e.g. households with annual consumption below 250 or above 30,000 kWh.

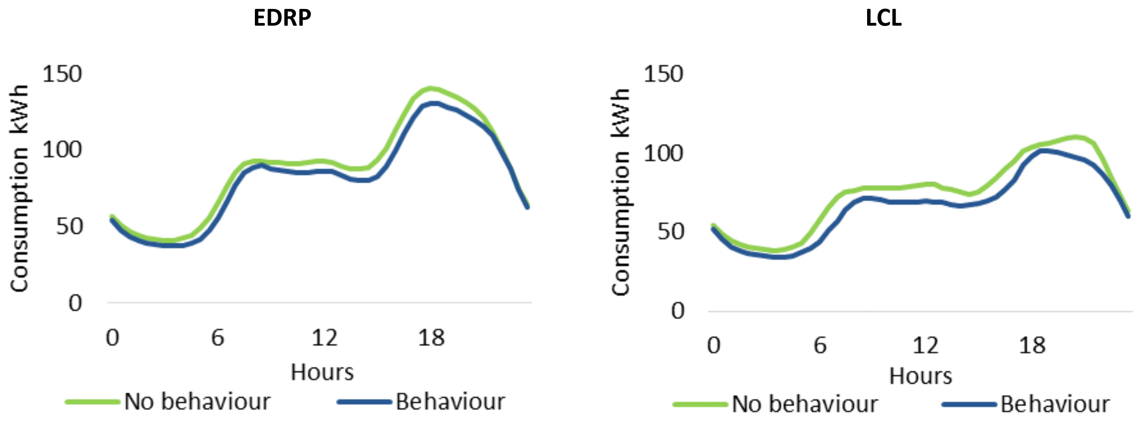
A.2. Consumption profiles

Some segments of the EDRP and LCL consumers experienced a ToU tariff (Treatment group), while other did not and experienced a flat tariff (Control group). As shown in Figure A.1 consumers on both trials responded to price signals.

While the incentives to shift demand away from expensive peak periods were stronger for LCL households, they responded far more strongly to reward (cheap electricity) than penalty (expensive electricity). Hence, we observe an asymmetry in the behavioural response.

[50] Domestic Economy 7 Customers. Economy 7 has a different price per kWh based around day and night-time usage, with the price/kWh being cheaper at night.

Figure A.1: Annualised average daily consumption profiles across trials and groups



For simplicity and to reflect the modelling approach, throughout this document, we present consumption profiles by price points; i.e. default, low, peak, as illustrated in Figure A.2.

Figure A.2: Annualised average consumption profiles across trials, groups and price points in kWh

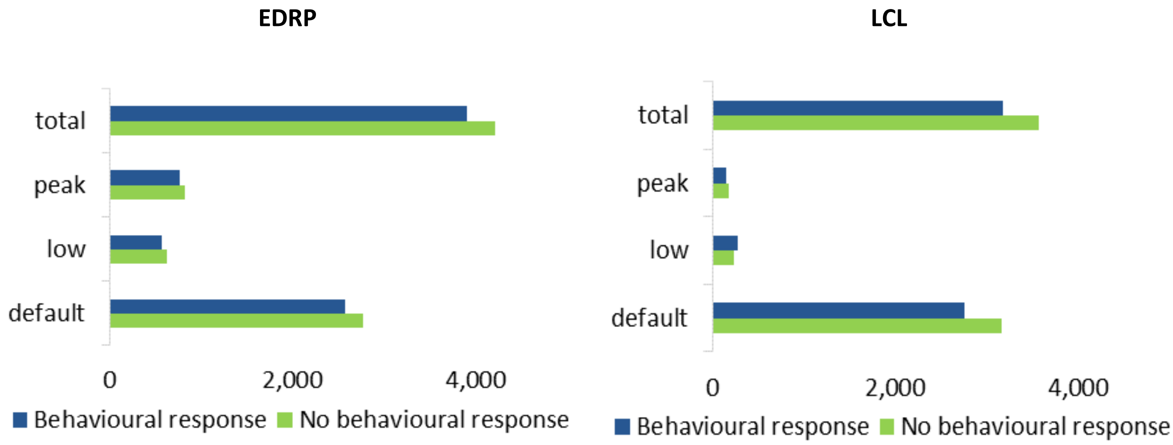
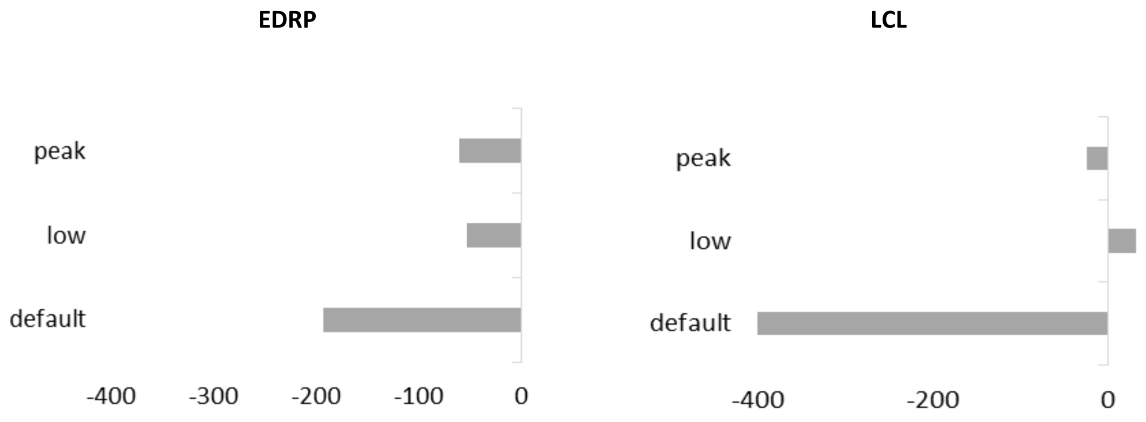


Figure A.3 (overleaf) shows the consumption difference in kWh between control and treatment groups. It shows that for EDRP the main driver was a decrease in consumption in the default pricing period, though consumption also decreased at peak and low price points. Reduction at the low price point indicates that the impact of cheaper electricity did not materialise. LCL consumers' reduction in total consumption was also driven by a reduction at the default price point. However, they responded to time of use tariffs by increasing their off-peak consumption.

Trial findings suggest that whatever strategy consumers used to react to the high peak prices had the side-effect of also reducing consumption at other times. And whatever factor encouraged savings, it outweighed any effect from the price differences.

Figure A.3: Annualised average difference between the controls and treatments groups in kWh



A.3. Tariff schedule and price points used in the trials

Before turning to the tariff used in the model, it is useful to get a sense of the tariffs used in the two trials for which we have data; i.e. the EDRP and LCL trials.

Figure A.4 below gives an overview of the pricing schedule for each dataset. It shows the count of different price events (default, peak and off-peak [referred to as 'low' in this document]) across a given year. The schedule of EDRP price points was the same each day of the year, while LCL had variable price events, although slightly more frequently at peak consumption time. Figure A.5 shows the actual proportion of default, low, and peak price points across the two trials and illustrates that the frequency of low and peak price point was much less under the LCL trial.

Figure A.4: Pricing schedule of the EDRP and LCL data

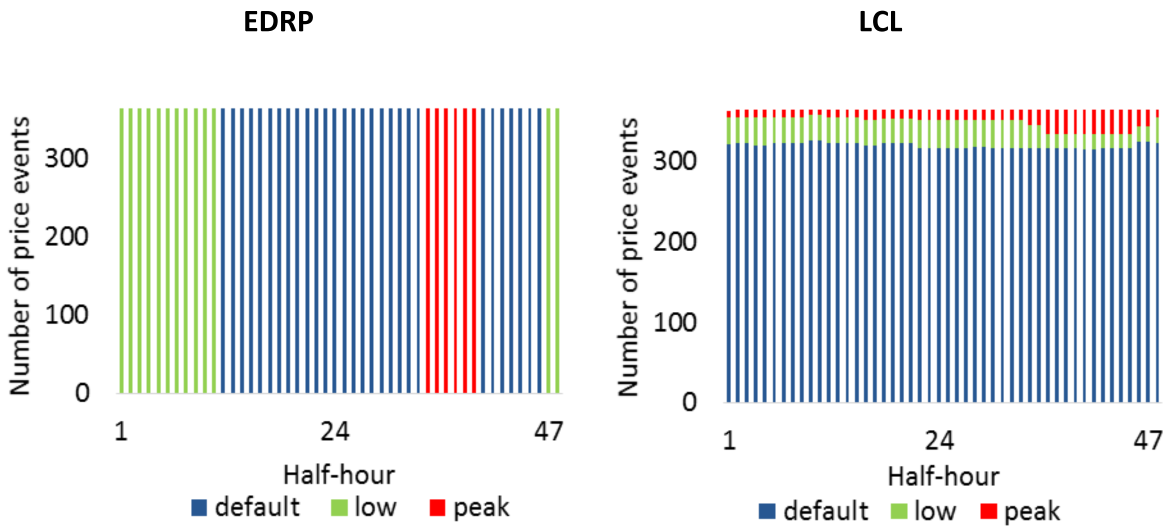
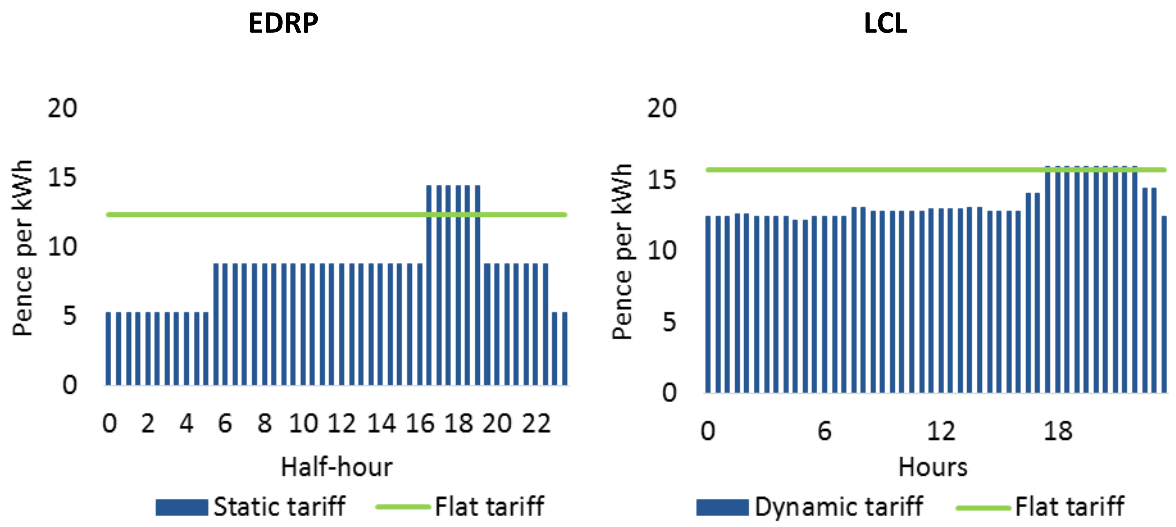


Figure A.5: Proportion of default, low, and peak price points across the trials

Tariff schedule	Default	Low	Peak
EDRP	60%	27%	13%
LCL	88%	8%	4%

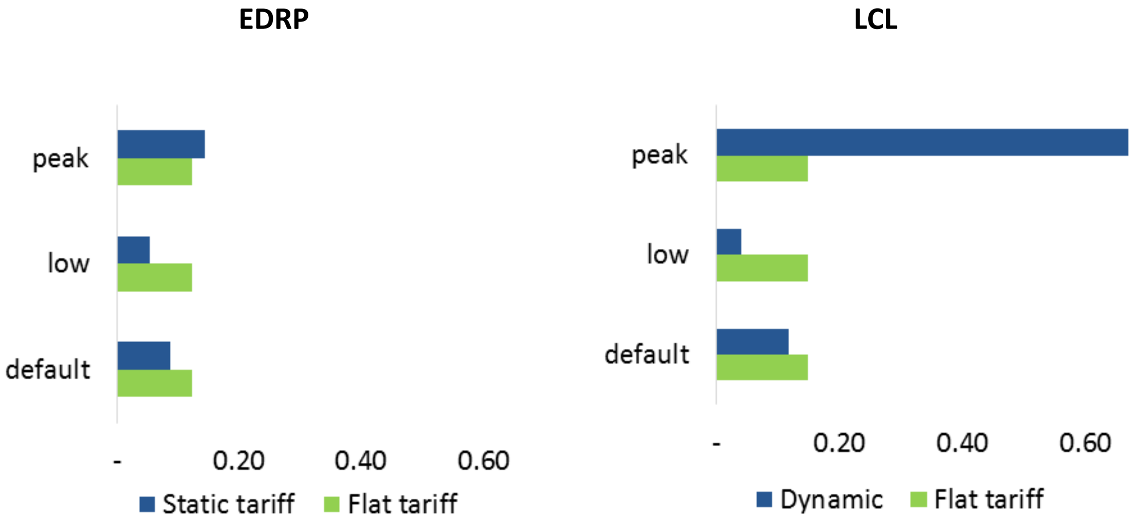
Figure A.6 shows the average tariff consumers faced across the EDRP and LCL trials on a typical day. The blue line represents the average daily price per kWh for each half-hour. The green line represents the flat tariff that was charged at the time in the UK. CEPA estimated the average flat tariff faced by customers at the time to be 12.3 pence for EDRP (average 2008-2010) and 15.7 pence for LCL (average 2013). Our methodology for estimating the flat tariff at the time is set out below.

Figure A.6: Average tariff level across trials



An examination of the price event level gives a clearer picture of the differences across tariffs, as shown in Figure A.7, the incentives placed across both tariffs is quite different. In the tariff scenarios introduced below, we present tariffs in this fashion.

Figure A.7: Sample Tariffs across price points in £/kWh



A.4. Level of the flat tariff

CEPA was unable to locate publically available historical domestic electricity prices for specific suppliers in specific locations. Instead we found historical consumer price indices and from that estimated typical historical prices. Our approach is detailed in the paragraph that follows:

- We collected data on current electricity prices: the average UK domestic electricity price (incl. taxes) for medium user customers (Table A.1).
- We used the historical electricity price index (Table A.2) to derive historical prices (Table A.3), where price(2008) = price(2015) * index(2008) / index(2015)
- We retained the deflated electricity value and took an average between 2008 and 2010. It gives us an estimate of 13.41 pence per kWh.

Table A.1: Average UK domestic electricity price (incl. taxes) for medium user customers for period Jul to Dec 2015

Time	Value
Jul - Dec 2015	0.1571

Source: Ofgem from BEIS Quarterly prices

Table A.2: Electricity prices historical index

Year	Quarter	Electricity index	Electricity index (deflated)
2008	NA - whole year value	98.08	101.11
2009	NA - whole year value	102.56	104.14
2010	NA - whole year value	100.00	100.00
2011	NA - whole year value	107.30	105.18
2012	NA - whole year value	113.32	109.40
2013	NA - whole year value	121.77	115.36
2014	NA - whole year value	128.43	119.70
2015	Q1	128.30	119.08
2015	Q2	127.91	118.28
2015	Q3	127.91	119.07
2015	Q4	127.91	119.24

Source: BEIS

Table A.3: Average UK domestic electricity historical prices

Year	Quarter	Electricity price	Electricity index (deflated)
2008	NA - whole year value	0.1205	0.1332
2009	NA - whole year value	0.1260	0.1372
2010	NA - whole year value	0.1228	0.1317
2011	NA - whole year value	0.1318	0.1386
2012	NA - whole year value	0.1392	0.1441
2013	NA - whole year value	0.1496	0.1520
2014	NA - whole year value	0.1577	0.1577
2015	Q1	0.1576	0.1569
2015	Q2	0.1571	0.1558
2015	Q3	0.1571	0.1569
2015	Q4	0.1571	0.1571

Source: CEPA

ANNEX B ACORN SEGMENTATION

B.1. Overview

ACORN is the segmentation of residential neighbourhoods in the UK. It classifies each postcode in the country into one of 6 categories, 17 groups and 62 types, and gives a detailed socio-economic profile of each area. A household level version is also available which makes that classification for each household, but the anonymised EDRP data is classified at postcode ACORN level. The smaller LCL dataset uses household ACORN, and thus provides more precise sociodemographic information. But in practice we have to use these datasets alongside each other so the relative imprecision of the EDRP sociodemographic information pervades much of what we are able to say.

The table below shows an illustrative example of the type of data provided for each ACORN segment. Each household has been assigned to an ACORN category, group and type. But it should be understood that when postcode ACORN is used, this is the ACORN of that postcode, not necessarily that household. As a result, ACORN categories at postcode level have a distribution of household characteristics.

Table B.1 Illustrative ACORN households

Household ID (illustrative)	Half-hour	Date	Consumption	ACORN category	ACORN group	ACORN Type
A	1	01/01/2010	0.5	1	A	1
B	1	01/01/2010	0.6	4	Q	46

ACORN sets out a distribution of household characteristics within each category, group and type. The category is the coarsest grouping, and the type the finest.

The following table shows how household characteristics are displayed in the ACORN database. These characteristics are represented as a percentage (or index) against the UK average for that feature. In the example below, 35% of households in the UK earn between £0 and £20,000. In comparison, only 20.3% of households in ACORN Category 1 fall within this income band. This implies that this category is under-represented in the low-income band.

Table B.2: Illustrative overview of ACORN postcode data

Household Annual Income	UK average	ACORN Category 1	ACORN Category 2	ACORN Category 3	ACORN Category 4	ACORN Category 5
£0-£20,000	35.0	20.3	18.6	31.2	47.6	51.1
£20,000-£40,000	31.1	28.0	26.7	33.6	32.7	31.7
£40,000-£60,000	17.5	21.7	22.6	19.6	13.3	11.9
£60,000-£80,000	8.2	13.0	13.9	8.8	4.2	3.5
£80,000-£100,000	4.2	8.0	8.5	3.9	1.5	1.2
£100,000+	4.0	9.2	9.6	3.0	0.7	0.5
Average Income	£36,352	£49,802	£51,256	£36,352	£26,537	£24,719

Source: ACORN

ACORN segmentation therefore allows us to understand household characteristics in a statistical sense. However, it is important to note that while we know from an ACORN classification that a household is likely to have certain characteristics, we do not know for sure the actual value of this characteristic. For example, if we examine the annual income of household A that belongs to ACORN type 1, we know that the household has a probability of having an income above £40,000 of 52%.

B.2.Other household characteristics

The EDRP data only has ACORN postcode segmentation, but for the LCL dataset we also have results from three surveys of participants:

- **Appliance survey**: Issued at the beginning of the trial to all households, this consisted of appliance ownership numbers, physical parameters of the premises (e.g. insulation, number of rooms etc.) and basic details of its occupants (e.g. number of occupants, age categories etc.). 1,870 submissions were received from the control group and 990 from the treatment group (the one that faced dynamic tariffs).
- **dToU survey**: Issued at the beginning of the trial to the treatment group of households on the dynamic tariff, it was designed to assess attitudes and behaviour change related to dynamic electricity pricing. Additional focus was given to the factors that enabled and hindered responsiveness. 714 submissions were received in total.
- **Post-Trial dToU survey**: Issued shortly after the end of the trial to the treatment group only, it aimed at assessing attitudes and behaviour change related to dynamic electricity pricing and reaction to actual savings achieved.

Results from these surveys offer additional value to balance out the limitations of the ACORN segmentation. It is possible that attitudinal characteristics such as these are more important for distributional effects than ACORN segments. However, we can only use them for the dynamic tariff analysis, as the public release of the EDRP data did not contain equivalent information.

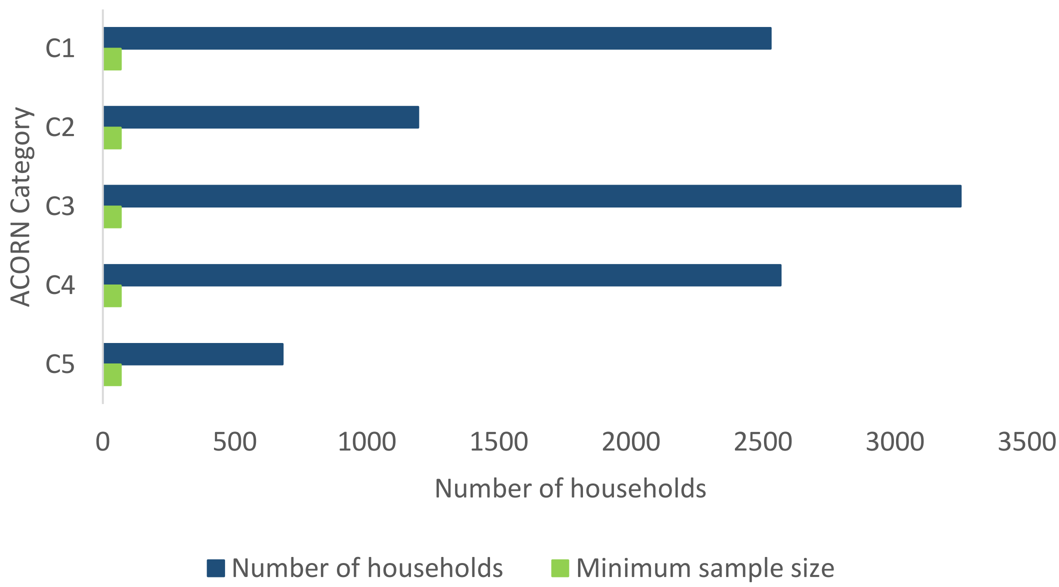
B.3. External validity of results using ACORN segments

External validity is the degree to which the results from a sample can be asserted to hold for the general population; it is typically one the most difficult validity types to achieve. This section sets out the level of aggregation across ACORN groups necessary to draw externally valid conclusions. This discussion of external validity is concerned only with whether we have a large enough sample for it to be, in principle, externally valid, if it were a representative sample. We have a separate concern that the selection methods of the trials mean that the samples may not be representative, which remains a problem however large the sample is.

To find out whether results are externally valid, we must first establish the minimum sample size that would ensure that our results can be trusted. Some statistics[51] can help us find this minimum[52] sample size requirement. We find that in order to draw externally relevant conclusions, all groups must hold at least 68 households.

Next we examine how many households there are in the EDRP and LCL datasets used in the model. As detailed in Section D.3. we use the control groups of the two datasets for baseline consumption. As shown in Figures B.1. B.2. and B.3., ACORN grouping is the lowest level of segmentation for which all groups meet the minimum size criteria. For ACORN Types, many segments are simply too small to be a representative sample of their actual population.

Figure B.1. Number of households per ACORN Category across EDRP and LCL control groups



[51] We use the following formula for the sample size n:
n = N*X / (X + N – 1),
where,
X = Zα/22 - *p*(1-p) / MOE^2,
and Zα/2 is the critical value of the Normal distribution at α/2 (e.g. for a confidence level of 95%, α is 0.05 and the critical value is 1.96), MOE is the margin of error, p is the sample proportion, and N is the population size. Note that a Finite Population Correction has been applied to the sample size formula.
[52] We use a MOE = 10% and a confidence interval = 90%. These are relatively unconservative values.

Figure B.2. Number of households per ACORN Groups across the EDRP and LCL control groups

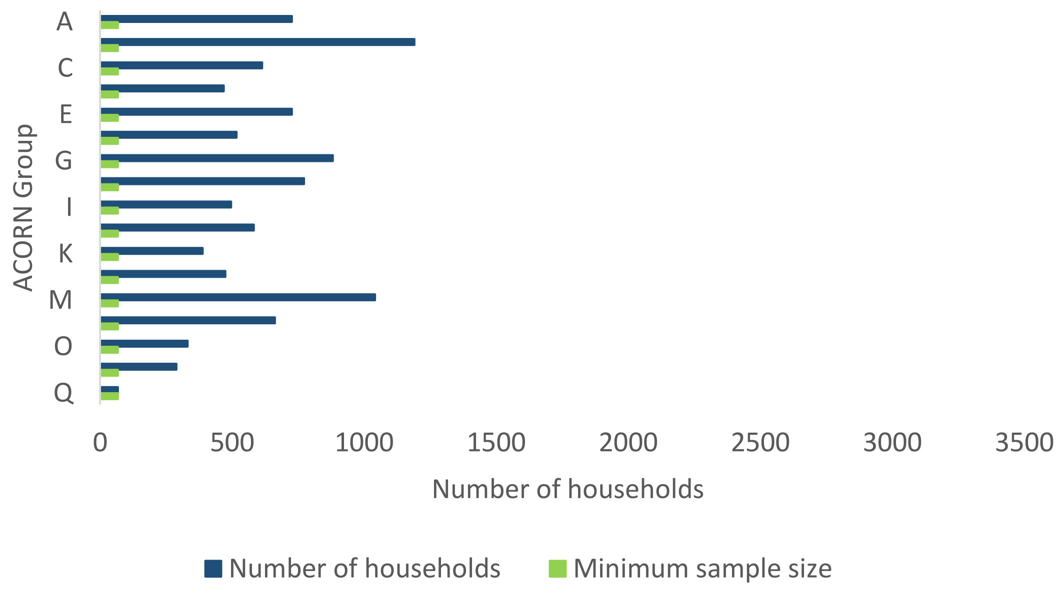
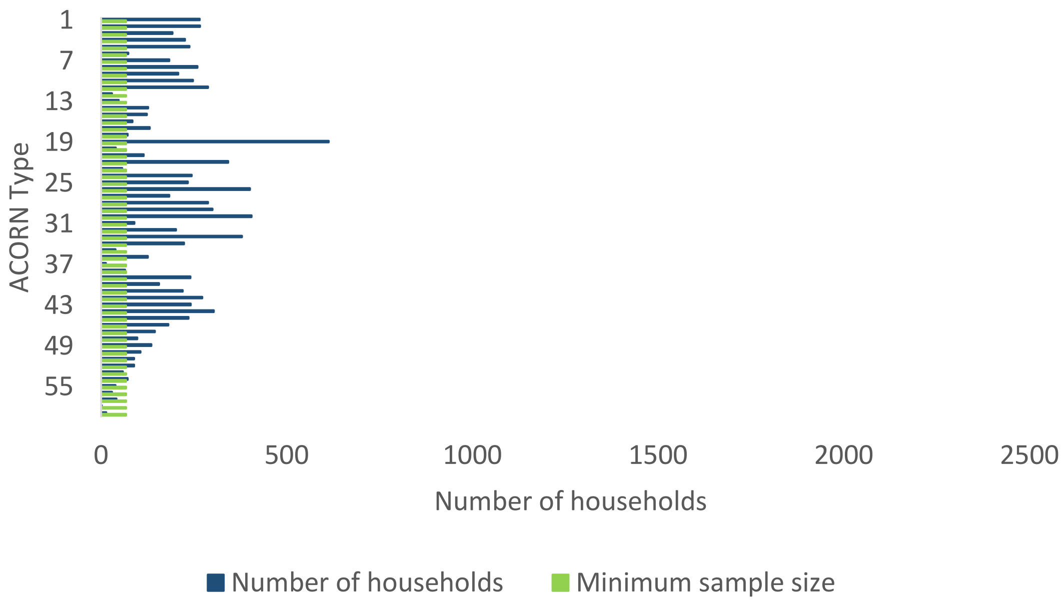


Figure B.3. Number of households per ACORN Types across the EDRP and LCL control groups



ANNEX C TECHNOLOGY ASSUMPTIONS

C.1. Peak shifting potential of smart appliances

Smart appliances can reduce and/or alter consumption in several ways. For simplicity, our modelling focusses on the peak-shifting impact of smart appliances. Table C.1 summarizes findings from the literature. We find that smart appliances can be mainly applied to wet and cold appliances. Other studies refer to peak shifting potential using water and space heaters. However, because only a small share of the population uses electricity to heat water and space, these findings are not as conclusive. The estimates of peak shifting range from 3-14.5%.

Table C.1 Literature review: Peak shifting assumptions

Study	Impact	Estimate	Drivers
Sastry et al. (2010)[53]	**Aggregate** effect of smart appliances on peak demand	3-6%	Dishwashers, cold appliances, washing appliances and tumble driers
Bilton et al. (2014)[54]	**Specific** effect of smart appliances on peak demand	10%-13%	Wet appliances
Palmer et al. (2013)[55]	**Specific** effect of smart appliances on peak demand	8%	Wet appliances
Palmer et al. (2013)[56]	**Specific** effect of smart appliances on peak demand	1.5%[57]	Cold appliances

C.2. Peak shifting potential of battery storage

Figure C.1. shows the current power and capacity of residential battery products available in the market. The median value for current commercial batteries is around 2 kW maximum power output and 5 kWh of capacity for daily cycle applications. The EDRP and LCL data shows that the typical household's power requirement at peak time is close to 0.4 kW and 0.1 kW respectively, while consumption is around 2 kWh and 0.5 kWh. Current technology is therefore already capable of shifting the entire peak consumption in most cases.[58] In our

[53] Sastry C, Pratt R, Srivastava V, Li S (2010) Use of Residential Smart Appliances for Peak-Load Shifting and Spinning Reserves. Washington: US Department of Energy/Pacific Northwest.

[54] Bilton et al. (2014)[54] have demonstrated that the potential for peak shifting using smart wet appliances, and assuming a penetration rate of 50%, is of 13% regardless of the income group. M. Bilton, M. Aunedi, M. Woolf, G.Strbac, (2014) 'Smart appliances for residential demand response', Report A10 for the 'Low Carbon London' LCNF project: Imperial College London

[55] Palmer et al. (2013) Further Analysis of the Household Electricity Survey
Early Findings: Demand side management

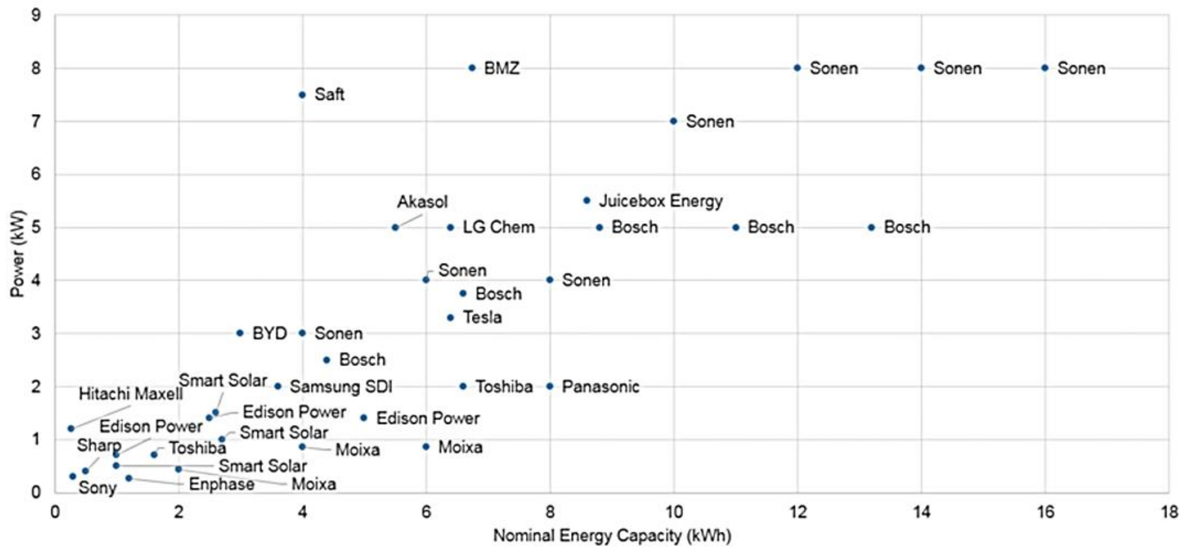
[56] Palmer et al. (2013) Further Analysis of the Household Electricity Survey
Early Findings: Demand side management

[57] Empirical evidence find 10% peak shifting for half an hour. Given that in both trials peak period last for 6 half-hours, we have divided 10% by 6 ~ 1.5%.

[58] This is actually not quite true. Domestic power demand figures such as 0.4kW are averaged over at least half an hour, disguising large fluctuations within that period. For example electric ovens, kettles and so forth have temporary demands of several kW each. In practice batteries of present technology would have to be shared or interlinked between groups of some tens of households to be able to smooth their power demand to enable the batteries reliably to cover most of it.

modelling we assume that 99% of consumption can be shifted. We choose 99% instead of 100% in order to avoid introducing errors in the calculation; e.g. #DIV/0.

Figure C.1: Residential commercial battery products in the market



Source: IDTechEx

ANNEX D ELASTICITY CALCULATIONS AND IMPACT ON BILLS

D.1. Elasticity calculation methodology

The EDRP and LCL trial datasets hold consumption data during, but not before, the trial. As a result, we cannot tell how consumption has changed due to the ToU tariff. Two methodologies were attempted to address this issue and are presented below. In practice we were compelled to follow the second approach, but we detail the first approach to record our considerations and the fact that it did not work.

- A first approach is to calculate demand price elasticity; i.e. the responsiveness of households to price movements under the EDRP and LCL trials. Given the size of these two datasets, we may tentatively generalise the results to the whole population. However, as section D.1.1. demonstrates, we found our results to be inconsistent under this approach and so do not use them.
- A second approach is to calculate the elasticity of substitution for the LCL dynamic trial; detailed in section D.1.2. This approach provides sensible results and, crucially, provides a responsiveness profile across a typical day. This finding is however based on the smallest dataset available (LDL dynamic trial), which limits the external validity of the results, which cannot systematically be generalised to the entire population.

Since the selected approach calculates an elasticity for each household and each half hour time period of the day, we can calculate averages for any sub-group of customers and any half hour (see Figure 3.2). Results for sociodemographic groups and other classes are based upon the average elasticities for the relevant class.

D.1.1. Price elasticity of demand using the control group

This method was ultimately rejected for reasons mentioned below. For both the LCL and EDRP trials attempted to use the control group to determine counterfactual consumption, as shown in the equation below. We averaged elasticities by tariff time period (e.g. default, low, and peak) as we expect the magnitude of the behavioural response to vary with the time of the day: a price increase during work hours or overnight is harder to respond to than when present at home.

$$\varepsilon_p = \frac{\frac{Q_t - Q_c}{Q_c}}{\frac{P_t - P_c}{P_c}}$$

Where

ε_p is the demand price elasticity

Q_t = average energy use per hour in the peak period of the average day for the treatment group

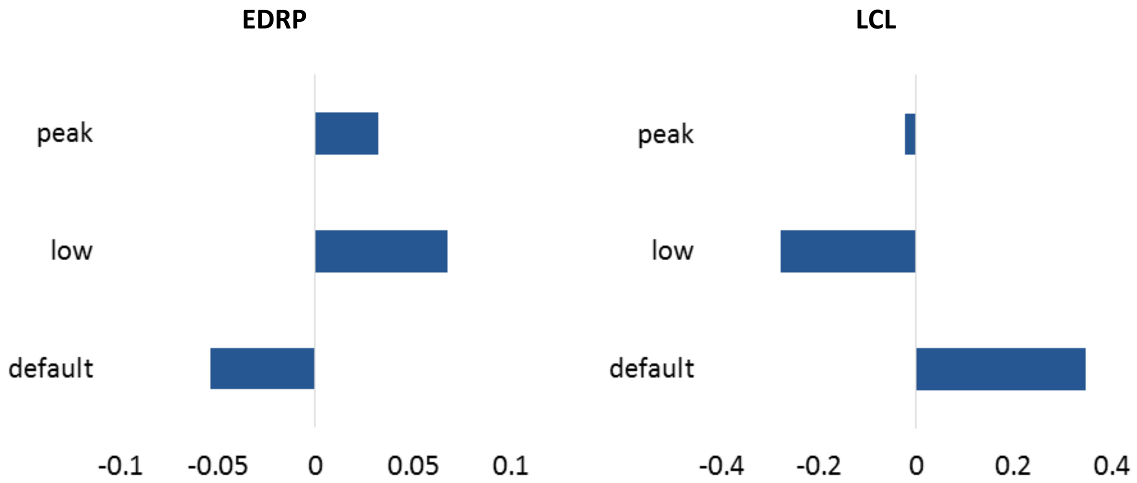
Q_c = average energy use per hour in the peak period of the average day for the control group

P_t = Per price point ToU rate

P_c = Per price point flat rate

Using this approach we find elasticities which are consistent for the LCL trial at peak and off-peak time, but inconsistent at default time. Elasticities in the EDRP trial were broadly positive and therefore not relevant, as shown in Figure D.1.

Figure D.1. Elasticity using the control group as counterfactual



D.1.2. Elasticity of substitution using the within half-hour variation in the LCL trial

Since LCL was a dynamic trial, we can extract change in demand as a result of a change in price between pairs of half-hours. For example, on day T a given half-hour may be priced at the default price point, but at day T+1 it may be priced at a peak or default price point. We can therefore examine the change in demand as a result of a change in price. This approach can only be applied to the LCL trial since the price point under the EDRP trial was the same throughout the sampling period.

This method, in effect, is to calculate the elasticity of substitution between price point ratios, as shown in the equation below.

$$\varepsilon_{p/op} = \frac{\frac{Q_p - Q_{op}}{Q_{op}}}{\frac{P_p - P_{op}}{P_{op}}}$$

Where

$\varepsilon_{p/op}$ = the elasticity of substitution between peak and off-peak energy use

Q_p = average energy use per hour in the peak period for the average day

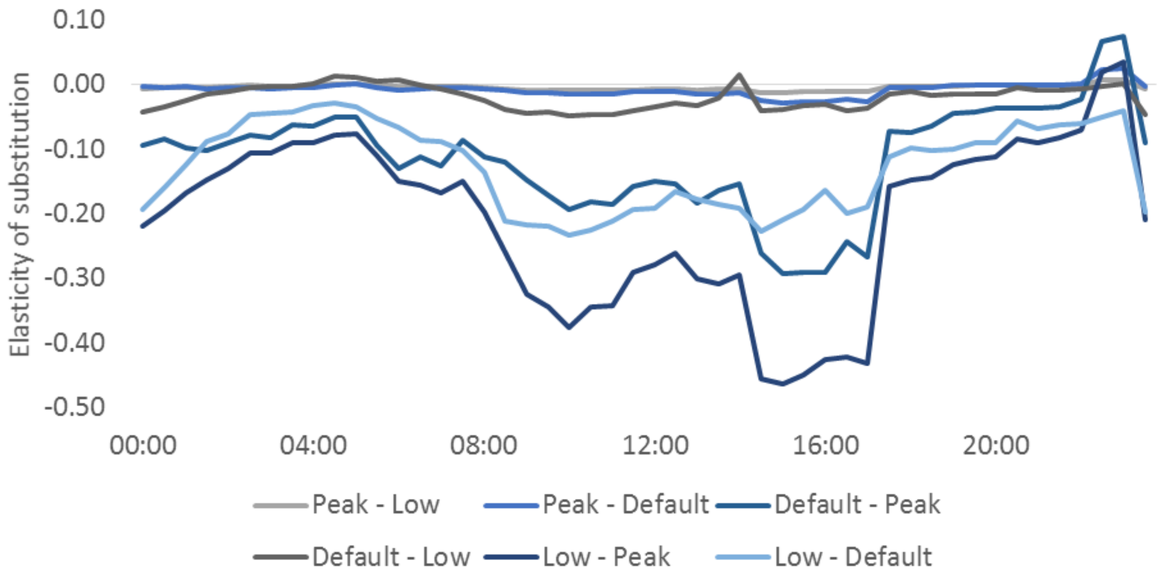
Q_{op} = average energy use per hour in the off-peak period for the average day

P_p = average price during the peak pricing period

P_{op} = average price during the off-peak pricing period

We compute six equations of this type to capture the six substitution effects taking place between default, low and peak price points. This calculation is applied for every household in the dataset and for every half-hour. The results are expressed below:

Figure D.2. Elasticities of substitution between the three price points on an average day for the average household



From that we take the median of all positive values to obtain the average elasticity profile as shown in Figure D.3. Elasticity is typically expressed as a negative value, but for presentation purpose, we ignore its sign.

Figure D.3. Median elasticity profile

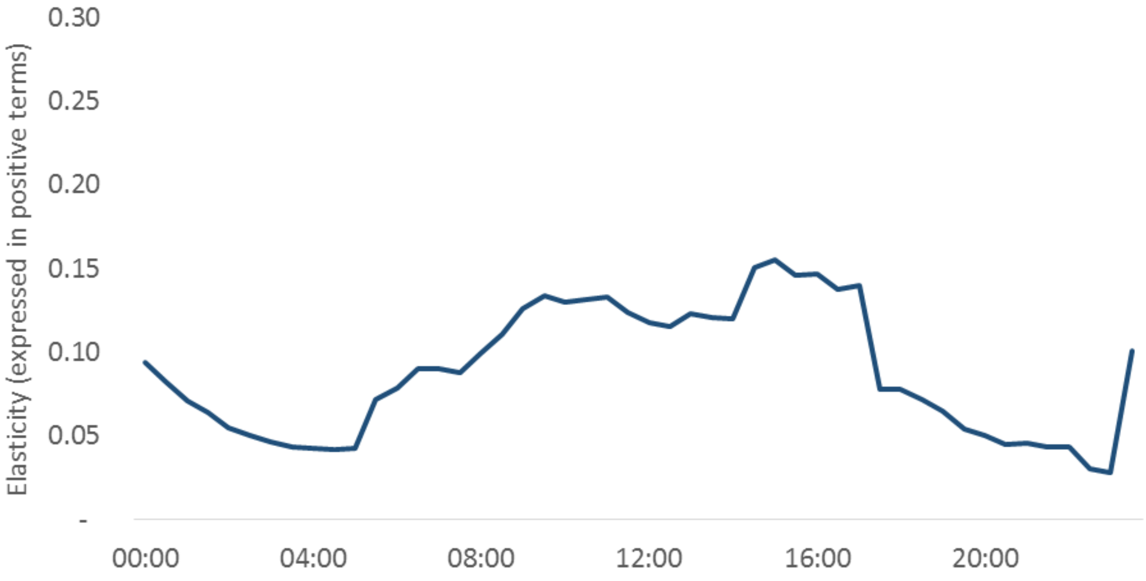


Figure D.4 represents not only the responsiveness profile of the average consumer but the behavioural profile of the whole range of consumers.

Figure D.4. Median elasticity profile including range

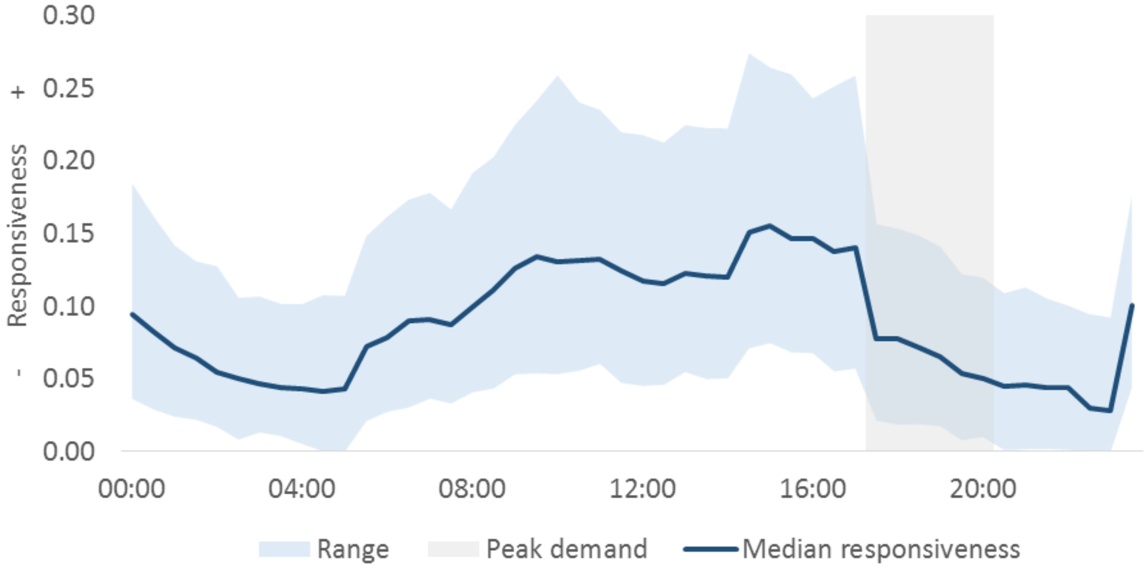


Table D.1. Elasticity values

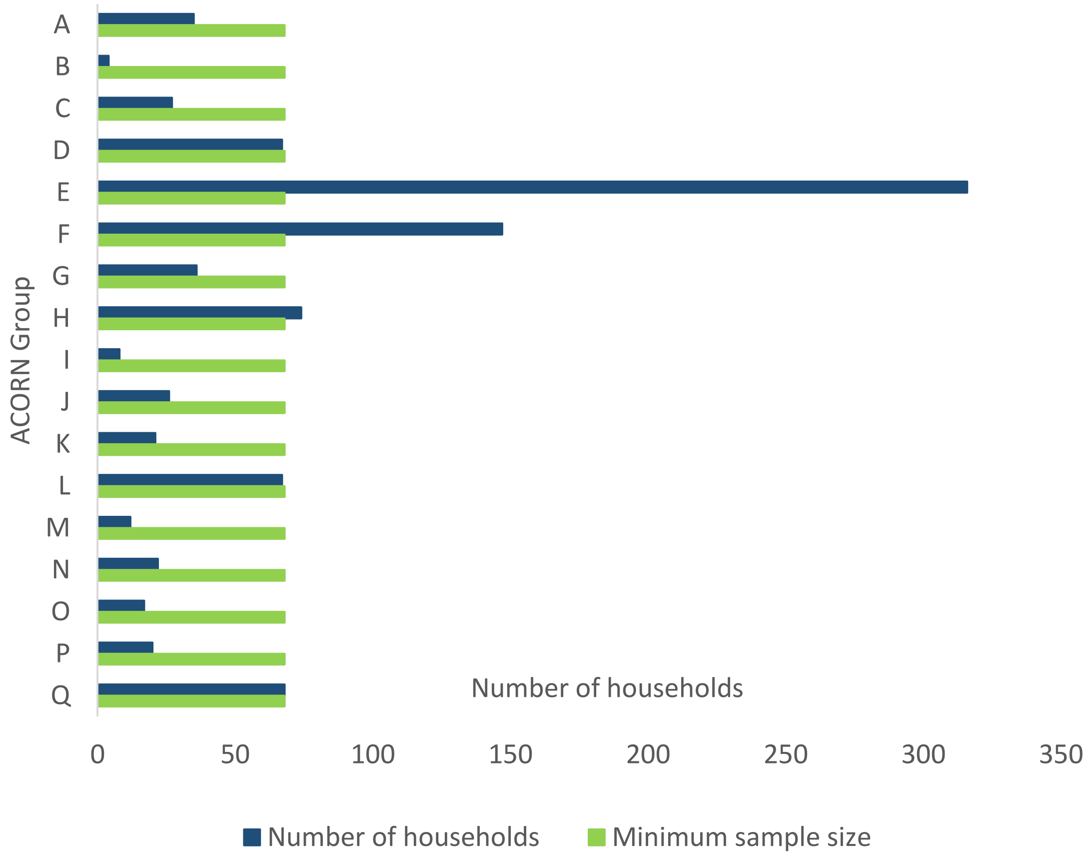
AM Half hour	AM Elasticity	PM Half hour	PM Elasticity
00:00	-0.09	12:00	-0.12
00:30	-0.08	12:30	-0.12
01:00	-0.07	13:00	-0.12
01:30	-0.06	13:30	-0.12
02:00	-0.05	14:00	-0.12
02:30	-0.05	14:30	-0.15

03:00	-0.05	15:00	-0.16
03:30	-0.04	15:30	-0.15
04:00	-0.04	16:00	-0.15
04:30	-0.04	16:30	-0.14
05:00	-0.04	17:00	-0.14
05:30	-0.07	17:30	-0.08
06:00	-0.08	18:00	-0.08
06:30	-0.09	18:30	-0.07
07:00	-0.09	19:00	-0.07
07:30	-0.09	19:30	-0.05
08:00	-0.10	20:00	-0.05
08:30	-0.11	20:30	-0.05
09:00	-0.13	21:00	-0.05
09:30	-0.13	21:30	-0.04
10:00	-0.13	22:00	-0.04
10:30	-0.13	22:30	-0.03
11:00	-0.13	23:00	-0.03
11:30	-0.12	23:30	-0.10

This approach requires us to make two assumptions, which we highlight as they significantly affect the results:

- Because we wish to make use of the static trial consumption, we also used elasticities from the LCL trial for static tariff calculations. In order to do this, we have to assume that **the values derived from the LCL trial are valid and can be applied to the general population**. This is a limitation of this work, since the LCL dynamic trial was the smallest of all samples collected (only ~1,000 households). As shown in Figure D.5, some ACORN groups did not contain a sufficient number of households to draw results that could be applied to the general population. Only groups E, F, H, L and Q meet the minimum sample size criteria set in Annex B.

Figure D.5. LCL dynamic trial - number of households per ACORN groups



- **We embedded short-term elasticities only**. In practice, responsiveness may only materialise in the long term when people uptake new appliances. The implication of this is that we can expect consumers to be more responsive over time than the elasticities would suggest. Conversely, responsiveness may weaken over time as consumers start taking their smart meter and in-home display for granted – unless consumers succeed in building strong habits.

More generally, elasticity measurement has some limitations. Our survey (using the LCL dynamic tariff) suggests that households do not attend closely to the actual price points. Rather, they focus on the savings they expect to make. Thus their attention is not only or even precisely on the peak price level, but, instead, they focus on a fairly complex but approximate combination including:

- the details of the tariff design (price points, timing and duration of price events);
- responsiveness (household characteristics, ability, willingness to shift load, reduction of overall consumption, attitudes towards the tariff such as trust in supplier's agenda, technology to support shifting/reduction); and
- feedback and information received (which informs them of their financial savings and other impacts of interest – such as helping system efficiency).

D.2. How elasticities are used to adjust consumption

With estimated elasticities, we can model a consumption profile as follows:

As the user changes the price points of the ToU tariff, the model computes the resulting percentage change in price relative to the flat tariff.

% change in price for a given tariff = (Flat tariff ÷ TOU tariff) − 1

Together with the value for elasticity, one can find the resulting percentage change in demand (or net impact of behaviour).

% change in consumption = % change in price for a tariff designed × Elasticity

Finally, we adjust the control group's consumption to estimate the what the household's consumption would have been if faced with the ToU tariff.

Consumption (TOU) = Consumption of the control group × % change in consumption

D.3. Impact on bill calculation methodology

We can now compute the ToU bill and net impact on bill. Impact on bill is simply the product of the ToU consumption previously calculated and the ToU tariff.

TOU tariff bill (with behaviour) = Consumption (TOU) × TOU tariff

To establish a net impact, we also calculate a flat tariff bill (or counterfactual bill), which is what consumers would have paid if they had remained on the flat tariff. Note that this is the same consumption profile as Consumption (ToU), but is not adjusted for elasticity. That is, it is equal to the control group's consumption.

Consumption (Flat) = Consumption of the control group

Flat tariff bill = Consumption (Flat) × Flat tariff

The difference between the two gives us the net impact of a ToU tariff.

Net impact of TOU (with behaviour) = Flat tariff bill − TOU tariff bill (with behaviour)

We were also asked to estimate the impact on bill in the event that consumers do not respond to prices.

To do so, we take the product of the ToU tariff with the flat tariff consumption (as if consumers did not react).

TOU tariff bill (assuming no behaviour) = **Consumption (Flat)** × **TOU tariff**

Similarly, we take the difference with the flat tariff bill to find the net tariff impact.

Net impact of TOU (assuming no behaviour) = **Flat tariff bill** − **TOU tariff bill (assuming no behaviour)**

ANNEX E TARIFF AND TECHNOLOGY UPTAKE: SUPPORTING EVIDENCE

E.1. Literature review

E.1.1. Static tariff uptake and annual Income

Consumers with higher incomes are more likely to switch to smart tariffs.[59] This positive correlation is supported by both the literature in Tables E.1-10, and the data in Figure E.1, below. Consumer Focus (2012) finds that ToU static tariff users are more likely to have a higher income; this theory is supported by Figure E.1 where interest in the tariff decreases with income.

Table E.1: Literature review - income and tariffs

Study	Findings	Methodology	Limitations
Bulkeley, et al., 2015.	Higher income households had a greater capacity for energy use, and more potential for energy use flexibility: benefitting more from the static tariff.	628 participants in a ToU trial, 3 band static ToU tariff. British Gas customers.	Small sample size.
Bulkeley, et al., 2014.	Higher income groups are more flexible than lower income groups with regards to reducing peak evening demand. Able to reduce peak consumption by more and therefore save more under static ToU tariff.	Participants placed under a static ToU tariff. Methods used were: Interviews (250) Online Survey (750) Consumption Data (1000)	
Consumer Focus, 2012.	ToU tariff users are more likely to have a higher household income.	Quantitative survey of 620 ToU tariff users. In-depth face-to-face interviews (15). Using a static ToU tariff.	Study did not perform any statistical significance testing so the apparent relationships may be spurious.

E.1.2. Static tariff uptake and age

Table E.2: Literature Review – Age and Static Tariff

Study	Findings	Methodology	Limitations
Fell, 2016.	Significant associations between age and acceptance for the static and dynamic ToU. The tariffs are both less popular with people aged 65-74. Static ToU is more popular amongst people U45.	Mixed methods strategy: Focus Groups Survey Interviews	Sample size.

[59] Source: BEIS Consumer panel (2016)

		Sample of 2002 GB bill-payers.	
IPA, 2016.	As age increases, the benefit of static ToU tariffs increase, with 19-34 being worse off, and 65-74 experiencing the most benefits.	Static ToU tariff introduced to 251 households, all part of the Household Electricity Survey. Households were analysed by observed electricity consumption.	
BEIS Consumer Panel, 2016.	18-34 year olds among 4 groups most likely to switch to a smart tariff for savings up to £200, whilst people aged 55+ are amongst the least likely groups.	Nationally representative survey of 1000 respondents.	
Bulkeley, et al., 2015.	Households with U5s and 65+ are less flexible with their electricity use. Therefore unable to engage with the tariff.	628 participants in a ToU trial, 3 band static ToU tariff. British Gas customers.	
CER, 2011.	Presence of children U15 years results in a greater reduction in peak and overall usage. Research suggests this is strongly driven by school-based initiatives.	Static ToU tariff. Residential customer behaviour trial, 5028 participants. Test and control group.	
IPA, 2016.	Households with children are worse off than those without children, as more of their consumption occurs during peak periods.	Static ToU tariff introduced to 251 households, all part of the Household Electricity Survey. Households were analysed by their observed electricity consumption.	
BEIS Consumer Panel, 2016.	Negative correlation between household age and intention to uptake the static ToU tariff.	Nationally representative survey of 1000 respondents.	

E.1.3. Static tariff uptake and household Size

Table E.3: Literature Review – Household Size and Static Tariff

Study	Findings	Methodology	Limitations
CER, 2011.	Homes with more than 6 persons saved on average £19.14 more than homes with a single resident. Savings rose with size of household.	Static ToU tariff. Residential customer behaviour trial, 5028 participants. Test and control group.	
Fell, 2016.	Living alone is positively associated with uptake of Static ToU.	Mixed methods strategy: Focus Groups	

		Survey Interviews Sample of 2002 GB bill-payers.
BEIS Consumer Panel, 2016.	Households with 4+ people are among the 4 groups most likely to switch for a saving of up to £200.	Nationally representative survey of 1000 respondents.
Spence et al. 2015.	1 person households are amongst the 4 most likely to switch to a smart tariff for savings up to £200.	

E.1.4. Static tariff uptake and other characteristics

Table E.4: Literature Review – Other factors and Static Tariff

Study	Characteristic	Findings	Methodology	Limitations
CER, 2011.	Education level	Those who have spent more time in formal education exhibit more success in terms of achieving a reduction in energy usage under a static ToU tariff.	Static ToU tariff. Residential customer behaviour trial, 5028 participants. Test and control group.	
Fell, 2015.	Existing ToU Customers	Existing ToU tariff customers are more likely to report being interested in signing up to a static ToU tariff than the general population.	Two separate online surveys: The Design Study (n = 2002) The Framing Study (n = 2020)	Based on self-reported interest in tariffs rather than actual take-up. Participants had no experience of or exposure to smart ToU tariffs.
Fell, 2015.	Vehicle type	Electric or hybrid vehicle owners were more likely to report being interested in signing up to a static ToU tariff.	Two separate online surveys: The Design Study (n = 2002) The Framing Study (n = 2020)	
Fell, 2015.	Wet Goods w/timers	People with wet goods with times (e.g. Dishwasher) were more likely to report being interested in signing up to a static ToU tariff.	Two separate online surveys: The Design Study (n = 2002) The Framing Study (n = 2020)	
Fell et al. 2015.	Privacy	People who were more concerned about their privacy were less likely to report being	Two separate online surveys: The Design Study (n = 2002)	

	interested in signing up to the tariffs, both static and dynamic.	The Framing Study (n = 2020)	

E.1.5. Dynamic tariff uptake and household Size

Table E.5: Literature Review – Household Size and Dynamic Tariff

Study	Findings	Methodology	Limitations
BEIS Consumer Panel, 2016.	Households with 4+ people are among the 4 groups most likely to switch for a saving of up to £200.	Nationally representative survey of 1000 respondents.	
Spence et al. 2015.	1-person households are amongst the 4 most likely to switch to a smart tariff for savings up to £200.		

E.1.6. Dynamic tariff uptake and age

Table E.6: Literature Review – Consumer Age and Dynamic Tariff

Study	Findings	Methodology	Limitations
Fell, 2016.	Significant associations between age and acceptance for the static and dynamic ToU. The tariffs are both less popular with people aged 65-74.	Mixed methods strategy: Focus Groups Survey Interviews Sample of 2002 GB bill-payers.	Sample size.
BEIS Consumer Panel, 2016.	18-34 year olds among 4 groups most likely to switch to a smart tariff for savings up to £200, whilst people aged 55+ are amongst the least likely.	Nationally representative survey of 1000 respondents.	

E.1.7. Dynamic tariff uptake and other characteristics

Table E.7: Literature Review – Other factors and Dynamic Tariff

Study	Characteristic	Findings	Methodology	Limitations
Carmichael, et al., 2014.	Exposure	77% of trialists who responded indicated they would want to stay on the dynamic ToU tariff.	Dynamic ToU Tariff taken up by customers in the London Power Networks area (1119 participants).	All trials were designed to be revenue neutral if the average customer did not change their profile. Tariff design was not informed by factors affecting cost-reflectivity (e.g., likely wind generation patterns). The trial was attempting to investigate

				flexibility in all time periods rather than estimate impacts on bills.
Fell, 2016.	Environmental Awareness	Concern about future climate change was positively associated with the uptake of the dynamic ToU tariff.	Mixed methods strategy: Focus Groups Survey Interviews Sample of 2002 GB bill-payers.	
Fell et al. 2015.	Privacy	People who were more concerned about their privacy were less likely to report being interested in signing up to the tariffs, both static and dynamic. The effect was largest for dynamic.	Two separate online surveys: The Design Study (n = 2002) The Framing Study (n = 2020)	Based on self-reported interest in tariffs rather than actual take-up. Participants had no experience of or exposure to smart ToU tariffs (some Economy 7 households). Respondents were asked to imagine having electric heating and factor in this consideration.

E.1.8. Automation uptake and information

Consumers provided with little information surrounding automation are less likely to take up the technology.

Table E.8: Literature review – Automation Uptake and Information

Study	Characteristic	Findings	Methodology	Limitations
Buchanan, et al., 2016.	Available Information	76% of British consumers know little or nothing about smart meters, resulting in them being less likely to adopt.	Literature Review	No actual primary data used.

E.1.9. Distributed Energy

When renewable energy technology is linked to the ToU tariff, consumers are more likely to take up the tariff.

Table E.9: Literature review – Renewable Energy and ToU Tariffs

Study	Findings	Methodology	Limitations
Carmichael, et al., 2014.	60% of trialists who responded (708) were more likely to sign up to a dynamic ToU if price changes were	Dynamic ToU Tariff taken up by customers in the London Power	All trials were designed to be revenue neutral if the average customer did not change their profile. Tariff design not informed by factors affecting cost-reflectivity

	linked to renewable energy generation, in order to support more renewable power.	Networks area (1119 participants).	(e.g. wind generation patterns). The trial was attempting to investigate flexibility in all time periods rather than estimate impacts on bills.

E.1.10. Automation Availability

Dynamic ToU tariffs that come with automation are more likely to be taken up.

Table E.10: Literature review – Automation Availability and ToU Tariffs

Study	Findings	Methodology	Limitations
Fell et al. 2015	Consumers who are given the option of automation are more likely to switch to the dynamic ToU tariff.	An online survey of a representative sample of GB bill-payers (n = 2002).	

E.2. Consumer panel research

Data collected by BEIS Consumer Panel (2016) shows that:

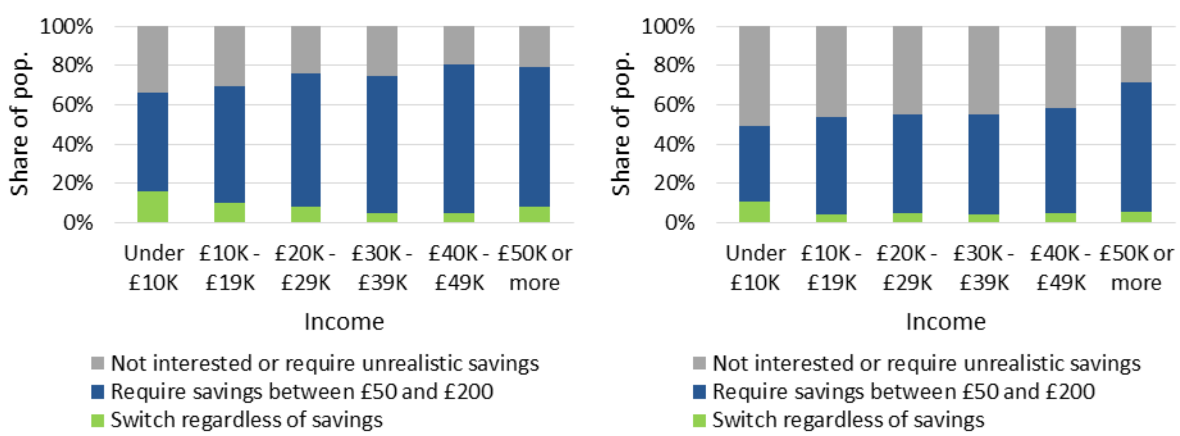
- Static tariffs are preferred over dynamic tariffs.
- Income and household size are positively associated with likelihood of uptake across both tariffs. Age is mildly negatively correlated with likelihood of uptake across both tariffs.
- Storage is preferred over smart appliances.
- Income is positively correlated with technology uptake. As for age and household size, the correlation with technology is not so clear.

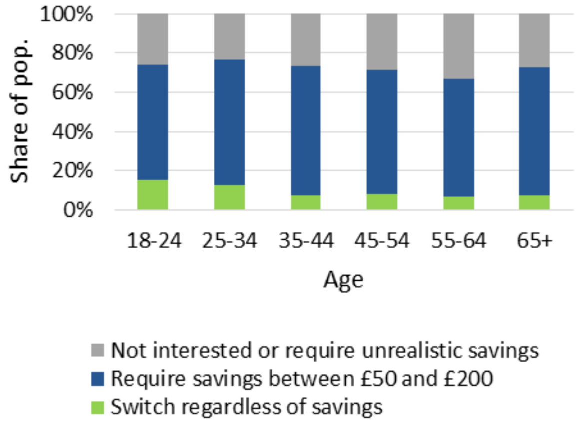
The data associated with the graph below is used in the model to calculate the likelihood of switching to a given tariff and technology.

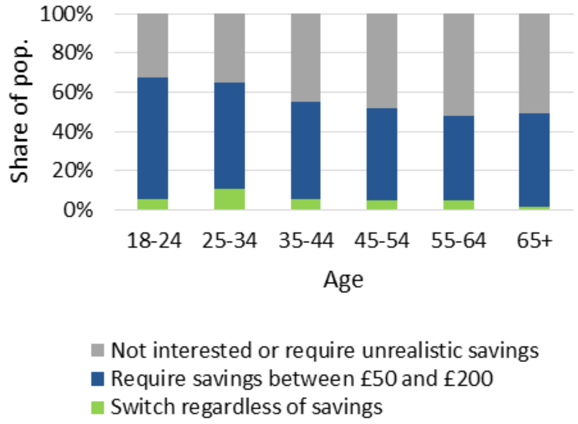
Figure E.1. Findings from the Household Electricity Survey

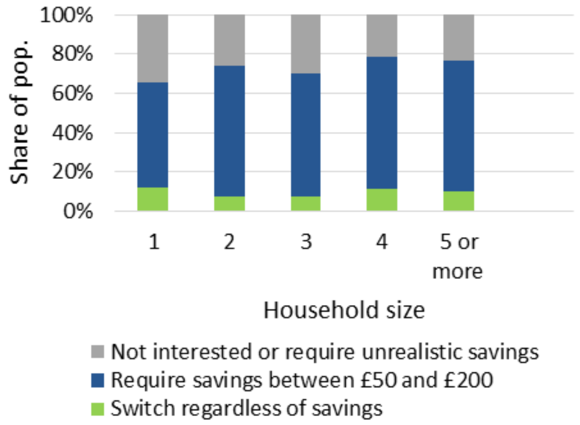
Static **Dynamic**

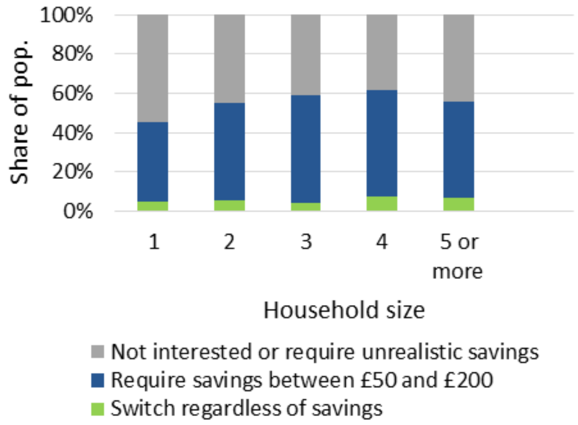
What level of annual savings would be enough to persuade you to switch to this tariff?




100%
80%
60%
40%
20%
0%
Share of pop.
18-24
25-34
35-44
45-54
55-64
65+
Age
Not interested or require unrealistic savings
Require savings between £50 and £200
Switch regardless of savings

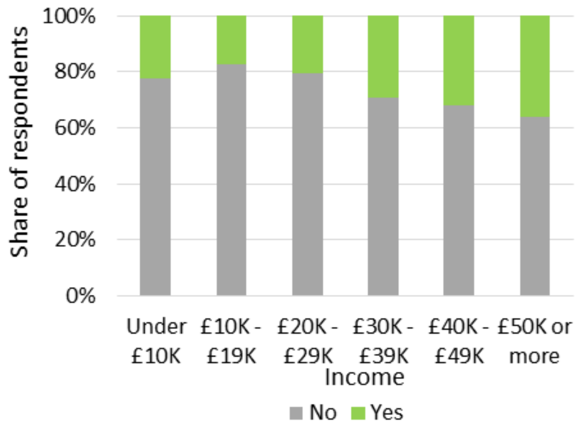

100%
80%
60%
40%
20%
0%
Share of pop.
18-24
25-34
35-44
45-54
55-64
65+
Age
Not interested or require unrealistic savings
Require savings between £50 and £200
Switch regardless of savings

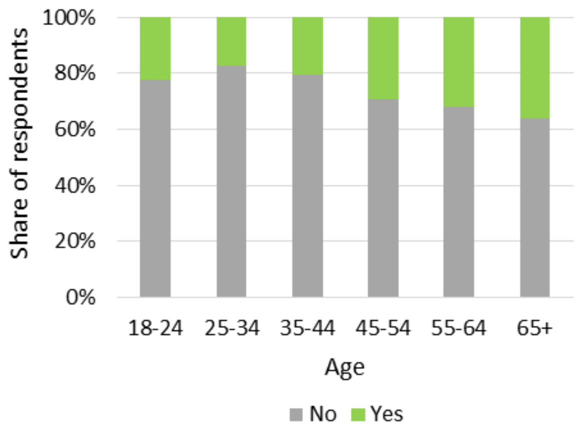

100%
80%
60%
40%
20%
0%
Share of pop.
1
2
3
4
5 or more
Household size
Not interested or require unrealistic savings
Require savings between £50 and £200
Switch regardless of savings

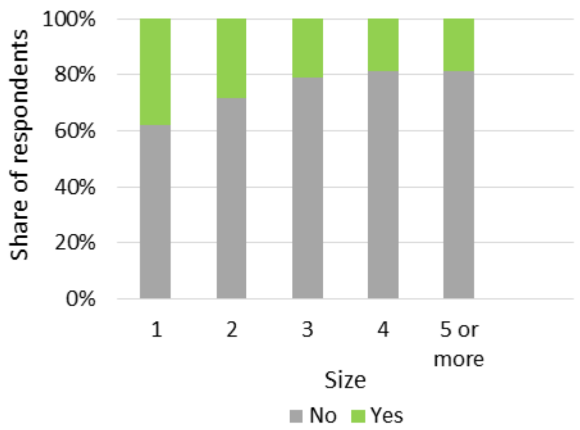

100%
80%
60%
40%
20%
0%
Share of pop.
1
2
3
4
5 or more
Household size
Not interested or require unrealistic savings
Require savings between £50 and £200
Switch regardless of savings

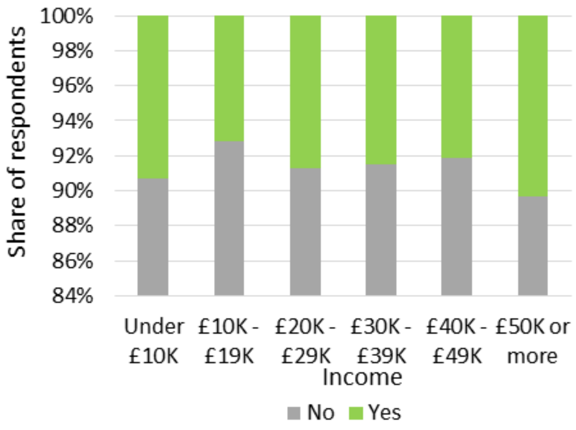
Smart appliances **Storage**

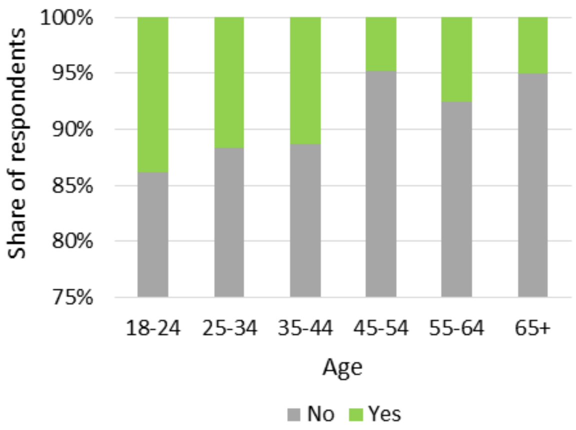
Would you be interested in buying any smart appliances or a battery?[60]

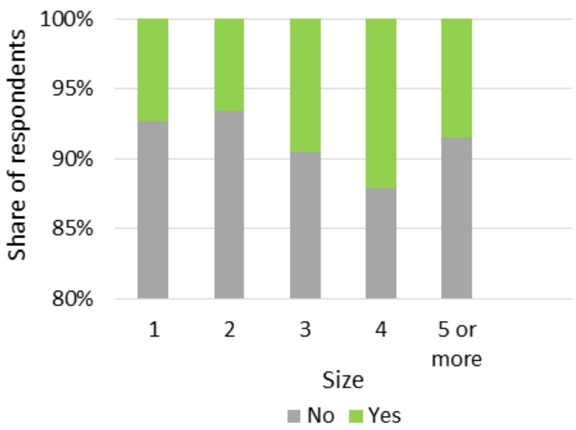












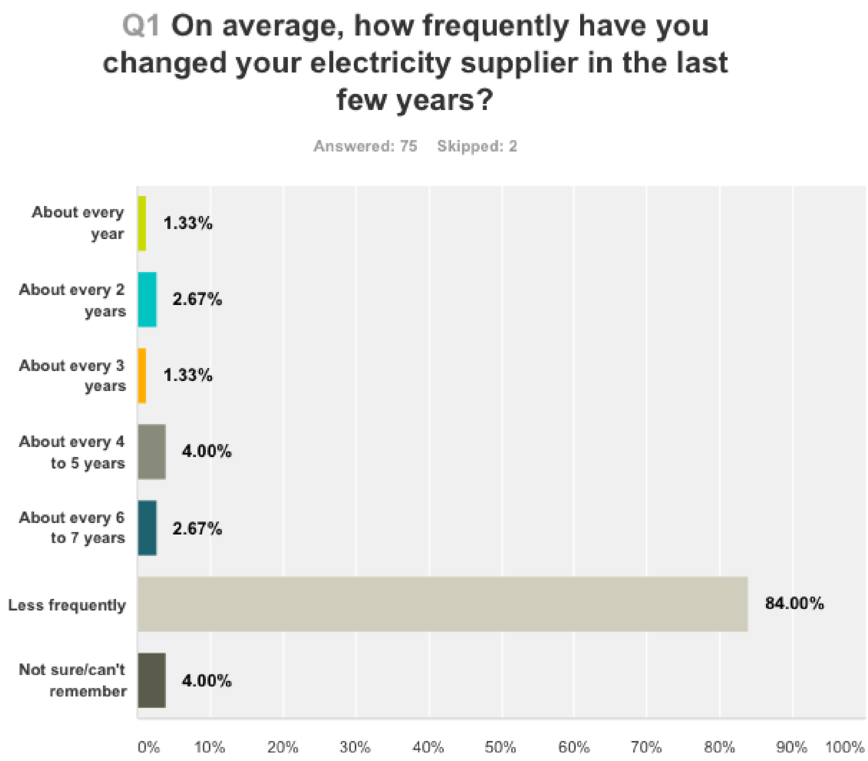
[60] Note that this question was asked without presenting customers with a representative price of the cost of technology.

ANNEX F SURVEY RESULTS

F.1. Recruitment and respondents

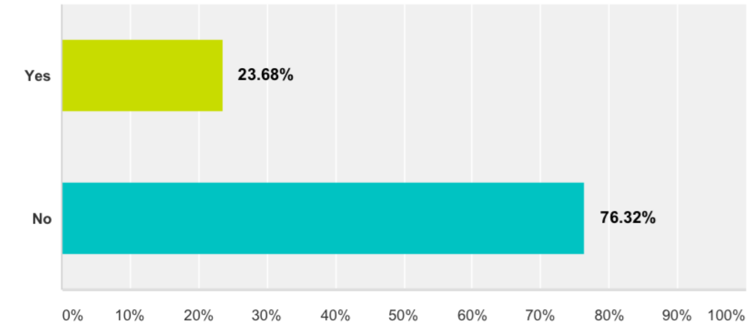
A subset of participants from the Low Carbon London dynamic time-of-use trial had given permission to be contacted for future research on smart meters enabling dynamic pricing research. These participants were contacted by email and invited to complete a survey on attitudes to smart ToU tariffs for the research in this report. The number of respondents was 77. After accounting for out-of-date email addresses, this is a response rate of about 55%. Although this is a small sample, the value of the data is increased by the fact that these households have had first-hand experience of a dynamic ToU tariff for twelve months during 2013. These respondents' attitudes towards smart ToU tariffs are therefore better informed than those of consumers with no exposure to smart ToU tariffs (Faruqui and Palmer 2011; Faruqui 2011). Their responses also give a better indication of customer satisfaction after signing up to a smart ToU tariff. The vast majority of these survey respondents were "sticky" or loyal customers who had not used a switching website (e.g., uSwitch) – see below. This is broadly consistent with OFGEM figures that 60% of consumers (and 75% of renters) have never switched energy supplier and 75% are still on their supplier's default tariff.

F.2. Results



Q2 Have you used a comparison website such as uSwitch or CompareTheMarket.com to switch energy suppliers?

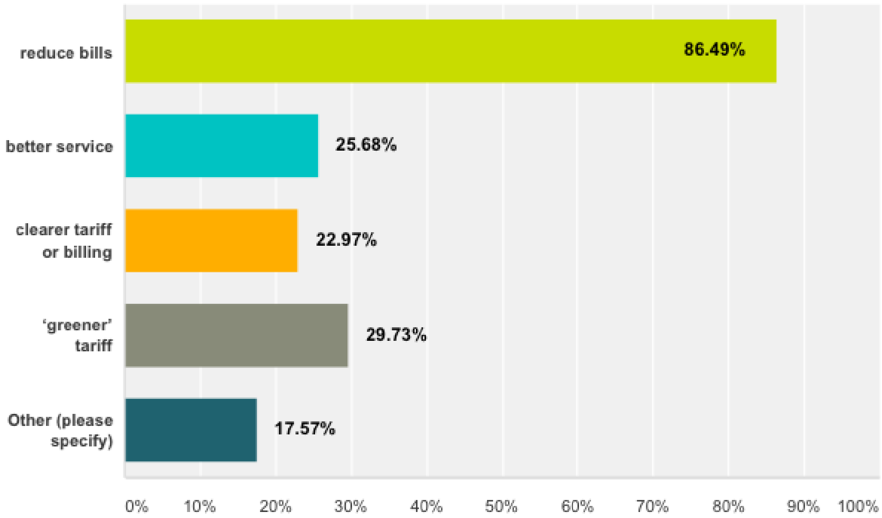
Answered: 76 Skipped: 1

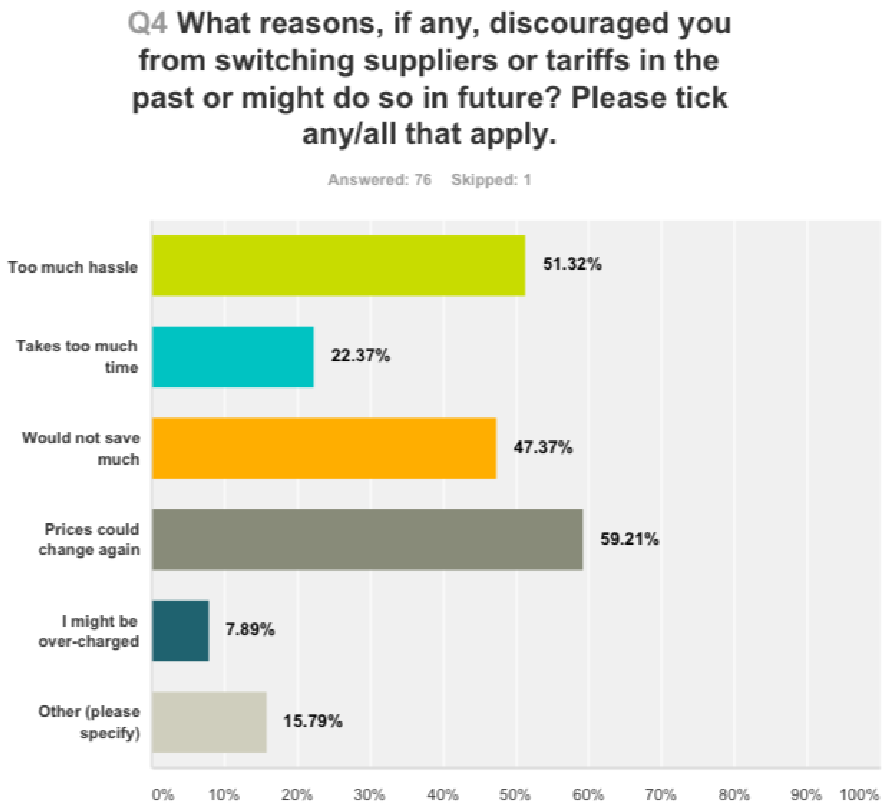


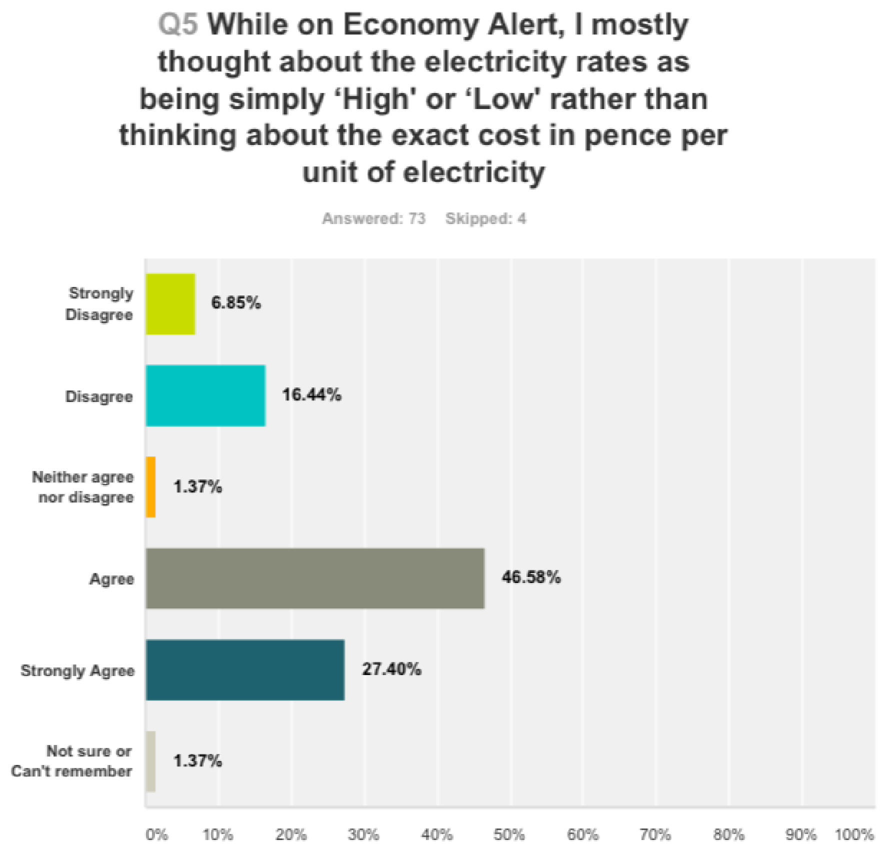
.

Q3 What reasons, if any, prompted you to switch or might make you consider switching suppliers/tariffs in the future? Please tick any/all that apply.

Answered: 74 Skipped: 3

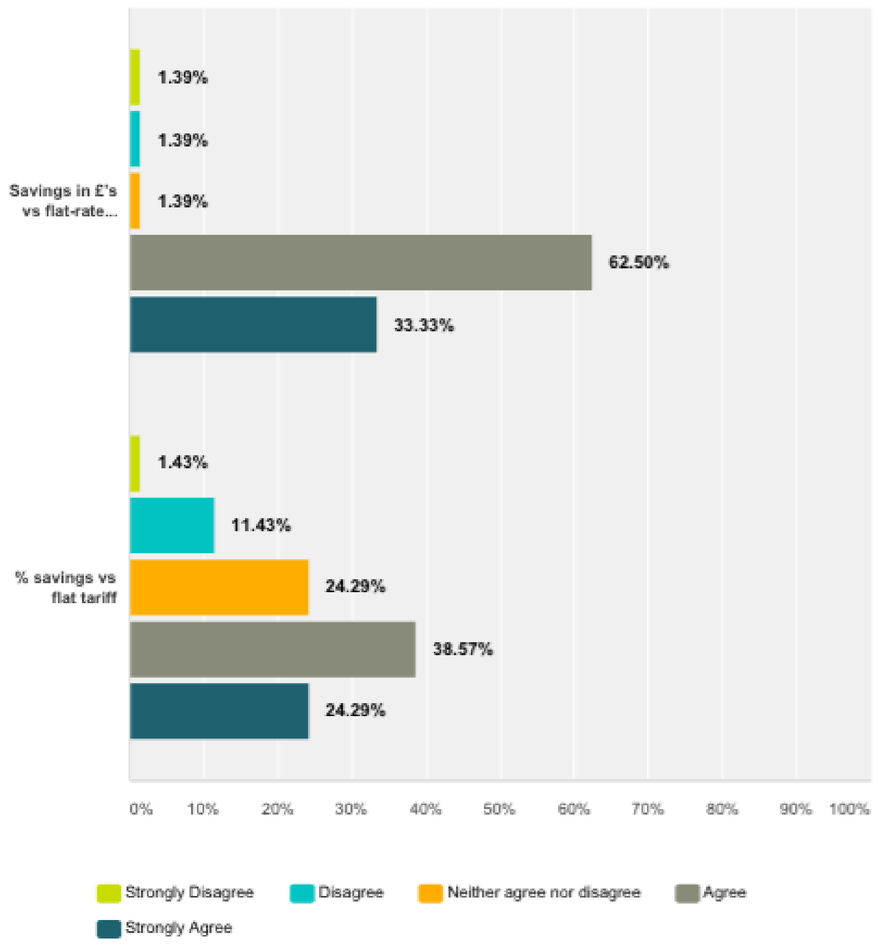



Q4 What reasons, if any, discouraged you from switching suppliers or tariffs in the past or might do so in future? Please tick any/all that apply.
Answered: 76 Skipped: 1
Too much hassle
51.32%
Takes too much time
22.37%
Would not save much
47.37%
Prices could change again
59.21%
I might be over-charged
7.89%
Other (please specify)
15.79%
0%
10%
20%
30%
40%
50%
60%
70%
80%
90%
100%


Q5 While on Economy Alert, I mostly thought about the electricity rates as being simply 'High' or 'Low' rather than thinking about the exact cost in pence per unit of electricity
Answered: 73 Skipped: 4
Strongly Disagree
6.85%
Disagree
16.44%
Neither agree nor disagree
1.37%
Agree
46.58%
Strongly Agree
27.40%
Not sure or Can't remember
1.37%
0%
10%
20%
30%
40%
50%
60%
70%
80%
90%
100%

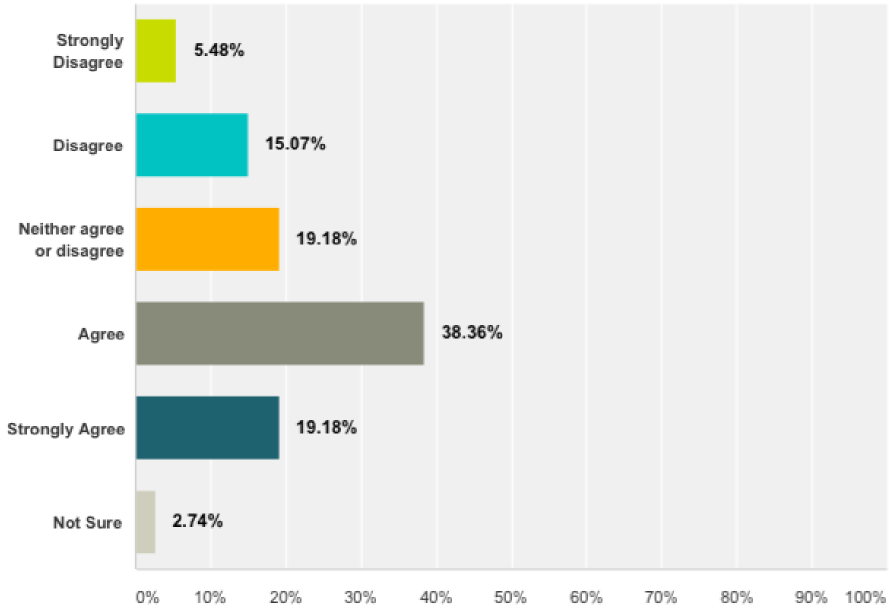
Q6 On the Economy Alert trial you received a letter each month with graphs showing you how much electricity you used at the Low, Normal and High rates but this letter did not include information about how much money you were saving compared to your previous flat rate tariff. If you were on a similar TOU tariff what information would you like to receive?

Answered: 73 Skipped: 4



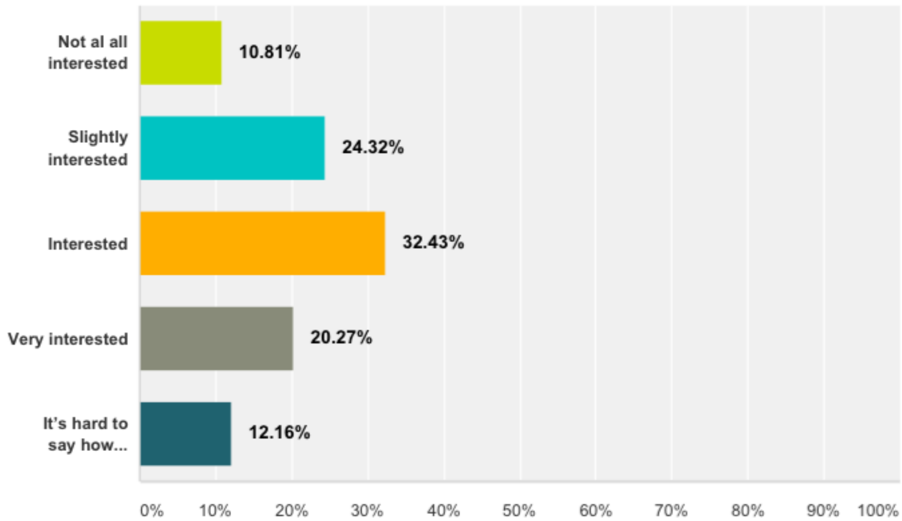
Q7 If Economy Alert had continued on a long-term basis (rather than just one year) I would probably have invested in some more energy efficient appliances, especially those I tend to use in peak/High rate periods (e.g., lightbulbs, cooker)

Answered: 73 Skipped: 4



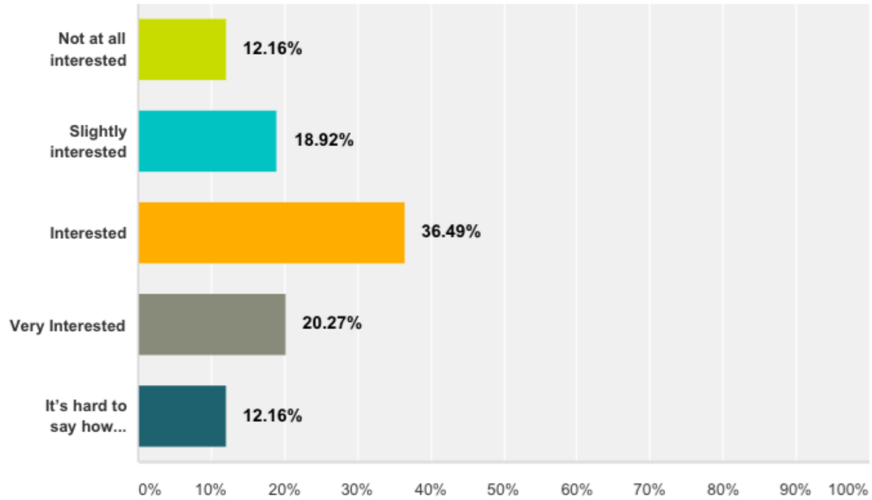
Q9 Dynamic TOU – The times of price changes varies from day to day with notifications being sent to you the day before. Economy Alert was closest to this type.

Answered: 74 Skipped: 3



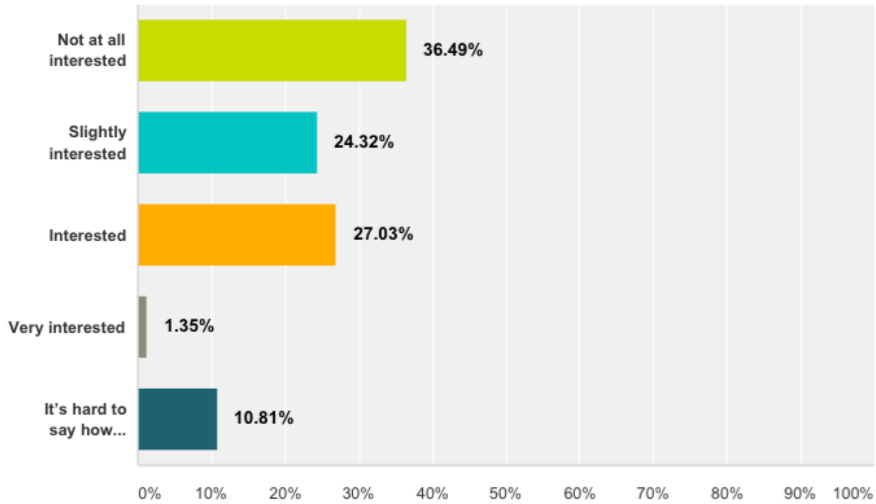
Q10 Fixed TOU – Higher prices every weekday at the same time during morning and early evening, and lower prices overnight and on weekends.

Answered: 74 Skipped: 3



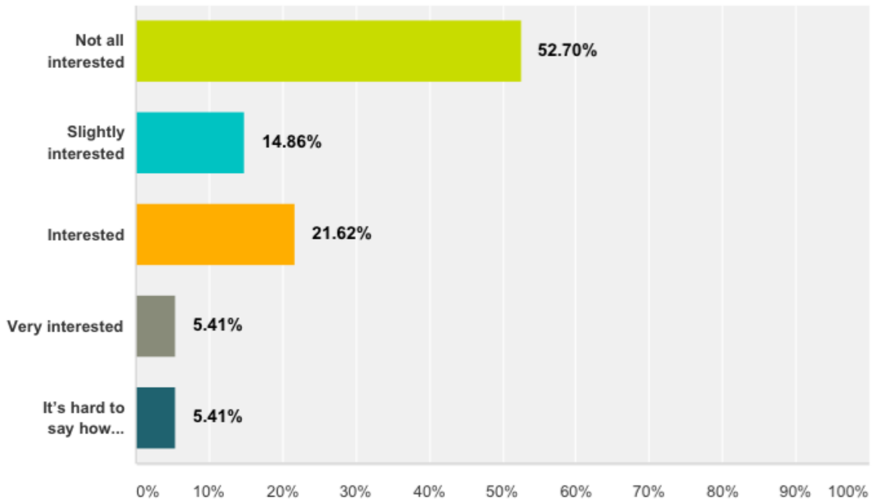
Q11 Critical Peak Pricing – This gives you a slightly cheaper electricity price but charges a much higher price during the peak period on a very limited number of days (about 15) per year

Answered: 74 Skipped: 3



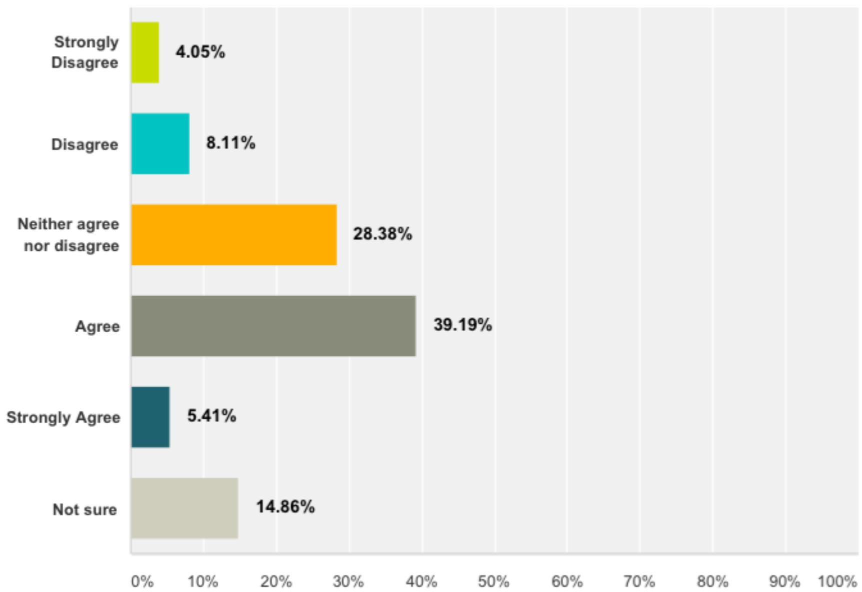
Q12 Direct Load Control – This gives you a lower flat rate in exchange for your supplier being able to sometimes reduce the consumption of certain appliances in your home during periods of very high demand (e.g., they might turn the freezer off for very short periods but not long enough to affect the performance).

Answered: 74 Skipped: 3



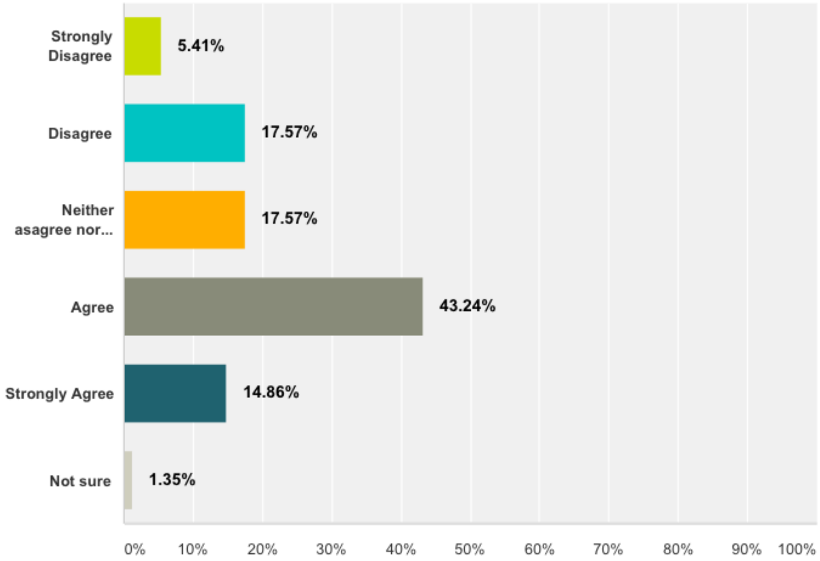
Q14 If a range of time-of-use tariffs (such as those mentioned on the previous page) became available I would be more likely to consider switching tariffs or suppliers than I have in the past.

Answered: 74 Skipped: 3



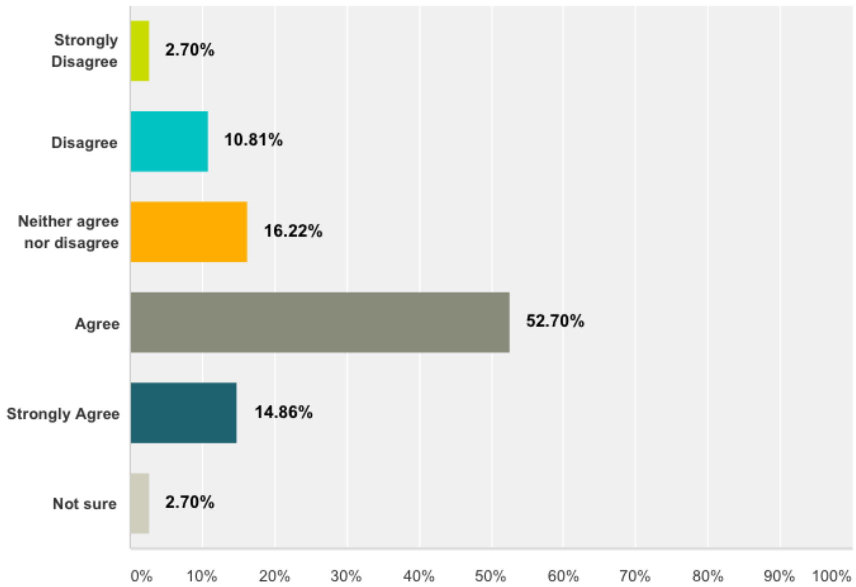
Q17 I would be willing to share information about my household (e.g., which appliances I use, number of occupants..) with third parties of my choosing to get tailored advice on tariffs.

Answered: 74 Skipped: 3



Q18 I would be willing to share my smart meter data (showing how much electricity you consume and at what times) with third parties of my choosing to get tailored advice on tariffs (data shared would be for your past, say, 6 months consumption and would not give them access to ongoing or future consumption).

Answered: 74 Skipped: 3



Q20–Q29: "Which of the following might make you more inclined to take up some kind of smart time-of-use (ToU) tariff in the future? Please indicate your views for each of the nine options below."

Responses indicate that the characteristic of a ToU offer that would have greatest appeal for consumers is **"If you were able to try a new smart ToU tariff but could instantly and easily switch back to your old tariff if you were not happy with it"** for which 87% of respondents indicated that this would make taking up a smart ToU tariff either Slightly More Attractive, More Attractive or Much More Attractive.

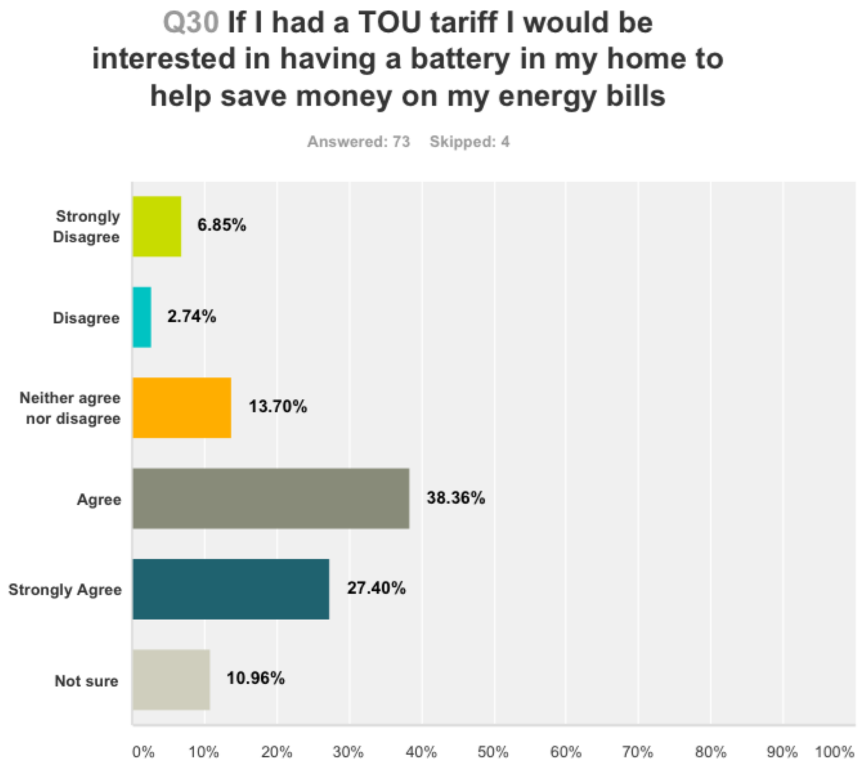
"If you had a clear explanation to show the reasons why the price changes occur when they do": 85% of respondents indicated that this would make taking up a smart ToU tariff either Slightly More Attractive, More Attractive or Much More Attractive.

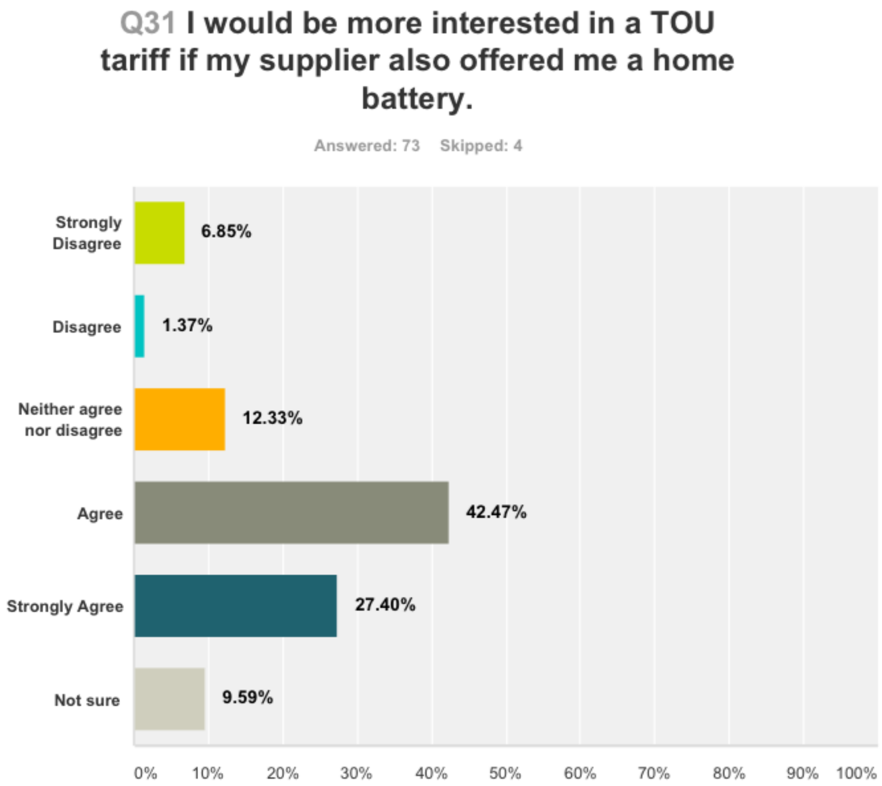
"If you had clear information to show how well your consumption was helping to maximise use of renewable energy generated in the UK": 78% of respondents indicated that this would make taking up a smart ToU tariff either Slightly More Attractive, More Attractive or Much More Attractive.

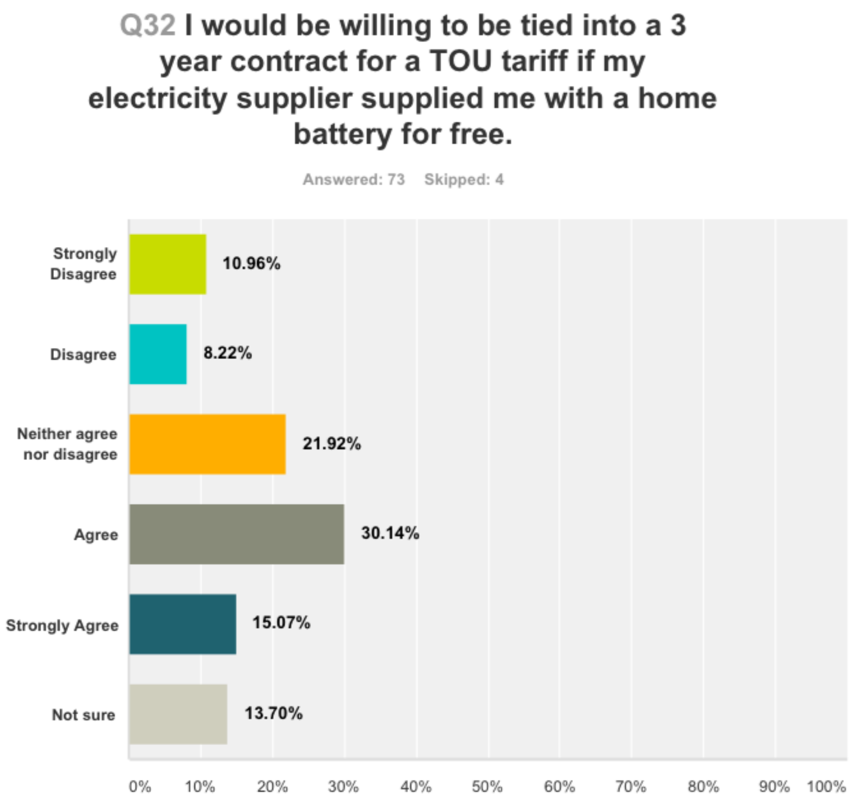
"If you had clear information to show how much your consumption is helping the UK energy system to be more efficient": 85% of respondents indicated that this would make taking up a smart ToU tariff either Slightly More Attractive, More Attractive or Much More Attractive.

"If smart ToU tariffs became very common and most people were doing their bit to be somewhat flexible in their electricity consumption": 73% of respondents indicated that this would make taking up a smart ToU tariff either Slightly More Attractive, More Attractive or Much More Attractive.

Telephone helpline and capping High rate units to manage risk were not attractive but having automated appliances would make smart ToU either Slightly More Attractive, More Attractive or Much More Attractive for the majority respondents (70%).


Q30 If I had a TOU tariff I would be interested in having a battery in my home to help save money on my energy bills
Answered: 73 Skipped: 4
Strongly Disagree
6.85%
Disagree
2.74%
Neither agree nor disagree
13.70%
Agree
38.36%
Strongly Agree
27.40%
Not sure
10.96%
0%
10%
20%
30%
40%
50%
60%
70%
80%
90%
100%


Q31 I would be more interested in a TOU tariff if my supplier also offered me a home battery.
Answered: 73 Skipped: 4
Strongly Disagree
6.85%
Disagree
1.37%
Neither agree nor disagree
12.33%
Agree
42.47%
Strongly Agree
27.40%
Not sure
9.59%
0%
10%
20%
30%
40%
50%
60%
70%
80%
90%
100%

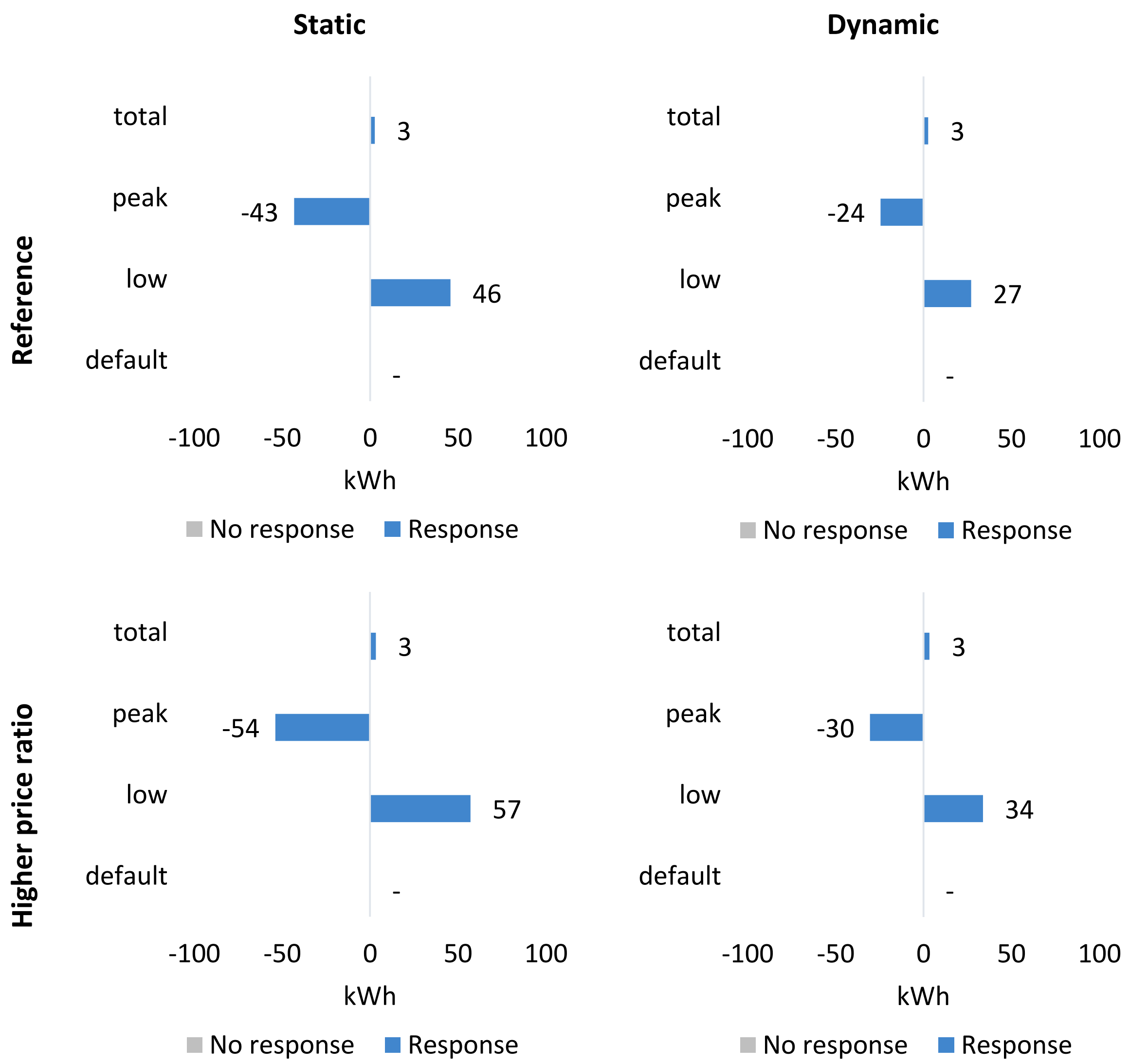


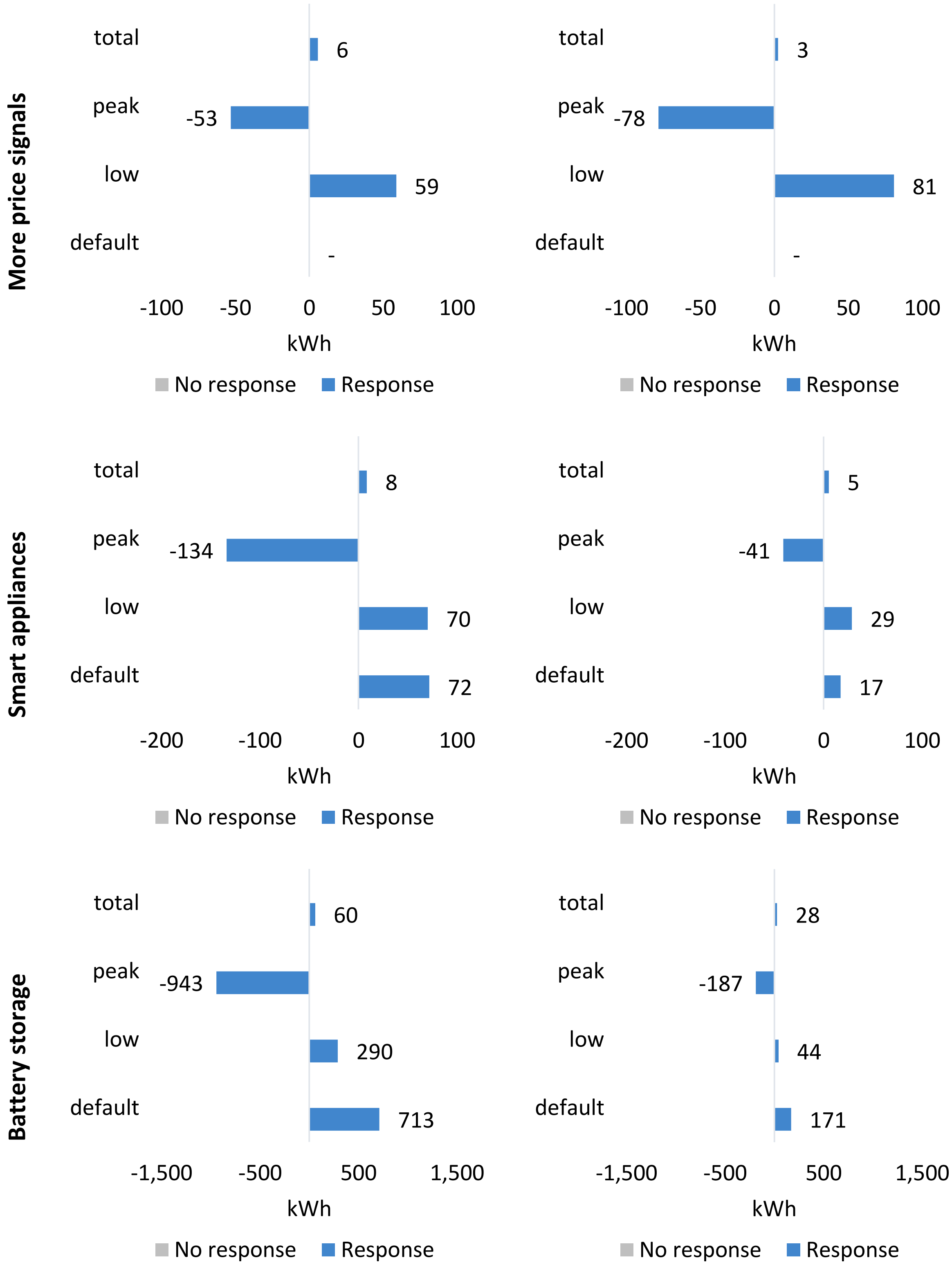
Q32 I would be willing to be tied into a 3 year contract for a TOU tariff if my electricity supplier supplied me with a home battery for free.
Answered: 73 Skipped: 4
Strongly Disagree
10.96%
Disagree
8.22%
Neither agree nor disagree
21.92%
Agree
30.14%
Strongly Agree
15.07%
Not sure
13.70%
0%
10%
20%
30%
40%
50%
60%
70%
80%
90%
100%

ANNEX G DISTRIBUTIONAL IMPACT ASSESSMENT RESULTS

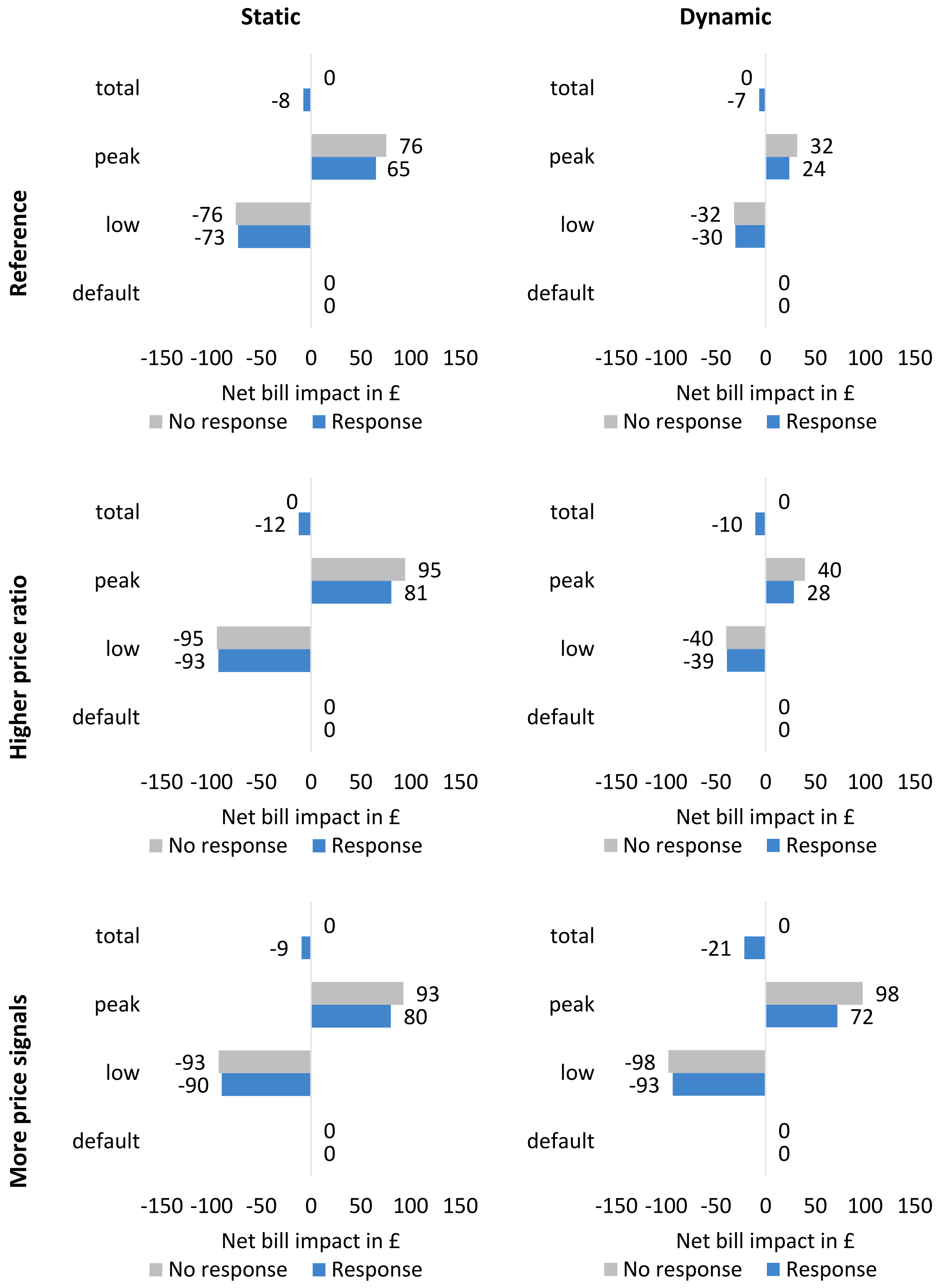
In this section we present the net impact on bill, impact across groups and impact across characteristics.

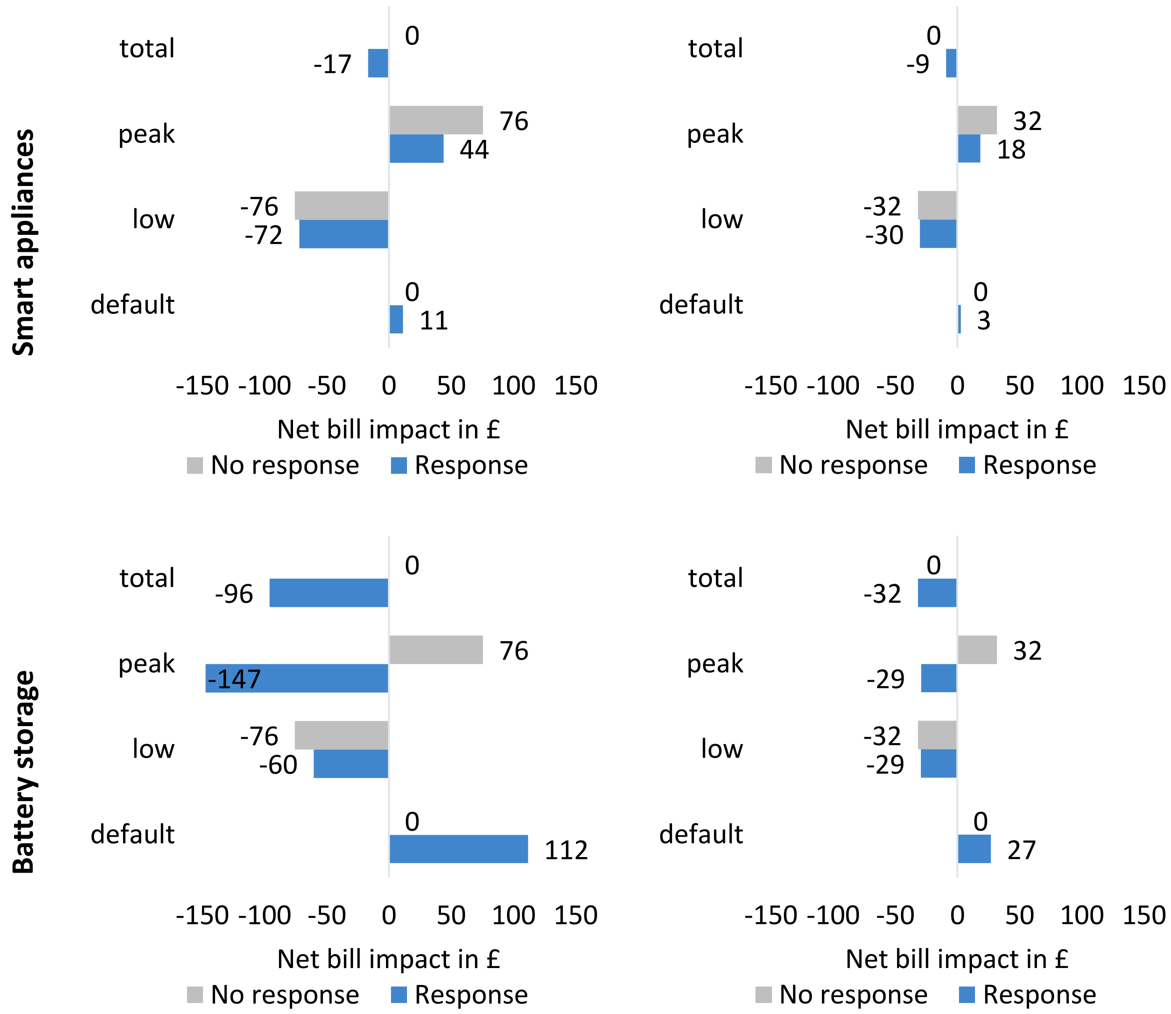
G.1. Net change in consumption across scenarios




More price signals
total
peak
low
default
6
-53
59
-
-100
-50
0
50
100
kWh
No response
Response
total
peak
low
default
3
-78
81
-
-100
-50
0
50
100
kWh
No response
Response
Smart appliances
total
peak
low
default
8
-134
70
72
-200
-100
0
100
kWh
No response
Response
total
peak
low
default
5
-41
29
17
-200
-100
0
100
kWh
No response
Response
Battery storage
total
peak
low
default
60
-943
290
713
-1,500
-500
500
1,500
kWh
No response
Response
total
peak
low
default
28
-187
44
171
-1,500
-500
500
1,500
kWh
No response
Response

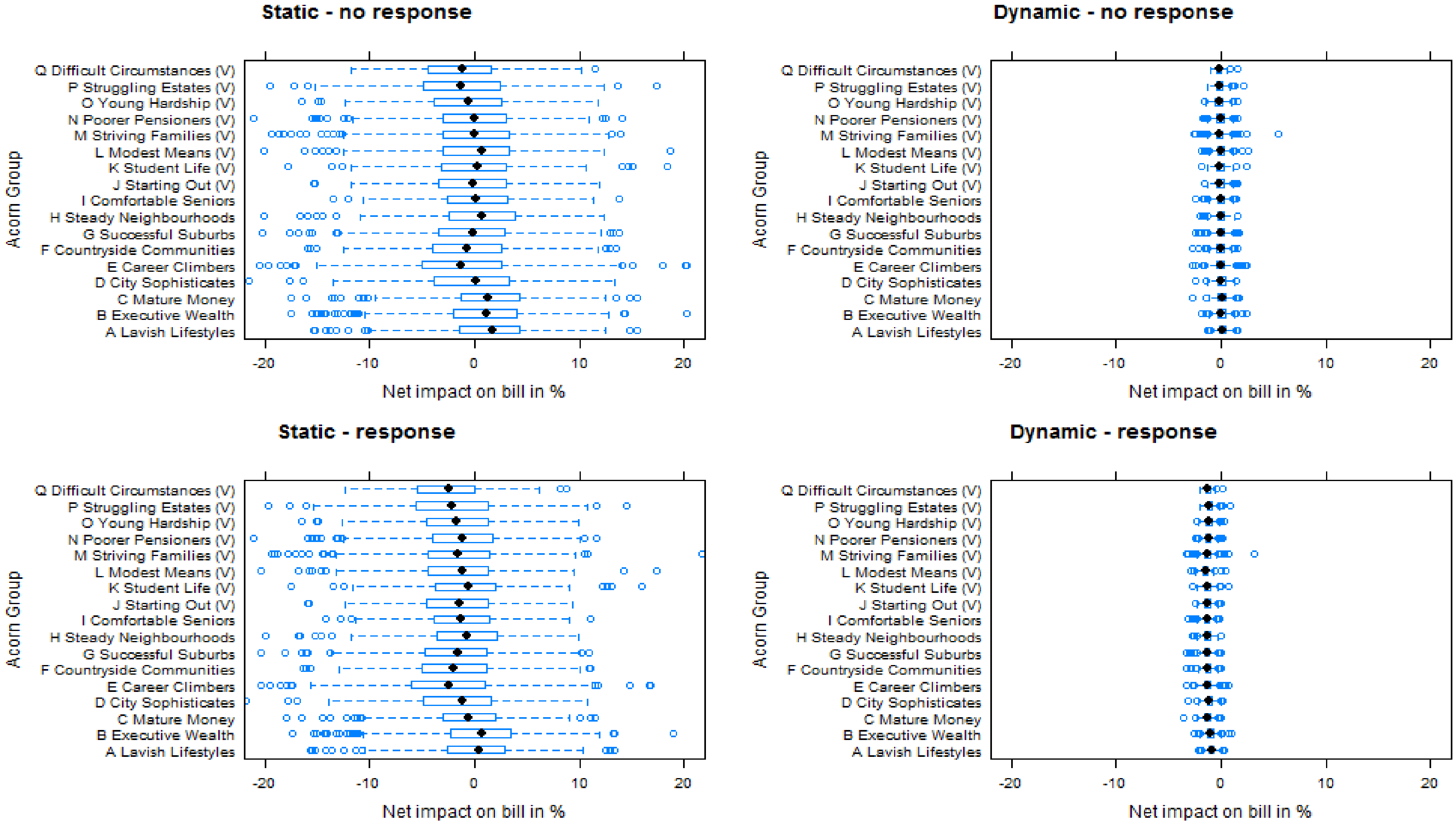
G.2. Net impact on bills across scenarios




Smart appliances
Battery storage
total
peak
low
default
0
-17
76
44
-76
-72
0
11
-9
32
18
-32
-30
3
-96
-147
-60
112
-29
27
-150 -100 -50 0 50 100 150
Net bill impact in £
No response
Response

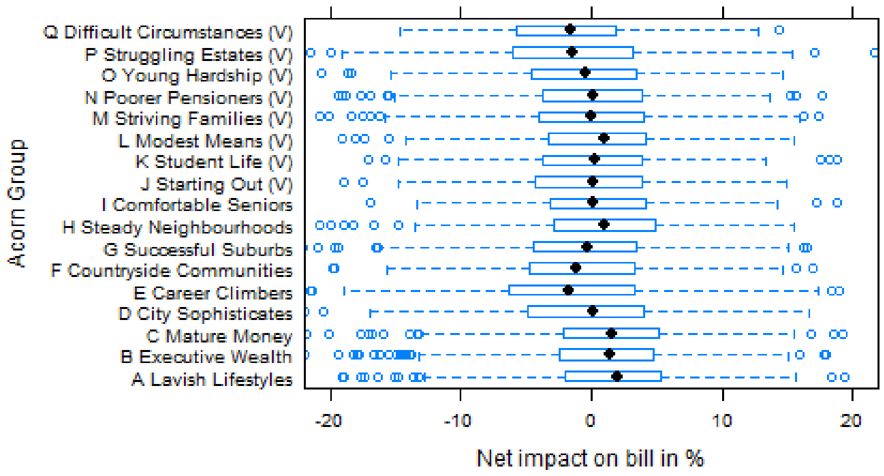
G.3. Impact across sociodemographic groups

G.3.1. Reference

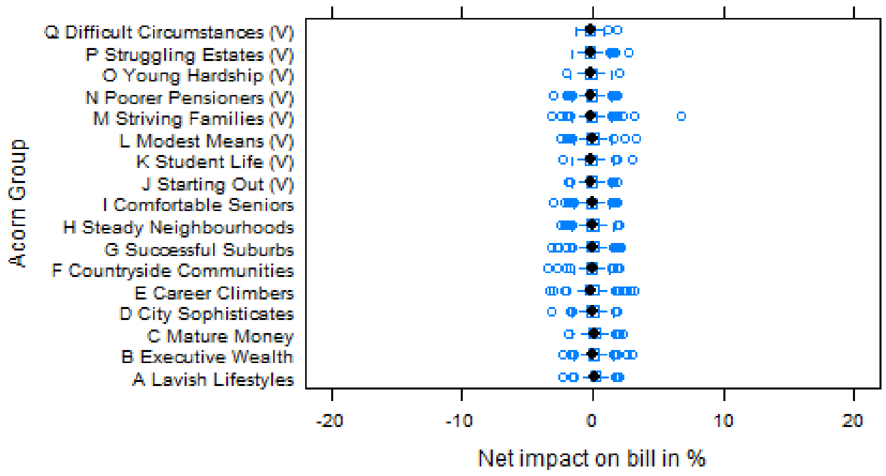


G.3.2. Higher price ratios

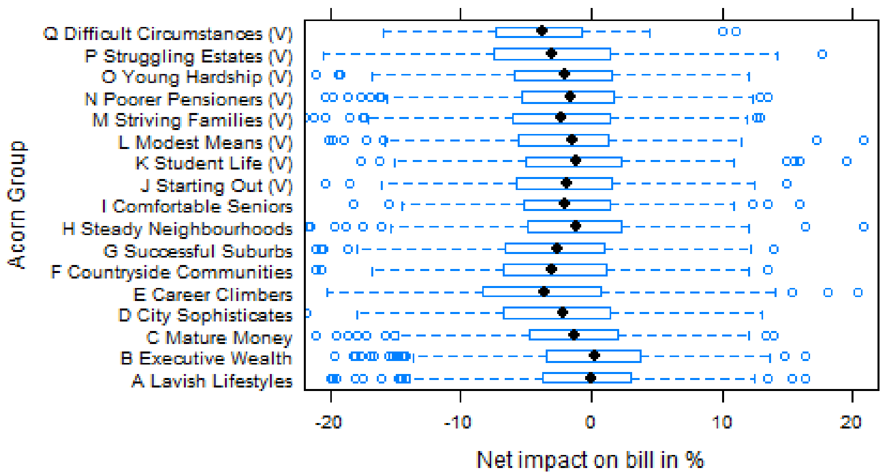
Static - no response



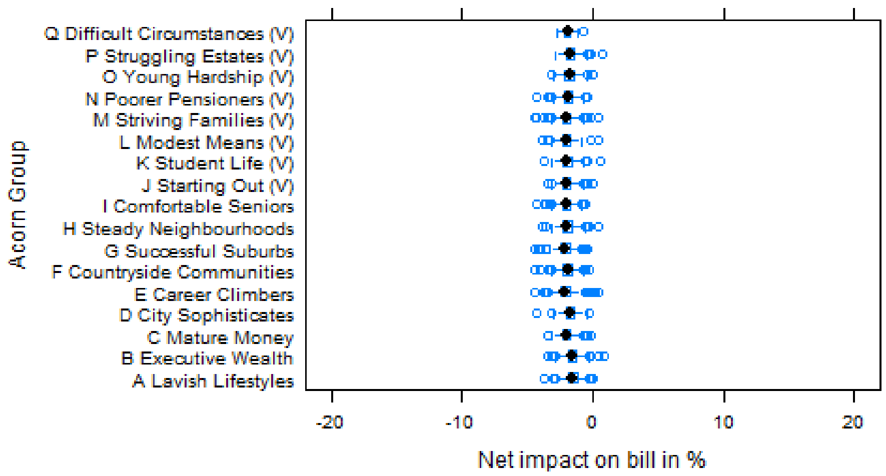
Dynamic - no response



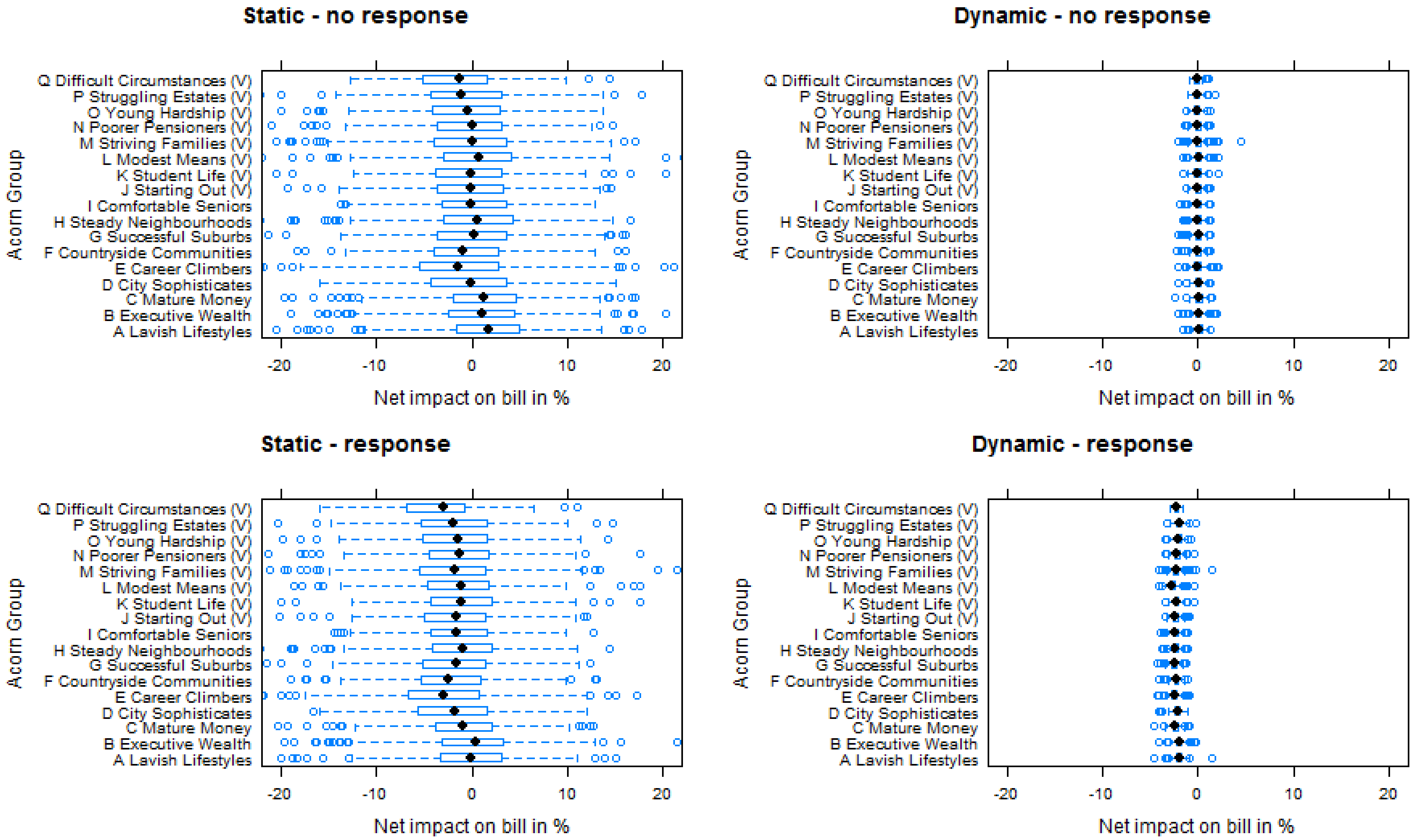
Static - response



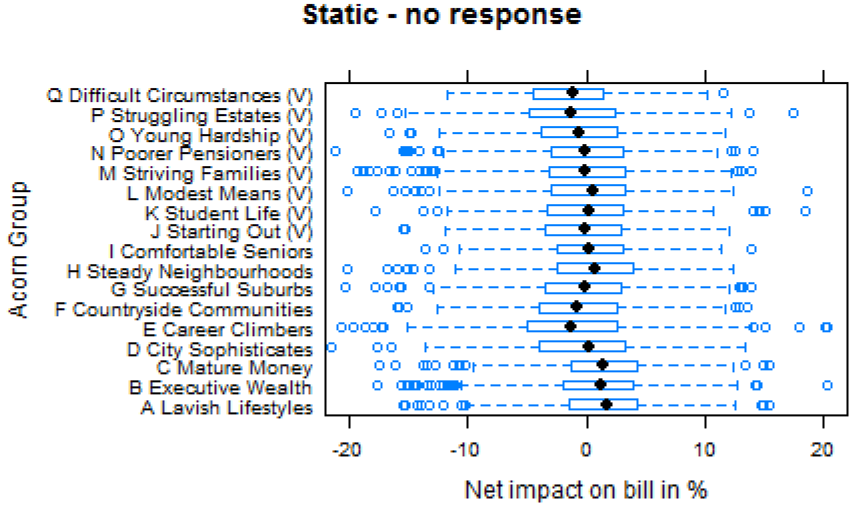
Dynamic - response

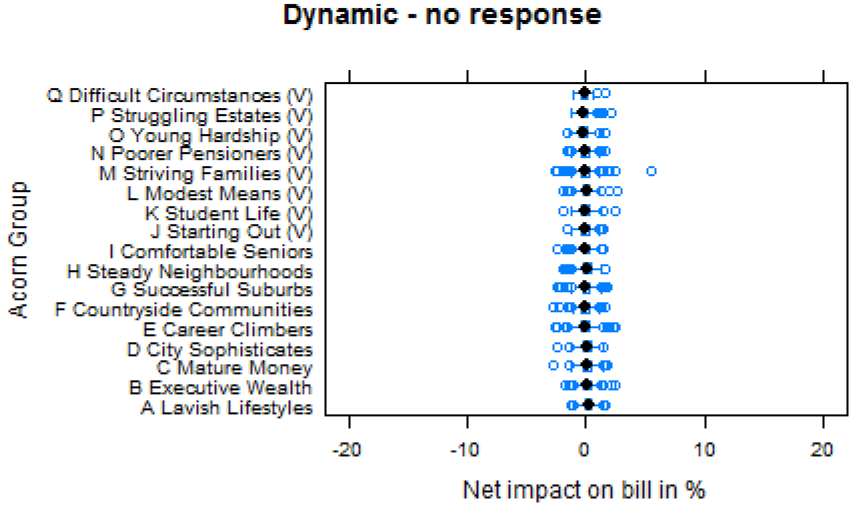


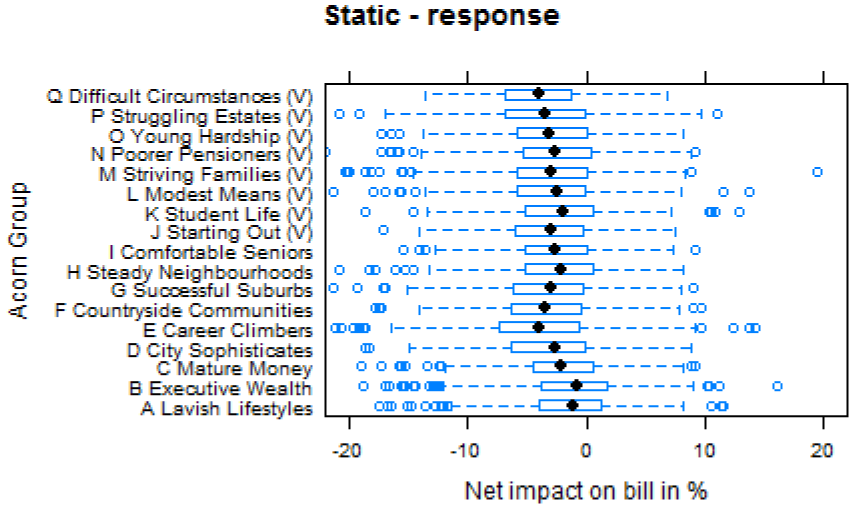
G.3.3. More price signals

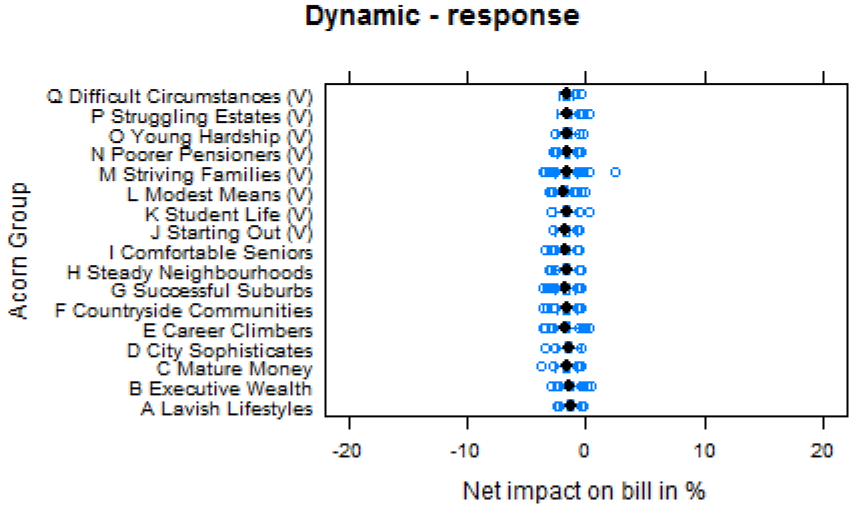


G.3.4. Smart appliances

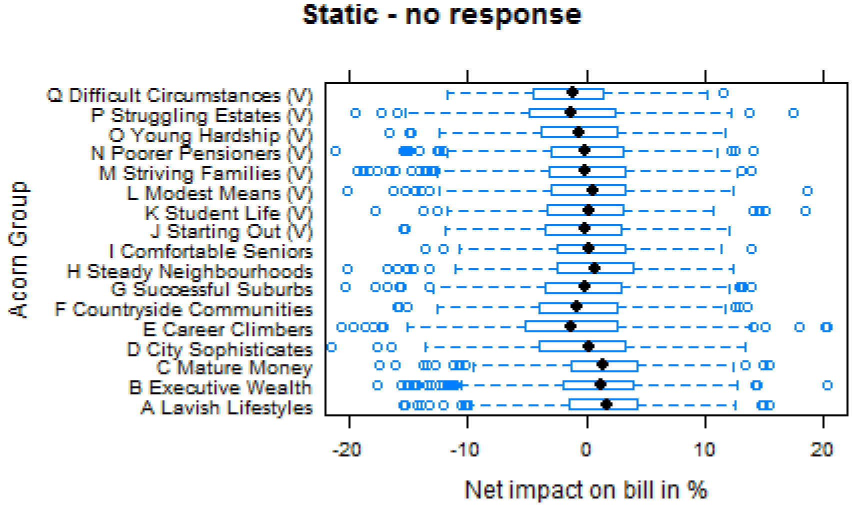


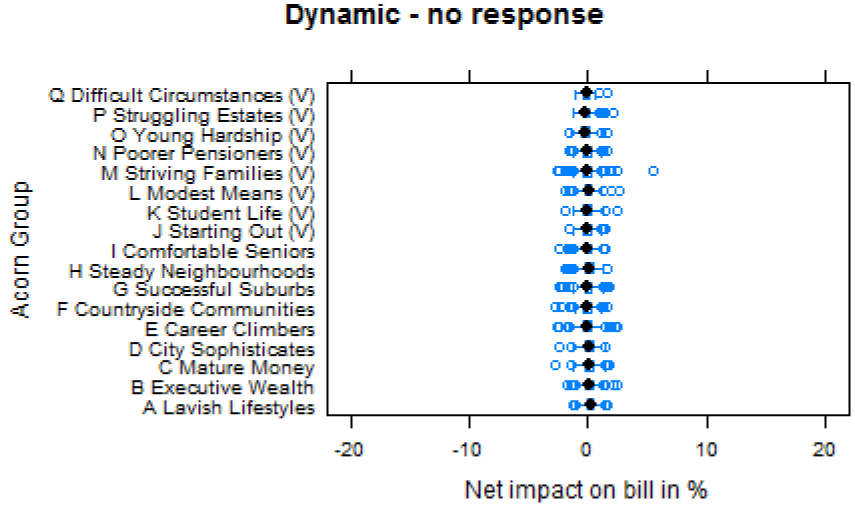


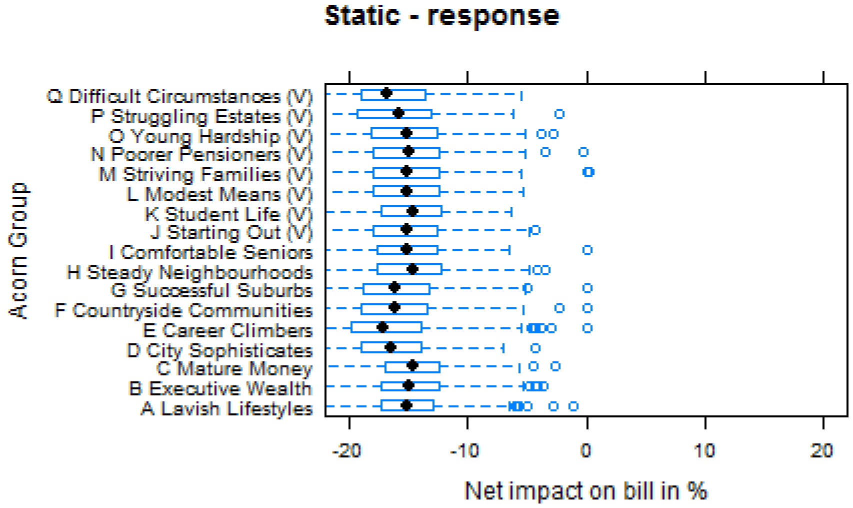


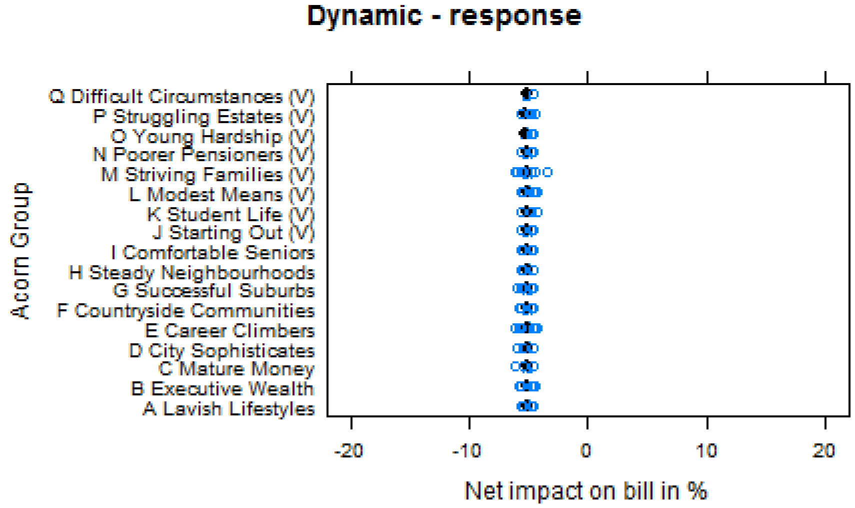


G.3.5. Battery Storage









G.4. Impact across characteristics

G.4.1. Reference

Characteristics	Net impact on bill	Peak elasticity	Off-peak elasticity
Average	-£8.6	-0.092	-0.096
Privately rented	-£5.0	-0.07	-0.11
Social renting	-£9.6	-0.09	-0.09
Household size : 5+ persons	-£6.9	-0.07	-0.11
Children at home : 3+	-£10.3	-0.09	-0.09
Couple with children	-£9.4	-0.11	-0.10
Lone parent with children	-£11.7	-0.09	-0.09
Work mainly at or from home	-£4.8	-0.08	-0.10
Employee Full-Time	-£7.8	-0.09	-0.09
Employee Part-Time	-£10.1	-0.11	-0.10
Unemployed and seeking work	-£11.8	-0.09	-0.09
Looking after home or family	-£11.7	-0.09	-0.09
Student	-£4.9	-0.07	-0.12
Retired	-£7.2	-0.09	-0.08
£0-£20,000	-£9.3	-0.09	-0.09
Income Support	-£10.1	-0.11	-0.10

Note: The association between low impact, off peak and peak elasticities is illustrated by highlighting lower savings, low peak elasticities and high off-peak elasticities in blue. In each case, we highlight the most extreme quarter of the column.

G.4.2. Higher price ratios

Characteristics	Net impact on bill	Peak elasticity	Off-peak elasticity
Average	-£13.1	-0.092	-0.096
Privately rented	-£8.7	-0.07	-0.11
Social renting	-£14.3	-0.09	-0.09
Household size : 5+ persons	-£10.8	-0.07	-0.11
Children at home : 3+	-£14.9	-0.09	-0.09
Couple with children	-£14.6	-0.11	-0.10
Lone parent with children	-£16.8	-0.09	-0.09
Work mainly at or from home	-£8.3	-0.08	-0.10
Employee Full-Time	-£11.9	-0.09	-0.09
Employee Part-Time	-£15.4	-0.11	-0.10
Unemployed and seeking work	-£16.9	-0.09	-0.09
Looking after home or family	-£16.7	-0.09	-0.09
Student	-£8.6	-0.07	-0.12
Retired	-£11.1	-0.09	-0.08
£0-£20,000	-£13.9	-0.09	-0.09
Income Support	-£15.4	-0.11	-0.10

G.4.3. More price signals

Characteristics	Net impact on bill	Peak elasticity	Off-peak elasticity
Average	-£10.4	-0.092	-0.100
Privately rented	-£6.3	-0.07	-0.12
Social renting	-£11.6	-0.09	-0.09
Household size : 5+ persons	-£8.1	-0.07	-0.11
Children at home : 3+	-£11.7	-0.09	-0.09
Couple with children	-£12.0	-0.11	-0.11
Lone parent with children	-£13.2	-0.09	-0.10
Work mainly at or from home	-£6.4	-0.08	-0.10
Employee Full-Time	-£9.9	-0.09	-0.10
Employee Part-Time	-£12.1	-0.11	-0.10
Unemployed and seeking work	-£13.4	-0.09	-0.10
Looking after home or family	-£13.2	-0.09	-0.10
Student	-£6.3	-0.07	-0.12
Retired	-£9.0	-0.09	-0.09
£0-£20,000	-£11.2	-0.09	-0.09
Income Support	-£12.1	-0.11	-0.10

G.4.4. Smart appliances

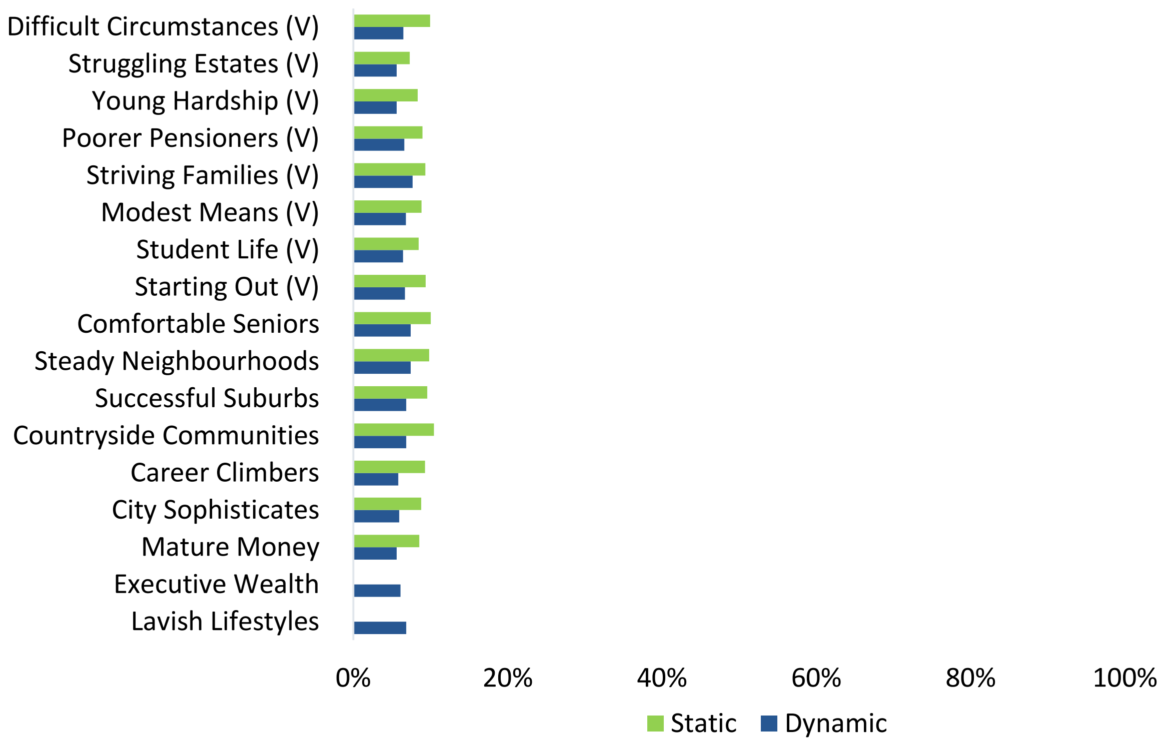
Characteristics	Net impact on bill	Peak elasticity	Off-peak elasticity
Average	-£16.3	-0.092	-0.096
Privately rented	-£13.0	-0.07	-0.11
Social renting	-£17.4	-0.09	-0.09
Household size : 5+ persons	-£14.4	-0.07	-0.11
Children at home : 3+	-£17.3	-0.09	-0.09
Couple with children	-£17.7	-0.11	-0.10
Lone parent with children	-£18.8	-0.09	-0.09
Work mainly at or from home	-£13.0	-0.08	-0.10
Employee Full-Time	-£15.3	-0.09	-0.09
Employee Part-Time	-£18.3	-0.11	-0.10
Unemployed and seeking work	-£18.9	-0.09	-0.09
Looking after home or family	-£18.7	-0.09	-0.09
Student	-£13.0	-0.07	-0.12
Retired	-£15.0	-0.09	-0.08
£0-£20,000	-£17.1	-0.09	-0.09
Income Support	-£18.3	-0.11	-0.10

G.4.5. Battery storage

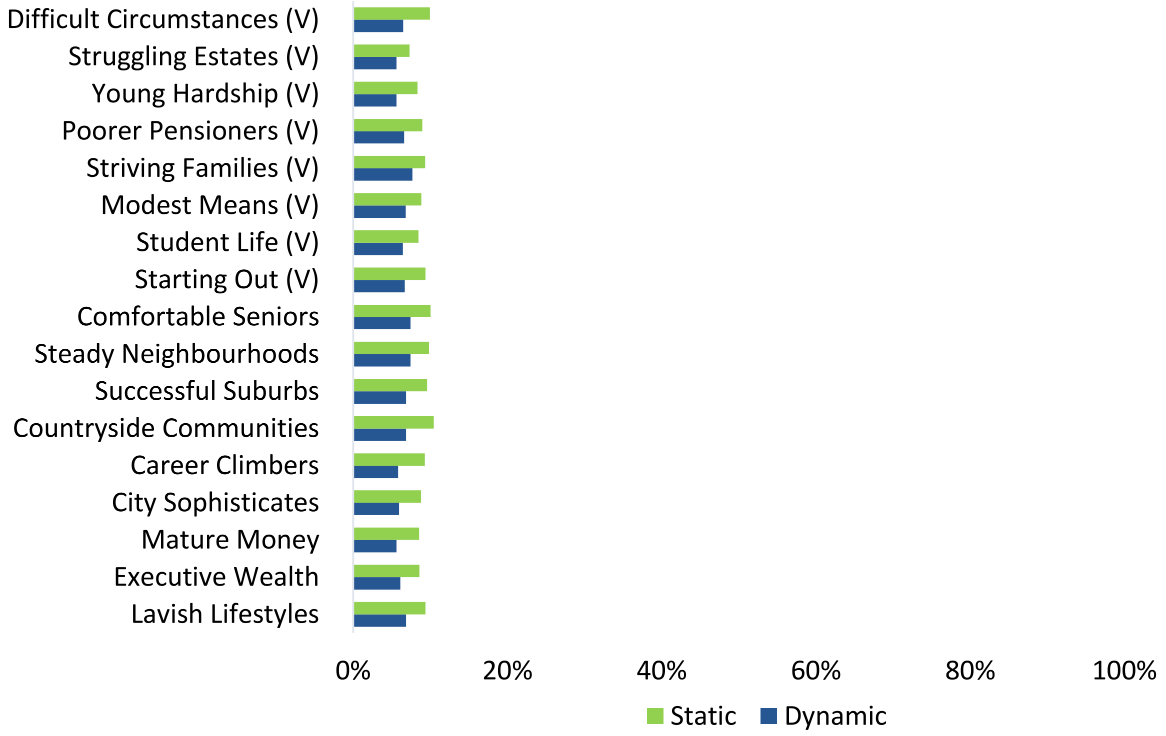
Characteristics	Net impact on bill	Peak elasticity	Off-peak elasticity
Average	-£85.3	-0.092	-0.096
Privately rented	-£84.0	-0.07	-0.11
Social renting	-£86.6	-0.09	-0.09
Household size : 5+ persons	-£81.4	-0.07	-0.11
Children at home : 3+	-£79.0	-0.09	-0.09
Couple with children	-£91.4	-0.11	-0.10
Lone parent with children	-£81.6	-0.09	-0.09
Work mainly at or from home	-£85.5	-0.08	-0.10
Employee Full-Time	-£82.2	-0.09	-0.09
Employee Part-Time	-£91.6	-0.11	-0.10
Unemployed and seeking work	-£82.3	-0.09	-0.09
Looking after home or family	-£81.4	-0.09	-0.09
Student	-£85.2	-0.07	-0.12
Retired	-£84.2	-0.09	-0.08
£0-£20,000	-£86.3	-0.09	-0.09
Income Support	-£91.7	-0.11	-0.10

G.5. ToU tariff uptake

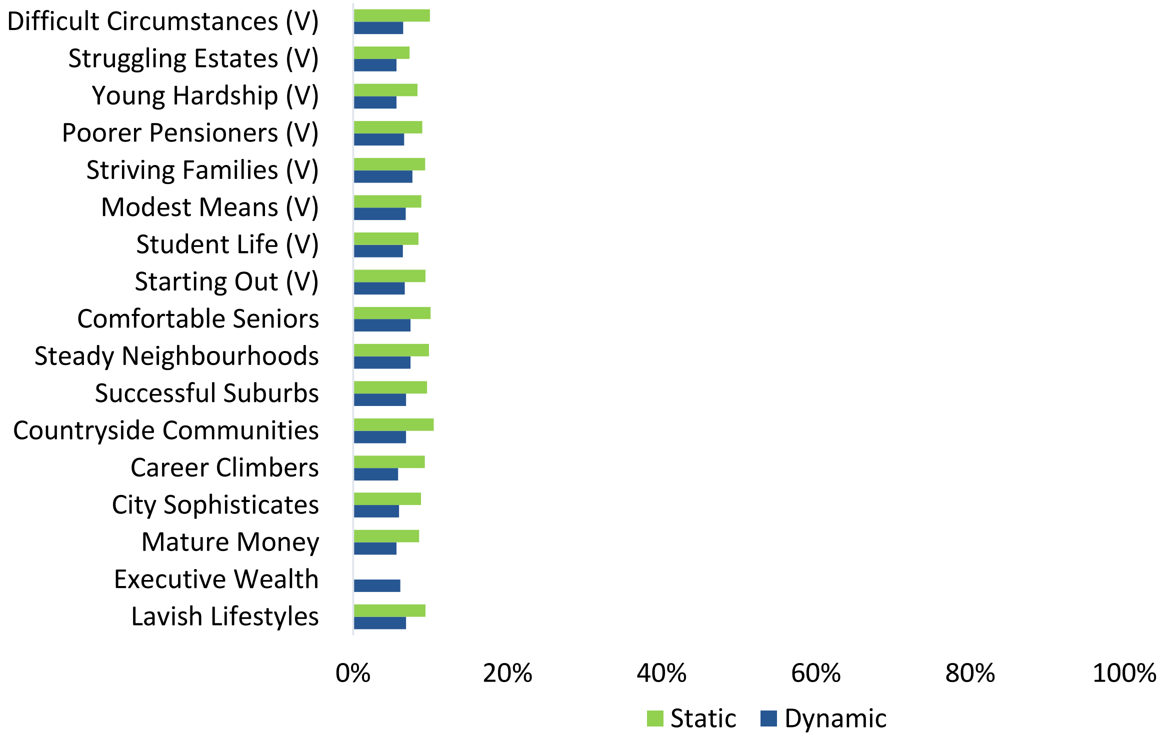
G.5.1. Reference



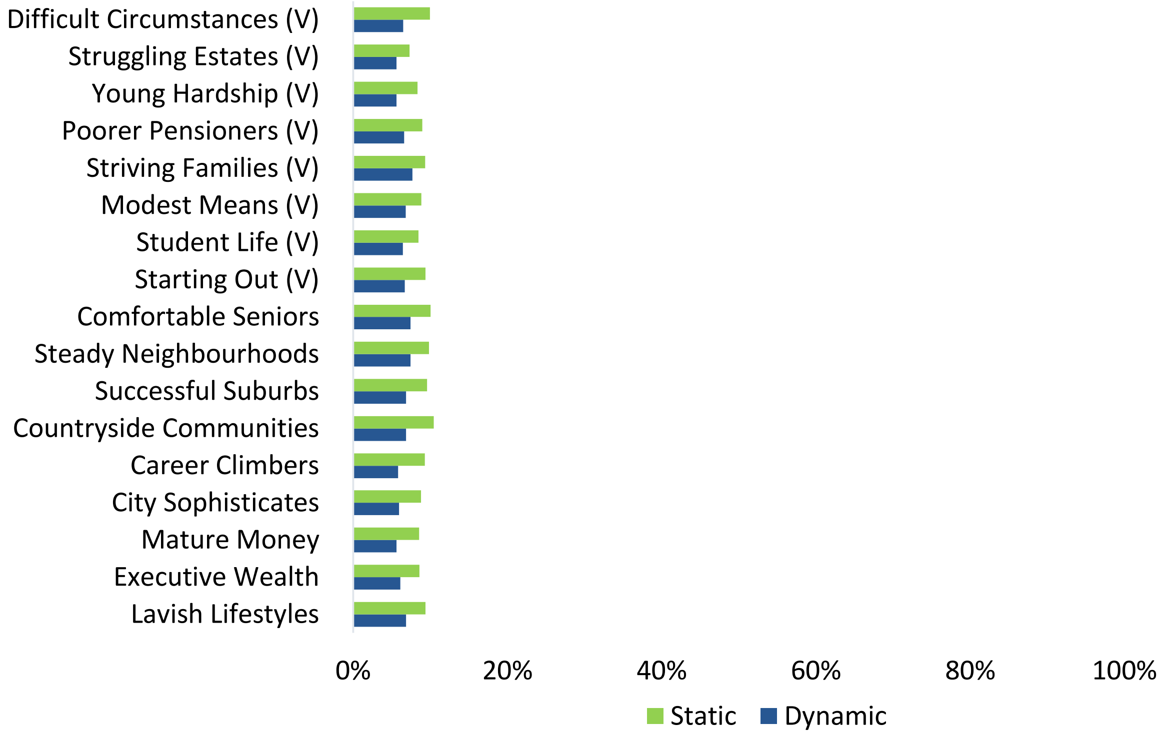
G.5.2. Higher price ratios



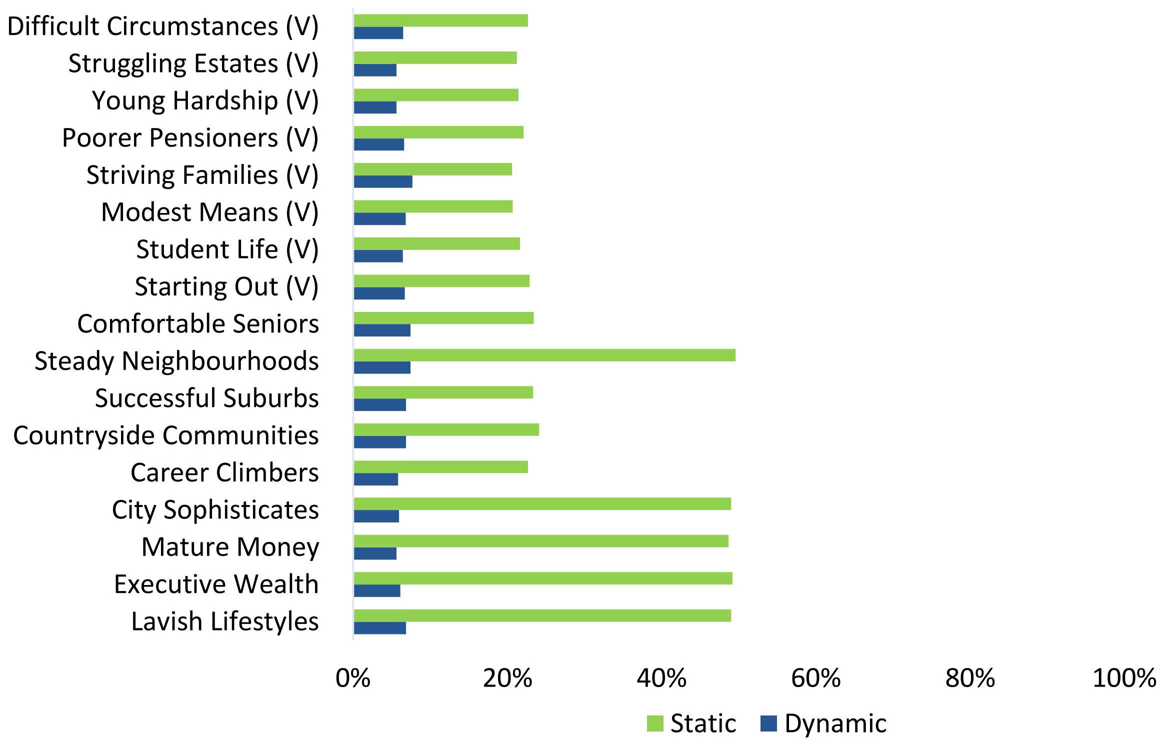
G.5.3. More price signals



G.5.4. Smart appliances



G.5.5. Battery storage



ANNEX H TABLE OF FIGURES

Figure 2.1: Schematic representation of vulnerability 16
Figure 2.2: Whisker diagram of peak** time consumption (in kWh) across sociodemographic groups* 20
Figure 2.3: Reference tariff 26
Figure 2.4: Higher price point than reference tariff 27
Figure 2.5: More frequent price signals than reference tariff 28
Figure 3.1: Elasticity in the LCL trial 32
Figure 3.2: Average peak elasticities across ACORN groups 33
Figure 3.3: Cumulative probability distribution of tariff uptake 35
*Figure 4.1: Flat tariff consumption and bill (£)** 41
Figure 4.2: ToU tariff consumption and bill (£) under the Reference Scenario 42
Figure 4.3: Net ToU consumption and bill under the Reference Scenario 43
Figure 4.4: Net impact on bills (in relative term) across sociodemographic groups under the Reference tariff 47
Figure 4.5: Distribution of impact across all scenario – static tariff with response only 51
Figure 4.6: Impact on bill in £ across sociodemographic characteristics associated with vulnerability 54
Figure 4.7: Likelihood of uptake for the reference tariff* 56
Figure 4.8: Uptake of ToU tariffs across all scenarios 57

ANNEX I BIBLIOGRAPHY

Annala, S., Viljainen, S., Tuunanen, J., Hukki, K., (2013) Smart use of electricity - How to get consumers involved? In: Industrial Electronics Society, IECON2013 - 39th Annual Conference of the IEEE, IEEE. pp.7056–7061.

BEIS Consumer Panel (November 2016), BEIS Smart Energy Research, Summary Report and associated dataset, https://www.gov.uk/government/consultations/call-for-evidence-a-smart-flexible-energy-system.

Bird, J. (2015b), 'Smarter, fairer?' A discussion paper on cost-reflectivity and socialisation of costs in domestic electricity prices. Sustainability First.

Buchanan, K., Banks, N., Preston, I. and Russo, R. (2016), The British public's perception of the UK smart metering initiative: Threats and opportunities. Energy Policy 91: 87-97.

Bulkeley, H., Matthews, P., Whitaker, G., Bell, S., Wardle, R., Lyon, S. and Powells, G. (2015) High Level Summary of Learning: Domestic Smart Meter Customers on Time of Use Tariffs, Customer-Led Network Revolution, Durham, UK, Durham University.

Bulkeley, H., Bell, S., Lyon, S., Powells, G., Judson, E. and Lynch, D. (2014) 'Customer-Led Network Revolution: Durham University Social Science Research': March 2014 Report, Durham, UK, Durham University.

Carmichael, R., Schofield, J., Woolf, M., Bilton, M., Ozaki, R. and Strbac, G. (2014) Residential consumer attitudes to time-varying pricing, Report A2 for the 'Low Carbon London' LCNF project, Imperial College London.

CER, Electricity Smart Metering Customer Behaviour Trials (CBT) Findings Report (2011).

Consumer Focus (2012), 'From Devotees to the Disengaged: A summary of research into consumers' experiences of Time-of-Use tariffs and Consumer Focus's recommendations'.

Fell, M.J. (2016), 'Taking charge: Perceived control and acceptability of domestic demand-side response', UCL Energy Institute, University College London.

Fell, M.J., Nicolson, M., Huebner, G.M., and Shipworth, D. (2015b), 'Is it time? Consumers and time of use tariffs: Trialling the effect of tariff design and marketing on consumer demand for demand-side response tariffs', March 2015. Smart Energy GB. UCL Energy Institute.

Faruqui, A. (2011) 'Dynamic Pricing the Top Ten Myths', paper presented at University of Texas, Austin, April 2011.

Faruqui, A. and Palmer, J. (2011) Dynamic Pricing and Its Discontents; *Regulation, Vol. 34, No. 3, p. 16, Fall 2011*

He, X. and Reiner, D. (2015) *Why Do More British Consumers Not Switch Energy Suppliers? The Role of Individual Attitudes*; Working Paper of Energy Policy Research Group, Cambridge University.

He, X, Hancher, L., Azevedo, I., Keyaerts, M., Meeus, L., and Glachant, J-M. (2013) Shift, Not Drift: Towards Active Demand Response and Beyond (THINK Topic 11) Final Report June 2013 http://www.eui.eu/Projects/THINK/Documents/Thinktopic/Topic11digital.pdf

IPA (2016) 'Initial analysis on distributional effects of half-hourly settlement by sociodemographic group'.

Ofgem (2015) Ofgem's Consumer Vulnerability Strategy Progress Report: September 2015 https://www.ofgem.gov.uk/sites/default/files/docs/2015/09/cvs_progress_report_for_website_final.pdf

KPMG (2016) Development of decentralised energy and storage systems in the UK: A report for the Renewable Energy Association. KPMG, London.

US Department of Energy (2013), 'Analysis of Customer Enrollment Patterns in Time-Based Rate Programs - Initial Results from the SGIG Consumer Behavior Studies', July 2013. 1.usa.gov/1DOJZQD