Residential demand-side response in the UK: maximising consumer uptake and response

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Abstract

Residential demand-side response (DSR) is a key strategy for meeting the challenges facing the UK electricity system. Leveraging residential flexibility should help to enhance system reliability, reduce carbon emissions, support the integration of renewables into the energy mix and deliver a lower-cost electricity system. However, the viability of residential DSR hinges on two critical factors: consumers will first need to switch to DSR programmes in sufficient numbers and then successfully respond by adjusting their consumption patterns accordingly.

This thesis explores how to optimise the impact of residential DSR by examining the enablers and constraints of uptake and response. While participation is primarily encouraged through financial incentives, studies suggest that some consumers may be willing to participate for non-financial reasons. As such, this thesis also explores how environmental and pro-social motivations could be leveraged to help promote uptake and response.

The thesis contributes to the knowledge on DSR by testing UK consumer preferences for different programme models through a large-scale online survey and identifying measures which could help to maximise uptake. It also explores the potential afforded by dynamic information-only programmes through a trial based on available wind generation. The thesis further makes a theoretical contribution by exploring how the Fogg Behaviour Model (FBM) can be used to conceptualise the enablers and constraints of uptake and response. By mapping these factors to the FBM's core components of ability, motivation and trigger, the model is refined as a tool for understanding how to optimise the impact of residential DSR.

The research reveals that information-only DSR programmes may represent a significant untapped resource. Approximately 8% of a representative sample of UK consumers indicated a preference for this model over more conventional price-based programmes; while trial households succeeded in reducing electricity consumption by 9.9% on average when asked to consume less and increasing consumption by 4.4% on average when asked to consume more. These promising findings may help to inform policy and programme design as the UK energy system evolves towards a renewables-based future.

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Abbreviations

BEIS	Department for Business, Energy & Industrial Strategy
CER	Commission for Energy Regulation
CLNR	Customer Led Network Revolution
DAA	Day-ahead alert
DECC	Department of Energy and Climate Change
DNO	Distribution network operator
DSR	Demand-side response
DTI	Department of Trade and Industry
DToU	Daily Time of Use
DUKES	Digest of UK Energy Statistics
EA	Environmental Alert
EDRP	Energy Demand Research Project
EPRI	Electric Power Research Institute
FBM	Fogg Behaviour Model
FRS	Family Resources Survey
HCI	Human-computer interaction
kWh	Kilowatt-hour
LCL	Low Carbon London
LOG	Logarithm
MW	Megawatt
OECD	Organisation for Economic Cooperation and Development
OR	Odds ratio
P	Probability value
ToU	Time of use
UK	United Kingdom
US	United States
WTS	Willingness to switch

1. Introduction

1.1 Introduction

The UK electricity system faces considerable challenges over the coming decades. The government has committed to reduce carbon emissions by 57% below 1990 levels by 2030 and 80% below 1990 levels by 2050 (Committee on Climate Change, 2016). This will primarily be achieved through the decommissioning of carbon-intensive power plants, the gradual electrification of heating and transport, and increased generation from low-carbon sources such as wind and nuclear (Carbon Trust and Imperial College London, 2016). However, this transformation will come at a cost: the electrification of heating and transport will increase peak demand, and as more electricity is generated from renewables, supply will become less flexible and less predictable. This heightened variability in generation presents difficulties, given that supply and demand must be balanced to maintain the stability of the electricity system.

In this context, leveraging flexibility on the demand side could result in more efficient use of existing generation and transmission assets, reduce the need for additional investment in energy infrastructure and generate significant financial savings (Borenstein, 2012; Carbon Trust and Imperial College London, 2016).

Section 1.2 of this chapter defines demand-side response (DSR) and explains how it can help to meet the challenges facing the UK energy sector. Section 1.3 explains the rationale for the focus of this thesis on residential demand and Section 1.4 outlines the different residential DSR programme[1] models available. Section 1.5 defines the aims of the thesis and the central research questions that underpin it; while Section 1.6 concludes and outlines the structure of the thesis.

1.2 Demand-side response

The term ‘demand-side management’ refers to a range of technologies and interventions designed to achieve greater efficiency and flexibility on the demand side of the electricity system (DECC, 2008). These include energy efficiency and conservation programmes, as well

[1] The term ‘programme’ is used throughout this thesis to refer to the different models for DSR that have been developed, and includes price-based tariffs, direct load control and information-only programmes.

as electricity management strategies such as demand-side response (DSR) – the focus of this thesis.

DSR can be distinguished from other demand-side management approaches in that it is specifically aimed at shifting consumption times, rather than at reducing overall consumption (Owen *et al*, 2011). There are various definitions of the term in the energy literature (eg, Element Energy, 2012; Owen *et al*, 2011; Ofgem, 2013),[2] but this thesis adopts Sustainability First's definition of 'DSR' as:

> changes in electricity usage by end-use customers from their normal consumption patterns… Designed (1) to induce lower electricity use at peak periods or to encourage use in off-peak periods and / or (2) to provide flexibility at any time of the day in support of cost-efficient balancing of the electricity system overall. (Owen *et al*, 2011, p.22)

DSR has many potential benefits: it can help to integrate renewable sources into the energy mix,[3] support system reliability, reduce carbon emissions and deliver a lower-cost electricity system (Albadi and El-Saadany, 2008; Carbon Trust and Imperial College London, 2016; Ward and Darcy, 2014). For instance, a report prepared for the National Infrastructure Commission (Strbac *et al*, 2016) predicts that DSR – alongside increased interconnection and storage – could save consumers[4] up to £8 billion a year by 2030 and help the UK to meet its carbon targets.[5]

Although DSR programmes have been available for some time for large customers in the industrial and commercial sectors in the UK (Owen and Ward, 2010; Torriti *et al*, 2009),[6] until recently no DSR programmes were available for residential customers, apart from the legacy

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[2] Demand-side response is also often referred to as 'demand response' in the energy literature (Aghaei and Alizadeh, 2013; Owen *et al*, 2011; Parrish *et al,* 2015). However, since 'demand response' is sometimes used in a narrower sense to refer to reduced demand only, and does not always encompass the notion of increasing electricity consumption at certain times (Federal Energy Regulatory Commission, 2012), the term 'DSR' is preferred in this thesis.

[3] By encouraging greater consumption when surplus generation from renewables is available and reduced consumption when generation from renewables is low.

[4] The term 'consumer' is used throughout this thesis to refer to residential electricity customers.

[5] Research conducted at Imperial College estimates that the cumulative total net savings from flexibility over the next 30 years would amount to between £1.4 billion and £2.4 billion in 2030 (CarbonBrief, 2017). While lower than the National Infrastructure Commission's figures, the Imperial College estimates are for savings net of the costs of achieving flexibility and are based on meeting a weaker carbon target (100 grammes of carbon dioxide per kilowatt-hour) than those that used in the National Infrastructure Commission analysis (50 grammes of carbon dioxide per kilowatt-hour) (ibid).

[6] Some 117,000 end users that consume large amounts of electricity are participating in DSR programmes (Houses of Parliament, 2014). Since 2016, National Grid's Demand Turn Up scheme has provided financial incentives for non-residential energy users to increase consumption at times when electricity is oversupplied (National Grid, 2015).

Economy 7 and Economy 10 tariffs[7] which provide cheaper electricity at night.[8] However, this situation is now changing: Tide – the first 'second-generation' residential static time of use (ToU) electricity tariff (see Section 1.4) was introduced by Green Energy UK in January 2017 (*The Guardian*, 2017).

Other technical, regulatory and commercial developments serve as further indications that opportunities for residential DSR are likely to grow. These include the ongoing roll-out of smart meters: if government targets are met, around 53 million of these will be installed in over 30 million households and business premises across the UK by the end of 2020 (Smart Energy GB, 2017). Smart meters are a key facilitator of residential DSR programmes, as they can precisely record electricity consumption in real time and transmit this information to suppliers.

Smart meters are also vital to Ofgem's ongoing half-hourly settlement reform, which aims to create an environment conducive to efficient system-wide use of DSR (Ofgem, 2016). Under the current settlement arrangements – which are set out in the Balancing and Settlement Code and estimate actual electricity use for each half-hour based on a profile of the average consumer – "suppliers remain insulated from the true value of any changes in when their customers use energy" (Ofgem, 2014, p.11). This disincentivises them from promoting DSR: essentially, those suppliers which choose to implement DSR programmes cannot capture the full benefits of their investment, while their efforts make the system more cost efficient to the benefit of competitors (Owen *et al*, 2011). By contrast, the planned introduction of elective half-hourly settlement for domestic customers will expose "the true cost of supplying that customer in any given half-hour" (Ofgem, 2016, p.4), and encourage "suppliers to identify commercial opportunities to offer time-of-use and other smart tariffs" (ibid, p.9).

Rising non-commodity costs – the compulsory charges, levies and taxes imposed on suppliers in delivering electricity[9] – may further spur the roll-out of DSR programmes. At present, these costs are passed directly onto end consumers (ibid) and account for a growing percentage of their total electricity bills; this figure is predicted to rise to over 60% by 2020 (Utilitywise,

[7] The term 'tariff' is used throughout this thesis to refer specifically to price-based programmes only.
[8] Although around 4.5 million UK consumers are still on these multi-rate tariffs, they were primarily designed so that customers using electrically charged thermal storage heaters could meet their space heating needs and to complement the nuclear power programme in the 1960s (Torriti, *et al*, 2010).
[9] These include Transmission Network Use of System charges, Distribution Use of System charges, the Balancing Service Use of System charge, the Climate Change Levy, the Carbon Reduction Commitment, the Capacity Market Supplier Charge, the Renewables Obligation, the Feed-in Tariff and contracts for difference. (Inenco, 2017).

2016). As Ward and Darcy (2014) suggest: "Arguably, this will become a very significant portion of the bill simply to pass through to each customer on a wholly flat p/kWh averaged-cost basis" (p.16) – which may prompt calls for reforms in how such costs are recovered.

Were non-commodity costs to be recovered from suppliers based on actual real-time supply, this would leave them significantly more exposed to peak-related variations – which would incentivise them to implement programmes that encourage customers to use less electricity at peak times (ibid).

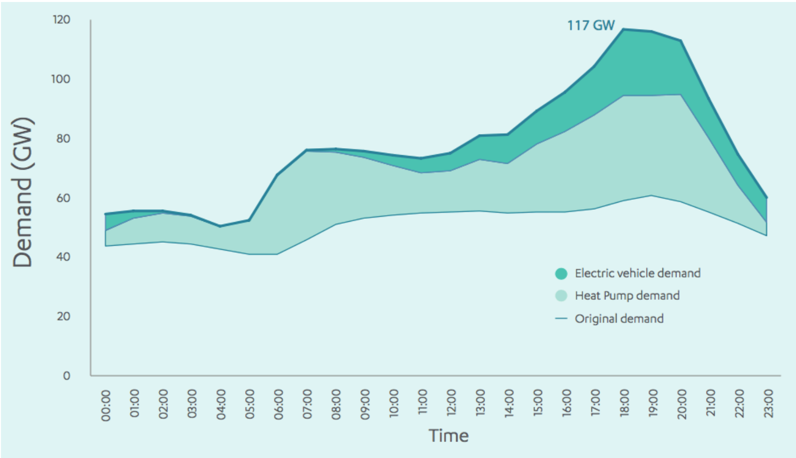
1.3 Research scope: residential demand

The research presented in this thesis focuses on residential demand, given that this represents a substantial load for National Grid, totalling 108.2 terawatt hours in 2015 (DUKES, 2016). The residential sector accounted for 30% of total consumption in 2015 – more than either the commercial or industrial sector – and contributes disproportionally to peak demand: household consumption accounts for around half of all electricity demand during the system peak between 5:00pm and 7:30pm (Hesmondhalgh *et al*, 2014).

These trends are expected to intensify in future with the increased electrification of heating and transport. Full penetration of electric vehicles and heat pumps could see daily consumption rise by around 50%, while doubling the system peak (Pudjianto *et al*, 2013). Figure 1 illustrates the potential scale of the problems that this could cause, depicting hypothetical electricity demand for a typical day in the UK with heating and transport electrified, but with no measures implemented to address attendant increases in peak demand.

In this context, residential DSR could play an important role in mitigating peak demand and reducing the need for system reinforcement. As Pudjianto *et al* (2013) explain: "By optimising demand response the increase in the peak demand could be restricted to only 29% [rather than 200%], resulting in massively improved utilisation of generation and network capacity, and significantly reduced network investment." (p.77)

Figure 1. Possible future daily demand scenario with sub-optimal power system (Source: National Infrastructure Commission, 2016)



Residential DSR programmes could also generate substantial financial savings for suppliers. DECC's predictions (DECC, 2014) that 20% of residential and small and medium-sized enterprise consumers will have switched to static ToU tariffs by 2030 could yield annual savings of £26 million from short-run marginal cost savings,[10] £23 million from displaced infrastructure investment, £10 million from reduced carbon emissions and £1 million from network capacity investment savings.[11]

In this thesis – as in many previous DSR studies (EU-DEEP, 2009; Faruqui *et al*, 2010a; Feuerriegel and Neumann, 2013; Owen and Ward, 2014) – it is thus assumed that, at least in the short term, most DSR programmes will be supplier led, given the attendant advantages they present. Suppliers have direct commercial exposure to the wholesale, capacity and balancing markets, and can use DSR programmes to reduce their payments to other parts of the energy system supply chain through cheaper wholesale energy purchase and lower charges for network use and system balancing (Ward and Darcy, 2014).

However, suppliers are not the only electricity stakeholders[12] likely to be interested in implementing residential DSR programmes. Distribution network operators (DNOs) may be able to use DSR to defer upgrading parts of their network by reducing demand in specific areas

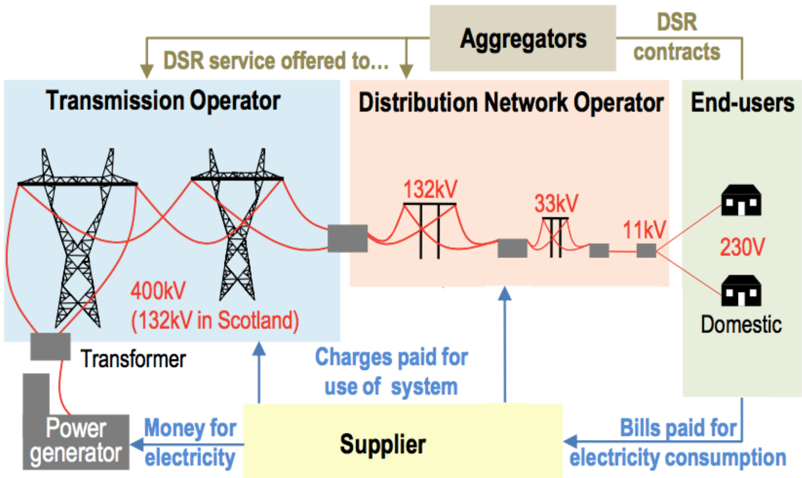
[10] Short-run marginal savings occur because shifting demand off-peak makes it possible to generate electricity at a lower average cost (DECC, 2014).
[11] Savings from DSR could end up even higher than these estimates: DECC's figures only include savings from static ToU tariffs, when in reality a range of DSR programmes might be available for residential consumers before 2030 (see Table 1).
[12] The term 'electricity stakeholders' is used throughout this thesis to refer to all entities with an interest in the successful implementation of residential DSR, including suppliers, DNOs, government, regulators etc.

at certain times (Pudjianto *et al*, 2013).[13] Indeed, the imperatives for DNOs to implement DSR programmes are likely to increase as heating and transport are electrified, leading to greater demand at network hotspots at peak times.

Aggregators or energy service companies could also compete to sell DSR services and reward consumers for modifying their consumption patterns (Gkatzikis *et al*, 2013; Owen *et al*, 2011).[14] Should this model succeed, it could represent a stable DSR system resource which could be used to provide services such as spinning reserve, frequency control or short-term operating reserve (Pallonetto *et al*, 2016).

The various electricity stakeholders that are relevant in the context of residential DSR are shown in Figure 2.

Figure 2. Electricity stakeholders relevant for residential DSR (Source: adapted from Houses of Parliament, 2014)



1.4 DSR programme models

DSR programmes can be classified into two main models: incentive-based programmes and price-based programmes (Albadi and El-Saadany, 2008).

Incentive-based programmes may be sub-divided into:

[13] See, for example, the Power Saver Challenge (Electricity North West, 2016).
[14] In this regard, the government's Smart Systems and Flexibility Plan includes proposals to allow DSR aggregators to participate in the balancing market (HM Government and Ofgem, 2017).

- 'classical' programmes – such as direct load control[15] and interruptible/curtailable load programmes – which reward customers for participation, usually through a bill credit or discount rate; and
- market-based programmes – such as demand bidding, emergency DSR programmes, the capacity market and the ancillary services market – where rewards are contingent on the extent to which customers reduce their load during critical periods (ibid).

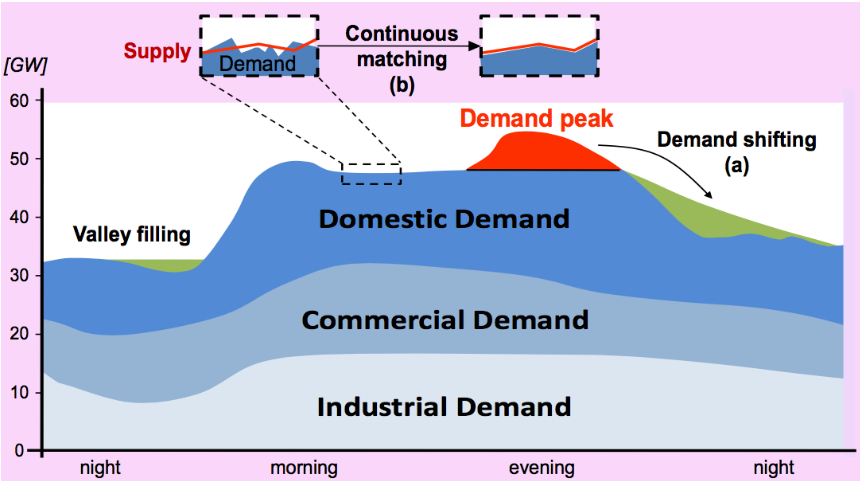
Although incentive-based programmes are offered to large consumers in the industrial and commercial sectors in the UK, they are not currently available for residential consumers.

Price-based programmes, on the other hand, involve dynamic pricing under which electricity rates vary at different times. These programmes aim to flatten the demand curve using higher prices during peak periods and lower prices during off-peak periods (ibid), or to encourage customers to vary their consumption patterns depending on available generation (Owen *et al*, 2011). Many different price-based programmes exist, with common variants including static ToU pricing, critical peak pricing and real-time pricing (see Table 1 for a summary of the most common DSR programme models).[16]

Figure 3 shows how two of these price-based programmes – static ToU tariffs and real-time pricing – can help to manage demand. Static ToU pricing encourages consumers to shift some of their consumption off-peak (Figure 3(a)), while real-time pricing helps to smooth fluctuations in the balance of supply and demand in real time (Figure 3(b)).

[15] That is, where electricity system stakeholders such as suppliers and DNOs temporarily control specific appliances – including central air conditioning, electric storage heaters and water heating cylinders – in return for a one-off payment and/or monthly bill reductions (Finn *et al*, 2011).
[16] Hybrid tariffs also exist which combine ToU pricing and critical peak pricing. These have the fixed daily peak and off-peak periods which are characteristic of ToU tariffs, together with critical peak prices on a certain number of days per year (Faruqui and Sergici, 2010).

Figure 3. Effects of DSR on typical UK demand profile (Source: Houses of Parliament, 2014)



Of the various price-based programmes, static ToU programmes are considered the most likely to be offered to residential consumers in the UK in the short term (until at least 2020), since by reducing peak consumption, they can help to lower wholesale electricity purchase costs for suppliers and maximise the use of existing generation assets (Darby and McKenna, 2012; Hesmondhalgh *et al*, 2014). In future, however, as more of the UK's electricity is generated from renewables,[17] the value of dynamic forms of DSR – including real-time pricing, critical peak pricing and dynamic ToU pricing – is expected to increase. Suppliers may be able to use these programmes to hedge their wholesale electricity purchases over different timeframes and thereby reduce market risks (Ward and Darcy, 2014). [18] As Feuerriegel and Neumann (2013) explain:

> Rising electricity prices and increasing price volatility will encourage electricity retailers to implement and extend their demand response activities. The underlying reason is, as the literature on renewables suggests, that an increase in intermittent wind and solar generation comes at the cost of an increase in the spot-price variance. (p.366)

[17] Both BEIS (2016b) and the Committee on Climate Change (2015) estimate that onshore wind and solar will be as cheap or cheaper than gas by 2020, and BEIS estimates that renewable capacity will reach 36 gigawatts by 2030.

[18] Since these tariffs can additionally be used to encourage greater consumption at times of oversupply, they can also contribute to lower prices by preventing the need to 'spill' excess generation.

Table 1. DSR programme models

Price-based programmes	Description	Examples
Static time of use (static ToU)	Customers are charged two or three fixed rates which occur during the same periods each day.[19]	The Customer Led Network Revolution (CLNR) ToU trial[20] (Bulkeley *et al*, 2014); Ontario's time of use programme (Faruqui and Sergici, 2010a)
Dynamic time of use (dynamic ToU)	Customers are charged two or three fixed rates which occur at different times each day. Notification of when these different rates will apply is provided one day in advance.	The Low Carbon London (LCL) dynamic ToU trial (Schofield *et al*, 2014)[21]
Critical peak pricing	Customers are charged higher prices on a limited number of event days per year when wholesale market prices for electricity are expected to be high or when system stability is threatened.	California Statewide Pricing pilot (Charles River Associates, 2005)
Real-time pricing	The price of electricity fluctuates depending on the wholesale market price. The price may vary instantaneously or over shorter time periods (eg, every 15 minutes or hourly).	ComEd Hourly Pricing programme (ComEd, 2017)
Incentive-based programmes	Description	Examples
Direct load control	Customers receive payments for allowing their supplier or an aggregator to control energy-intensive appliances such as electric heating systems or central air-conditioning.	California Statewide Pricing pilot (Rocky Mountain Institute, 2006)
Critical peak rebate	Customers receive billing credits for reducing their demand at critical times below a baseline level of consumption.	Ontario Energy Board Smart Price Pilot (Faruqui and Sergici, 2010a)
Non-price based programmes	Description	Examples
Information-only	Customers receive notifications asking them to voluntarily reduce or increase their consumption at certain times. Programme notifications could be based on factors such as peak demand, security of supply or generation from renewables.	Onzo Smart Energy Kit Trial (Onzo, 2011)

[19] Rates on static ToU tariffs can vary on weekdays and weekends, as well as seasonally. Hybrid DSR programmes also exist which combine static ToU pricing with critical peak pricing.
[20] The CLNR ToU trial was a Low Carbon Network funded project involving 650 British Gas customers (Bulkeley *et al*, 2015).
[21] The Low Carbon London Dynamic ToU trial was a Low Carbon Network funded project involving 1,119 customers living in the London Power Networks area (Schofield *et al*, 2014).

In addition to the price-based programmes described – and of particular relevance to this thesis – a number of initiatives eschew financial incentives altogether and instead seek response[24] by asking consumers to voluntarily reduce or increase their consumption at certain times. While in much of the DSR literature – and in the industry's approach to DSR to date – "the fundamental assumption has been that there is no better signal than price and that socially optimum behaviour can be brought about with 'high' prices" (Gyamfi, 2013, p.76), these 'information-only' programmes may also hold promise for residential DSR. They are discussed in further detail in Chapter 2.

1.5 Research objectives

Although residential DSR programmes could offer many benefits for suppliers, their roll-out is likely to be expensive, requiring dedicated resources for marketing, data handling, billing and customer support (Carmichael *et al*, 2015; Ofgem, 2010; Stromback *et al*, 2011). Consequently, consumers will need to sign up in sufficient numbers to ensure their commercial viability. As Stromback *et al* (2011) explain: "Any smart meter enabled program rollout is costly and entails risk… The cost/benefit of a program will therefore be directly impacted by the number of end-customers who successfully engage with it." (p.35)

The US Electric Power Research Institute has further highlighted that the success of such programmes is also contingent on the extent to which consumers successfully respond by changing their electricity consumption patterns once enrolled (EPRI, 2012). Similarly, Hobman *et al* (2016) explain that for DSR programmes to satisfy the desired outcomes of suppliers, "there are at least two critically important and inextricably linked requirements: first, there must be sizeable and widespread uptake among customers; and second, there must be optimal usage (i.e., appropriate demand response) that is sustained over time" (p.456).

A simple thought experiment demonstrates the equal significance of these two factors. If 10% of consumers switched to a DSR programme and rescheduled 1% of their consumption off peak, 0.1% of their electrical load would be shifted. Likewise, if 1% of consumers switched to a DSR programme and rescheduled 10% of their consumption off peak, 0.1% of their electrical load

[24] The term 'response' is used throughout this thesis to refer to the various actions that participants on DSR programmes take to adjust their electricity consumption according to the requirements of the programme.

would be shifted. As such, it is clear that uptake and response are of equal importance if residential DSR programmes are to achieve their objectives.

This reality informs the two central research questions explored in this thesis:

- What measures could electricity stakeholders – energy suppliers, DNOs, aggregators and other parties with an interest in promoting DSR – implement to maximise uptake[25] of residential DSR programmes?
- What measures could electricity stakeholders implement to maximise response on such programmes?

To answer the first question, a large-scale online survey of consumer preferences for residential DSR programmes was conducted (the 'switching survey'). This explored consumer willingness to switch (WTS) to several different DSR programme models which are well suited either to the current UK electricity system or to conditions which are likely to prevail as renewables become an increasingly important part of the UK energy mix.

Secondary research questions in this regard included the following:

- Do any specific consumer characteristics – such as socio-demographic, economic or attitudinal factors – increase WTS?
- To what extent are consumers willing to participate in DSR programmes when no financial incentives are provided?
- Can uptake of DSR programmes be increased by protecting consumers from financial losses if they choose to participate?

The second question was explored by conducting an information-only DSR trial, analysing the results and interviewing participants to learn more about the enablers and constraints of response experienced on the trial.

[25] The word 'uptake' is used throughout this thesis to refer to the act of switching to residential DSR programmes.

Secondary research questions in this regard included the following:

- What specific barriers prevent consumers from responding and what measures could help to mitigate those barriers?
- What consumer motivations can be leveraged to increase response?
- How can the way in which consumers are notified of periods when response is sought be optimised to increase response?

As the success of residential DSR programmes is contingent on high levels of consumer engagement, the research questions were analysed through the prism of the Fogg Behaviour Model (FBM) – a framework for driving behavioural change conceived at the intersection of computer science and psychology. By mapping the different aspects of switching and response to the FBM, the thesis aimed to identify strategies that would optimise the impact of residential DSR.[26]

1.6 Conclusions and thesis structure

This chapter began by outlining the role that residential DSR can play in the future UK electricity system. It also described the rationale for focusing this thesis on residential DSR and framed the principal research questions which the thesis sets out to answer.

The chapter went on to highlight the importance of both consumer uptake of new programmes and response once enrolled to the success of residential DSR, and explained how these considerations informed the principal research questions.

The remaining chapters of this thesis are structured as follows:

- Chapter 2 reviews the existing literature on consumer WTS to DSR programmes and response on such programmes, and explores the various factors that have been found to enable and constrain both uptake and response.
- Chapter 3 explores the different frameworks that have previously been used to conceptualise energy behaviours and explains the choice of the FBM as the main

[26] That is, elicit the greatest possible response from the greatest possible number of participating households.

theoretical framework for this thesis. It also describes how the framework was applied to understand the various factors involved in WTS and response.

- Chapter 4 presents details of the research methodology, explaining the rationale behind each method applied in furtherance of the research and the steps taken to ensure the reliability and validity of the data collected at each stage.
- Chapter 5 presents the results of the switching survey, which was conducted to explore consumer preferences for DSR programmes and to identify factors which might increase WTS. Drawing on the analysis of the survey data, this chapter also proposes measures for maximising uptake of DSR programmes.
- Chapter 6 discusses the DSR trial which was conducted to explore consumer response on an information-only DSR programme, describing the trial design and presenting the results of the quantitative analysis used to test response.
- Chapter 7 presents the findings from qualitative interviews conducted with trial participants and draws on this feedback to propose various measures which would help to maximise response.
- Chapter 8 outlines the main findings of the thesis and its contribution to the knowledge on residential DSR, and presents conclusions. The chapter also addresses limitations of the research and highlights avenues for future study that could build on the work presented in this thesis.

2. Residential DSR literature review

2.1 Introduction

This chapter reviews the literature on residential DSR in order to analyse the current thinking on how best to maximise uptake and response among UK consumers – the two central questions of this thesis.

In relation to uptake, the following is reviewed:

- literature which examines consumer preferences for different DSR programmes;
- literature which explores the factors that influence consumer decisions to switch to DSR programmes; and
- literature which identifies measures that might be adopted to increase WTS.

In relation to response, the following is reviewed:

- literature which examines consumer response on DSR programmes; and
- literature which explores the enablers and constraints of response on DSR programmes.

Given the focus of this thesis on UK consumers, the literature is predominantly UK based, although international literature was also reviewed where this helped to contextualise the analysis. The review encompasses both academic literature and policy-oriented papers and reports, since there is a growing body of research on DSR by UK government departments, Ofgem and other industry organisations.[27]

Section 2.2 of this chapter explores consumer preferences for different DSR programmes and discusses estimates of predicted uptake. Section 2.3 examines the factors which have been found to influence WTS, while Section 2.4 discusses measures for increasing WTS. Section 2.5 explores the response recorded on different DSR programmes and Section 2.6 explores enablers and constraints of response. Section 2.7 summarises the main findings from the literature review and identifies gaps which informed the empirical research for this thesis.

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[27] The methodology used to identify the literature for this review is discussed in Appendix I.

2.2 Consumer preferences for DSR programmes

As discussed in Chapter 1, for DSR programmes to be viable, a sizeable number of consumers will first need to switch to them and then successfully respond once enrolled. However, given the liberalised electricity supply market in the UK and the limited political and public appetite for energy demand reduction initiatives, DSR programmes are likely to be introduced on an opt-in basis (Faruqui *et al*, 2010; Ofgem, 2010). As such, it is important to understand what types of programme would be most acceptable to UK consumers, so that suppliers can tailor their offerings to maximise uptake. As Dütschke and Paetz (2013) observe: "the question of consumer preferences is crucial, because even if (some) dynamic pricing programs could influence electricity demand in a desired way, this presumes that consumers are also willing to opt for them." (p.227)

2.2.1 Predicted uptake of DSR programmes

Several studies have estimated the potential uptake of DSR programmes once these are rolled out (BEIS, 2016; DECC, 2010; DECC, 2012; DTI, 2005; Fell *et al*, 2015). While a 2005 government report calculated the potential benefits of residential DSR on the assumption that 10% of customers would switch to static ToU tariffs (DTI, 2005), subsequent government reports have forecast that 20% of consumers will have switched to static ToU tariffs by 2030 (DECC, 2010; DECC, 2012).[28]

However, this estimate may be optimistic. A systematic international review of residential DSR trials, pilots and programmes revealed that voluntary recruitment to such programmes rarely results in participation rates of more than 10% (Parrish *et al*, 2015). Likewise, in an analysis of 19 different DSR programmes offered in the US – including static ToU, critical peak pricing, critical peak rebate and variable peak pricing tariffs[29] – the US Department of Energy (2013) found that on average, 11% of consumers chose to switch.

The lacklustre uptake of DSR programmes thus far has been blamed on inertia and loss aversion (Hobman *et al*, 2016; Letzler, 2006). Loss aversion is the tendency to place greater weight on

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[28] In addition to those consumers on existing time-varying tariffs, such as Economy 7 and Economy 10.
[29] Variable peak pricing is similar to static TOU pricing, except that peak period prices change daily instead of seasonally, to reflect daily changes in system costs and reliability conditions (US Department of Energy, 2013).

potential losses than on similarly sized potential gains (Kahneman *et al*, 1991; Tversky and Kahneman, 1986). In the context of residential DSR, the potential losses that consumers associate with such programmes – whether financial or in terms of reduced utility from having to reschedule appliance use – could thus disproportionality reduce WTS:

> loss-aversion does not just apply to money…switching from a flat-rate to a TOU tariff also means losing flexibility over when household appliances can be run, which could reduce comfort and convenience (losses), which studies of loss-aversion suggest will be weighed twice as high as the potential gains (savings from off-peak usage) (Nicolson *et al*, 2017, p.83).

In a recent study of British consumers (N=2020), Nicholson *et al* (2017) found that 93% of the electricity bill payers surveyed were loss averse and had lower WTS to the ToU tariff presented ($p < 0.001$). Their findings suggest that financial incentives alone may be insufficient to overcome this pervasive tendency, and that alternative engagement strategies will likely be required to encourage people to switch (ibid).

Given the power of loss aversion in decision making, some scholars have suggested that the benefits of DSR tariffs should be framed in ways that focus on how they can help consumers to avoid losses or minimise risks (Hobman *et al*, 2016). Despite the apparent logic of this approach, however, studies have found that framing savings on DSR tariffs as avoided losses does not in fact increase WTS (Fell *et al*, 2015a; Nicolson *et al,* 2017).

A further potential obstacle to uptake of DSR programmes is the significant financial compensation that consumers may demand in exchange for greater flexibility in their consumption (Broberg and Persson, 2016; Richter and Pollitt, 2016). This may not align with the financial incentives on offer in practice: analysis commissioned by DECC predicts that between 2025 and 2030, households on static ToU programmes would save around £15 per year while those on critical peak pricing tariffs would save around £50 per year (Redpoint and Element Energy, 2012).[30] These figures may be insufficient to motivate many consumers to switch.

The low uptake of opt-in DSR programmes thus far – together with the fact that the financial incentives on offer may not be sufficiently attractive to encourage participation – underscores

[30] Even these estimates may be optimistic, since they assume that all savings – including operational, DNO reinforcement and open cycle gas turbine plant build costs – will be passed on to consumers (Redpoint and Element Energy, 2012).

the importance of understanding how such programmes can be best designed and marketed to maximise WTS.

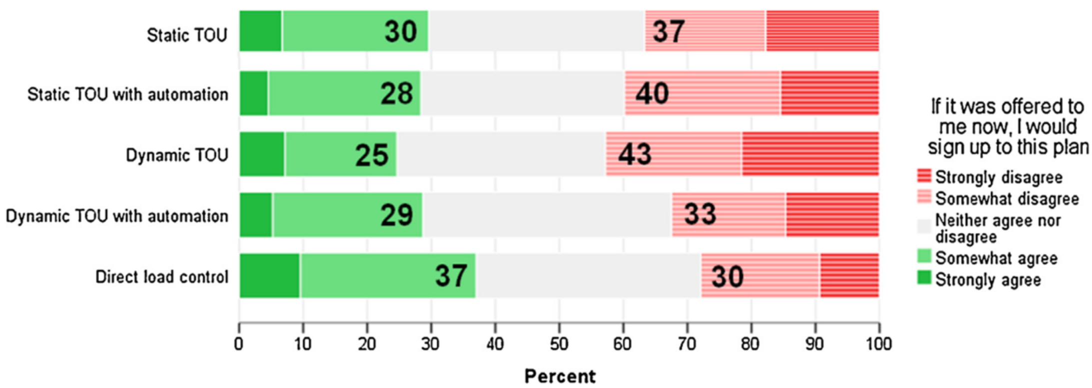
2.2.2 Preferences for different programme models

Fell *et al* (2015a) conducted a representative survey of British consumers (N=2148) to examine WTS to five different DSR programmes:

- a static ToU tariff (with and without automation);
- a dynamic ToU tariff (with and without automation); and
- direct load control of electric central heating systems.

The direct load control programme proved most popular, with 37% of respondents agreeing or strongly agreeing that they would switch to this programme if it were available, compared to 30% for the static ToU tariff without automation and 25% for the dynamic ToU tariff without automation (see Figure 4).

Figure 4. Preferences for ToU and direct load control programmes (Source: Fell *et al*, 2015a)



According to the authors, these findings demonstrate that "the principle of external control is acceptable to many people, in a context where the limits of control are strictly defined and the option of overriding it clearly available" (Fell *et al*, 2015a, p.8). Notably, the direct load control arrangements applied only to space heating, which was guaranteed to remain within one degree Celsius of user-determined settings and could be overridden at any time without penalty. While the authors acknowledge that these features may have increased the appeal of the proposed programme, there are further reasons for scepticism as to whether the findings of Fell *et al* (ibid) could be replicated in a real-world setting.

First, any benefit which might be derived from direct load control of central heating systems will be reduced if consumers are free to override external control at will. In practice, limits on the number of permitted overrides or override penalties will likely be a necessary feature of any such arrangements, since suppliers – and other electricity stakeholders such as DNOs and aggregators – will need to have confidence that response will be 'firm' to enable them to reduce wholesale, network and balancing costs (Owen *et al*, 2013; Owen and Ward, 2010; Workstream Six Interim Report, 2014). However, such restrictions would likely detract from the popularity of these programmes. As Fell *et al* (2015) themselves acknowledge, "there is clear prior evidence...that having an override function made, for some people, the unacceptable acceptable" (p.8).

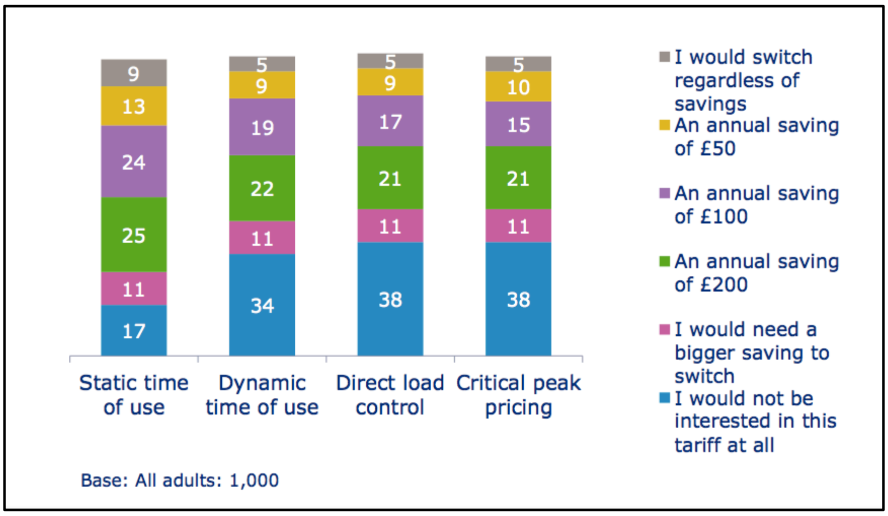
Second, as many respondents did not have electric heating, they were asked to imagine how they would respond if they had an alternative heating system; the hypothetical nature of this question may have distorted their response.

Finally, the fact that many respondents indicated that they would be willing to accept direct load control of their heating systems does not necessarily imply that this acceptance would extend to other types of external control. In this regard, a willingness to pay study conducted in Sweden revealed that consumers demanded greater financial compensation (Kr1,409) for accepting restrictions on electricity use between 5:00pm and 8:00pm than for allowing their heating systems to be controlled during the same period (Kr643) (Broberg and Persson, 2016).

The findings of Fell *et al* (2015) also contrast with those of several other studies (BEIS, 2016; Buryk *et al*, 2015; Darby *et al*, 2013) which suggest that consumers tend to prefer ToU tariffs to direct load control. A UK government survey which explored consumer preferences for different DSR programmes (N=1000) found that static ToU and dynamic ToU tariffs were both favoured over direct load control (BEIS, 2016). In Darby *et al*'s (2013) focus group research, which also explored UK consumer preferences for various DSR programmes (N=47), participants voiced concerns about the uncertainty and risk of direct load control, expressing "visceral unease" about "what was seen as invasion or disruption of household decision-making" (Darby *et al*, 2013, p.2330). Richter and Pollitt's 2016 survey of British consumer preferences for smart electricity service contracts (N=1892) likewise revealed that nearly 50% of respondents had reservations about external control of appliances – primarily due to privacy issues, but also over concerns that this could damage appliances or reduce the flexibility of appliance use. Finally, Buryk *et al*'s (2015) survey of US and EU consumers (N=160) similarly found that "services that ceded customer control of shifting to the utility were seen unfavourably" (p.193).

The literature further reveals that consumers prefer static ToU tariffs to dynamic ToU tariffs (BEIS, 2016; Buryk *et al*, 2015; Dütschke and Paetz, 2013; Fell *et al*, 2015a; Hall *et al*, 2016). For instance, a UK government study found that when offered the opportunity to save up to £200 annually on their electricity bills, 71% of respondents indicated WTS to a static ToU tariff, compared to 66% to a dynamic ToU tariff (BEIS, 2016).[31] Further, 34% indicated that they would not be willing to switch to a dynamic ToU tariff under any conditions, compared to 17% for a static ToU tariff. The preferences that respondents expressed for the DSR programmes presented in the study are shown in Figure 5.

Figure 5. Annual savings that would persuade people to switch to DSR programmes (Source: BEIS, 2016)



Qualitative research has confirmed this consumer preference for static ToU tariffs over dynamic ToU tariffs; for instance, Darby *et al* (2013) found that focus group participants (N=47) had greater WTS to static ToU tariffs than to dynamic ToU tariffs. As such, both quantitative and qualitative studies suggest that – at least initially – suppliers will likely see greater uptake of DSR programmes where these are based on static ToU tariffs.

Static ToU tariffs may thus represent a "staging post" on the consumer DSR journey, "preparing the way for real time pricing by accustoming users to the time-dependent value of electricity"

[31] These estimates are likely over-optimistic, as it is unlikely that annual savings of £200 could be realised in the foreseeable future (see Redpoint and Element Energy, 2012 and also Section 4.4). Furthermore, the preferences expressed may have been affected by hypothetical bias (see Chapter 4 for a discussion of how hypothetical bias can affect the results of stated preference studies).

(Darby and McKenna, 2012, p.768). This transition reflects the evolution of the UK electricity system itself. At present, the periods when residential DSR would afford the greatest benefits for suppliers – in terms of reduced wholesale costs – correspond closely to peaks in residential demand, which occur in the winter months on weekday mornings (7:00am-9:00am) and during the early evening (4:00pm-7:00pm) (Dudeney *et al*, 2014; Owen and Ward, 2010). However, from 2020 onwards – due to the predicted increase of renewables in the energy mix – these periods will not always coincide with peak residential demand (ibid). Consequently, dynamic DSR programmes are likely to become increasingly important for suppliers after 2020; in the meantime, static ToU tariffs can help to acclimatise consumers to new pricing models, promote awareness of the rationale for DSR and initiate changes in consumption patterns.

2.3 Factors that influence WTS

2.3.1 Ability and willingness

Many commentators suggest that WTS is primarily determined by two factors: consumers' ability and willingness to adapt their consumption patterns in response to changes in electricity prices (Ericson, 2011; Ofgem, 2010; Salies, 2013). As Ericson observes: "Whether consumption is flexible enough and suited for adjustment to the price will vary across households according to their ability and willingness to change behaviour." (2011, p.2542)

Ability depends on multiple factors, including household occupancy (Darby *et al*, 2012; Torriti, 2013), household composition (Ofgem, 2010), the types of appliance in households (Broberg and Persson, 2016; Ericson, 2011; Reisse and White, 2005), and whether those appliances have timers to facilitate unattended use (Fell *et al*, 2015a).

Studies suggest that consumers' ability to adapt their consumption patterns influences WTS. For instance, using a discrete choice model to analyse data from a residential dynamic pricing experiment in Norway, Ericson (2011) found that greater demand flexibility[32] increased WTS to a dynamic ToU tariff. Similarly, in a survey choice experiment involving US and EU consumers (N=160), individuals who thought that it would be easy to shift consumption off-peak were prepared to accept smaller financial rewards in exchange for switching: the discount they demanded was 17.5% lower than that sought by respondents who thought that shifting would be

[32] The study identified a number of household characteristics as indicators of flexibility, including whether households possessed home energy management systems or electric central heating, or were detached homes. All of these indicators were associated with increased WTS (Ericson, 2011).

difficult, effectively meaning that they would be willing to switch for almost any level of financial saving (Buryk *et al*, 2015). However, the authors note that the study involved a convenience sample and as such its indicative results should not be generalised; it should rather "be viewed as a feasibility study for a larger study with a more representative sample" (p.194). This suggests further scope for investigating how perceived ability to shift consumption influences WTS among a representative sample of the UK public.

That said, some consumers already use a significant amount of their electricity off-peak and may thus be in a position to save money on ToU tariffs without having to change their consumption patterns. This is potentially problematic for suppliers, as they would end up losing revenue if ToU tariffs were primarily taken up by these consumers (Ericson, 2011). As Ericson acknowledges:

> Offering electricity consumers time-differentiated tariffs may reduce peak consumption if consumers choosing the tariffs are demand responsive. However, one concern is that time-differentiated tariffs may attract consumers who benefit without responding to the price, simply because they have a favourable consumption pattern. (2011, p.2541)

Several studies have explored whether consumers choose to switch to static ToU tariffs because their existing consumption patterns will enable them to save money, but the results of these are inconclusive. Aigner and Ghali (1989), Train (1987) and Patrick (1990) found that consumers who switched to these tariffs already had more favourable consumption patterns than consumers on standard rates. However, Caves *et al* (1989), Baladi *et al* (1998) and Mountain and Lawson (1995) found no difference in consumption patterns; while Ericson (2011) likewise found that pre-existing favourable consumption patterns did not influence WTS to dynamic ToU tariffs.

These conflicting results mean that it is uncertain whether existing consumption patterns in fact influence WTS. Arguably, however, consumers may increasingly base switching decisions on their consumption patterns once the wider availability of technological devices such as smart meters and in-home displays gives them greater insight in this regard (Ericson, 2011).

Meanwhile, consumers' willingness to adapt their consumption patterns will largely depend on whether the benefits of doing so will outweigh the costs (Broberg and Persson, 2015; Ericson, 2011). These costs include the time and effort required to monitor pricing information, and any inconvenience associated with rescheduling household activities (ibid; Ofgem, 2010). As Broberg and Persson (2016) observe: "rescheduling energy use is by no means a costless task as it may impose significant disutility on households and firms in the form of transaction costs and everyday discomfort." (p.5)

2.3.2 Economic and socio-demographic factors

Economic and socio-demographic factors may also influence WTS. Two recent UK studies used survey choice experiments to explore UK consumer preferences for DSR programmes and investigate the factors that influence WTS (Fell *et al*, 2015; BEIS, 2016). Fell *et al* (2015) (N=2178) found no relationship between educational qualifications, income, housing tenure, gender, age, employment status or social grade and WTS.

By contrast, a 2016 UK government panel study (N=1000) found that certain demographic characteristics influenced WTS to DSR programmes including a static ToU tariff, a dynamic ToU tariff, a critical peak tariff and a direct load control programme (see Table 2) (BEIS, 2016). The authors report that: "There is an obvious split when it comes to smart tariffs whereby younger people, those in higher social grades, and those living in larger households are more receptive to the idea of switching to one. Older people, those in social grade DE, and those living on their own are least receptive to smart tariffs." (ibid, p.3)

Table 2. Consumers who were found to be most and least likely to switch (Source: BEIS 2016)

Most likely to switch to a smart tariff for savings up to £200	Least likely to switch to a smart tariff for savings up to £200
Aged 18-34	Aged 55+
Social grade AB	Social grade DE
4 or more people in the household	1 person households
Under 16s in the household	Over 65s in household

These divergent findings may be due to sampling differences. While both studies used quota sampling to ensure that respondents were broadly representative of the UK population, different methods were used to recruit respondents – one factor which explains why panels can sometimes produce widely varying results (Ipsos MediaCT, 2010). In the BEIS study, respondents were recruited "via a profiling survey covering background information on a range of variables including; demographics, characteristics of their property, and their attitudes, knowledge and behavior in relation to key BEIS policy areas" (BEIS, 2016, p.1). By contrast, respondents in Fell *et al* (2015a) were recruited by research agency Populus and comprised members of a panel assembled through online advertising.

A Swedish study which also used a survey choice experiment (N=918) to explore WTS to a direct load control programme supports the BEIS (2016) findings that younger respondents and those living in households with children may have greater WTS[33] (Broberg and Persson, 2016). Respondents who were university educated were also found to have greater WTS (ibid).

The same study found that higher-income households and apartment dwellers had lower WTS. The authors suggest that the latter may be less likely to own appliances such as dishwashers and washing machines, which may have made it more difficult for them to relate to the hypothetical contracts;[34] and in some cases they may also have limited control over the temperature of their homes (ibid). Although the authors do not speculate why higher-income households in their study had lower WTS, other scholars have suggested that this may be because the marginal utility that such households derive from the limited financial savings offered by DSR programmes is lower (Ericson, 2011).

The divergent findings of these studies suggest the value of further research to identify which socio-demographic factors influence WTS.

2.4 Increasing WTS to DSR programmes

2.4.1 Understanding the rationale for DSR

Residential consumers have a limited understanding of the environmental and societal benefits of participating in DSR programmes (Dütschke and Paetz, 2013; Hall *et al*, 2016; Kim and Shcherbakova, 2011; Ofgem, 2010), as such programmes primarily rely on financial incentives to promote uptake. Helping consumers to understand the attendant benefits – for themselves, the energy system and the environment – is thus regarded as an important step in fostering acceptance of such programmes (Buryk *et al*, 2015; Darby and Pisica, 2013; Faruqui *et al*, 2010b; Lewis *et al*, 2012; Salies, 2013).[35] As Lewis *et al* (2012) explain, consumers need to understand why suppliers are "embarking on this action, why the customer should be interested and why the community should be working together". (p.1)

[33] In this study, children under the age of 12.
[34] Not having these appliances may also have influenced WTS because they can provide opportunities for consumers to respond by rescheduling use.
[35] As has been done by the California Public Utilities Commission (Salies, 2013).

The premise that leveraging consumers' environmental and pro-social motivations in this way can increase WTS is supported by research showing that consumers place a high value on many of the potential benefits of DSR for the energy system and the environment. Exploring consumer attitudes through deliberative workshops in England, Scotland and Wales, and through a nationally representative survey (N=2441), Parkhill *et al* (2013) found that energy efficiency is almost universally regarded as important – as is protecting the environment and moving from a predominantly fossil fuel-based system to one based on renewable energy.

Kowalska-Pyzalska *et al* (2014) used agent-based modelling to study consumer switching to DSR tariffs and likewise found that reducing consumer "indifference" towards DSR increases WTS. The authors recommend that government, suppliers and environmental organisations cooperate to "communicate to consumers the potential benefits of adoption at social and personal levels [and] provide clear and full information to consumers – to reduce confusion and to increase the interest in dynamic pricing" (ibid, p.173).

Similarly, in a representative survey (N=2,441) conducted by Spence *et al* (2015), respondents who expressed greater concern about climate change were more accepting of a range of demand-side management measures, including external control of their water heating, fridge-freezers, washing machines and other appliances which switched themselves off if left on standby. The authors suggest that this finding implies that "environmental reasons for deploying demand side management should be considered when engaging members of the public" (ibid, p.553).

Further evidence that tapping non-financial motivations can increase WTS comes from the Low Carbon London (LCL) dynamic ToU trial. While trial participants received no explanation of why rates on the tariff were higher at certain times than at others, 60% of those interviewed once the trial had concluded indicated that highlighting the link between dynamic ToU tariffs and renewables would increase their WTS, with 70% stating that they would be interested in "helping society to use energy more efficiently" by switching (Carmichael *et al*, 2014). The authors concluded: "A strong piece of learning from the LCL dynamic ToU trial is that consumers are likely to engage more with dynamic ToU if the reasons or rationale for the tariff design, rate change events etc are explained clearly." (p.8)

That this approach can translate into higher uptake of DSR programmes is borne out by a successful initiative rolled out by the Pacific Gas and Electric Company in the United States. The utility successfully enrolled around 75,000 customers on a smart air-conditioning cycling programme based on a one-off payment of $25 and an appeal that participation would help to prevent power cuts and protect the environment (Faruqui *et al*, 2010).

When it comes to communicating the rationale for DSR to consumers, many studies emphasise the need for clarity and simplicity (Citizens Advice Bureau, 2014; Faruqui *et al*, 2010; Kowalska-Pyzalska *et al*, 2014; Ofgem, 2010). Hobman *et al* (2016) draw on concepts from psychology and behavioural economics to "identify how cost reflective pricing can be designed, depicted and delivered to enhance customer uptake and optimal usage" (p.455). The authors emphasise the importance of "keeping things simple", as when people are overwhelmed by the amount or complexity of information presented, they tend to 'satisfice' – that is, they process only enough information to reach a satisfactory rather than optimal decision (Simon, 1955), stick with the status quo (Kahneman *et al,* 1991; Samuelson and Zeckhauser, 1988), choose default options (Johnson and Goldstein, 2003) or avoid making a decision altogether (Anderson, 2003).

The way in which such information is presented can also influence WTS. Fell *et al* (2015b) conducted a representative survey of UK consumers (N=2178) to examine whether WTS could be increased by highlighting that participation in DSR benefits the environment and can help to prevent electricity blackouts. But although UK consumers often express strong preferences for a secure, environmentally sustainable electricity system (Parkhill *et al*, 2013; Ipsos Mori, 2012), this framing failed to increase WTS in Fell *et al*'s study. The authors thus argue that: "British consumers are unlikely to prioritise the environment and energy security when deciding whether to switch to a time-of-use tariff and that we need to find other ways of appealing to consumers." (Fell *et al*, 2015b, p.7)

However, one possible reason for the lacklustre response is that this information was presented in digital leaflets designed to resemble suppliers' promotional materials, and may thus have been ignored or mistrusted by the recipients. This hypothesis is lent credence by findings that consumers tend to be more sceptical of information provided by commercial companies than that provided by public bodies (Devine-Wright and Devine-Wright, 2005). UK consumers appear to be especially sceptical of information provided by suppliers: an Accenture study revealed that although globally 28% of consumers would trust their electricity suppliers to provide them with information to help them to manage their energy consumption, this figure drops to 16% in the UK (Accenture, 2011).

By contrast, in Buryk *et al*'s (2015) web-based choice experiment – which emphasised the environmental and system benefits of switching to DSR tariffs, but did not present tariff options as marketing from suppliers – participants required lower discounts in order to switch, demanding a 9.8% lower discount to switch to a static ToU tariff and a 12.8% lower discount to switch to a critical peak pricing tariff. The authors thus conclude that "customers may be more receptive to dynamic tariffs if the environmental and system benefits of these tariffs are highlighted" (ibid, p.194).

These findings suggest that the impact of highlighting environmental and system benefits of DSR on WTS may be affected by the way in which this information is presented. Since consumers are often sceptical of suppliers' profit motivations (Navigator, 2012; Simcock *et al*, 2013), it would be preferable if trusted independent organisations were to communicate the environmental and electricity system benefits of DSR to the wider public (ibid; Breukers and Mourik; Hobman *et al*, 2016). As Simcock *et al* (2013) observe:

> expecting energy companies to provide advice when the information they give may be considered suspect seems counter-productive… there is a need for government policies to encourage and nurture, in part through financial support, sources of impartial information that do not have, and are not perceived by the public to have, a financial or other vested interest in providing advice. (p.463)

To this end, Smart Grid GB has recommended that a "collaborative cross-value chain group" be established to promote consumer education and awareness of DSR and other smart grid benefits (Smart Grid GB, 2013).

2.4.2 Previous experience of ToU tariffs

Studies suggest that consumers who already have experience of ToU tariffs may have greater WTS. In a study which used focus groups to investigate consumer preferences for ToU tariffs, all participants with previous experience of a three-band ToU tariff (n=8) indicated that they would be interested in switching to static ToU tariffs once these became available (Darby and Pisica, 2013). While the small sample size of this study precludes generalisation (N=42), in another large-scale survey respondents on legacy ToU tariffs such as Economy 7 and Economy 10 were also found to have greater WTS to new DSR programmes (N=2178) (Fell *et al*, 2015a). That previous experience of ToU tariffs might translate into greater WTS is further supported by

Opower's findings (2013) that participation in one energy efficiency programme drives increased participation in subsequent programmes.[36]

Consumers with prior experience of more complex dynamic DSR tariffs also appear to be more accepting of these arrangements. While in theory, as discussed, consumers usually express greater WTS to static ToU tariffs than to dynamic tariffs (Buryk *et al*, 2015; Dütschke and Paetz, 2013; Hall *et al*, 2016), evidence suggests that in practice, consumers "find dynamic time of use tariffs better to live with than they might expect" (Fell *et al*, 2015, p. 9). In other studies, participants even indicated a reluctance to return to fixed-rate tariffs: 77% of those surveyed who took part in the LCL dynamic ToU trial (N=708) indicated that they would have liked to remain on the tariff after the trial concluded (Carmichael *et al*, 2014), while customers participating in the ComEd CAP real-time pricing programme indicated greater satisfaction with their tariff and supplier than customers on other tariffs (Parrish *et al*, 2015).

2.4.3 Guarantees and tariff opt-out arrangements

One major concern for consumers that may negatively affect WTS is the risk that their electricity bills may increase on ToU tariffs (Neuberg, 2013). Risk-averse consumers are thus considered less likely to switch to DSR programmes (Faruqui *et al*, 2010b). To address these concerns, participants on the UK Customer Led Network Revolution (CLNR) and LCL ToU trials were guaranteed that they would not be charged more than they would have paid on a standard fixed-rate tariff (Bulkeley *et al*, 2014; Schofield *et al*, 2014).

Given that consumers with experience of ToU tariffs are often willing to continue on these tariffs or try new ToU tariffs, guarantees that consumers will not pay more on such tariffs for an introductory period might represent one way to increase WTS and maximise uptake of DSR programmes. Time-limited guarantees of this nature have previously been offered by electricity suppliers in the United States (US Department of Energy, 2013).

Guarantees will likely become even more important to encourage switching to dynamic ToU tariffs once these are rolled out. In Darby *et al*'s study (2013), many focus group members indicated that they would not consider switching to real-time pricing in the absence of such guarantees. Further, while in future new technologies might help consumers to estimate the savings they could make from switching to static ToU tariffs (Erikson, 2011; Fischer *et al*,

[36] This finding was based on analysis of Opower deployments by 11 US utilities (Opower, 2013).

2013), it may prove impossible to predict potential savings for dynamic tariffs, as the timing of price periods will fluctuate from day to day depending on available generation (Faruqui, 2010; Neuberg, 2013). Auer *et al* (1997) discuss a dynamic ToU study in Finland which guaranteed participants that their annual electricity bill under the trial tariff would not exceed the amount they would have paid under their previous tariff. At the end of the pilot, 75% of participants indicated that they would be prepared to switch permanently to the tariff – a result which suggests that price guarantees might encourage a larger number of consumers to switch to dynamic DSR programmes. As Lewis *et al* (2012) argue:

> If customers are to willingly involve themselves in a relationship step change, such as adopting dynamic tariffs, something that demands trust in the provider of those tariffs, it can be beneficial to provide promises and guarantees, at least initially, until the customer's perception of risk of change is overcome or sufficiently reduced. (p.42)

Similarly, if consumers are locked into ToU tariffs – for example, by penalties for switching back if the tariffs prove unsuitable – this may also reduce WTS. Some have thus argued that consumers should be given the chance to try DSR programmes with the possibility to opt out penalty free if they find that these do not suit their needs (Citizens Advice Bureau, 2014; Kowalska-Pyzalska *et al*, 2014; Lewis *et al*, 2012; Neuberg, 2013).

2.4.4 Potential risks of financial incentives

The importance of harnessing non-economic motivations to promote WTS is further underpinned by studies which have shown that in certain circumstances, financial incentives can actually discourage the desired behaviour.

Deci (1971) explains that an individual is "said to be intrinsically motivated to perform an activity when he receives no apparent rewards except the activity itself" (p.105). However, when people are offered extrinsic incentives such as financial rewards, this can 'crowd out' intrinsic motivation, reducing overall motivation to engage in behaviour (Deci, 1971; Gneezy *et al*, 2011; Pritchard *et al*, 1977). Frey and Oberholzer-Gee (1997) present an example in the energy context: when residents of a Swiss town were asked whether they would accept the construction of a nuclear waste facility in their community, over 50% agreed. However, when the residents were each offered compensation of between \$2,175 and \$6,525, acceptance for the facility dropped to around 25%. The authors argue that: "The use of price incentives need to be reconsidered in all areas where intrinsic motivation can empirically be shown to be important. We speculate that this may be the case in work relationships characterized by incomplete contracts as well as in environmental policy." (p.754)

Sütterlin *et al* (2011) likewise contend that financial incentives *per se* can discourage environmentally conscious consumers from conserving electricity by crowding out intrinsic motivation. To avoid this, they recommend that financial incentives be presented as supporting other reasons for conserving energy, rather than as an end in themselves (ibid). In the context of WTS, an MTurk survey (N=1406) found that emphasising the monetary benefits of participation in a peak load shifting programme reduced WTS, compared to when the environmental benefits alone were highlighted (Schwartz *et al,* 2015).

Studies have further shown that modest financial rewards can have a particularly detrimental effect on intrinsic motivation. Gneezy and Rustichini (2000) discuss two examples. In the first, students who were offered a small reward (equivalent to $0.03) for each IQ test question answered correctly gave fewer correct answers (23) than a control group offered no reward (28); two further groups which were offered either $0.30 or $1 for each question answered correctly gave a higher number of correct answers (34 or more). In the second, students who collected charitable donations invested more effort when not financially incentivised than when a small incentive was offered – although larger incentives led to increased effort. Taken together, these studies suggest that if financial incentives are used to incentivise behaviour, it is best "to pay enough, or don't pay at all" (*ibid*, p.1).

This is particularly relevant in the case of residential DSR since, as previously discussed, the savings that are likely to be passed on to consumers in exchange for participation are likely to be modest. This limited financial incentive may thus undermine some consumers' environmental and pro-social motivations for participating in DSR and thereby reduce WTS.

2.5 Response on DSR programmes

2.5.1 Response on DSR tariffs

There is abundant evidence that ToU tariffs can successfully promote load shifting to off-peak periods (Chan *et al*, 2014; DECC, 2012; Faruqui and Sergici, 2009; Parrish *et al*, 2015; Stromback *et al*, 2011). Frontier Economics and Sustainability First reviewed 15 residential ToU tariff trials that took place between 2000 and 2010 and found that financial incentives normally resulted in load shifting, but that the average reduction in peak demand varied considerably between trials (between 0% and 22%) (DECC, 2012).[37] The Carbon Trust's analysis of trials in the US, the UK and Ireland likewise revealed that residential ToU tariffs usually resulted in load shifting; peak demand reductions ranged from 0% to 11.6%, with an unweighted average of 7% (Carbon Trust, 2012).

Stromback *et al* (2011) reported the findings from a systematic international review of around 100 DSR pilots involving over 450,000 consumers. On average, critical peak pricing yielded the largest reductions in demand (16%), followed by critical peak rebates and real-time pricing (both 12%) and static ToU tariffs (5%). Parrish *et al* (2015) found similar levels of response to static ToU tariffs (6%), critical peak rebates (12%-13%) and real-time pricing (16%), but a greater response to critical peak pricing (24%).

The LCL dynamic ToU trial in the UK explored whether consumers could be financially incentivised to vary their electricity consumption depending on available wind generation (Schofield *et al*, 2014). As discussed in Chapter 1, dynamic ToU tariffs are especially beneficial where a significant proportion of electricity is generated from intermittent renewable resources: if consumers can adjust their consumption according to availability, these resources can be more efficiently integrated into the energy mix.

The reported response on the LCL dynamic ToU trial was an average increase in demand of 0.05 kWh per household during high price periods, which occurred at any time of day, and an average decrease of 0.05 kWh per household during weekday morning and evening peaks (Schofield *et al*, 2014).[38] Perhaps unsurprisingly, when participants were called on to increase demand at night, response was significantly lower – even those households which responded the most were unable to increase demand by more than 0.05 kW/hour. In the authors' view, this suggests that consumers' capacity to assist in balancing supply and demand is currently limited to waking hours; but that in future, "a more consistent response may be possible using autonomously responding appliances" (ibid, p.9). The potential for such appliances to facilitate response is discussed further in Section 2.6.4.

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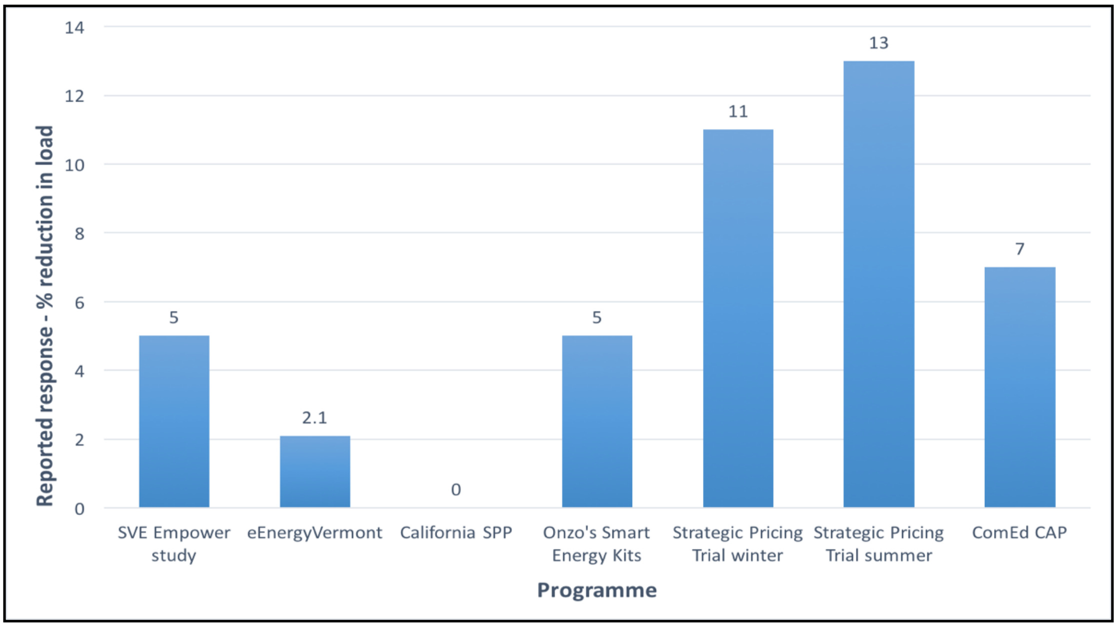
[37] The tariffs reviewed offered peak to off-peak price differentials ranging from 140% to 408% (DECC, 2012).
[38] Based on average annual household consumption estimates from Intertek (2012) of 3567 kWh, this change is equal to a 24% reduction or increase in demand at these times.

2.5.2 Response on information-only programmes

As part of the literature review, seven information-only residential DSR trials which took place between 2006 and 2012 were compared. The response reported for each of these trials is presented in Figure 6.[39]

Figure 6. Reported reduction of peak load for information-only DSR programmes (Source: adapted from Parrish *et al*, 2015)



The reported average peak reduction on these trials varied from 0% in the case of the California SPP trial to -13% in the case of EnergyAustralia's summer Strategic Pricing Trial.[40] However, although some of the trials resulted in peak load reductions, the efficacy of information-only DSR programmes remains uncertain. The California SPP trial reported no clear response (Parrish *et al*, 2015); while the -2.1% response on Green Mountain Power's eEnergyVermont trial was not statistically significant (Blumstack and Hines, 2013).

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[39] Figure 6 is based on information-only programmes reviewed in Parrish *et al*, 2015, Onzo, 2011 and Strengers, 2010.

[40] One possible explanation for the greater response seen on EnergyAustralia's Strategic Pricing trial than the other information-only programmes is the relative infrequency of events: a maximum of 12 events were held per year for each year of the trial (Miller, 2007). This contrasts with some of the other programmes such as Onzo's Smart Energy Kit trial, which required the kind of frequent response that would be sought from consumers on ToU programmes.

In the UK context, evidence of the efficacy of information-only DSR programmes is also scarce, with Onzo's Smart Energy Kit trial the only known example. In this trial – which took place between October 2010 and June 2011 – Scottish and Southern Electricity issued 25,000 of its customers with in-home displays that provided notifications of peak demand between 4:00pm and 7:00pm each day. Customers responded by reducing demand by an average of 5% at these times (Onzo, 2011).

This dearth of evidence has prompted some scholars to suggest that further studies are needed to examine how non-financial signals might be used to facilitate response (Hall *et al*, 2016; Song *et al*, 2014; Strengers, 2010). Strengers (2010), for example, points out that since some consumers have non-financial motivations for responding, the "entrenched assumptions underpinning variable pricing programs need to be expanded and extended to consider other potential theories, methods and motivations for change" (p.7320). Similarly, Hall *et al* (2016) highlight the need for further DSR research which explores "non-economic influences".

2.6 Increasing response on DSR programmes

2.6.1 Educational measures

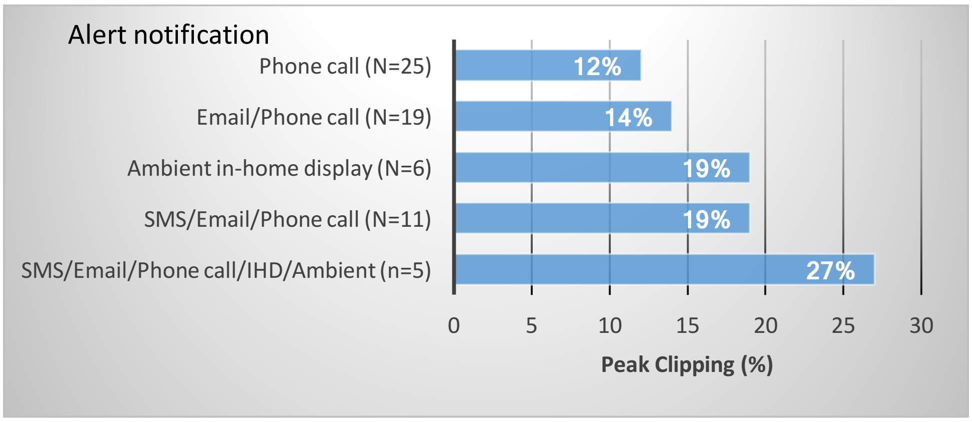
In order for consumers on DSR programmes to respond successfully, they need to know the timings of peak and off-peak price periods. However, studies have found that they often lack this essential information (Consumer Focus, 2012; Heberlein, 1982; Nicholls and Strengers, 2014). For example, some consumers mistakenly schedule appliance use for peak periods in the belief that these are in fact off-peak (Consumer Focus, 2012; Heberlein, 1982; Nicholls and Strengers, 2014). As Nicholls and Strengers (2014) observe, this can hinder response: "Householder confusion about their electricity tariff undermines opportunities for consumers to benefit, or avoid financial penalty, from time-of-use (or other variable pricing) tariffs." (p.49)

Moreover, some consumers fail to respond entirely. In a study of households on legacy ToU tariffs such as Economy 7 and Economy 10, Consumer Focus (2012) found that 38% of the survey sample did not have storage heating or use any appliances off-peak. Over half of the participants felt that additional information – especially regarding cheaper usage times – would have enabled them to make better use of the tariff (ibid). In this regard, a systematic international review of DSR pilots by Stromback *et al* (2011) revealed that when consumers were provided with detailed information about their ToU tariff and tips and advice on how to conserve energy, this increased response: peak demand reductions on ToU tariffs were on average 6% for those who received such information, compared with 4% for those who did not (for consumers on critical peak tariffs, the figures were 16% and 13%, respectively). Owen *et al* (2013) likewise argue that ToU tariffs should be supported with educational measures, and that these should go beyond mere explanations of tariffs to include suggestions regarding the use of timers, heating systems, digital control devices and appliances.

2.6.2 Multi-modal notifications

While fridge magnets and stickers can prove an effective way to provide consumers on static ToU tariffs with information about peak and off-peak periods (Commission for Energy Regulation, 2011), it is essential that consumers on dynamic ToU tariffs are notified when price periods change, since these periods will vary from day to day. Stromback *et al* (2011) compared peak reduction response on 66 critical peak pricing, critical peak rebate and real-time tariff trials, and found that response correlated positively with the number of different channels through which participants were notified about changes in price periods. Figure 7 shows the average peak reduction response on these trials depending on how participants were notified about changes in price periods.

Figure 7. Average peak reduction depending on alert notification (Source: adapted from Stromback *et al*, 2011)



Interestingly, ambient in-home displays – devices which provide notifications of changes in peak periods by changing colour – were found to be particularly effective, even when they were the only notification medium used (ibid). An average peak reduction of 19% was reported for programmes that notified participants using ambient in-home displays only – the same as for programmes that used a combination of email, phone call and text message (ibid). The authors suggest that these devices may be particularly effective facilitators of response because their attractive design means they are often prominently situated where everyone in the household can see them (ibid); others posit that ambient devices are more intuitive to understand than standard in-home displays and may thus promote greater response (Parrish *et al*, 2015).

2.6.3 Feedback

Consumers on DSR programmes are usually provided with feedback about their electricity consumption to encourage response (Parrish *et al*, 2015). The rationale for this is based on the information deficit model (Hargreaves *et al*, 2010), which assumes that consumers lack awareness of their electricity consumption owing to its "invisibility" (ibid; Fischer, 2007), and that feedback will increase energy visibility and give consumers greater insight into their consumption patterns (Buchanan *et al*, 2014). Analysis conducted by Stromback *et al* (2011) confirms that providing consumers with feedback about their electricity use – whether through details of the price they are paying for electricity at different times, information on how much electricity they are using or more frequent billing – is critical to the success of ToU trials: the authors found that peak reductions were 40% greater on trials involving feedback.

2.6.4 Smart appliances

Unsurprisingly, 'active occupancy' – defined as when consumers are both at home and awake – significantly influences response on DSR programmes (Torriti, 2013). However, appliances which can be controlled remotely or which automatically switch on or off can facilitate response even when households are not actively occupied (Faruqui *et al*, 2010b; Harding and Lamarche, 2016).

In their analysis of 15 pilot ToU programmes in the US, Faruqui *et al* (2010b) found that critical peak programmes supported by 'enabling technologies' – such as two-way programmable thermostats and gateway systems that allow multiple end uses to be controlled remotely – reduced peak usage by an average of 36%, compared to 17% for those without. Similarly, a recent randomised controlled trial in the US (N=1011) found that consumers with electric central heating systems reduced peak electricity consumption by 48% when provided with smart thermostats (Harding and Lamarche, 2016).

Other studies have shown that cold appliances could make a significant impact on peak demand: the Household Electricity Study (Intertek, 2012) revealed that if these appliances were fitted with controls that enabled them to avoid using electricity during the evening peak (6:00-7:00pm), up to 10% of peak power could be suspended for half an hour, or up to 70W per household (Palmer *et al*, 2013). However, while considerable benefit might be achieved through such controls, consumers may be reluctant to accept them: in a UK Energy Research Centre study (N=1800) which asked respondents whether they would accept three demand-side management scenarios,[41] external control of cold appliances was viewed least favourably, with 47% indicating it was unacceptable (Parkhill *et al*, 2013).

Several other studies have examined consumer attitudes towards smart appliances in EU countries (BEIS, 2016; Mert *et al*, 2008; Ofgem, 2010; Platchkov *et al*, 2010). In a survey of 2,900 households in Austria, Germany, Italy, Slovenia and the UK, Mert *et al* (2008) found that respondents were generally receptive to the idea of smart appliances, with 80% indicating that they would accept the smart operation of washing machines, tumble dryers, dishwashers, electric heating systems and cold appliances. However, the authors acknowledge that their findings should be treated cautiously, because participants were overwhelmingly male, academically educated and technologically knowledgeable (ibid). A recent UK government study (N=1000) likewise found that respondents were receptive to the idea of smart appliances, with 51% expressing interest in purchasing at least one form of smart appliance (BEIS, 2016). Respondents reported greatest interest in smart washing machines (39%), followed by smart dishwashers (37%).

2.6.5 Response constraints

(a) Immediate need and appliance use concerns

Consumers' willingness to reschedule appliance use in order to respond has previously been explored through surveys and focus groups (BEIS, 2016; Mert *et al*, 2008; Nicholls and Strengers, 2014; Ofgem, 2010; Platchkov *et al*, 2010), as well as through further research with DSR trial participants (Bulkeley *et al*, 2014). For instance, in a BEIS consumer panel study (N=1000), respondents reported that they would be most willing to be flexible about when they used washing machines (79%), dishwashers (68%), and chargers (68%) in order to respond on DSR tariffs (BEIS, 2016).

Wet appliances – washing machines, tumble dryers and dishwashers – are often considered most conducive to response in the UK context (Bulkeley *et al*, 2014). Were the use of washing machines, tumble dryers and dishwashers successfully rescheduled off-peak, this would

[41] The other two scenarios involved appliances such as digital boxes, televisions and computers that switched themselves off if left for an extended period on standby, and showers that turned off after a set period (Parkhill *et al*, 2013).

reportedly shift around 8% of residential peak demand (Palmer *et al*, 2013).[42] However, some consumers have expressed concerns that noise from these appliances might disturb the sleep of household members or neighbours, or that using them unattended might be unsafe (Butler *et al*, 2013; Darby, 2013; Mert *et al*, 2008; Ofgem, 2010). Others have indicated that they would be unwilling to leave clothes in washing machines or tumble dryers overnight (Cambridge Electricity Policy Research Group Survey, 2010).

A survey conducted by Platchkov *et al* (2011) explored whether UK consumers would respond on a ToU tariff by delaying the use of appliances until after 9:00pm. Respondents were relatively amenable to delaying the use of washing machines (65%) and dishwashers (38%), but were far less flexible about delaying watching television (17%) or cooking (1%). These findings are in line with other studies which confirm that consumers are often willing to reschedule the use of wet appliances to respond (Nicholls and Strengers, 2014; Powells *et al*, 2014), but reluctant to reschedule watching television or cooking meals (Ofgem, 2010).

By contrast, evidence from ToU trials in the UK suggests that in practice, some consumers are in fact willing to reschedule cooking times (Bulkeley *et al*, 2015; Carmichael *et al*, 2014). For instance, on the LCL dynamic ToU trial, 35% to 40% of participants who owned an electric hob or oven reported that cooking could more than "occasionally" be done flexibly, at times which coincided with the low rate.

This finding is significant, as the amount of electricity used for cooking accounts for a sizeable proportion of total residential demand – 17.5% in 2014 (DECC, 2015) – with much of this arising during the evening peak. There is thus scope for further studies to investigate "the types of lifestyle changes, particularly around cooking appliances (which contribute approximately 20% of evening peak loads), that UK consumers are willing to adopt under modern ToUT interventions" (Chan *et al*, 2014, p.5).

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[42] This figure is based on analysis carried out on data collected from the Household Electricity Survey (Palmer *et al*, 2013).

(b) Less responsive consumer segments

Many studies have found wide variations in individual household response on DSR programmes (Bulkeley *et al*, 2014; Faruqui and Sergici, 2010a; Reise and White, 2005; Schofield, 2014). For example, Faruqui and Sergici (2010b) found that 30% of households accounted for approximately 80% of the response on a California trial; while Reise and White (2005) found that 44% of a sample of 1,300 Californian households failed to respond to ToU pricing at all. Certain household demographics have been identified that correlate to reduced response, as discussed below.

Household income: Some scholars contend that where the costs of electricity are marginal for households, this may reduce sensitivity to price signals (Gyamfi, 2013; Reisse and White, 2005). Evidence from DSR studies is inconclusive in this regard. Some have found that the magnitude of DSR, when expressed as a percentage of peak load, is higher for low-income households than for high-income households (Thorsnes *et al*, 2012; Wolak, 2010). Conversely, the CLNR ToU trial found that high-income households reduced their evening peak consumption by a higher percentage than low-income households (Bulkeley *et al*, 2014); and in three of the five ToU trials in the US discussed in Faruqui *et al* (2010), high-income households exhibited above-average response.

Given these conflicting findings, it is uncertain how household income affects response. However, it seems reasonable to expect that some higher-income households may be less responsive because the marginal utility from saving money on their electricity bills is lower. At the same time, since household income is positively correlated with the amount of electricity that households consume (Bulkeley *et al*, 2014; Druckman and Jackson, 2008), higher-income households have greater potential for responding if they can be persuaded to participate in DSR programmes.

This uncertainty strengthens the hypothesis that the prevailing focus on price as the dominant motivator for participating in DSR may be misguided. As Gyamfi *et al* (2013) observe, DSR programmes too often rely on price-based mechanisms alone:

> From the literature on demand response, the fundamental assumption has been that there is no better signal than price and that socially optimum behaviour can be brought about with ‘high’ prices. Despite the growing interest in price-response, experience with such programs shows mixed results. (p.76)

As such, highlighting the non-financial benefits of DSR and providing opportunities for consumers to participate in information-only DSR programmes should help to maximise response.

Children: Studies have shown that family households on DSR programmes tend to be less responsive (Bulkeley *et al*, 2015; Nicholls and Strengers, 2014). For example, in contrast to other households, those with children under the age of five on the CLNR ToU trial did not reduce their electricity consumption during the 4:00pm to 8:00pm peak (Bulkeley *et al*, 2015). Nicholls and Strengers (2014) suggest that many family households are unlikely to shift household routines in response to ToU tariffs since energy use considerations are normally a low priority for them: "[They] may be more likely to deliberately ignore a time-of-use tariff, even when the times are known, because it represents an unacceptable trade-off against important family priorities and activities considered 'non-negotiable' during the family peak period." (Ibid, p.58)

However, although the families which took part in Nicholls and Strengers' study (2014) were mostly unenthusiastic about ToU tariffs, they were more receptive to the idea of receiving infrequent 'peak alerts'. These tended to be perceived as an acceptable disruption, since they shifted the emphasis away from financial penalties and towards rewards for "'do[ing] their bit' for the ongoing security and affordable supply of electricity for all" (ibid, p.59). This suggests that even family households may afford some potential for residential DSR if their participation is sought in a way that resonates with them and at a frequency that works for them.

2.7 Conclusion and research gaps

This section summarises the findings from the literature review in relation to maximising uptake and response, and highlights gaps in the literature which are subsequently explored in this thesis. These gaps are discussed further in Chapter 3 within the framework of the FBM.

2.7.1 Increasing WTS

Several recommendations for increasing WTS to DSR programmes can be identified from the literature review. The findings suggest that WTS is greater when consumers are informed of the environmental and pro-social benefits of DSR, and that this information should ideally be disseminated by organisations with no financial interest in such programmes, in order to engender trust.

The literature review also identified three important knowledge gaps. First, although one survey of British consumers found that socioeconomic attributes had no effect on WTS (Fell *et al*, 2015a), other studies suggest otherwise, with age, social class and household size all found to influence WTS (BEIS, 2016). There is thus scope for further research to examine the influence of these variables on WTS.

Second, although the literature suggests that offering time-limited financial guarantees and penalty-free opt-outs arrangements might help to increase WTS, no research has explored whether these incentives in fact increase WTS.

Finally, while some studies have explored WTS to various DSR programmes and direct load control arrangements, none has explored WTS to information-only programmes – in terms of both the number of consumers who might be willing to switch and whether any specific factors can be identified which influence WTS to such programmes.

2.7.2 Increasing response

The literature review revealed limited empirical evidence of how consumers who do decide to switch to information-only DSR programmes actually respond once enrolled; and no known studies have examined whether consumers would change consumption patterns on dynamic information-only programmes based on available wind generation. To investigate this gap in knowledge, a trial was designed and conducted as part of this research (see Chapters 4, 6 and 7).

The literature review revealed several factors which increase response on DSR programmes, including educational measures, the provision of feedback and possession of smart appliances. Multi-modal notifications were further found to increase response on dynamic DSR programmes.

The literature review also revealed that some consumers on DSR programmes changed cooking times in order to facilitate response. As this could have a significant impact on demand were it to happen at scale, the interviews with participants on the dynamic information-only trial conducted for this thesis sought to explore whether interviewees responded by changing their kitchen practices.

Finally, studies suggest that family households – and in particular, households with young children – find response more difficult. The interviews discussed in Chapter 7 thus aimed to determine whether this was the case for families on the trial and explore whether anything might facilitate response for such households on future DSR programmes.

The next chapter discusses the theoretical frameworks that have been used to understand energy related behaviours. It also discusses the rationale for using the FBM as the principal model for exploring the DSR behaviours studied in this thesis.

3. Theoretical framework

3.1 Introduction

This chapter analyses the theoretical frameworks that commonly inform energy research and interventions to identify the most suitable model for exploring the key behaviours examined in this thesis: switching to DSR programmes and response on such programmes.

Section 3.2 discusses the two opposing paradigms that have predominantly informed approaches to energy research and interventions. Section 3.3 characterises the DSR behaviours explored in this thesis, with the aim of arriving at a suitable framework through which to conceptualise them. Section 3.4 discusses the discipline of captology pioneered by Fogg and Section 3.5 introduces the FBM: a model rooted in this discipline which is used in this thesis to explore the factors which influence uptake and response on residential DSR programmes. Section 3.6 explains how the FBM is applied in the thesis to this end and Section 3.7 concludes.

3.2 Theoretical conceptualisations of energy behaviours

Eliciting change in energy behaviours requires both a sophisticated understanding of behavioural drivers and an appreciation of how these could inform interventions to best effect. Over the years, numerous frameworks from across the social sciences have been applied to conceptualise energy behaviours, with varying degrees of success.

Wilson and Dowlatabadi (2007) categorise these different frameworks as falling within one of two distinct paradigms. The first – which underpins disciplines as diverse as conventional and behavioural economics, technology adoption and planned behaviour theory, and social and environmental psychology – is predominantly personal, foregrounding the primacy of the individual as a "rational actor", albeit one whose decisions are informed by a range of influences, both conscious and unconscious, internal and external (ibid). The dominant paradigm of modern discourse, this has traditionally informed much energy policy and interventions. In the UK, for example, Ofgem has used behavioural economics to explore tariff switching in the retail electricity market (Ofgem, 2011), highlighting four factors which can prevent consumers from switching or lead them to make sub-optimal switching decisions:

- Status quo bias (Kahneman *et al*, 1991; Samuelson and Zeckhauser, 1988) – the tendency to stick with one's current position;

- Limited consumer capacity (Ofgem, 2011) – that consumer decision making is limited by the time, attention and knowledge available;
- Loss aversion (Kahneman *et al*, 1991; Tversky and Kahneman, 1991) – that potential losses have a stronger influence on preferences than potential gains; and
- Time inconsistency (Ainslie and Haendel, 1983; Shui and Ausubel, 2005) – that preferences change over time, creating potential inconsistencies.

Hobman *et al* (2015) have likewise drawn on insights from behavioural economics to explore how DSR programmes could be designed to increase uptake and response. The measures they propose include:

- designing tariffs where the potential gain to be made (ie, the off-peak reduction in price) is greater than the potential loss (ie, the peak increment in price) (to address loss aversion);
- taking advantage of 'trigger points' – such as when customers are moving home or their contracts are ending – at which they may be more amenable to switching (to address status quo bias);
- presenting information on tariffs and DSR to consumers in a clear, concise and understandable format (to address limited consumer capacity); and
- providing customers with hints and tips, as well as automated technology, to help them change their consumption patterns (to address limited consumer capacity).

The second, more contemporary paradigm identified by Wilson and Dowlatabadi (2007) is rooted in sociology and challenges the assumption of an autonomous decision maker, positing that "decisions are instead 'constructed' or determined by social and technological systems" (p.186). It is thus contextual, foregrounding the social matrix within which decisions are made and the external structures that serve to inform and constrain individual actions. In the energy context, this sociotechnical framework was adopted for the research conducted in the CLNR ToU trial, which conceptualised energy use as a 'gear system' comprising five distinct cogs:

- Conventions – the parameters of what is generally regarded as 'normal' energy use;
- Capacities – the ability of different objects to use energy and provide energy services;
- Rhythms – the temporal patterns of activity;
- Economies – the management of social, natural and financial resources; and
- Structures – the systems and constructs that govern the socio-material world (Bulkeley *et al*, 2014).

Wilson and Dowlatabadi (2007) further observe that, regardless of which paradigm is adopted, a discrepancy – the 'energy efficiency gap' – has traditionally persisted between the technological and economic potential afforded by different interventions and actual market behaviour. Decision models predicated on the assumption of the autonomous agent seek to resolve this "by targeting individuals with universally applicable technologies, practices, and standards" (ibid, p.186). By contrast, those premised on social and technical systems view household energy uses as "adaptive responses to particular local conditions and norms" which "are highly heterogeneous" (ibid, p.186), and seek to close the gap through a greater understanding of this social dimension of energy use.

But ultimately, suggest Wilson and Dowlatabadi (2007), this dichotomy is unhelpful, as neither paradigm is in itself sufficient to bound all possible energy behaviours – as the limited impact of many interventions bears out. They further posit that any attempt to reconcile these diametric positions in a single universally applicable framework may be doomed to failure as "a quixotic simplification, idealized and with merit perhaps, but quite mad given its scant chance of success" (p.191). Instead, they advocate a collaborative multi-disciplinary approach, with decision models matched to the type and context of the specific behaviour targeted on a case-by-case basis. In selecting the appropriate decision model to achieve a desired outcome, "critical questions for intervention designers to ask are where on the individual-to-social, instinctive-to-deliberative, psychological-to-contextual, and short-to-long-term decision continua their interventions are targeted and which of the determinants of decisions they are aiming to influence". (p.192)

3.3 Characterising DSR behaviours

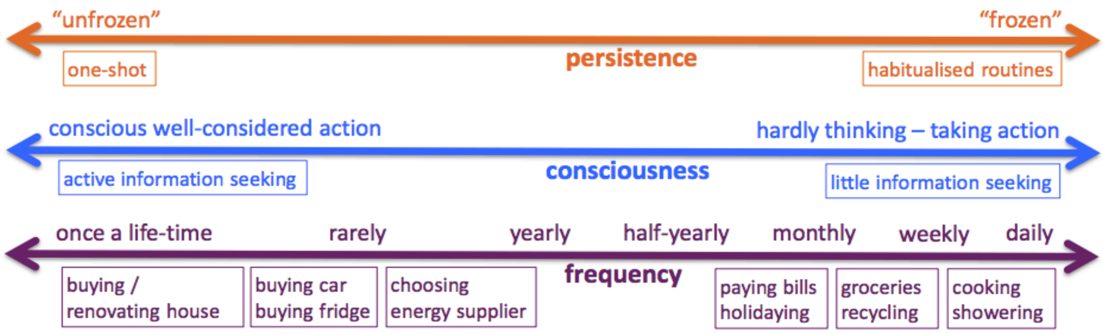
In applying this approach to arrive at a theoretical framework for this thesis, the starting point was thus to characterise the behaviours with which the research is primarily concerned – that is, switching to DSR programmes and response on such programmes.

In their study of DSR programme design, Breukers and Mourik (2013) distinguish between 'intentional' and 'routine' behaviours. 'Intentional' behaviours are performed at a single point in time with a greater degree of conscious awareness, such as investing in energy efficiency improvements (eg, installing double glazing or purchasing more efficient appliances) or changing thermostat settings. By contrast, 'routine' behaviours are recurring, habitual activities which are performed with less conscious awareness (eg, cooking, washing and cleaning).

While switching to a DSR programme is an intentional one-off behaviour, responding requires changes to routine behaviours, such as rescheduling appliance use and changing the way in which habitual household practices are performed. Before they can be changed, these routine behaviours need to be ‘unfrozen’ by introducing a greater degree of conscious awareness in their performance (Breukers and Mourik, 2013; Jackson, 2005; Powells *et al*, 2014). As Jackson explains: “A vital ingredient for changing habits is to ‘unfreeze’ existing behaviour – to raise the behaviour from the level of practical to discursive consciousness.” (Jackson, 2005, p.xi-xii)

Figure 8 illustrates the continuum on which these behaviours are situated, with intentional behaviours towards the left and routine behaviours towards the right.

Figure 8. Behavioural spectrum (Source: Breukers and Mourik, 2013)



The positioning of the two DSR behaviours at opposite ends of this behavioural spectrum presented challenges in identifying a framework for this thesis that could successfully accommodate both. Each appears firmly rooted within one of Wilson and Dowlatabadi’s opposing paradigms: the one a considered, conscious decision of a ‘rational actor’; the other often unconscious routine behaviour performed within a specific social and technical context. This inherent tension frustrated initial attempts to parse the two behaviours through many frameworks that are commonly used to explore energy behaviours.

For instance, the theory of planned behaviour (Ajzen, 1985) – an extension of the theory of reasoned action (Fishbein and Ajzen, 1975) – has been used to predict and understand behaviour in the energy domain (Ago *et al*, 2017; Chen, 2016; Wang *et al*, 2014) as well as in pro-environmental and health contexts (Armitage and Conner, 2001; Kalafatis *et al*, 1999; Taylor *et al*, 2006). According to this theory, attitudes toward behaviour, subjective norms and perceived behavioural control combine to shape both behavioural intentions and actual behaviours (Ajzen, 1985). Although widely applied, the theory of planned behaviour has been criticised for its limited predictive validity: opponents contend that most of the variability in observed behaviour cannot be accounted for by the measures of the theory (Sniehotta *et al*, 2014). Notably, the problem of ‘inclined abstainers’ – individuals who form an intention, but then fail to act on it – is a significant limitation that the theory fails to address (Orbell and Sheeran, 1998).

The theory of planned behaviour has also been criticised for focusing exclusively on rational reasoning and thus failing to account for unconscious influences on behaviour (Sheeran *et al*, 2013). This is a significant shortcoming, since many behaviours are performed without deliberative control: as Jackson observes, “we use a variety of mental ‘short-cuts’ – habits, routines, cues, heuristics – which reduce the amount of cognitive processing needed to act and often bypass cognitive deliberation entirely” (Jackson, 2005, pvii). As this would accurately describe many of the behaviours involved in DSR response, the theory of planned behaviour was thus rejected as a primary framework for this thesis.

By contrast, social practice theory – which has more recently emerged as a paradigm for exploring energy behaviours (Bulkeley *et al*, 2015; Shove and Walker, 2010; Strengers, 2012) – shifts the focus from “individual and autonomous agents, or self-directive and purposive technologies, and onto assemblages of common understandings, material infrastructures, practical knowledge and rules, which are reproduced through daily routines” (Shove and Walker, 2010, p475). Under this theory, it is the social practices themselves – such as cooking, washing and cleaning – that become the unit of analysis, rather than the individuals who perform them. “Anti- or pro-environmental actions, and more or less sustainable patterns of consumption, are not seen as the result of individuals’ attitudes, values and beliefs constrained by various contextual ‘barriers’ but as embedded within and occurring as part of social practices” (Hargreaves, 2011, p82)

Once again, however, the theory fell short as a primary framework for this thesis as tariff switching is effectively an intentional, one-time individual decision and thus does not easily lend itself to such analysis. However, as social practice theory does afford a useful lens through which to examine complex routine behaviours, some of its principles were applied – as Wilson and Dowlatabadi (2007) might advocate – to complement the FBM in specifically exploring DSR response (see Chapter 7).

Given the apparently irreconcilable tensions between these two distinct types of behaviour, attention turned to context, to investigate whether this might reveal any commonalities between them. In this regard, it was observed that both behaviours examined in this thesis are contextualised within a highly computerised environment. Consumer interactions with suppliers increasingly take place online, with features such as online bill payment facilities, tariff checks

(British Gas, 2017) and product guides all common elements of supplier websites. Consumers also often consult online comparison sites when making switching decisions and are informed of new tariffs through online and email marketing (eg, supplier Green Energy UK is promoting its Tide DSR tariff through its website (Green Energy UK, 2017)). Meanwhile, response on DSR programmes is sought, effected and measured through a variety of computerised devices, from in-home displays to mobile phones, smart appliances and smart meters (Stromback *et al*, 2011). The technological matrix in which these behaviours are embedded thus served as the prime determinant in the choice of theoretical framework.

3.4 Captology as a preferred theoretical framework

Scholars are increasingly highlighting the role that human-computer interaction (HCI) can play in shaping behaviours in the energy context. For instance, Pierce *et al* (2010) have examined how HCI influences both consumption and sustainability from a sociotechnical perspective; although their study focuses on everyday interactions which they suggest are “unconscious, habitual, and irrational” (p.1) – an approach that appears less suited to those conscious, deliberative actions involved in switching and response which are also explored in this thesis (and whose sociotechnical focus also arguably falls into the trap highlighted by Wilson and Dowlatabadi (2007) of attempting to paint a range of different energy behaviours with a single paradigmatic brush). Meanwhile, Froehlich (2009) and Kjeldskov *et al* (2012) have applied feedback intervention theory to explore how the wealth of data that can be gathered on individual household consumption might be best processed and delivered back to consumers in order to effect changes in consumption behaviour. However, while this approach is obviously relevant to ongoing behaviours such as response on DSR programmes, it is of less relevance to one-time decisions such as switching. Given the broader scope of the DSR behaviours examined in this thesis, a similarly broad theoretical framework was thus sought to conceptualise them and inform their analysis.

‘Captology’ – a discipline pioneered by BJ Fogg, director of the Persuasive Tech Lab at Stanford University, to explore the power of ‘computers as persuasive technologies’ – presented itself as a framework that was well matched to these behaviours, in terms of both type and context. Focused on the “design, research, and analysis of interactive computing products created for the purpose of changing people’s attitudes or behaviors” (Fogg, 2002, p.5), captology could serve equally well as a lens through which to explore switching as response, as it can equally accommodate both behaviour types – one-time and ongoing, intentional and routine. As a discipline conceived within the computing space, meanwhile, it is also firmly rooted in the contextual realities of DSR.

Although still primarily applied to the design of websites and other apps (the founder of Instagram is perhaps Fogg's most celebrated student), its principles have also been successfully imported into other fields, including moral influence (Berdichevsky and Neuenschwander, 1999), the promotion of sporting activity (Consolvo *et al*, 2006) and transportation (Gharibpour and Madzinova, 2016). Meanwhile, the ubiquity of computers in modern life – in particular, the microcomputer that is today's smartphone, which Fogg hails as "the next step in human evolution" (Fogg, 2010) – suggests that those principles deserve wider application beyond this niche space.

In elucidating the power of persuasive technologies, Fogg (2002) highlights several advantages that they afford over traditional media or human agents of persuasion:

- They are more persistent in seeking to elicit a desired response: "They can work around the clock in active efforts to persuade, or watch and wait for the right moment to intervene" (Fogg, 2002, p.8).
- They allow for anonymity, which Fogg suggests can help "overcome social forces that lock people into ruts and routines" (ibid, p.8).
- They can store, access and process huge amounts of data, allowing them to "predict what a user is likely to buy or do and make recommendations to the user based on that" (ibid, p.8).
- They can leverage multiple modalities – essentially, the different ways through which information is presented – to produce the optimum persuasive effect.
- They can scale easily as demand increases, replicating the same persuasive experience for a multiplicity of users.
- They are ubiquitous – "embedded in everyday objects and environments" in the form of mobile phones, smart appliances and networked systems – giving them the power to persuade "at precisely the right time and place" (ibid, p.10)

Fogg identifies seven different types of persuasive activity which can be carried out through persuasive technologies:

- Reduction – simplifying target behaviours to increase the likelihood of performance;
- Tunnelling – leading users through a step-by-step process;
- Tailoring – or "persuasion through customization" (ibid, p.37);
- Suggestion – intervening at precisely the right time to elicit the desired response;
- Self-monitoring – enabling people to monitor their own behaviour in order to achieve a

predetermined goal;
- Surveillance – or "persuasion through observation" (p.46); and
- Conditioning – reinforcing target behaviours.

Implicit in these ideas – in particular, those of reduction and suggestion – is the germ of what would eventually become the FBM.

3.5 The Fogg Behaviour Model

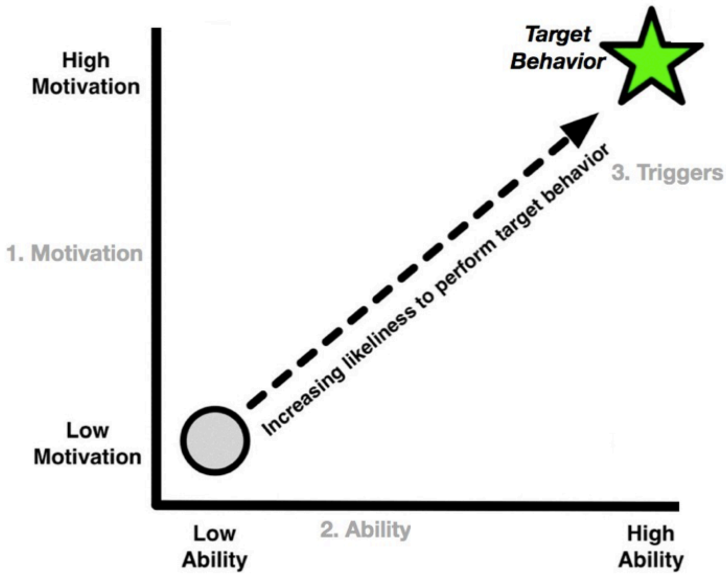
While persuasive technologies are powerful tools, they are only as effective as their application. Recognising that designers and researchers often fail to harness their full capabilities, Fogg developed the FBM as a behavioural framework to assist in deploying persuasive technologies to best effect.

According to the FBM, for someone to perform a target behaviour:

- he or she must be sufficiently motivated;
- he or she must have the ability to carry out the behaviour; and
- the behaviour must be 'triggered' (Fogg, 2009a).

The three factors must all be present simultaneously; otherwise, the target behaviour will not happen. As motivation and ability increase, the target behaviour becomes more likely; once the 'behaviour activation threshold' is reached – that is, where a person has both sufficient motivation and ability – the use of a trigger will then prompt the target behaviour (ibid). Figure 9 shows how these factors combine in the FBM.

Figure 9. The Fogg Behaviour Model (Source: adapted from Fogg, 2009a)



In incorporating the factors of motivation and ability, the FBM shares similarities with other consumer behaviour models which have previously been applied to conceptualise energy behaviours, such as the motivation-opportunity-ability (MOA) model proposed by Ölander and Thøgerson (1995). It is their combination with the concept of the trigger that distinguishes the FBM from its predecessors and makes it so conducive to understanding the DSR behaviours explored in this thesis.

There follows a detailed discussion of the three factors of the FBM and how they operate together to drive behaviour.

3.5.1 Ability

Under the FBM, an individual's ability to perform a behaviour significantly influences the likelihood of its performance. For Fogg, 'ability' equates to simplicity – in other words, the behaviour must be easy to do. Fogg identifies six 'elements of simplicity' which "relate to each other like links in a chain: If any single link breaks, then the chain fails":

- Time - if there is insufficient time available to perform the behaviour, it is not simple.
- Money - if there is insufficient money available to perform the behaviour, it is not simple.
- Physical effort - if the behaviour involves too much physical effort, it is not simple.
- Brain cycles - if the behaviour involves complex thinking, it is not simple.

- Social deviance - if the behaviour involves contravening social norms, it is not simple.
- Non-routine - if the behaviour involves breaking routines, it is not simple.

These elements of the FBM reflect some key concepts from behavioural economics. For instance, under the ‘brain cycles’ element, behaviour is considered not simple if it is cognitively challenging. This idea is also central to behavioural economics, which recognises that when the volume or complexity of information increases, people have a greater tendency to satisfice by processing only enough information to reach a satisfactory rather than optimal decision (Simon, 1955), sticking with the status quo (Kahneman *et al*, 1991; Samuelson and Zeckhauser, 1988), choosing default options (Johnson and Goldstein, 2003) or refraining from making decisions altogether (Anderson, 2003).

Likewise, the ‘non-routine’ element reflects the fact that people tend to maintain routines even if these behaviours take longer or are more expensive than alternatives (Fogg, 2009). As such, it acknowledges that habits and heuristics can lock people into existing patterns and prevent them from developing new behaviours – another central concept of behavioural economics (Pollitt and Shaorshadze, 2011) which is further highlighted in the literature on energy behaviours (Huebner *et al*, 2013; Pierce *et al*, 2010).

3.5.2 Motivation

The FBM likewise identifies three core motivators, each with two sides, that influence behaviour:

- Pleasure/pain – a “primitive” immediate or near-immediate emotional reaction to stimuli;
- Hope/fear – anticipation of a future outcome, good or bad; and
- Social acceptance/rejection – a social dimension which controls much of our social behaviour and which may be “hardwired” into humans and all other creatures that rely on communal living for survival.

These motivators are not ranked in order of potency, although Fogg does go so far as to venture that hope is perhaps “the most ethical and empowering” of the three.

3.5.3 Trigger

Fogg argues that even if both ability and motivation are high, a behaviour will not occur in the absence of a successful trigger. Whatever form they take, triggers share three characteristics: they are noticed by the recipient, they are associated with a specific behaviour and they then serve to prompt that behaviour if the behaviour activation threshold has been reached (ie, if the recipient has sufficient ability and motivation to perform the behaviour). Timing is therefore crucial - the trigger must be deployed at the appropriate moment to elicit the desired response; poorly timed triggers will serve only to annoy and frustrate. Fogg terms this the '*kairos* factor', invoking the ancient Greek rhetorical concept of presenting one's message at the opportune point, and observes that mobile devices are a particularly powerful trigger medium as they can exploit this *kairos* factor to optimum effect, given that they are almost always with us (2002, p.187).

The FBM identifies three different types of trigger:

- 'Facilitator' triggers aim to increase ability by making the behaviour easier to perform;
- Spark' triggers aim to increase motivation by leveraging one of three core motivators identified in the FBM; and
- 'Signal' triggers work best when the recipient already has sufficient ability and motivation, and serve merely as a reminder to perform the behaviour (ibid).

Arguably, it is Fogg's positioning of the trigger as an integral driver of behaviour that makes the FBM particularly apposite for understanding the DSR behaviours explored in this thesis. Switching to DSR programmes is predominantly triggered through websites, advertising and promotional materials and other consumer communications and interactions, and each trigger delivered through these different touchpoints must be carefully designed to ensure that it can function as a spark or facilitator as appropriate and thus increase the likelihood of switching. For example, renewable supplier Bulb uses both a 'spark' trigger by offering consumers generous financial incentives to switch and a 'facilitator' trigger by covering any exit fees charged by their existing providers to switch (Bulb, 2017).

Meanwhile, consumers on DSR programmes are notified of peak and off-peak periods in a variety of ways (eg, through in-house displays, email notifications, text messages and voicemails) (Bulkeley *et al*, 2015; UK Power Networks, 2014; Raw and Ross, 2011), with each such notification likewise functioning as a trigger that plays a vital role in eliciting response.

Although some consumers on static ToU tariffs may not need regular reminders if they have developed new habits and routines which are synchronised with recurring tariff periods (Breukers and Mourik, 2013), the variable timings of peak events in a renewables-rich energy system will make the design and delivery of these triggers even more important in the case of dynamic programmes. This component of the FBM was thus considered valuable for exploring response on DSR programmes: triggers serve as potent reminders of when behaviours can or should be performed (Fogg, 2009a), and can also help to elevate unconscious energy behaviours to the conscious level (see Figure 8).

As Fogg recognises, the deployment of triggers must also be carefully timed: studies have shown that response on dynamic DSR programmes is greater when pricing periods are announced in a timely fashion (Battle and Rodilla, 2008; Dütschke and Paetz, 2013). Key factors which may affect the efficacy of these triggers in facilitating response include the following:

- Type of trigger – for example, text message, email or in-home display?
- Timing – how far in advance should event notifications be sent (eg, 24 hours or one hour in advance)?[43]
- Multimodal triggers – is response more likely when notifications are sent through several different channels?
- Repetition – should more than one notification be sent per event?
- Design – what form should trigger notifications take (eg, words, colours, sounds)?

[43] There is a body of research which suggests that the efficacy of notifications varies depending on when they are received (The Behavioural Insights Team, 2014).

3.6 Practical application of the FBM

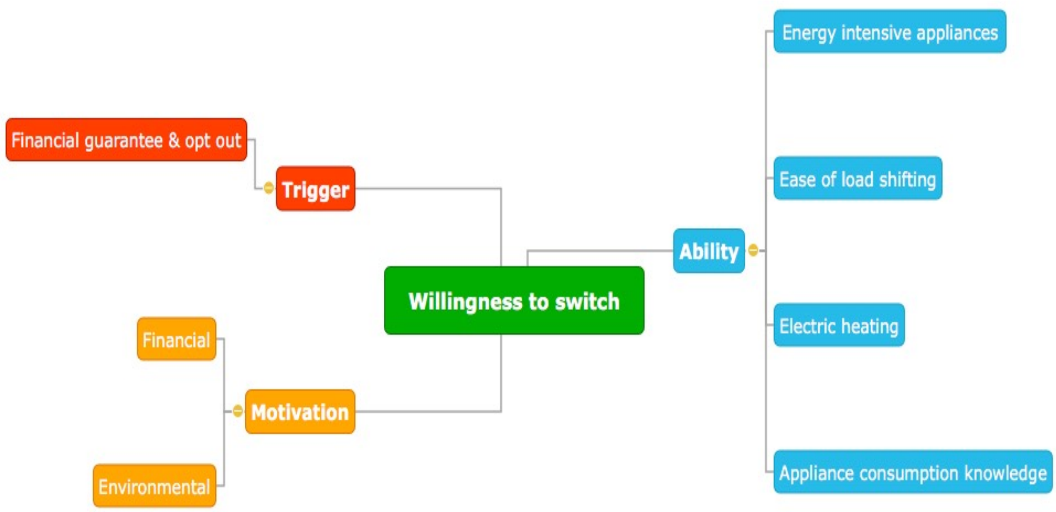
While the FBM was conceived within the framework of captology and is thus still primarily utilised within this space, Fogg suggests that it has general relevance beyond the field and could be used to understand all types of human behaviour. The model has already been successfully applied in other spheres: for instance, in a study of how credit card fraud might be detected (Haratinik *et al*, 2012), the FBM was used to create a 'fraud tendency weighting' for merchants by examining their ability and motivation to commit fraud. The FBM was also applied in a previous DSR study (Sugarman, 2014), which explored the experiences of Canadian consumers participating in a critical-peak DSR programme, with the aim of designing a HCI system to promote DSR. The FBM was used to identify ways in which the system could be improved to encourage response and to inform the design of a smartphone app that sought to reduce consumers' use of air conditioning systems at peak times.

This section explains how the FBM is applied in this thesis to explore switching and response on DSR programmes.

3.6.1 Switching to DSR programmes

The preferences of UK consumers for different DSR programme models were examined through the online switching survey described in detail in Chapter 5. The survey tested the relationship between various factors influencing WTS which can be mapped to the ability, motivation and trigger factors of the FBM. These are described below and depicted schematically in Figure 10.

Figure 10. Conceptualising WTS through the FBM



(a) Ability

The DSR literature identifies several factors which are likely to increase WTS by simplifying the process of switching tariffs. Under the FBM, these would be classified as measures which influence ability. They include:

- measures which make it easier to switch, such as 'one-click' switching (Fischer *et al*, 2013);
- simplified tariff information (ibid; Hobman *et al*, 2015; Kowalska-Pyzalska *et al*, 2014); and
- price comparison tools which facilitate the comparison of expected costs under different DSR tariffs (Ericson, 2011; Fischer *et al*, 2013).

Given the extensive treatment of these measures in the existing literature, this thesis does not re-examine how they might affect WTS, but rather focuses on how WTS is influenced by consumers' perceived ability to respond successfully on such programmes – that is, whether they consider that they have the requisite ability to alter their consumption patterns. The factors discussed in Chapter 2 that are linked to this perceived ability and might therefore influence WTS include:

- the availability of certain energy-intensive appliances in their homes;
- the availability of electric central heating systems; and
- the perception that it would be easy to reschedule appliance use.

Although this is not discussed in the DSR literature, Fogg's 'brain cycle' ability element would further suggest that a good understanding of how much electricity different appliances consume (hereinafter referred to as 'appliance consumption knowledge') would also contribute to perceived ability to respond. As such, this was also investigated in the survey.

These ability factors informed four hypotheses that were tested in the research:

- (H1) Having a larger number of energy-intensive appliances increases WTS.[44]
- (H2) Having electric central heating increases WTS.

[44] The specific appliances that were explored in the switching survey are discussed in Chapter 5.

- (H3) The perception that shifting is easy increases WTS.
- (H4) Greater perceived appliance consumption knowledge increases WTS.

(b) Motivation

Two motivational factors were tested: financial and environmental motivation. Financial motivation was explored because of the prevailing focus in the DSR literature - and in the industry's approach to DSR to date - on price as the dominant incentive for participation; it maps onto the hope/fear motivator of the FBM as leveraging the anticipation of making future financial gains. The survey tested two key motivations in this regard. First, the degree to which respondents were motivated to save money on their electricity bills was examined by developing a composite indicator and testing whether respondents with higher scores on the measure had greater WTS. The survey also investigated whether the level of savings on offer influenced WTS by manipulating this external variable and analysing how this affected the results.

Meanwhile, environmental motivation was explored to investigate whether the environmental benefits to be realised from DSR could serve as an effective alternative incentive for participation. This once again maps onto the hope/fear motivator of the FBM by tapping into fears about the effects of climate change and hopes that individual response could help to mitigate its effects. Its influence was measured by developing a composite indicator of each respondent's attitude towards environmental sustainability and then testing whether respondents with higher scores on this measure had greater WTS (how the composite indicator was created and its relationship with WTS are discussed further in Chapter 5 and Appendix II).

The motivational influences discussed above led to three hypotheses that were tested by the research:

- (H5) Greater motivation to save money on electricity bills increases WTS.
- (H6) Doubling the potential savings to be made on DSR programmes increases WTS.
- (H7) Greater commitment to environmental sustainability increases WTS.

(c) Trigger

As discussed in Chapter 2, it has been suggested that offering consumers guarantees that they will not pay more on DSR tariffs for an introductory period and allowing them to opt out of DSR arrangements on a penalty-free basis should the tariff turn out to be unsuitable might both increase WTS.

A ‘spark trigger’ was therefore included in the survey which guaranteed that consumers would not pay more for an introductory period and could opt out of the programme penalty free if they found that it did not suit their needs. Whether this trigger would increase WTS was tested by offering the guarantee to half of the survey respondents and statistically testing whether they had greater WTS than the other half.

This spark trigger was used to test the following hypothesis in the research:

- (H8) A guarantee that consumers will not pay more on DSR tariffs for an introductory period, together with penalty free opt-out arrangements over the same period, increases WTS.

Table 3 provides details of the hypotheses that were tested in the switching survey and the relationship of each to the FBM.

Table 3. Hypotheses tested in the switching survey and relationship to FBM

Ability factors	Hypotheses	Supporting literature
Perceived ability	Having a larger number of energy-intensive appliances *increases* WTS (H1)	Darby and McKenna, 2012; Ericson, 2011; Heberlein and Warriner, 1983; Reiss and White, 2005
Perceived ability	Having electric central heating *increases* WTS (H2)	Ericson, 2011
Perceived ability	The perception that shifting is easy *increases* WTS (H3)	Buryk *et al*, 2015
Perceived ability	Greater perceived appliance consumption knowledge increases WTS (H4)	N/A
Motivation factors	Hypotheses	Supporting literature
Financial (internal)	Greater motivation to save money on electricity bills *increases* WTS (H5)	Bartusch and Alvehag, 2014; Ericson, 2011; Hall *et al*, 2016; Lewis *et al*, 2012
Financial (external)	Doubling the potential savings to be made on DSR programmes increases WTS (H6)	Fischer *et al*, 2013; Heberlein and Warriner, 1983; Kowalska-Pyzalska *et al*, 2014
Environmental	Greater commitment to environmental sustainability *increases* WTS (H7)	Buryk *et al*, 2015; Gyamfi and Krumdieck 2011; Spence *et al*, 2015
Trigger (spark)	Hypothesis	Supporting literature
Price guarantees and opt-outs	A guarantee that consumers will not pay more on DSR tariffs for an introductory period, together with penalty free opt-out arrangements over the same period, increases WTS (H8)	Citizens Advice Bureau, 2014; Darby and Pisica, 2013; Fell *et al* 2015b; Kowalska-Pyzalska *et al*, 2014; Lewis *et al*, 2012

3.6.2 Response on DSR programmes

The design of the dynamic information-only DSR trial that was conducted to investigate response was informed by the FBM, while the interviews conducted once the trial had ended aimed to explore participants' experiences through this lens and develop practical insights which could help to maximise response.

(a) Trial design

Triggers were a crucial feature of the trial design. These took the form of event notifications which requested participants to use more or less electricity during specified periods, depending on available wind generation. Providing triggers through different channels (text message, email or both) made it possible to explore how these resonated with participants and how receipt of multiple triggers affected response.

Meanwhile, the motivation factor of the FBM was reflected in the trial design by providing participants with regular feedback throughout the trial. This took the form of text messages that used positive or negative emoticons (😀 or 😔) to inform participants of how both their own and overall consumption during DSR events compared against normal consumption levels. In this way, the feedback sought to leverage the pleasure/pain motivator of the FBM.

(b) Interviews

The FBM likewise informed the selection of questions posed to interviewees once the trial had concluded. Specific questions aimed to determine:

- how ability to respond on such a programme might be improved;
- how motivation to respond on such a programme might be improved; and
- how the triggers used to elicit response might be rendered more effective.

Below are several examples of questions that participants were asked that were based around the different conceptual elements of the FBM:

- Was there anything that would have made you more motivated to respond? (Motivation)
- Was there anything that would have made it easier for you to respond? (Ability)

- Did you find it easier to respond when you were notified through multiple triggers? (Ability)
- How could the in-home displays with which you were provided have been improved to make it easier for you to respond? (Ability)
- Would it have been easier for you to respond if you had been notified of DSR events in a different way? (Trigger)

The qualitative data from the interviews was also used to enhance the suitability of the FBM as a tool for examining DSR by mapping participants' experiences to its different components. Themes identified in the interview data were also explored, to identify ways to develop the FBM as a heuristic model for exploring their influence on DSR.

3.7 Conclusions

This chapter outlines the traditional theoretical approaches to understanding consumer energy behaviours and explains why the nascent discipline of captology was selected as the preferred framework through which to explore the two behaviours of specific interest in this thesis: switching to DSR programmes and response on such programmes. The chapter also describes the FBM – a model rooted in this discipline which identifies three crucial factors that combine to elicit a target behaviour. These core constructs of ability, motivation and trigger were explored through the switching survey and analysis of the qualitative data collected in the post-trial interviews.

The following chapter describes the mixed methods approach that was used in this thesis and the ways in which the primary data was collected. It also discusses the advantages of each data collection method and how limitations which were identified in relation to these methods were addressed.

4. Methods

4.1 Introduction

The research for this thesis was carried out using a mixed methods approach involving three main data collection phases: an online switching survey, a dynamic information-only trial and a set of interviews with trial participants (see Figure 11).

Figure 11. Data collection stages

Section 4.2 of this chapter examines the rationale for using mixed methods and explains why the research lent itself to this approach. Sections 4.3, 4.4 and 4.5 describe the data collection for the switching survey, the DSR trial and the trial participant interviews, respectively. In each case, the rationale for the choice of research method is presented, alongside a discussion of the strengths and limitations of the approach and the steps taken to address these limitations. Section 4.6 concludes.

4.2 Mixed methods approach

Mixed methods research combines at least one quantitative method and one qualitative method in a single study (Greene *et al*, 1989; Johnson and Onwuegbuzie, 2004). The data collected is then analysed through mixed analysis, which involves the use of both quantitative and qualitative analytical techniques within the same framework (Onwuegbuzie and Combs, 2011).

Greene *et al* (1989) identified five purposes of mixed methods research:

- Development – to use the results from one method to develop or inform the other.
- Initiation – to discover paradoxes and contradictions that lead to the reframing of research questions.
- Expansion – to extend the breadth and range of inquiry by using different methods for different inquiry components.
- Triangulation – to seek convergence, corroboration or correspondence of results from the differing methods.

- Complementarity – to seek elaboration, enhancement, illustration and clarification of the results from one method with the results from the other.

The primary purposes of adopting a mixed methods approach for the data collection for this thesis were expansion and complementarity.

4.2.1 Expansion

The purpose of expansion was central to the choice of the mixed methods approach for this research. As Greene *et al* (1989) observe, this purpose "is commonly illustrated by the use of qualitative methods to assess program processes and by quantitative methods to assess program outcomes" (p.260). The research follows this model, with the two key research questions of how to increase uptake and how to maximise response addressed through quantitative and qualitative methods, respectively.

Quantitative data from the switching survey was used to answer the following secondary questions to explore how to increase uptake:

- Which types of DSR programme do consumers prefer and how many consumers would be likely to switch to DSR programmes once these become widely available?
- Do price guarantees and fee-free opt-outs increase WTS?
- Do larger financial incentives for switching increase WTS?
- Which socio-economic variables influence WTS?
- Which attitudinal variables influence WTS?

Meanwhile, qualitative data collected through interviews with participants on the DSR trial was used to identify enablers and constraints of response from their experiences, and identify measures that could help to maximise response on such programmes.

4.2.2 Complementarity

According to Greene *et al* (1989), complementarity seeks to "measure overlapping but also different facets of a phenomenon, yielding an enriched, elaborated understanding of that phenomenon" (p.258). This was another key purpose of the mixed methods approach in this research. Collecting quantitative consumption data on the DSR trial made it possible to determine whether the consumption patterns of participating households during trial events differed from their normal consumption patterns. However, this raw data alone could not identify the causes of such changes. For instance, consumption during turn-down events (when trial households were asked to use less electricity) could have been lower because household members had changed when or how they performed certain activities, or simply because they had not been at home. As such, the interviews added depth to the research and made it possible to realise one of the key benefits of mixed methods: "rul[ing] out rival explanations of observed change and reduc[ing] skepticism of change-related findings" (Hinds, 1989, p.442).

Analysis of the qualitative data also facilitated a deeper understanding of anomalous results during the trial, such as when aggregate consumption was lower than usual during turn-up events (when trial households were asked to use more electricity) and vice versa. In these cases, qualitative feedback from the interviewees made it possible to explore what might have caused these unexpected findings.

As in previous mixed methods studies (Rossman and Wilson, 1985; Fry, Chantavanich and Chantavanich, 1981), this approach likewise allowed for additional analysis of exceptional cases of individual response: "[This] involves selecting those cases that are the most outstanding successes or failures related to some topic of interest. Such extreme successes or failures are expected to yield especially valuable information about the topic of interest." (Teddlie and Yu, 2007, p.81)

Comparing the baseline consumption of trial households against their consumption during events made it possible to identify those lying at either end of the spectrum: extreme cases whose response was either exceptionally high or exceptionally low. As the complementary qualitative data was collected through semi-structured interviews, it was possible to tailor questions to learn more about the contributing factors to these extreme cases. This in turn revealed valuable information about specific enablers and constraints of response (see Chapter 5).

The mixed methods approach also added texture to other findings in this thesis: for example, the qualitative interviews complemented the statistical data collected from the switching survey by exploring whether interviewees' experiences on the trial had influenced their preferences for different DSR programme models.

4.3 Switching survey

As discussed in Chapter 2, the UK government has relied on statistics from DSR programmes in other countries to estimate the number of consumers who are likely to switch to ToU tariffs once these become widely available (DECC, 2012; DTI, 2005). However, the robustness of this approach is questionable, given that results from one region may not readily be replicated in others due to differences in market and customer characteristics (Parrish *et al*, 2015).

Some previous UK studies have explored consumer preferences for DSR using focus groups (Darby and Pisica, 2013) and consumer panels (Ofgem Consumer First Panel, 2009). However, the small samples on which such studies are based cannot be considered representative of the overall population (Teddlie and Yu, 2007; Wunsch, 1986). As such, these methods are not suitable for estimating WTS or for using statistical methods to explore the influence of specific socio-economic or attitudinal factors on WTS.

By contrast, surveys with larger samples can allow inferences to be drawn about the wider population from which the sample is obtained (Fricker, 2008). Such surveys also make it possible to statistically test the correlation between different variables (Oppenheim, 2007). A large-scale survey was thus identified as the optimal method to estimate potential uptake of residential DSR and test the influence of socio-economic and attitudinal factors on WTS. This information could then be used to inform the marketing of DSR programmes. As Cappers *et al* (2013) observe:

> If the decision to participate can be associated with observable or measurable customer characteristics, the quantification of the relative importance of those factors and how they correlate with customer responsiveness will greatly improve the effectiveness of recruitment campaigns. (p.4)

The switching survey was conducted online through market research company Bilendi, which recruits consumers to participate in online market and social research surveys. Respondents receive points for every survey they complete, which can be redeemed for vouchers for various rewards. By paying Bilendi for a guaranteed number of responses, it was possible to ensure a large sample for the survey (N=1312).

Collecting the data online afforded several advantages. Online surveys are faster to conduct than surveys by mail or telephone, and do not require the hiring and training of interview personnel (Dillman, 2000). The costs relative to the number of responses collected are also low, and data is instantly available for analysis because digital storage and coding occur at the same time as data collection (Potoglou and Kanaroglou, 2007). Online surveys further make it possible to present highly customised choice scenarios to respondents (ibid). This latter feature was particularly useful for this survey: respondents could be randomly allocated into four treatment groups to explore the effects of price guarantees and larger financial savings on WTS (see Chapter 5).

On the other hand, online surveys are sometimes criticised for their limited demographic coverage and for producing non-random samples (Broberg and Persson, 2015; Potoglou and Kanaroglou, 2007). The former issue can be particularly problematic in developing countries, where often only higher-income, better-educated segments of the population have internet access (Iraguen and Ortuzar, 2004). However, this is unlikely to have significantly biased the results of the switching survey, since around 93% of the UK population now have internet access (Internet Live Stats, 2016), and the survey was designed so that it could be completed on a range of internet-enabled devices.

The issue of non-random sampling was addressed through quota sampling. "A 'quota' in this context is a cell within an overall sample, designed to have the same sociodemographic characteristics as its population" (Oppenheim 2007, p.41). Quota sampling makes it possible to match selected socio-demographic characteristics in the sample to the population of interest. As such, its use in the switching survey helped to ensure that the preferences expressed would likely reflect those of the wider UK population. The socio-demographic characteristics used in the quota sampling are outlined in Chapter 5, together with a comparison of the sample against the UK population.

Further sources of potential bias must be acknowledged. First, respondents opted to participate in the survey in return for a fee and thus may not be representative of the overall population (Nicolson *et al*, 2017). Second, while all respondents were provided with incentives for participating in the survey, those who completed the whole survey may have had a greater interest in energy issues than the average consumer (Spence *et al*, 2015). However, both of these potential sources of bias are common problems in national panel surveys and were thus considered acceptable limitations in the present study.

4.3.1 Hypothetical bias

The switching survey used a stated choice experiment method, presenting a hypothetical choice situation with a finite number of alternatives and asking respondents to choose their preferred option (Fifer, 2011). While this design is often used to obtain responses to hypothetical questions about future behaviour (Whitehead and Blomquist, 2006), respondents can sometimes find it difficult to predict how they might behave in circumstances that they have not previously experienced (Fowler, 1995). This can result in hypothetical bias – that is, "The difference between results generated via stated preference studies and corresponding evidence stemming from real-world data" (Fifer, 2011, p.1).

There is thus a risk that stated preference studies may produce data that does not reflect how individuals would behave in real life (ibid). For example, research has shown that such studies often overstate consumers' valuation of goods: a meta-analysis of willingness to pay studies by Murphy *et al* (2005) found a median overstatement of 1.35; while analysis of both willingness to accept and willingness to pay studies by List and Gallet (2001) and Little and Berrens (2004) found that, on average, individuals overstated their preferences by a factor of three. Hypothetical bias can thus diminish the utility of stated preference data: "If the results from stated preference studies are to be used in real-life policy decisions, it is important that these results accurately reflect or be able to predict what would happen in a real market application" (Fifer, 2011, p.3)

The most common techniques to mitigate hypothetical bias in stated preference studies are 'cheap talk' and certainty correction (Fifer, 2011; Samnaliev *et al*, 2006). 'Cheap talk' is an *ex-ante* technique where respondents are shown a text script before they complete the experiment which explains hypothetical bias and asks them to adjust for this when answering (Samnaliev *et al*, 2006). Certainty correction (Antil, 1983; Loomis, 2014) is an *ex-post* technique where respondents are asked to indicate how certain they are that they would act in accordance with their stated preference – otherwise known as their "intensity of preference" (Whitehead *et al*, 2014). Intensity of preference responses are then used to calibrate the stated preferences by recoding those below a certain threshold as negative or uncertain.

While opinion is divided on the efficacy of cheap talk as a means of addressing hypothetical bias (Aadland *et al*, 2006; Fifer, 2011; Samnaliev *et al*, 2006), numerous studies have shown that certainty correction can effectively reduce hypothetical bias (Antil, 1983; Champ *et al*, 1997; Fifer, 2011; Loomis, 2014; Samnaliev *et al*, 2006; Whitehead *et al*, 2014). As such, respondents who indicated WTS were asked to rate their intensity of preference on a 10-point certainty scale. Previous studies which have recalibrated response data using a numerical certainty scale have generally adopted one of two approaches. The first assumes that respondents would act in accordance with their stated preferences where they rate their intensity of preference as seven or higher out of 10 (eg, Champ and Bishop, 2001); the second assumes that this would be the case where the respondent's intensity of preference equals or exceeds the mean score for all intensity of preference responses provided (Champ *et al*, 2009). There was no need to choose between these approaches in analysing the switching survey data, since the mean score for all intensity of preference responses provided by respondents was seven (rounded up from 6.7). Thus, after the correction was applied, only those respondents who indicated an intensity of preference of seven or higher were classified as WTS to one of the DSR tariffs.

4.4 DSR trial

Analysis of the switching survey data revealed that a sizeable percentage of respondents (8% after certainty correction) would be willing to participate in a dynamic information-only DSR programme. However, there was obviously no way to predict how consumers who indicate willingness to switch to such programmes might behave on such a programme in practice. It was thus decided to conduct a dynamic information-only trial to investigate how consumers who chose to switch to such a programme might respond once enrolled.

Consumer behaviour studies can be used to explore both whether and how consumers respond to inducements to change their consumption patterns (Cappers *et al*, 2013). To this end, a mixed methods approach was adopted for the trial, as the use of quantitative or qualitative methods alone would have made it impossible to determine precisely how households had responded to the trial events. Although some electricity trials have reported intervention effects based solely on self-reported energy-related behaviours, these do not necessarily reflect the changes that consumers make to their energy consumption (Abrahamse *et al*, 2005). Moreover, self-reported behaviours can be influenced by social desirability bias (ibid; Fisher, 1993) and recall bias (Last, 2000).[45] As such, the use of quantitative methods made it possible to explore whether households had successfully changed their consumption patterns during trial events. Meanwhile, the qualitative data made it possible to gain insight into how observed changes in consumption had most likely occurred.

4.4.1 Trial collaboration

The original aim was to conduct the DSR trial in partnership with a supplier or DNO, recruiting participants from its existing customer base as would happen on an actual DSR programme.

[45] 'Social desirability' refers to systematic error in self-report measures which arises from respondents' desire to avoid embarrassment and project a favourable image to others (Fisher, 1993). 'Recall bias' refers to systematic error which arises due to inaccurate or incomplete recollections of past events or experiences (Last, 2000).

This would have provided greater confidence that the response from the trial group could be replicated in a real-world setting (Davis *et al*, 2013; Faruqui *et al*, 2009). Further, with additional funding from an industry partner, it would have been possible to purchase a larger number of in-home displays and thus recruit a larger sample of trial households, thereby increasing the statistical power of the tests used to explore trial response (Field, 2009).

Between October 2012 and September 2014, three separate attempts were made to collaborate with electricity stakeholders. The first, with British Gas and researchers at Durham University, would have recruited participants on the CLNR ToU trial (Bulkeley *et al*, 2015), to explore whether notifying them of different tariff periods using ambient in-home displays (see www.ambientdevices.com) would increase DSR. Unfortunately, after several months of negotiations, the proposed collaboration failed when British Gas concluded that it was unable to make a real-time smart meter data feed available for the trial.[46]

The second attempt at collaboration was with DNO Electricity North West. The proposal was to provide ambient in-home displays to some of the households participating in the Power Saver Challenge – a competition to reduce electricity use between 4:00pm and 8:00pm each day during Winter 2014/2015 (Electricity North West, 2015). Electricity North West eventually withdrew because it was concerned that the ambient in-home displays would give the households that received them an unfair advantage in the competition.

The third potential partner was renewable provider Good Energy. In this case, the proposal was for a dynamic information-only DSR trial, which would have asked participants to try to use more electricity when available wind generation across the UK was high and less electricity when available wind generation was low (the same model as was ultimately adopted for the trial). Once again, however, this attempt at collaboration eventually foundered, due to concerns on the part of Good Energy that the trial might end up creating an unexpected administrative burden.

After these attempts at collaboration failed, it was decided to conduct an independent trial, recruiting a convenience sample by advertising on the Centre on Innovation and Energy Demand website, the Your Energy Sussex Twitter account and the West Sussex County Council email bulletin.[47] Although this method of recruitment meant that participants may have been

[46] This would have been required to measure the effects of the intervention.
[47] The confirmation of ethical approval for the trial is reproduced in Appendix V.

more interested in energy issues than the average consumer, this is not unusual in the case of DSR trials. Even in trials organised by electricity stakeholders, which can recruit large samples from their existing consumer base, participants may also be considered atypical of the wider population, as simply by choosing to sign up they demonstrate that they "are, by default, interested in the subject matter and interested enough to engage in early adopter projects" (Smart Grid GB, 2013, p.23). While this admittedly creates a risk of bias, it also reflects the realities of the UK energy market, in which consumers are free to choose between tariffs and providers, but only a small proportion are sufficiently interested and engaged to switch: according to Ofgem, as of January 2017 some two-thirds of UK households remained on standard variable tariffs, which are typically more expensive than other deals available on the market; while between July 2016 and June 2017, just 17% of UK consumers switched provider (Ofgem, 2017c).

4.4.2 Within-subjects design

Although randomised controlled trials and randomised encouragement designs[48] are the preferred model for electricity trials (Cappers *et al*, 2013; Hobman *et al*, 2016), such methods were not viable for this study, because electricity interval data could be gathered only from customers who agreed to participate in the trial. Instead, a within-subjects design[49] was used, in which the measured load of participants during non-event periods was compared with their consumption during events (Cappers *et al*, 2013).

The internal validity of the within-subjects experiment required that two assumptions be met. The first was that there be a set of non-event days that was 'sufficiently' comparable to the set of event days:

> so that it is reasonable to assume that the only difference in customer behavior during event days and the comparable non-event days is that they experienced the treatment in effect during event days (for example, the comparable non-event days have similar temperatures and daylight hours to those of the event days). (p.44)

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[48] In randomised encouragement designs, customers are randomly assigned to either a treatment group, which is encouraged to sign up for the treatment through an op-in or opt-out method, or a control group, which is not notified of the study (Cappers *et al*, 2013).
[49] Within-subjects designs compare the treatment group during periods when it receives the treatment to times when it does not receive the treatment (Cappers *et al*, 2013).

The second was that trial participants were on non-variable tariffs, as in this case "the assumption is that customers [will] not alter their non-event behavior very much as a result of being on the rate". (p.44)

In this study, the first assumption was met by conducting the trial in summer (from May to September 2015). This meant that the period during which baseline consumption data was collected to generate a reference load (May 10 to June 19) was similar in terms of temperature and daylight hours to that in which trial events were held (June 20 to September 3). The second was met by recruiting consumers who were on non-variable tariff rates (ie, not on Economy 7 or Economy 10). Cappers *et al* (2013) observe that when these conditions are satisfied, "non-treatment days are an acceptable approximation of what the load would have been if the treatment group had never been on the rate" (p.44).

4.4.3 Sample bias

An important consideration when conducting electricity trials is to minimise the risk of bias affecting results (Davis *et al*, 2013). Davis *et al* (2013) identified six common biases recognised in the context of medical trials which might also affect electricity trials. Four of these – intervention selection bias, sequence generation bias, allocation concealment bias and blinding bias – are relevant only when the trial involves more than one participant group (eg, multiple intervention groups or an intervention group and a control group). Since the DSR trial used a within-subjects design, these biases could be discounted. A fifth – attrition bias, where participants who are not benefiting from the trial are excluded or withdraw from the trial before it ends – could be discounted as no participants withdrew or were excluded from the trial. The one remaining bias that could affect the findings of the trial was volunteer selection bias,[50] which arises "when the people who choose to participate in a study differ from the study's intended population" (p.402).

The initial attempts to collaborate with either a supplier or a DNO aimed to minimise volunteer bias by recruiting a larger sample directly from the customer base of the collaborating stakeholder. While – as previously discussed – this would not have eliminated such bias altogether, it would have afforded a wider pool from which to recruit and more closely reflected the real-world scenario. Ultimately, however, these efforts proved unsuccessful.

[50] This bias is also commonly referred to as 'self-selection bias' (see Aubin *et al*, 1995 and Ham *et al*, 1997).

Given the greater risk of volunteer bias presented by the smaller convenience sample that was eventually recruited, the sample was analysed to test how accurately it reflected the intended population: households that would choose to switch to a dynamic information-only DSR programme.

The switching survey identified three factors which were positively correlated with WTS to such a programme:

- environmental motivation (as measured by the "Commitment to environmental sustainability" measure – see Chapter 5);
- education level; and
- household income.

Data pertaining to these factors was collected from the volunteer trial participants through an enrolment questionnaire – essentially a shorter version of the switching survey which was administered before the trial began. The volunteers' responses on these three measures were then compared with those of the survey respondents who had indicated WTS to the dynamic information-only DSR programme. The results were closely matched for two of the three criteria – education level and environmental motivation (see Chapter 6) – providing greater confidence that, notwithstanding the limitations of selection, the trial sample was broadly representative of the intended population.

However, this of course could not exclude the risk of volunteer bias altogether. As Davis explains, volunteers and non-volunteers matched on observable characteristics may respond differently "if they differ in other relevant ways that are not represented in the available measures or if the act of volunteering changes their behaviour" (Davis *et al*, 2013, p.402).

4.5 Interviews

The third data collection phase involved a series of semi-structured telephone interviews with trial participants. Interviews are a suitable research method for exploring individuals' views, experiences, motivations and beliefs on specific matters (Gill *et al*, 2008); "In simple terms interviewing provides a way of generating empirical data about the social world by asking people to talk about their lives." (Holstein and Gubrium, 2004, p.140)

Qualitative methods such as interviews can provide deeper individual insights than quantitative methods such as questionnaires (Silverman, 2000). As Aberbach and Rockman (2002) observe:

“Interviewing is often important if one needs to know what a set of people think, or how they interpret an event or series of events, or what they have done or plan to do.” (p.673)

The interviews were thus intended to complement the quantitative trial data by delving deeper into participants’ experiences during the trial. While the quantitative data revealed whether consumption patterns during events differed from baseline consumption patterns, the interviews made it possible to explore the reasons for these changes. Learning about the experiences of individuals in a specific behavioural context can also generate insights which can be used to tailor interventions and maximise behavioural response (The Behavioural Insights Team, 2014; Fogg, 2009b). As such, this approach made it possible to identify actual (rather than hypothetical or assumed) enablers and constraints of response, and make recommendations for the design of future programmes informed by first-hand insights.

Telephone interviews afforded several advantages over face-to-face interviews, including lower costs in terms of both travel expenses and travel time, and the speed with which the data could be collected (Lavrakas, 1993; Oppenheim, 2007). The use of telephone interviews also made it easier for individuals to participate, since they could be interviewed at a time and place that suited them best. These advantages were reflected in the size of the interview sample: all 46 households which took part in the trial were invited to participate in this stage of the research and interviews were ultimately conducted with more than half of them (N=24).

The interviews were semi-structured to afford some flexibility in responses, while still allowing comparisons to be made between them (May, 2001). The semi-structured format also made it possible to tailor some of the questions depending on interviewees’ previous responses in the enrolment questionnaire, and further allowed for “the discovery or elaboration of information that [was] important to participants but may not have previously been thought of as pertinent by the research team” (Gill *et al* 2008, p.291).

4.5.1 Limitations

A key objective of the interviews was to identify findings that could inform future DSR strategies with a view to maximising response. However, the qualitative nature of the interview data made it difficult to draw definitive conclusions in this regard. Therefore, where the interview data suggested possible measures for maximising response, the potential efficacy of these measures was explored further through a review of the DSR literature.

As the interview sample was once again a convenience sample, it is possible that outlying households – those that responded to the greatest or least extent – may not have volunteered to be interviewed. There was therefore a risk that particularly potent enablers and constraints of DSR may have been missing from the interview data. To address this issue, households in the top and bottom 10% in terms of response were specifically targeted with follow-up interview requests; interviews were ultimately conducted with six out of eight such households (ie, 75% of the households that fell within this response spectrum).

4.6 Conclusion

This chapter presented the methodological approach adopted to data collection and analysis in this thesis. It explored the advantages and limitations of the various data collection methods, and outlined the steps which were taken to address those limitations.

The following chapter describes the switching survey, which examined UK consumer preferences for different DSR programme models. It explains how the survey was designed and conducted to collect switching preference data and identify the socio-demographic and economic variables that influence WTS. It also reveals DSR programme preferences both before and after certainty correction was applied to the survey results, and uses statistical models to explore the relationship between several independent variables and WTS to the different programme models.

5. Switching survey

5.1 Introduction

This chapter discusses the online survey that was conducted to explore UK consumer preferences for DSR programmes. The survey aimed to estimate potential uptake of several different programme models and identify specific consumer characteristics that might influence WTS to such programmes. These insights should prove valuable in marketing residential DSR programmes: correlating different customer characteristics with WTS and quantifying their relative importance should translate into more effective recruitment campaigns (Cappers *et al*, 2013).

Although previous studies have investigated consumer preferences for DSR in the UK context (see BEIS, 2016; Fell *et al*, 2015a; Nicolson *et al*, 2016), questions that remain unresolved include the following:

- Is there a relationship between consumers' perceived ability to respond on DSR programmes and WTS?
- Does stronger financial or environmental motivation increase WTS and, if so, which has the greater influence on WTS?
- Can WTS be increased by offering price guarantees?
- What is the predicted uptake of information-only DSR programmes?

By exploring these questions, the survey aimed to identify various measures to assist electricity stakeholders in maximising uptake of DSR programmes.

Section 5.2 of this chapter explains how quota sampling was used to obtain a representative sample of households and provides details of the survey sample. Section 5.3 describes the questionnaire design and the rationale behind specific questions. Section 5.4 presents the main results from the survey data analysis, including details of respondents' switching preferences and the factors that were correlated with WTS in the statistical modelling. Section 5.5 discusses the results of the various hypotheses regarding WTS that were tested, which were structured around the FBM elements of ability, motivation and trigger. Section 5.6 concludes and explains how the findings in this chapter informed the design of the dynamic information-only trial described in Chapters 6 and 7.

5.2 Survey sample

As in previous studies exploring consumer preferences for DSR among representative samples of the UK population (BEIS, 2016; Fell *et al*, 2015a; Nicolson *et al*, 2017), respondents were recruited from an online panel of consumers. In this case, market research company Bilendi was commissioned to provide a sample from its 450,000 UK panellists, who complete online surveys in return for points which can be exchanged for various rewards (Bilendi, 2015).

To be eligible to complete the survey, respondents had to be over 18 years old, live in the UK and be solely or jointly responsible for choosing their electricity supplier. This ensured that respondents were representative of those UK consumers who would be involved in the decision to switch to DSR programmes in a real-world context. Bilendi ensured that the first and second criteria were met when recruiting panellists; while the first survey item ensured that only respondents who identified themselves as solely or jointly responsible for choosing their household's electricity supplier could continue with the survey.

Socio-demographic quotas were applied to ensure that the sample was broadly representative of the UK population. These related to age, country of residence, number of household members, household income and ownership status, and were established using data from the 2011 UK Census and the 2014 Family Resources Survey (FRS) (Census, 2011; Department for Work and Pensions, 2014). Table 4 illustrates how the survey sample compared with this data.

Table 4. Survey sample compared to 2011 UK Census and 2014 Family Resources Survey data

		Respondents (%)	Census and FRS data (%)
Country of residence	England	84.4	83.9
	Scotland	8.4	8.4
	Wales	4.6	4.9
	Northern Ireland	2.6	2.8
Household	Owner	72.0	64.0
	Renter	28.0	36.0
Age	18-64	79.0	79.1
	65+	21.0	20.9
Gender	Male	56.9	49.0
	Female	43.1	51.0
Household members	1	23.6	31
	2	40.2	34.0
	3	16.2	15.0
	4	13.8	13.0
	5+	6.2	7.0
Gross household income per week	£0 - £199	8.2	9.0
	£200 - £399	21.1	25.0
	£400 - £599	18.2	20.0
	£600 - £799	12.6	14.0
	£800 - £999	8.9	10.0
	£1000+	17.7	22.0
	Don't know/prefer not to say	13.3	

Although quota sampling made it possible to closely match the sample with the 2011 Census and the 2014 Family Resources Survey data for most of the socio-demographic and economic characteristics in Table 4, home owners and males were over-represented, while multiple occupancy households were under-represented.[52] As such, a weighting parameter based on gender, household ownership and household size was used in the analysis (see Table 5).

[52] Except for households with five or more occupants, which were slightly underrepresented in the sample.

Table 5. Weighting parameters

	1-person households	2-person households	3-person households	4-person households	5-person+ households
Female renter	2.05	1.32	1.44	1.47	1.76
Female owner	1.37	0.88	0.96	0.98	1.17
Male renter	1.49	0.96	1.05	1.07	1.28
Male owner	0.99	0.64	0.70	0.71	0.85

5.3. Survey design and research hypotheses

A 56-item survey[54] containing a mix of closed and open-ended questions was designed with the aims of:

- collecting socio-demographic and household data from respondents;
- obtaining data for creating various measures of perceived ability to respond on DSR programmes and financial and environmental motivation to switch to such programmes;
- describing three different models for DSR programmes and determining respondents' WTS to each; and
- exploring the influence of various factors on respondents' stated preference to switch to one of the DSR programmes or remain on their current tariff.

5.3.1 Perceived ability to respond

As discussed in Chapter 2, consumers with greater perceived ability to respond on DSR programmes may have greater WTS to such programmes. To explore whether this is the case, four measures of perceived ability were created, as follows.

(a) Ability to use energy-intensive appliances to respond

In the UK, washing machines, dishwashers and tumble dryers can facilitate response on DSR programmes because these appliances are energy intensive and can often be operated flexibly (Bartusch *et al*, 2011; Ofgem, 2010). As Owen and Ward (2010) explain:

[54] The full survey is reproduced in Appendix II.

> As of today, the main appliances where households could benefit from off-peak tariffs are wet appliances such as washing machines, dishwashers and tumble dryers. Households can vary the times at which they use these and they are large enough electrical loads to make it worth changing behaviour. (p.28)

To test whether consumers with more of these appliances have greater WTS (H1), respondents were asked to indicate which of these appliances they had in their households. Responses were then used to create the measure "Household appliances" by awarding one point for each appliance they possessed (range 0 to 3).[55]

(b) Ability to use electric central heating systems to respond

Due to thermal inertia, households remain warm for a period even when heating systems are turned off. Consequently, one way in which consumers with electric central heating systems[56] might respond on DSR programmes is by varying their heating demands at certain times (Ericson, 2011; Mountain and Lawson, 1995). As such, it was hypothesised that consumers living in households with electric central heating systems might have greater WTS (H2). To test this, the "Household heating" measure was created by asking respondents to indicate how their households were heated from one of four categories:

- electric central heating;
- storage heating;
- gas central heating; and
- other types of heating, such as wood or coal burners.

(c) Potential to change appliance use times

To test the hypothesis that consumers who believe it would be easy to reschedule appliance use might have greater WTS (H3), respondents were asked to indicate how easy it would be to reschedule the use of each energy-intensive appliance that was present in their households (Question 17). The responses provided were used to create the measure "Ability to change appliance use times" (range 1 to 5).[57]

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[55] Households with combined washer dryers were awarded two points on this measure, since both the washing and drying functions of this appliance could be used to respond.
[56] Excluding those consumers with storage heating systems, as the times at which these switch on and off are dictated by suppliers (usually overnight) and cannot be manually overridden.
[57] Respondents were asked to indicate how easy it would be change when each of these appliances were used, from response options of "Very difficult", "Difficult", "Neither easy nor difficult", "Easy" and "Very easy".

(d) Appliance consumption knowledge

Consumers who believe they have a good understanding of appliance energy consumption may have greater WTS (H4), as this knowledge should assist them in responding. To explore this hypothesis, the measure "Perceived appliance consumption knowledge" was created by asking respondents to indicate how much they thought they knew about the amount of electricity used by different household appliances (range 0 to 4).

5.3.2 Financial and environmental motivations for switching

Two measures were used to explore the influence of financial and environmental motivations on WTS. The first, "Commitment to environmental sustainability", was based on a measure of the same name developed using archive data from the British Household Survey and originally discussed in Alcock (2012). The seven attitudinal questions used to create this measure in the Alcock study (2012) were adapted for the survey, with the changes made to these questions discussed in Appendix III.[58]

Three questions were used to construct the second measure: "Motivation to save money by switching electricity tariffs". The design of these questions was informed by the survey pre-test, together with input from energy demand experts.[59]

Principal component analysis is a statistical technique that can be applied to a set of variables to identify those which form coherent sub-sets that are relatively independent of one another (Tabachnick, 2001). Following the survey pilot (N=90), principal component analysis was performed on the response data collected for these 10 attitudinal questions (shown in Table 6): the seven adapted from Alcock (2012) and the three used to produce the "Motivation to save money by switching" measure. In this case, principal component analysis was used to explore the relationship between the 10 attitudinal questions and the two constructs – "Commitment to environmental sustainability" and "Motivation to save money by switching tariffs" – that these questions were being used to measure.

The measure was created by converting each of these responses into a score (range 1-5), summing these scores and then dividing this by the number of these appliances they possessed.

[58] Appendix III also discusses the steps taken in designing the survey to reduce the incidence of bias.

[59] Appendix III includes further discussion of the pre-testing and pilot phases used to refine the attitudinal questions in the survey.

The outputs of principal component analysis include Bartlett's test of sphericity and Kaiser-Meyer-Olson's measure of sampling adequacy tests, which test whether the data is suitable for the analysis (Field, 2009). Bartlett's test of sphericity was statistically significant (P=.00), indicating that relationships existed between the data – the responses to the attitudinal questions collected from the survey pilot – that was being compared (ibid). Furthermore, the Kaiser-Meyer-Olson value was 0.7, which is considered a good score for this test and further confirmed that the data was suitable for principal component analysis (Hutcheson and Sofroniou, 1999). After orthogonal rotation using Varimax[60], each of the questions loaded onto one of three components[61] and the component loading values ranged from 0.54 to 0.86, indicating that each of the variables was contributing to its component in a meaningful way[62] (Field, 2009) (see Table 6). The three components were interpreted as:

- personal commitment to environmental protection (Component 1);
- the need for lifestyle changes to protect the environment and limit climate change (Component 2); and
- motivation to save money by switching tariffs (Component 3).

[60] This method is considered easier to interpret, describe and report than oblique rotation methods, since it simplifies components by maximising the variance of the loadings within components, across variables (Tabachnick, 2001).
[61] Components are thought to reflect the underlying processes that have created the correlations among the variables being examined (Tabachnick, 2005).
[62] Typically, loadings greater than 0.3 are considered to be important (Field, 2009).

Table 6. Attitudinal survey questions

Component 1: Personal commitment to environmental protection
It takes too much time and effort to do things that are environmentally friendly.
The environment is a low priority for me compared with a lot of other things in my life.
I am environmentally friendly in most things that I do.
The need to reduce carbon emissions frequently influences what I do – for example, by choosing to drive less or to turn lights off when I can.
Component 2: The need for lifestyle changes to protect the environment and limit climate change
Most people will have to make big changes to their way of life to help to solve climate change.
Most people need to change their way of life so that future generations can enjoy a good quality of life and environment.
I need to change my way of life so that future generations can enjoy a good quality of life and environment.
Component 3. Motivation to save money by switching tariffs
When choosing your electricity tariff, how important is it that you get the cheapest deal available?
How much effort would you be willing to put into comparing electricity tariffs to get the cheapest deal?
How worried are you about the cost of electricity rising in the future?

As in Alcock (2012), the scored responses to the questions that loaded onto Components 1 and 2 were combined to produce the measure "Commitment to environmental sustainability" (range 0 to 29). This measure was used to explore whether consumers who are more environmentally motivated have greater WTS (H7). Scores for Component 3 questions were combined to create the measure "Motivation to save money by switching tariff" (range 0 to 12), to test whether consumers who are more motivated to save money by switching tariffs have greater WTS (H5).[63]

Two further independent variables were included in the models. The first was a categorical variable which captured respondents' educational qualifications.[64] Respondents were divided into three categories:

[63] Questions for both measures were coded so that higher scores corresponded with greater motivation.
[64] This data was obtained using the same question used to record educational qualifications in the 2011 Census (Census, 2011).

- those with no qualifications;
- those with qualifications below degree level; and
- those with degree-level or higher qualifications.

The second variable was household income. Respondents were asked to indicate their household's weekly income from a set of income bands ranging from <£100 to £2,000+. So that this data could be treated as continuous, households were accorded the midpoint value for their income band and those indicating incomes of £2,000+ were treated as having incomes of £2,500. The data was then recoded into £100 units.[65] For example, if a respondent indicated that household weekly income was between £300 and £400, this was recoded to 3.5. Since the income data was not normally distributed, it was converted into logarithmic form before being applied in the models.[66]

5.3.3 DSR programme models and randomisation of respondents into groups

Two of the three DSR programme models presented in the survey were based on tariffs that are well suited to the prevailing UK electricity system and have already been the subject of large-scale trials. The first – the daily ToU tariff – was a static ToU tariff that charged higher prices for electricity between 4:00pm and 8:00pm on weekdays. This was based on the tariff tested in the CLNR ToU trial (Bulkeley *et al*, 2014). The second – the day-ahead alert tariff – was based on the dynamic ToU tariff tested in the LCL trial (Carmichael *et al*, 2014). Households on this tariff would be notified daily of how much their electricity would cost at specific times the following day.

The third model – the environmental alert – was a dynamic information-only programme. Under this model, respondents would be sent notifications asking them to increase or reduce their electricity consumption at certain times the following day, depending on predicted wind generation. Respondents were informed that such programmes will help to increase the share of

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[65] The data was recoded into £100 units to facilitate interpretation of the influence of this variable on WTS. Without this adjustment, the odds ratios produced by the models for household income would have indicated how the odds of choosing the DSR programmes changed for each £1 increase in household income.

[66] As respondents were offered the option to answer "Don't know/prefer not to say" when asked about their household income, this led to missing values in the models (12.5% of cases). However, a comparison of the model with and without missing values for income revealed no substantive differences in model results. It was therefore decided to use a complete case analysis rather than to undertake a multiple imputation for missing values.

renewable energy in the UK electricity system by reducing demand when wind generation is low and preventing electricity from being wasted when wind generation is high.

This model was included in the survey because, while studies have found that some consumers would be willing to participate in information-only DSR programmes which ask them to adjust their consumption based on available wind generation (Mert, 2008), no research as yet has explored how popular such programmes would be among UK consumers.

As well as exploring consumer preferences for these programme models and whether financial or environmental motivations increase WTS, the survey was designed to answer two further questions:

- Does increasing the savings that consumers can make by switching to DSR tariffs increase WTS (H6)?
- Do price guarantees which allow consumers to try DSR tariffs without the risk of paying more increase WTS (H8)?

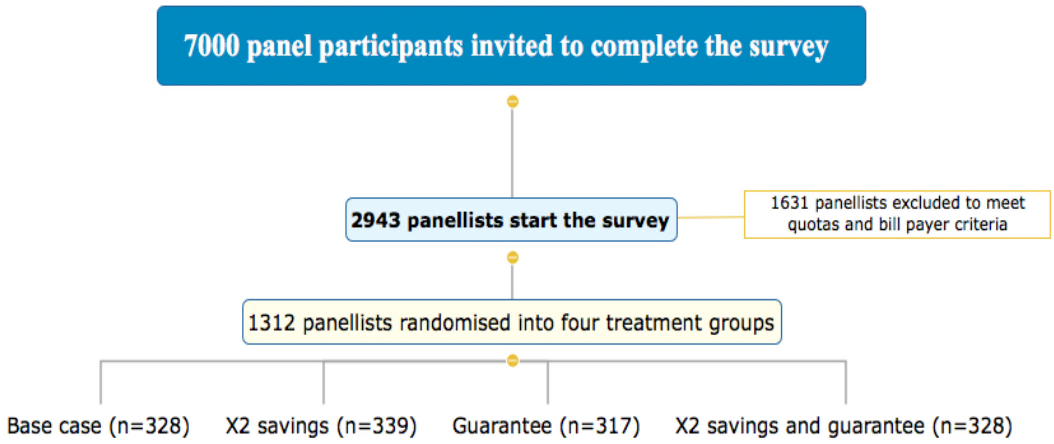
To this end, respondents were randomly assigned to four groups that were presented with different descriptions of the DSR tariffs:[67]

- Base case (Group 1) – informed that, on average, households would save 2% on the daily ToU tariff and 4% on the day-ahead alert tariff.
- x2 savings (Group 2) – informed that, on average, households would save 4% on the daily ToU tariff and 8% on the day-ahead alert tariff.
- Guarantee (Group 3) – informed that, on average, households would save the same as Group 1, but would pay no more for their electricity on a per unit basis for the first three months and could opt out with no penalty if they wished.
- x2 savings plus guarantee (Group 4) – informed that households would receive both the x2 savings and the guarantee.

Figure 12 shows how respondents were recruited, from the initial emails inviting them to complete the survey to their assignment to one of the four groups.

[67] The environmental alert programme was described in identical terms to respondents in all groups.

Figure 12. Recruitment and randomisation of respondents into groups



Although respondents were randomly assigned to one of the four treatment groups, the groups might still have differed in terms of the independent variables (Table 7). As this might have biased the comparison of WTS between the groups, one-way analysis of variance and chi-square tests were used to check for any statistically significant differences in terms of these independent variables across the four groups. These tests revealed no differences between groups (all P values <0.05).

5.4 Switching survey results

After the three DSR programme models were described to respondents, they were asked to specify their switching preferences as follows:

- Switch to one of the DSR programmes;
- Remain on their current tariff; or
- Don't know.[68]

Overall, 69% of respondents indicated that they would choose to switch to one of the three DSR programmes. The daily ToU tariff was the most popular, with over half of the switchers indicating that they would choose this tariff. The remaining switchers were almost evenly split between the day-ahead alert tariff and the environmental alert programme. This preference for the daily ToU tariff over the day-ahead alert tariff is in keeping with previous studies which have found that consumers tend to prefer simpler DSR tariffs with fixed pricing that does not

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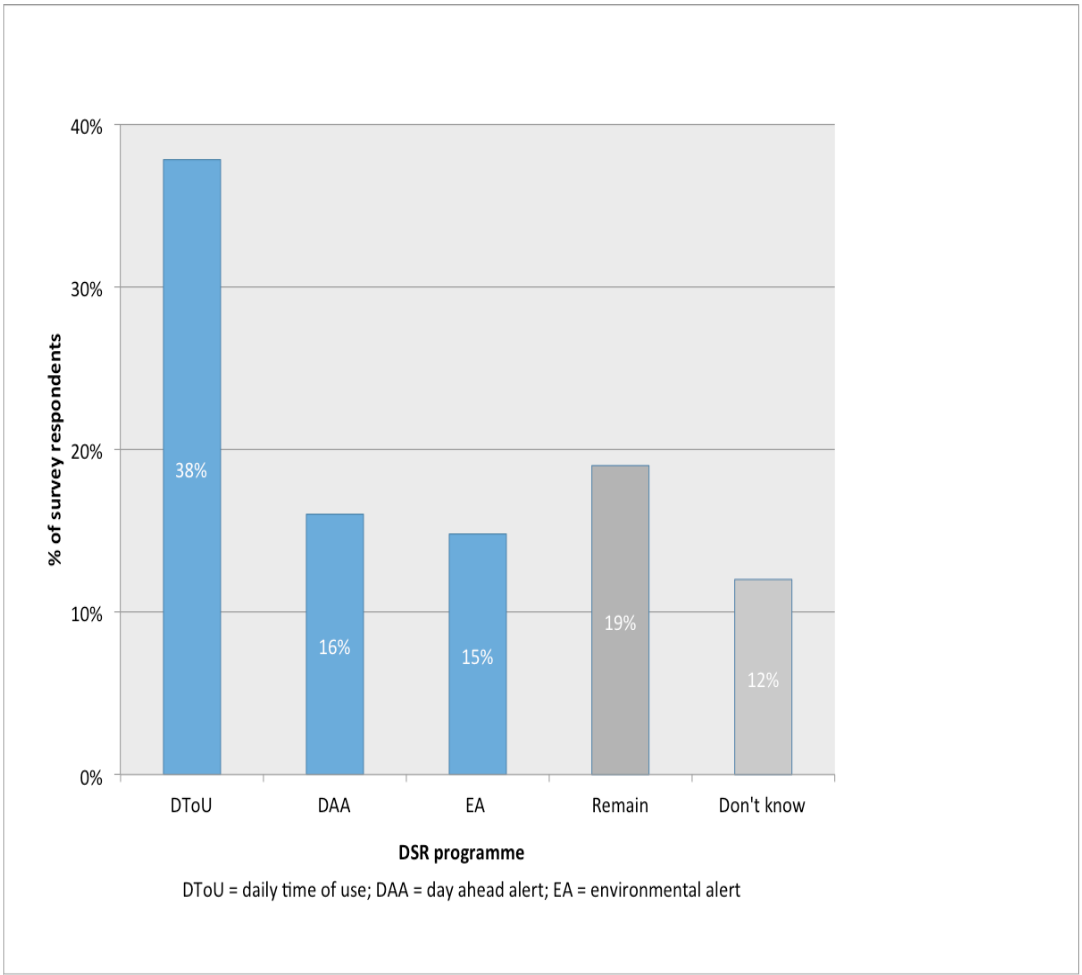
[68] The full survey is reproduced in Appendix II.

vary from day to day (Darby and Pisica, 2013; Ericson, 2011; Fell *et al*, 2015a). Figure 13 shows the distribution of responses.

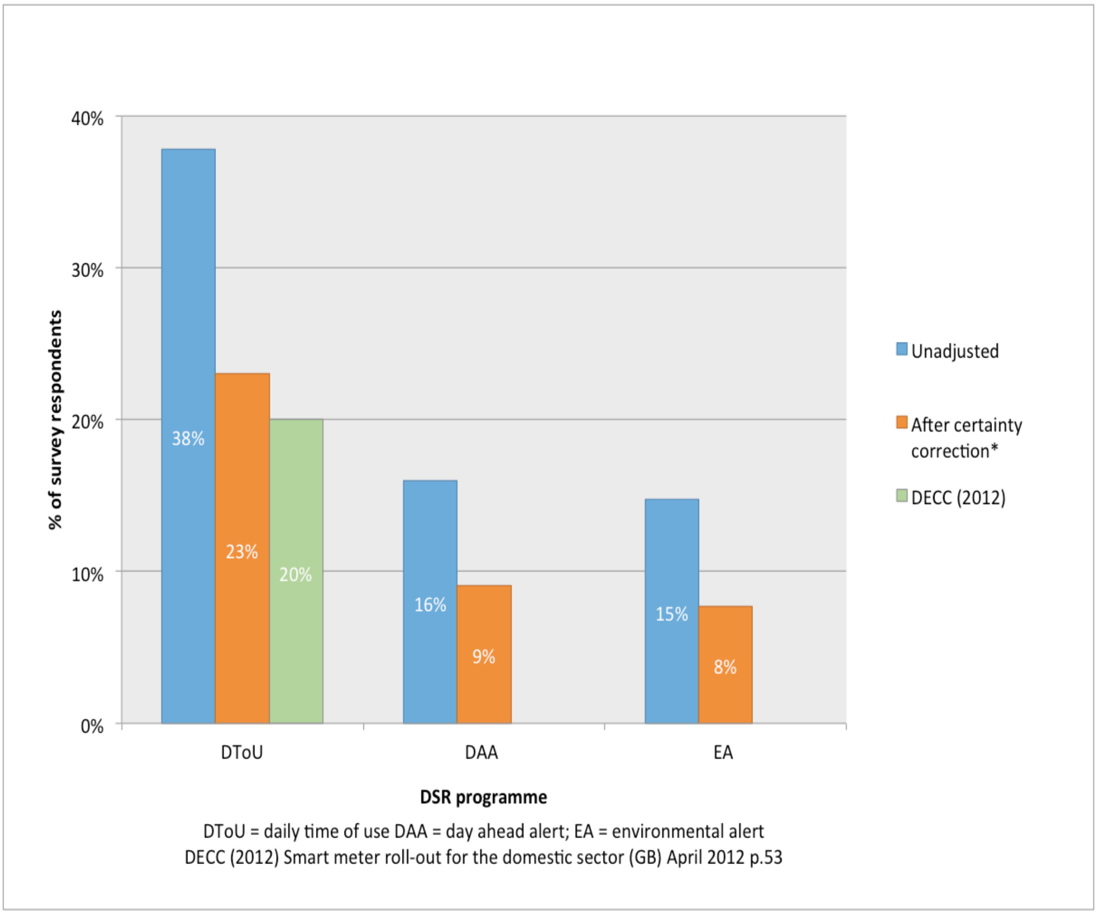
Figure 13. Stated willingness to switch (N=1312)



5.4.1 Certainty correction

As discussed in Chapter 4, hypothetical bias can influence respondents' choices in stated preference research (Fifer, 2011; Whitehead *et al*, 2014). In the context of this survey, this could have resulted in more respondents indicating WTS than would switch in a real-world setting. Consequently, and to provide a more conservative estimate of WTS, responses were certainty corrected through a follow-up question which asked respondents to rate how certain they were about their decision to switch, on a scale from 1 to 10. It was then assumed that only those with a certainty of seven or higher would actually switch. Figure 14 illustrates the percentage of respondents who indicated WTS before and after certainty correction.

Figure 14. Stated willingness to switch before and after certainty correction (N=1312)



After certainty correction, the percentage of respondents who indicated that they would switch to one of the DSR programmes dropped to 40% (previously 69%). However, even after certainty correction, the percentage who indicated that they would switch to the daily ToU tariff (23%) was in line with UK government estimates that 20% of residential consumers will switch to a static ToU tariff by 2030 (DECC, 2012).[69] In this regard, it is notable that respondents were asked whether they would switch to the DSR programmes now, whereas the UK government estimates are for 2030. This suggests that the government estimates might be conservative and that a larger number of consumers may choose to switch to these tariffs once they become widely available.

Although the certainty correction is an approximation, and it cannot be assumed that the certainty corrected data would necessarily reflect the number of actual switchers in a real-world setting, it nonetheless provided a useful adjustment to the hypothetical switching data for the purposes of this study.

[69] This is in addition to consumers who are already on Economy 7 and Economy 10 tariffs (DECC, 2012).

5.4.2 Factors that influence WTS

Statistical analysis was carried out to examine which socio-demographic, economic, household and attitudinal variables were correlated with WTS. The multinomial logistic regression model that was used for this purpose is an extension of the binomial logistic regression model, and is normally applied when the dependent variable can take three or more values and there is no obvious order to the alternatives (Friedman, 2010; Wooldridge, 2010). As in binomial logistic regression, multinomial logistic regression uses maximum likelihood estimation to evaluate the probability of categorical membership and is often considered an attractive method because it does not assume normality, linearity or homoscedasticity (Starkweather and Moske, 2015). Sample size guidelines indicate that there should be a minimum of 10 cases per independent variable (Schwab, 2002). These guidelines were satisfied since the sample consisted of 1,312 participants and 10 variables were included in the final model.

However, as in many statistical procedures, high levels of collinearity between independent variables can be problematic because they increase the standard errors of the coefficient estimates and can make it harder to attribute effects to specific variables (Field, 2009). Accordingly, correlation matrices were produced for all the interval and ratio independent variables that were included (see Table 7). The correlations between these variables were all less than 0.2, suggesting acceptable collinearity (ibid). Additional tests for collinearity were performed by carrying out linear regressions between these variables. Variation inflation factor values for all the variables were less than 1.6 and the average of all the variation inflation factors was less than 1. This provided further evidence that collinearity was within acceptable bounds (Bowerman and O'Connell, 1990; Myers, 1990).

Table 7. Independent variables included in the model

Variable	Type	Range
Country of residence	Nominal	NA
Gender	Nominal	NA
Qualifications	Ordinal	NA
Household income (log)	Interval	3.9 – 7.8
Household heating	Nominal	NA
Household appliances	Ratio	0 - 3
Perceived appliance consumption knowledge	Interval	0 - 4
Perceived ability to change appliance use times	Interval	1 - 5
Motivation to save money	Interval	0 - 12
Commitment to environmental sustainability	Interval	0 - 29

In this application of the multinomial logistic model, the dependent variable could take on one of four values: one of the three DSR programmes or 'non-switcher'.[70] 'Non-switcher' was used as the reference case, so that the statistically significant predictors of switching could be identified. Table 8 summarises the results of the multinomial logistic regression used to explore the relationship between the various individual and household variables in Table 7 and stated WTS to the three DSR programmes.[71]

[70] Respondents who indicated "Don't know" were classed as non-switchers.
[71] In addition, the final three rows of Table 8 report results for Groups 2, 3 and 4 (see Section 3.3).

Table 8. Switching model

Test variable	Daily time of use				Day-ahead alert				Environmental alert			
		95% confidence interval for odds ratio (OR)				95% confidence interval for odds ratio (OR)				95% confidence interval for odds ratio (OR)		
	B (Std. Error)	Lower	OR	Upper	B (Std. Error)	Lower	OR	Upper	B (Std. Error)	Lower	OR	Upper
Resident of Scotland	-.29 (.28)	.43	.75	1.29	.00 (.34)	.51	1.00	1.95	.61 (.32)	.98	1.84	3.45
Resident of Wales	.34 (.41)	.63	1.41	3.13	.44 (.51)	.56	1.55	4.23	.96 (.47) *	1.05	2.62	6.54
Resident of Northern Ireland	.01 (.57)	.33	1.02	3.14	-.21 (.76)	.18	.80	3.55	1.44 (.59)*	1.32	4.23	13.54
Gender (female)	.32 (.15)*	1.02	1.38	1.86	-.02 (.19)	.67	.98	1.44	.50 (.20)*	1.10	1.65	2.45
Degree+ qualifications	1.18 (.36)**	1.62	3.26	6.58	.81 (.46)	.90	2.25	5.60	1.04 (.46)*	1.14	2.82	6.98
Below degree qualifications	.83 (.35)*	1.16	2.30	4.57	.23 (.46)	.51	1.26	3.11	.62 (.46)	.76	1.86	4.56
Income (log)	.09 (.10)	.89	1.09	1.34	.47 (.14)**	1.22	1.60	2.10	.32 (.14)*	1.04	1.37	1.81
Electric central heating	.84 (.31)**	1.25	2.31	4.25	.26 (.42)	.56	1.29	2.97	1.00 (.37)**	1.32	2.73	5.65
Storage heating	-.46 (.36)	.31	.63	1.28	-.89 (.56)	.14	.41	1.22	-.92 (.55)	.13	.40	1.18
Other heating	-.52 (.31)	.32	.59	1.09	-.42 (.39)	.30	.65	1.42	-.68 (.41)	.22	.50	1.14
Household appliances	.16 (.09)	.97	1.17	1.41	.06 (.12)	.84	1.06	1.35	.14 (.12)	.90	1.15	1.47
Perceived appliance consumption knowledge	.16 (.08)*	1.00	1.17	1.37	.11 (.10)	.91	1.11	1.36	.19 (.11)	.98	1.21	1.50
Perceived ability to change appliance use times	.18 (.08)*	1.02	1.20	1.41	.36 (.11)**	1.15	1.43	1.76	.14 (.11)	.93	1.15	1.42
Motivation to save money	.05 (.02)	.99	1.05	1.12	.03 (.04)	.95	1.03	1.11	-.00 (.04)	.91	.99	1.08
Commitment to environmental sustainability	.05 (.02)**	1.02	1.05	1.08	.06 (.02)**	1.02	1.06	1.11	.17 (.02)**	1.13	1.19	1.24
x2 savings	-.30 (.21)	.49	.74	1.11	.31 (.26)	.82	1.36	2.28	-.12 (.26)	.53	.88	1.49
Guarantee	-.05 (.21)	.62	.95	1.45	-.11 (.29)	.51	.89	1.60	-.14 (.28)	.50	.87	1.49
x2 savings and guarantee	.23 (.21)	.83	1.26	1.91	.20 (.28)	1.23	.71	2.12	-.33 (.29)	.41	.72	1.28

N=1312, P <.05* P<.01**

5.4.3 Odds ratios

Odds ratios (ORs) are commonly used to report effect sizes in logistic models (see the boxout below for an explanation of how ORs are calculated). In the case of the ratio and interval variables included in the model – household income (log), household appliances, perceived appliance consumption knowledge, perceived ability to change appliance use times, motivation to save money and commitment to environmental sustainability – the ORs indicate the difference between the odds that respondents would choose a particular DSR programme and the odds that the respondent would choose not to switch for each one-unit increase in the variable. ORs greater than (less than) one indicate that as the variable increases, the odds of switching to the DSR programme increase (decrease).

In the case of the categorical variables included in the model – household heating, country of residence, gender, educational qualifications – the ORs indicate the difference between the odds of switching to the DSR programmes for each category of the variable and the odds of switching in the reference case. For instance, as the reference case used for household heating was gas, the ORs reported for the other heating categories – electric central heating, storage heating and other – indicate the difference between the odds that households with these heating systems would switch to the DSR programmes and the odds that households with gas central heating would switch to the DSR programmes.

Odds ratios (adapted from Liberman, 2005)

A common effect size measure is the ratio of two odds, known as the odds ratio (OR). Every probability has a corresponding odds, which equals the probability of the outcome occurring (e.g. switching to a DSR programme) divided by the probability of the outcome not occurring (e.g. not switching):

Odds = p / (1 – p)

For example, for p = .80, the odds are .80 / .20 = 4.0, colloquially “4 to 1” odds. Note that odds and p are not linearly related. A 1-point change in odds corresponds to varying changes in p, and vice versa. For example, odds = 2.0 versus 3.0 correspond to ps = .67 versus .75, and odds = 7.0 versus 8.0 correspond to ps = .875 versus .890.

Taking the ratio of two odds (i.e., dividing one by the other) gives the OR. For example, for those with electric heating the odds of switching to the static ToU tariff are .75 / .25 = 3.00, colloquially “3 to 1” odds; for those with gas heating the odds of switching are .50 / .50 = 1, colloquially “1 to 1” odds. The ratio of these two odds is OR = 3.0 / 1.0 = 3.0. Thus, the odds of households with electric heating switching to the static ToU are 3 times as large as the odds of households with gas heating switching.

$$\text{OR} = \frac{p_E/(1-p_E)}{p_G/(1-p_G)}$$

5.4.4 Hypothesis tests of ability, motivation and trigger

This section provides the results of the hypothesis testing based on the coefficients and significance values from the estimated model (see the summary in Table 9). As discussed in Chapter 4, each hypothesis related to the ability, motivation or trigger component of the FBM. Hypotheses 1 to 4 relate to ability factors; Hypotheses 5 to 7 to motivation factors; and Hypothesis 8 to the trigger (the price guarantee). Hypotheses were accepted in cases where they were found to be significantly correlated with at least two of the three DSR programmes.[72]

Table 9. Summary of switching hypotheses results

Hypothesis		Variable range	ToU	DAA	EA	Hypothesis accepted or rejected
			OR	OR	OR	
H1	More washing machines, tumble dryers and dishwashers increases WTS	0-3	1.17	1.06	1.15	Rejected
H2	Electric central heating increases WTS	NA	2.31**	1.29	2.73**	Accepted
H3	Greater perceived ability to change appliance use times increases WTS	1-5	1.20*	1.43**	1.15	Accepted
H4	Greater perceived appliance consumption knowledge increases WTS	0-4	1.17*	1.11	1.21	Accepted
H5	Greater motivation to save money by switching tariffs increases WTS	0-12	1.05	1.03	0.99	Rejected
H6	Doubling the financial savings to be made on the DSR tariffs increases WTS	NA	0.74	1.36	NA	Rejected
H7	Greater commitment to environmental sustainability increases WTS	0-29	1.05**	1.06**	1.19**	Accepted
H8	Offering consumers price guarantees increases WTS	NA	0.95	0.89	NA	Rejected

N=1312, P<.05* P<.01**

[72] H4 was an exception in this regard. This hypothesis was accepted even though it was significantly correlated with only the daily ToU tariff in the base model (P<.05). The justification in this case was that although greater perceived appliance consumption knowledge was correlated with greater WTS to the environmental alert programme at only the 10% confidence in the base model this increased to the 5% level when the analysis was carried out using the certainty corrected data (see Section 5.4.5).

Hypothesis 1 – Having a larger number of washing machines, tumble dryers and dishwashers increases WTS (ability)

Although it was hypothesised that having more washing machines, tumble dryers and dishwashers would increase WTS, this was not supported by the results. The relationship between the number of these appliances found in respondents' homes and the likelihood of choosing to switch to any of the programmes was not statistically significant for any of the DSR programmes ($P>0.05$ in each case).

Hypothesis 2 – Having electric central heating increases WTS (ability)

This hypothesis was strongly supported: the odds of respondents with electric central heating (n=93) choosing the daily ToU tariff were 2.3 times as large as the odds of respondents with gas central heating (n=929) choosing this programme. Similarly, the odds of respondents with electric heating choosing the environmental alert programme were 2.7 times as large as the odds of respondents with gas central heating doing so.

Hypothesis 3 – Having greater perceived ability to change appliance use times increases WTS (ability)

The results supported the hypothesis that consumers who believe it would be easier to reschedule appliance use have greater WTS. For each one-unit increase in this five-point measure, respondents were 43% more likely to choose the day-ahead alert tariff and 20% more likely to choose the daily ToU tariff. That this measure was most strongly correlated with WTS to the day-ahead alert tariff is unsurprising: consumers on this tariff – who would know only one day in advance of the electricity prices that would apply on the following day – would need to be more flexible about when appliances were used than those who switched to the daily ToU tariff.

Hypothesis 4 – Having greater perceived appliance consumption knowledge increases WTS (ability)

The hypothesis that respondents with greater perceived appliance energy consumption knowledge would have greater WTS was supported: for each one-unit increase in this measure, respondents were 17% more likely to choose to switch to the daily ToU tariff. For each one-unit increase in this measure, respondents were 22% more likely to choose the environmental alert programme; however, this was only significant at the 10% level (P=0.07).

Hypothesis 5 – Having greater motivation to save money by switching tariffs increases WTS (motivation)

As consumer interest in saving money on electricity bills is often cited as a motivation for switching to DSR programmes (Dütschke and Paetz, 2013; Namerikawae *et al*, 2015), it was hypothesised that consumers who are more motivated to save money by switching would have greater WTS. However, this hypothesis was not supported. The ORs for this measure for all three programmes were close to one (+/- 0.05 in each case) and the measure did not have a statistically significant relationship with WTS (P>0.05 for all three programmes).

Hypothesis 6 - Doubling the financial savings to be made on the DSR tariffs increases WTS (motivation)

The hypothesis that WTS would be increased by doubling the financial savings that consumers expect to receive was not supported. Although the tariffs presented to Group 2 respondents offered savings that were twice as high as those offered to Group 1 respondents, there was no statistically significant difference in the likelihood that respondents in these groups would switch (P=0.15 for the daily ToU tariff and P=0.23 for the day-ahead alert tariff).

Hypothesis 7 – Having greater commitment to environmental sustainability increases WTS (motivation)

As discussed in Section 3.2, a measure of each respondent's "Commitment to environmental sustainability" was created to explore whether consumers who are more motivated by environmental concerns have greater WTS. The model showed that respondents with higher scores on this measure were more likely to choose to switch to all three DSR programmes, with higher scores increasing the likelihood that respondents would choose the environmental alert programme the most. For each one-unit increase in scores on this measure, respondents were 19% more likely to switch to this programme (OR=1.19, P=0.00), 5% more likely to switch to the daily ToU tariff (OR=1.05, P=0.00) and 6% more likely to switch to the day-ahead alert tariff (OR=1.06, P=0.00).

Hypothesis 8 - Offering consumers price guarantees increases WTS (trigger)

Contrary to expectations, the results did not support the hypothesis that offering price guarantees would increase WTS. The ORs for the guarantee group (Group 3) were less than one for both the daily ToU tariff and the day-ahead alert tariff, indicating that respondents in this group were less likely to choose these tariffs than respondents in the group not offered the guarantee.[73]

5.4.5 Socio-demographic and economic variables and WTS

Respondents from higher-income households were more likely to choose both the day-ahead alert tariff and the environmental alert programme. For each one-unit increase in the logarithmic income measure, respondents were 60% more likely to choose the day-ahead alert tariff and 37% more likely to choose the environmental alert programme (OR=1.60, P=0.00 and OR=1.37, P=0.02 respectively). The day-ahead alert tariff was particularly popular with very high-income households (£2,000+ per week), with 33% of respondents in this income category choosing this tariff, compared with 16% who chose it across all income groups.[74]

The relationship between equivalised household income and WTS was also explored (see OECD, 2013). For each one-unit increase in the logarithmic equivalised income measure, respondents were 68% more likely to choose to switch to the day-ahead alert tariff and 27% more likely to choose to switch to the environmental alert programme (OR=1.68 and OR=1.27 respectively). However, as no data was collected about which households contained children between the ages of 15 and 17, the equivalised income measure was unable to accurately weight all households. Consequently, income before equivalisation was used in the final models.

As the highest income band that respondents could select was open-ended (£2,000+ per week), sensitivity analysis was carried out on the income results. The model was estimated with an assumed income for these households of £2,000, £2,250, £2,500 and £2,750 per week. For all values, the relationship between household income and WTS to the day-ahead alert tariff and environmental alert programme remained unchanged (OR=1.60, P=0.00 for the day-ahead alert tariff and OR=1.37, P=0.02 for the environmental alert programme).

[73] The difference was also not statistically significant for either tariff.
[74] The percentages reported are before certainty correction. After certainty correction, 18% of respondents from households with incomes of £2,000+ indicated that they would switch to the day-ahead alert tariff, compared with 9% of respondents who chose this tariff across all income groups.

Respondents with educational qualifications were more likely to choose both the daily ToU tariff and the environmental alert programme. The odds that respondents with a degree qualification or higher would choose the daily ToU tariff were 3.3 times as large as the odds of those without qualifications and 2.8 times as large as the odds of those without qualifications to choose the environmental alert programme (OR=3.26, P=0.00 and OR=2.82, P=0.02 respectively).

The odds that respondents with qualifications below degree level would choose the daily ToU tariff were also 2.3 times as large as those without qualifications (OR=2.30, P=0.02).[75] There was no statistically significant difference in the likelihood that respondents with qualifications would switch to the day-ahead alert tariff compared to those without qualifications (P>0.05 for all qualification categories).

Females were 38% more likely to choose the daily ToU tariff than males (OR=1.38, P=0.04), and 65% more likely to choose the environmental alert programme than males (OR=1.65, P=0.01). Consumers living in Northern Ireland, Scotland and Wales were much more likely to choose the environmental alert programme than those living in England. The odds that respondents in Northern Ireland would choose this programme were 4.2 as large as those in England; the odds of those in Scotland were 1.84 times as large; and the odds of those in Wales were 2.6 times as large (OR=4.23, 1.84 and 2.62 respectively).[76]

Several other variables were initially included in the model because previous studies have found that they influence WTS. These included variables pertaining to household size (BEIS, 2016; Ericson, 2011), whether households contained white goods with timers (Fell *et al*, 2015b) and whether households were on an Economy 7 or 10 tariff (Fell *et al*, 2015b; Nicolson *et al*, 2016). However, these variables were omitted from the final model because they did not show a statistically significant relationship with WTS to any of the programmes.

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[75] The model was also estimated using respondents with qualifications below degree-level as the reference case. This made it possible to examine whether WTS differed between respondents with degree+ qualifications and respondents with below degree-level qualifications. Respondents with degree+ qualifications were 42% more likely to choose the daily ToU tariff and 79% more likely to choose the day-ahead alert tariff than those with below degree-level qualifications (OR=1.42, P=0.03 and OR=1.79, P=0.00). Respondents with degree+ qualifications were also 51% more likely to choose to switch to the environmental alert programme than those with below degree-level qualifications, although this difference was not statistically significant (P=0.06).

[76] This relationship was statistically significant for respondents from Northern Ireland and Wales (P=0.01 and P=0.04 respectively), but not for respondents from Scotland (P=0.06).

5.4.6 Certainty corrected switching model

An additional model was estimated using the certainty corrected data (the 'certainty corrected switching (CCS) model'). This included an additional category for 'uncertain switchers' – respondents who had indicated that they would switch, but who then provided a certainty response below seven. This model was used to explore whether respondent certainty influenced the relationship between the independent variables and WTS.

The results of the CCS model provide further evidence that individuals with greater perceived appliance consumption knowledge have greater WTS (H4). In contrast to the base model – which only showed a statistically significant relationship between perceived appliance consumption knowledge and choosing the daily ToU tariff – the CCS model also showed a statistically significant relationship between perceived appliance knowledge and choosing the environmental alert programme (P=0.02).[77] For each one-unit increase in this measure, respondents were 36% more likely to choose this programme (OR=1.36).

The results of this model also supported the hypothesis that consumers who think it would be easier to change the times at which appliances are used have greater WTS (H3). Respondents were 30% more likely to choose the daily ToU tariff for each one-unit increase in perceived ability to change appliance use times, compared to 20% for the base model. Similarly, they were 53% more likely to switch to the day-ahead alert tariff for each one-unit increase in this measure (compared to 43% for the base model), and 28% more likely to choose the environmental alert programme. However, the latter was just outside the threshold for statistical significance (OR=1.28, P=0.06).

That respondents with higher commitment to environmental sustainability scores had greater WTS was also found in the CCS model (H7). In fact, this was the only variable which was positively correlated with switching to all three programmes in both models. This strongly supports the hypothesis that individuals who are more environmentally motivated have greater WTS.

[77] In the base model, this measure was not statistically significant for the environmental alert programme (P=0.07).

Figure 15 shows the factors that were found to have a positive and statistically significant correlation with WTS to each programme.[78]

Figure 15. Factors correlated with WTS to each DSR programme

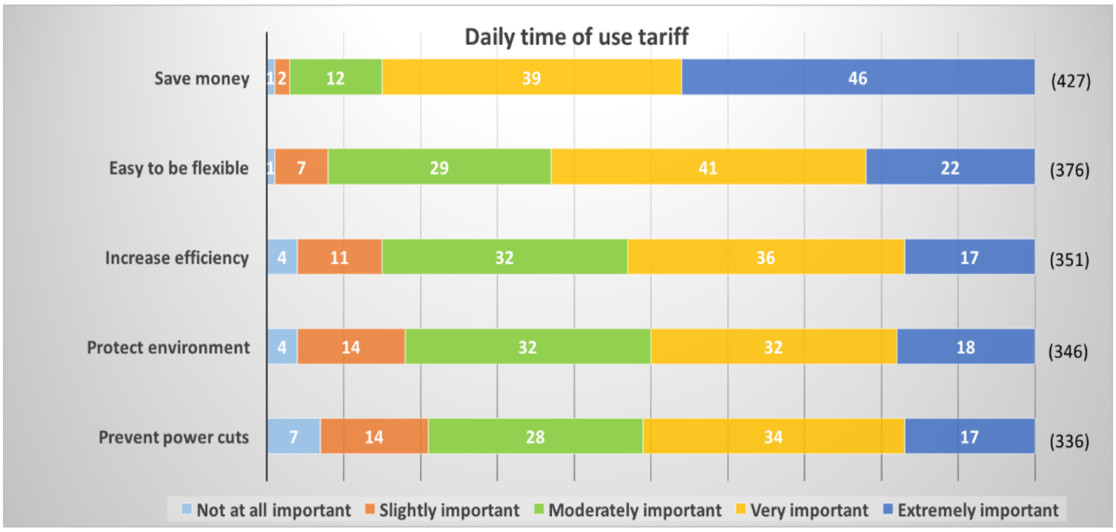
[78] In addition to being significantly correlated with WTS to the daily ToU tariff in both models, perceived appliance consumption knowledge was significantly correlated with switching to the environmental alert programme in the CCS model and is therefore marked with an asterisk in Figure 15.

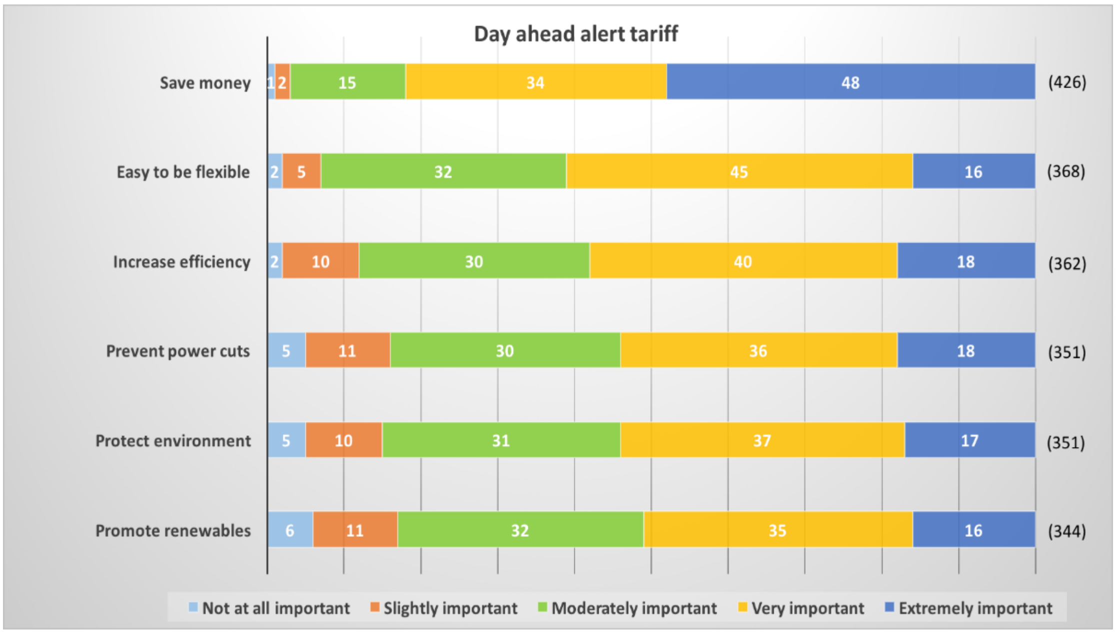
5.4.7 Factors influencing the decision to switch or remain

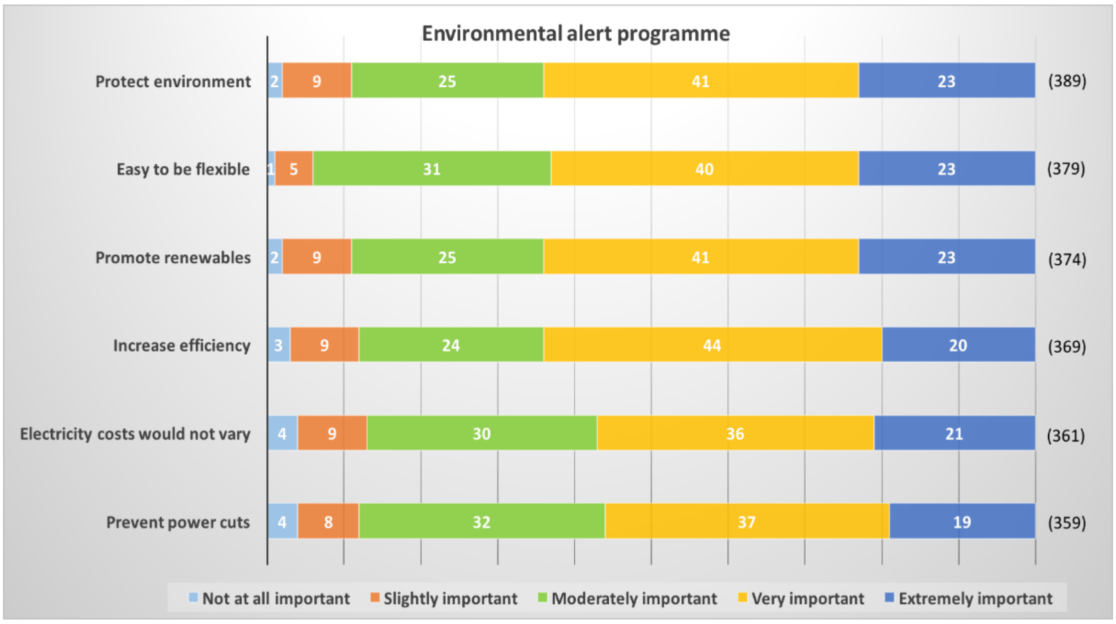
Respondents were asked to indicate the relative importance of several factors in their decision either to switch to one of the DSR programmes or to remain on their existing tariff, as appropriate. In each case, the factors were chosen because the DSR and wider energy literature suggest that they might influence WTS (see the discussion of the various factors in Appendix IV).

Figure 16 shows the percentage of respondents who indicated that each factor was not at all, slightly, moderately, very or extremely important in the decision to switch to their chosen DSR programme. The scores in parentheses on the right-hand side of the tables indicate the overall importance attributed to each factor by respondents who chose the programme. Scores were calculated by awarding one point for each 1% of respondents who indicated that the factor was not at all important, two points for each 1% of respondents who indicated that the factor was slightly important and so on (overall importance scores had a possible range of 50 to 500).

Figure 16. Reasons for switching







Respondents who chose the daily ToU and day-ahead alert tariffs indicated that the opportunity to save money by switching to these programmes had the greatest influence on their decision to switch. “Save money” received the largest number of “Extremely important” responses from respondents who chose to switch to these tariffs by a considerable margin, as well as the highest number of “Moderately important”, “Very important” and “Extremely important” responses combined. This is in line with previous research on consumer preferences for DSR: most of the consumers in studies by Darby and Pisica (2013) and Hall *et al* (2016) indicated that the opportunity to save money was the main reason they would consider switching.

Respondents who chose all three of the DSR programmes reported that the ability to be flexible about the times at which appliances were used was the second most important factor in their decision to switch. This supports the results of the switching models, which showed that consumers who thought it would be easier to reschedule appliance use had greater WTS to the daily ToU and day-ahead alert tariffs (H3).

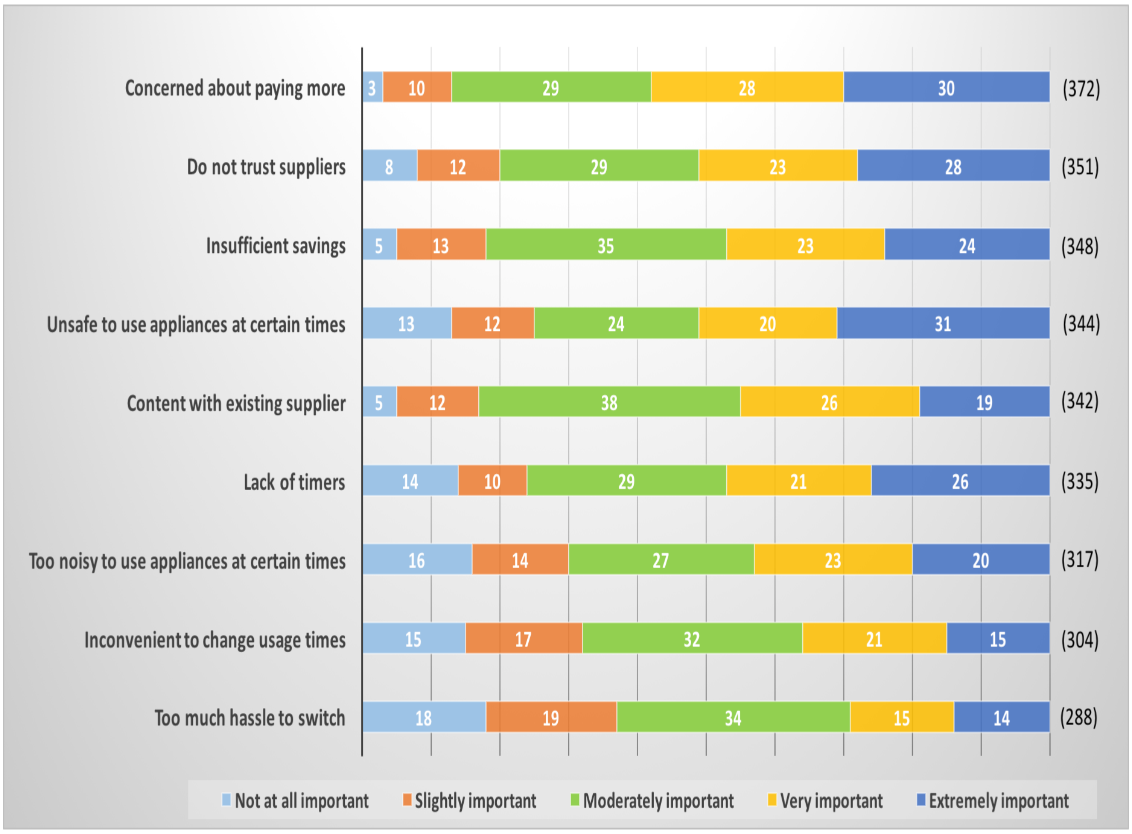
Respondents who chose the two DSR tariffs indicated that improving the efficiency of the electricity system was the third most important factor and rated this above protecting the environment, preventing power cuts and promoting renewables. This suggests that efficiency considerations resonate strongly with many consumers and that electricity stakeholders may help to encourage switching to DSR tariffs if they highlight concomitant efficiency benefits.

Respondents who chose the environmental alert programme indicated that the most important reason for doing so was that it would help to protect the environment. These respondents were also asked to rate the importance of fixed pricing on this programme, with 87% indicating that this was either moderately, very or extremely important in their switching decision. This suggests that information-only programmes could play an important role in maximising participation in DSR: these programmes may attract environmentally motivated consumers who might otherwise be dissuaded from switching to DSR tariffs by the inherent price uncertainty involved.

5.4.8 Factors influencing the decision not to switch

Respondents who chose not to switch were also asked to rate the importance of different factors in their decision. The responses to this question are shown in Figure 17.

Figure 17. Reasons for not switching



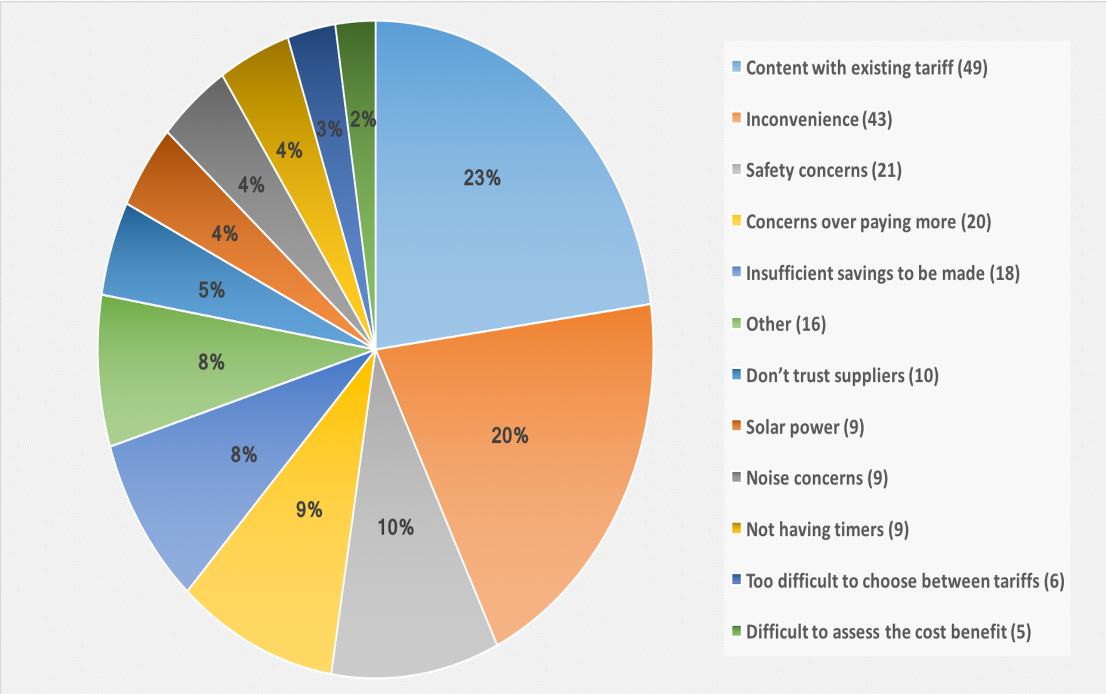
Overall, respondents indicated that concerns about paying more primarily influenced their decision not to switch: 87% indicated that this was either “Moderately important”, “Very important” or “Extremely important”. This accords with previous research which has found that “scepticism and uncertainty” regarding the potential impact on energy costs is the main barrier to uptake of DSR tariffs (BEIS, 2016), and that most UK electricity consumers are loss averse (Nicolson *et al*, 2016).

Respondents cited lack of trust in energy suppliers as the second most important reason for choosing not to switch. This is in line with the DSR literature, which identifies mistrust in energy suppliers as a further barrier to uptake of DSR programmes (Ofgem, 2013; Smart Grid GB, 2013; see also Chapter 2), and suggests that electricity stakeholders may need to take steps to engender consumer trust in order to address this. As Ofgem explains: “improving the base level of consumer trust and engagement is an important pre-condition for [DSR] developments.” (Ofgem, 2013, p.10)

Appliance safety was cited as the fourth most important reason for choosing not to switch, suggesting that such concerns may reduce WTS. To explore this issue further, respondents were also asked to indicate whether they would be prepared to use appliances such as washing machines, dishwashers and tumble dryers when household members were asleep or no one was at home. Many indicated that they would be unprepared to use one or more of these appliances at these times, with the most common reason for such reluctance being that unattended operation posed a fire risk.

In this section of the survey, respondents were also presented with an open-ended question asking them to indicate the single most important reason for having chosen not to switch. Two hundred and fifteen respondents completed this question, with responses provided in Figure 18.

Figure 18. Most important reason for not switching[79] (open-ended question)



Most of the considerations that respondents expressed in their answers to the open-ended question reflected the range of options presented in the previous closed-ended question. However, the fact that several individuals indicated that they would not switch to the DSR programmes because they already had solar panels is notable. These consumers indicated a reluctance to switch because the fact that they were generating their own electricity meant that they were already motivated to use electricity at certain times, and the timing of this usage might have conflicted with the requirements of the DSR programmes. Specific DSR tariffs

[79] The numbers in parenthesis next to the reasons presented in the key indicate the number of respondents providing this response.

which are tailored so that such households can still realise the benefits from their investment in solar may thus be needed to secure buy-in from this cohort (eg, Green Energy UK has partnered with energy storage developer Powervault to offer solar households a 20% discount on the price of a home battery which can be charged during cheap off-peak periods and then used at peak times (Green Energy UK, 2017)).

5.5 Discussion

This section discusses what was learned about the factors that increase WTS through the hypotheses that were tested in the survey, which were based on the FBM elements of ability, motivation and trigger. It also explores the implications of the survey results for maximising uptake of DSR programmes.

5.5.1 Perceived ability

Three of the four measures of perceived ability to respond that were explored (H2-H4) were correlated with greater WTS to one or more of the DSR programmes.

The second hypothesis relating to perceived ability – that having electric central heating increases WTS (H2) – was supported by the results of the switching survey. Respondents with these heating systems had greater WTS to both the daily ToU tariff and the environmental alert programme than respondents from households with gas central heating. As increased electrification of heating is expected to place a significant burden on the UK electricity system in the future (Ofgem, 2010; Strbac *et al*, 2016), electrically heated households represent an important target market for residential DSR, since some of the electrical load associated with heating these households will need to be shifted to avoid large spikes in demand at certain times of day and could also potentially be shifted to match supply output (ibid). As Darby explains, as "the future of heating will strongly influence the scale and shape of electricity demand in regions with cold winters", one way of responding is "to 'smarten' electrical heating, enabling it to respond to network conditions by storing energy at times of plentiful supply, releasing it in response to customer demands and offering rapid-response ancillary services to the grid" (Darby, 2017, p.1).

In this context, the fact that consumers with electric central heating systems had greater WTS is an important finding, suggesting that suppliers could maximise uptake of DSR programmes through targeted marketing directed at these households. At the same time, recruiting these households could help to reduce the burden that they might otherwise place on the electricity system in the form of increased peak demand.[80]

However, any such approach by suppliers may need to be accompanied by changes in housing policy. Households with poor thermal performance have less scope for thermal load shifting (Hong *et al,* 2012), and such loads could be shifted by at most two hours in households which are insulated to current standards before space temperatures dropped below widely accepted lower limits for thermal comfort (Kelly *et al*, 2012).[81] As such, tighter regulation of the thermal standards of new houses, along with increased retrofitting of existing houses to improve insulation standards, may be required to facilitate greater use of electric heating systems to respond on DSR programmes. This could represent a win-win from a policy perspective, since it would help to unlock DSR potential in electrically heated homes while simultaneously helping consumers to save money through household energy efficiency improvements.[82]

The third hypothesis relating to perceived ability to respond – that having greater perceived ability to change appliance use times increases WTS (H3) – was also supported by the results of the switching survey. Consumers who thought that it would be easier to reschedule appliance use times had greater WTS to both of the DSR tariffs. This finding is in line with findings by Buryk *et al* (2015), who found that consumers who thought that it would be easier to reschedule appliance use had greater WTS to a dynamic DSR tariff. Thus, measures which facilitate rescheduling – by promoting greater market penetration of smart appliances that can be controlled remotely by their owners or third parties – may help to increase uptake of DSR programmes.

The fourth hypothesis relating to perceived ability to respond – that having greater perceived appliance consumption knowledge increases WTS (H4) – was partially supported by the results of the switching survey. Greater perceived appliance consumption knowledge was positively correlated with WTS to the daily ToU tariff in the base model, and with WTS to both the daily

[80] This approach may also represent a win-win for operators if these households can then shift a larger proportion of their demand through by rescheduling use of their heating systems, as seen in other studies (Mountain and Lawson, 1995).
[81] Which is usually regarded as the lower limit for acceptable thermal comfort (Fanger, 1970).
[82] In this regard, a recent study by UK Energy Research Centre and the Centre for Innovation and Energy Demand found that measures, including a combination of energy efficiency improvements, heat pumps and heat networks that would be cost effective from now until 2035 could reduce household consumption by 25% by 2035 (UK Energy Research Centre and Centre for Innovation and Energy Demand, 2017). At current energy prices this would equate to energy cost savings of £270 per household per year (ibid).

ToU tariff and the environmental alert programme in the CCS model (H4). This suggests that educational measures which help consumers to learn more about the amount of energy consumed by different household appliances might also help to maximise uptake of DSR programmes. As measures of this kind could also play a role in increasing response on such programmes, they are discussed further in Chapter 7.

One of the measures of perceived ability – that having a larger number of washing machines, tumble dryers and dishwashers increases WTS (H1) – was not supported by the model results. Although it was hypothesised that having a greater number of energy-intensive appliances, which are commonly used to respond (Bulkeley *et al*, 2014; Schofield *et al*, 2014), would increase WTS (H1), respondents with more of these appliances in fact proved no more likely to switch.

5.5.2 Motivation

The switching survey explored the influence of internal and external financial motivations on WTS. The former – specifically, respondents' motivation to save money by switching – was explored using the measure "Motivation to save on electricity bills". As discussed, there was no statistically significant difference in WTS between respondents with different scores on this measure. This is perhaps unsurprising: while the prospect of saving may have increased WTS for some, the risk of potentially paying more on a new tariff may have been a countervailing factor which reduced WTS for others. This explanation seems even more likely given that most electricity consumers in the UK are loss averse (Nicholson *et al*, 2016), and may thus be discouraged from switching to DSR programmes if there is a risk that they might end up paying more.

External financial motivation was explored by varying the level of financial incentives offered. Half of the survey respondents were presented with the opportunity to save 2% on their electricity bills if they switched to the daily ToU tariff and 4% if they switched to the day-ahead alert tariff; while these savings were doubled to 4% and 8% respectively for the other half. The results were somewhat counterintuitive: while it was expected that WTS would be greater among those respondents offered the higher savings, this was not in fact the case.[83] One possible explanation is that the savings were presented as a percentage saving on electricity

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[83] In fact, the ORs for these respondents were lower than 1 indicating that they were less likely to have chosen to switch than those offered the base case savings of 2% on the daily ToU tariff and 4% on the day-ahead alert tariff.

bills, and thus may not have resonated as strongly as they might have had they been presented in pounds and pence.

The result may also reflect the relative price insensitivity which residential consumers have displayed in other DSR contexts. Studies measuring response on DSR programmes have found that the relationship between consumer price response and peak and off-peak rates is not linear, and that consumers often appear to respond more to the existence of price signals than to the differential between peak and off-peak prices (Neuberg, 2014; Stromback *et al*, 2011). Similarly, respondents' switching decisions may have been influenced more by the fact that savings could be made on such tariffs than by the magnitude of those savings.

In contrast to the financial motivations explored, environmental motivation was positively correlated with WTS. The fact that respondents who were more environmentally motivated had greater WTS to all three DSR programmes has important implications for maximising uptake. While Buryk *et al* (2015) found that environmentally motivated respondents had greater WTS when the environmental and system benefits of participating in DSR programmes were highlighted, sampling issues with that study precluded generalisation of these results.[84] By contrast, the sample for the switching survey was broadly representative of the UK population. Consequently, the finding that, when presented with information about the environmental benefits of DSR programmes, consumers who are more environmentally motivated have greater WTS can be generalised to the UK context, and suggests that highlighting the attendant environmental benefits of DSR programmes is likely to be an effective way of increasing uptake.

Several factors which served as barriers to switching were also identified through the survey. These can be summarised as follows:

- fears about the safety of using appliances unattended in order to respond;
- fears that using appliances to respond at certain times would be too noisy;
- fears over paying more;
- fears over associated inconvenience; and
- fears that responding would make it more difficult to benefit from existing solar panels.

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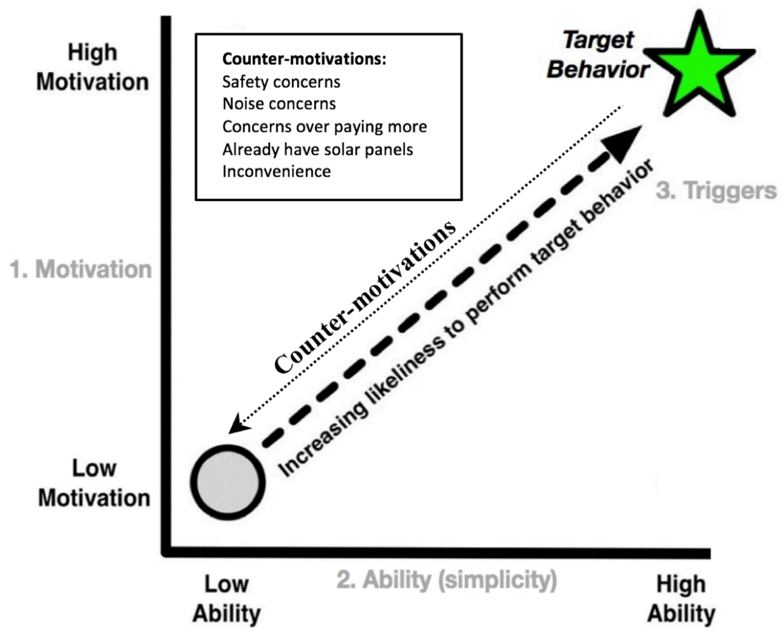
[84] The sample consisted of 160 consumers, a mix of US and EU citizens (Buryk *et al*, 2015).

These considerations were sometimes the most important reasons that respondents gave for deciding not to switch (see Figure 18). The fact that all related to fears about the potential implications of switching indicates that they map onto the hope/fear motivator of the FBM – although in this case, instead of acting as motivations to perform a certain behaviour as under the FBM, they acted as ‘counter-motivations’ that prevented its performance.

As these counter-motivations all reduced WTS, it may thus be argued that if ways can be found to mitigate their influence, this should correspondingly help to increase WTS. For example, to mitigate concerns about the incompatibility between personal solar generation and DSR, programmes could be designed which do not penalise such consumers for using electricity at times when their solar panels are likely to be generating. Similarly, regulations could be introduced to ensure that appliances are quieter and safer to operate.[85]

Figure 19 presents a modified version of the FBM which incorporates the additional concept of ‘counter-motivation’ described above. The dotted arrow running downwards shows how these serve to counter motivations for switching and reduce the likelihood that consumers will switch to DSR programmes.

Figure 19. Modified FBM



[85] See Electrical Safety First (2014) for a detailed discussion of measures which could be implemented to make it safer to use household appliances.

5.5.3 Trigger

The switching survey also explored whether a specific ‘spark trigger’ – a guarantee that consumers would not pay more under the DSR tariffs for the first three months – would influence WTS (H8). While this was expected to increase WTS (see Chapter 3), the results did not bear this out. The guarantee may possibly have had the opposite effect to that intended: instead of mitigating concerns about the risk of paying more during the initial three-month period, it may instead have highlighted the risk that bills might increase once the guarantee was withdrawn. Similarly, offering a penalty-free opt-out with the guarantee may have attracted respondents’ attention to the fact that they might need to switch tariff once again if they found that the DSR tariff was ultimately unsuitable for their needs; the associated inconvenience in turn may have dissuaded some respondents from switching. Regardless of the reasons, the results suggest that offering price guarantees is unlikely to be an effective way of maximising uptake of DSR programmes.

5.5.4 Income and WTS and consumer interest in information-only programmes

The finding that higher-income households had greater WTS is significant. Higher-income households are a key target segment for residential DSR, since they are normally higher electricity users and consume a greater proportion of their electricity during peak periods (Bulkeley *et al*, 2015; Druckman and Jackson, 2008). At the same time, they often have greater capacity to respond on DSR programmes than lower-income households: for example, those on the CLNR ToU trial shifted a greater proportion of their electricity use outside the 4:00pm to 8:00pm peak period and were often “socio-technically equipped to incorporate the tariff into their active rhythms of household management” (Bulkeley *et al*, 2015, p.6). The fact that these households had greater WTS to the day-ahead alert tariff and the environmental alert programme thus suggests that targeted marketing of certain DSR programmes towards these households could provide a win-win by helping to maximise both uptake and response.

Meanwhile, the fact that 20% of the respondents who indicated WTS to one of the DSR programmes chose the environmental alert programme, even though it provided no financial incentives, suggests that a significant residential DSR resource exists in the UK that might be tapped through similar information-only programmes. This resource is at least partially distinct from that which is captured by financial programmes: the variable pricing inherent in DSR tariffs was found to have dissuaded many respondents from switching, and most of those who chose the information-only programme indicated that the associated fixed pricing had significantly influenced their decision.

The popularity of the environmental alert programme among respondents from Northern Ireland, Scotland and Wales is also noteworthy, and suggests that electricity stakeholders in these countries may find it easier than their counterparts in England to recruit consumers to similar programmes. While the survey data does not reveal why respondents from these countries had greater WTS to this programme than their English counterparts, this may be because the wind industry in these countries was more mature than that in England when the survey took place. In 2015, wind capacity accounted for just 0.11 kilowatts per capita in England, compared to 1.03 kilowatts per capita in Scotland, 0.43 kilowatts per capita in Wales and 0.39 kilowatts per capita in Northern Ireland (Special feature – UK renewable electricity, 2016)

To the author's knowledge, the approach taken in this study to cross-check the results – comparing a model produced with the stated preference data before certainty correction with a second model produced after certainty correction – is not commonly undertaken in statistical analysis. The cross-check made it possible to collect additional evidence regarding the influence of the various independent variables included in the model on WTS, providing further support in this regard. This could thus represent a promising methodological approach for generating further insights when using statistical methods to analyse data from stated choice experiments.

5.6 Conclusion

This chapter explored consumer preferences for a range of DSR programmes that are likely to be suited to the UK electricity system context either now or in the future. The results of the stated choice experiment presented in the switching survey suggest that UK consumers have a considerable appetite for DSR programmes. Even the more conservative estimate, using the certainty corrected data, that 23% of consumers would switch to the static ToU tariff is comparable to UK government switching estimates for 2030 (DECC, 2012). Meanwhile, the fact that 9% of respondents indicated they would be willing to switch to the day-ahead alert tariff suggests that there is a market for dynamic DSR tariffs, which may become an increasingly attractive way for suppliers to manage the greater share of variable generation in the future UK electricity system (Deasley *et al*, 2014).

While previous research has estimated the number of UK consumers who might be willing to switch to DSR tariffs and direct load control arrangements (BEIS, 2016; Fell *et al*, 2015a; Nicolson *et al*, 2017), this study is the first to explore consumer interest in information-only programmes. In this regard, even after certainty correction, 8% of respondents indicated WTS to the environmental alert programme (20% of all respondents who indicated that they would switch to one of the DSR programmes). This suggests that such programmes could serve as a complementary offering to financially incentivised programmes, helping to expand the resource represented by residential DSR.

However, by its nature, the switching survey cannot provide any evidence as to whether the consumers who might be willing to switch to information-only DSR programmes might in fact respond once enrolled. To explore this further, a DSR trial was designed and conducted, using the environmental alert programme as the blueprint. The trial – described in detail in Chapters 6 and 7 – aimed to determine whether households on information-only DSR programmes would be willing and able to respond, and whether the theoretical resource revealed through the switching survey could be harnessed to help optimise the impact of residential DSR in practice.

6. The dynamic information-only trial

6.1 Introduction

The switching survey discussed in Chapter 5 included a discrete choice experiment which presented respondents with the hypothetical opportunity to switch to one of three DSR programmes: a static TOU tariff, a dynamic TOU tariff or a dynamic information-only programme. The static and dynamic TOU tariffs were based on price-based programmes that are well suited either to existing electricity system conditions or to those expected to prevail from 2020 onwards (see Chapter 2 and also Element Energy and Redpoint, 2012; Darby and McKenna, 2012). Under the third – the environmental alert programme – customers would be sent advance notifications requesting them to reduce or increase their electricity consumption depending on available wind generation, although prices would remain the same at all times.

While large-scale trials have been conducted in the UK to explore how consumers respond to tariffs that resemble the static and dynamic ToU tariffs presented in the switching survey (Bulkeley *et al* 2014; Schofield *et al*, 2014), none thus far have focused on dynamic information-only DSR programmes. Research in this area would be especially welcome for two reasons. First, as renewable generation increases, dynamic DSR programmes could help suppliers to match supply with demand, thus reducing the price they pay for electricity in the wholesale markets (Hesmondhalgh *et al*, 2014). Second, the switching survey revealed that some consumers may prefer the fixed pricing that is a feature of dynamic information-only programmes. Such programmes could therefore represent an additional demand-side resource for electricity system stakeholders if consumers on these programmes can successfully respond once enrolled.

To this end, a dynamic information-only DSR trial was carried out as part of the research for this thesis. It aimed to determine whether residential consumers could adjust their consumption patterns in response to day-ahead notifications based on forecast available generation from wind farms across the country. The trial focused specifically on wind generation because this is already the most abundant renewable electricity source in the UK (DUKES, 2016) and has strong potential for further growth, given that the UK is among the windiest countries in Europe (Ask For Evidence, 2017).

Section 6.2 of this chapter explains how participants were recruited to the trial, provides socio-demographic information about the sample and discusses self-selection issues. Section 6.3

describes the experimental design, including how electricity consumption data was collected from trial households and how changes in consumption during trial events were estimated. Section 6.4 presents the results, including estimations of response during trial events and the tests used to determine whether changes in consumption were statistically significant. Section 6.5 discusses the implications of these results for the use of information-only DSR programmes as an additional demand-side resource, and the potential benefits of implementing such programmes for electricity stakeholders. Section 6.6 sets out conclusions and discusses some limitations of the trial.

6.2 Trial recruitment, sample socio-demographics and participant self-selection

An invitation to participate in the trial was circulated through the Centre on Innovation and Energy Demand website, the Your Energy Sussex Twitter account and the West Sussex County Council email bulletin. The call for participation explained that as electricity cannot be easily stored, information-only DSR programmes can help to ensure that generation from wind is not wasted (see Appendix VI).

Forty-six individuals from households across Southeast England volunteered to participate in the trial (henceforth referred to as the 'lead participants').[86] These individuals then completed an online enrolment questionnaire – essentially, a shorter version of the switching survey – the results of which are summarised in Table 10.

Compared to UK statistics, most of the lead participants were from households with higher than average incomes and were also more likely to own their homes (Office for National Statistics, 2012). The sample also included a greater than normal proportion of four-person and five-person-plus households (ibid). However, the sample was intended to be representative not of the average UK household, but rather of those that would be most likely to sign up to similar information-only DSR programmes if they were made available in the future.

In this regard, studies suggest that individuals who self-select to participate in residential energy trials are often highly environmentally aware and inherently motivated to engage in energy

[86] The consent form for participation in the trial is reproduced in Appendix VII; the information form which participants were sent prior to commencement of the trial is reproduced in Appendix VIII.

saving (Ek and Söderholm, 2010). The fact that the trial sample was likely to include many such individuals was considered advantageous, given that the switching survey revealed that more environmentally motivated individuals – as tested through the "Commitment to environmental sustainability" measure – were more likely to choose to sign up to an equivalent information-only programme (see Chapter 5).

Table 10. Trial sample

Household location	East Sussex	20
	West Sussex	12
	London	8
	Other[87]	6
Household ownership	Owner	35
	Renter	11
Gender of lead participant	Male	25
	Female	21
Household members	1	4
	2	15
	3	7
	4	16
	5+	4
Household income per week	£100 - £399	4
	£400 - £699	4
	£700 - £999	14
	£1,000 - £1,499	13
	£1,500+	2
	Don't know/prefer not to say	9

The switching survey further revealed that individuals with degree-level educational qualifications or higher and those from higher-income households were more likely to choose to sign up to the environmental alert programme. The mean "Commitment to environmental sustainability" scores, mean household incomes and mean educational qualification levels[88] of

[87] These households were located in the West Midlands, Cornwall, the Southeast, Norfolk, Portsmouth and Cambridge.
[88] This four-point educational qualification measure was the same as that used in the Census 2011 (Office for National Statistics, 2012):

- Level 1 qualifications – one to four GCSEs or equivalent qualifications;
- Level 2 qualifications – five GCSEs or equivalent qualifications;

the lead participants were thus compared with those of the switching survey respondents who chose the environmental alert programme, to test whether they were representative of the cohort that would be most likely to participate in similar information-only programmes.[89] The results are set out in Table 11 which also includes this data for survey respondents who chose not to switch to any of the DSR programmes, for comparison.

Table 11. Comparison of trial sample and survey respondents

	Trial sample (N=46)	Environmental alert (n=194)	Non-switchers (n=412)
Commitment to environmental sustainability score (0-29)	20.9	20.2	16.5
Educational level (1-4)	3.5	3.3	2.8
Weekly household income[90]	£995	£748	£585

As Table 11 illustrates, while lead participants tended to come from higher-income households than respondents who chose the environmental alert programme in the switching survey, the two cohorts were closely matched in terms of mean educational qualification levels and commitment to environmental sustainability scores. This afforded greater confidence that the response from households on the trial could be representative of that which might be expected on a real-world information-only DSR programme.

- Level 3 qualifications – two or more A Levels or equivalent qualifications; and
- Level 4 qualifications – bachelor's degree or equivalent and higher qualifications.

[89] At least in terms of these characteristics. It was not possible to know for certain whether other consumer or household characteristics which were not measured had influenced respondents' decisions to choose the equivalent programme in the switching survey.

[90] Survey respondents and lead participants in the DSR trial who answered "Don't know/prefer not to say" to the income question were not included in this comparison.

6.3 Experimental design

In order to track response on the trial, participating households were provided with:

- a current transformer clip, which was attached to each household's electricity meter to record electricity consumption;
- a Geo Solo in-home display; and
- an internet bridge.

The in-home display presented participants with real-time information on their electricity consumption, in either kilowatt-hours (kWh), pence per hour or carbon dioxide emissions per hour. By default, it showed consumption in pence per hour, as illustrated in Figure 20.

Figure 20. Geo Solo II in-home display

The internet bridge, which was connected to each household's broadband router, allowed more detailed consumption data to be accessed online. Household members – and the author – could log onto the Energynote website (Energynote, 2014) to access historical consumption data presented in daily, weekly or monthly graphs. Crucially, 15-minute interval consumption data could also be downloaded from the site to determine whether each household's consumption patterns during trial events differed from its typical consumption patterns (described further below).

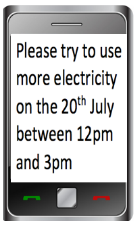
Many of the lead participants (n=24) were also interviewed at the end of the trial, to learn more about their experiences and explore how future DSR programmes could be designed to maximise response. The qualitative data from these interviews is discussed in detail in Chapter 7. However, when analysed alongside participants' consumption data, this often yielded further insights regarding household electricity use; in such cases, qualitative data from the interviews is also presented in this chapter to contextualise electricity use in the households.

6.3.1 Trial events

Lead participants registered the mobile phone numbers of one or more household members to receive event notifications by text and could also choose to receive additional notifications via email. Two notifications of each trial event were sent: the first 24 hours in advance of the event and the second one hour before it was due to start. The first notification aimed to give participants sufficient time to consider how they might respond during the event, while the second served as a reminder that the event was about to begin.

Twenty-four 'turn-up' events (where participants were asked to increase consumption) and 16 'turn-down' events (where participants were asked to reduce consumption) were held between June 23 2015 and September 5 2015. Five events took place in June, 19 in July, 14 in August and two in September. Each event lasted for between two and 18 hours. Figure 21 shows an example of a 'turn-up' notification.

Figure 21. Turn-up notification



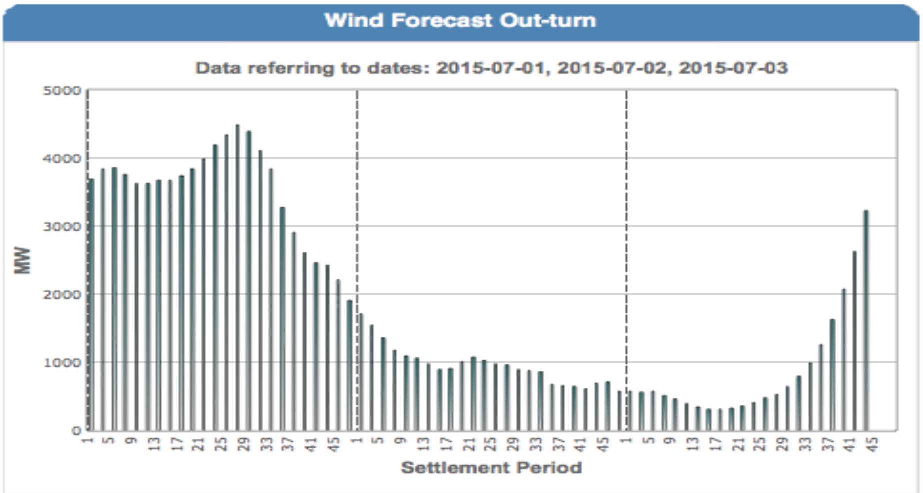
6.3.2 Timing of events

The events were timed based on data from National Grid's wind forecasting tool, which is published on the Balancing Mechanism Reporting System website (BM Reports, 2014). The tool predicts total electricity generation for the next 72 hours from wind farms which are monitored by National Grid.

This data was analysed daily throughout the trial to determine the timing and duration of events. Turn-down events were scheduled when total predicted output from all wind farms was under 850 MW, representing under 10% of installed wind capacity. Turn-up events were scheduled when total predicted output from all wind farms was over 3,000 MW, representing more than 33% of installed wind capacity.

Figure 22 shows an example of forecast data for the period between midnight on July 1 2015 (the first '1' on the X axis) and 10:00pm on July 3 2015 (the last '45' on the X axis). Minimum generation was predicted to take place between 7:00am and 11:00am on July 3 (15-23 on the X axis). As generation was forecast to be under 850 MW over this period, a turn-down event was scheduled (Event 7).

Figure 22. Forecast of generation from wind farms monitored by National Grid



Using wind generation forecasts to schedule events afforded greater realism to the trial, increasing the likelihood that events would occur at a similar frequency and last for a similar duration as would be expected on an equivalent real-world programme. This also made it less likely that participants would experience a disconnect between the timing of events and prevailing weather conditions in their local area, which might have led to disengagement from the trial and biased event response.

The timing of the events is shown in Table 12 and Table 13. The green events in Table 12 were turn-up events (n=24) and the red events in Table 13 were turn-down events (n=16).

6.3.3 Trial design

The trial design was informed by recommendations for consumer electricity behaviour studies made by Cappers *et al* (2013), who identified six design stages. One of these – estimating demand models – involves calculating price elasticities and was thus irrelevant for present purposes, as information-only DSR programmes do not provide financial incentives.

The remaining five stages are as follows:

- Identify the specific questions that the analysis seeks to answer.

- Select the optimal reference load model given the data available.
- Validate the reference load model.
- Estimate load impacts by measuring effects based on reference load and actual usage data.
- Report the results.

Stage 1 - Identify specific questions

The first stage involved identifying the questions that the trial was seeking to answer. In the case of the quantitative data analysis presented in this chapter, these were as follows:

- Did electricity consumption in each household during trial events differ from typical consumption?
- To what extent did response vary between households?
- Was response greatest for turn-up events or for turn-down events?

Stage 2 - Select reference load model

Although treatment control methods – such as randomised controlled trials and randomised encouragement designs[91] – are often preferred for electricity trials (Cappers *et al*, 2013; Hobman *et al*, 2016), these methods could not be used for this study because electricity interval data was available for participating households only. Instead, a within-subjects design was used, so that a reference load model could be produced and treatment effects estimated by comparing measured consumption during non-event periods against consumption during trial events (Cappers *et al*, 2013).

[91] In randomised encouragement designs, customers are randomised into a control or treatment group before they are contacted or encouraged to participate in a study (Cappers *et al*, 2013).

Table 12. Turn-up events

	Event																							
	3	4	6	8	10	11	13	14	15	17	19	21	22	23	25	27	29	32	33	34	35	36	39	40
12am																								
1am																								
2am																								
3am																								
4am																								
5am																								
6am																								
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9pm																								
10pm																								
11pm																								

Table 13. Turn-down events

	Event															
	1	2	5	7	9	12	16	18	20	24	26	28	30	31	37	38
12am																
1am																
2am																
3am																
4am																
5am																
6am																
7am																
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4pm																
5pm																
6pm																
7pm																
8pm																
9pm																
10pm																
11pm																

The validity of this within-subjects design rested on two assumptions (ibid). First, electricity consumption had to be measured on a set of non-event days with similar characteristics to event days (eg, days with similar daylight hours and temperatures). Second, participants had to be on non-variable tariffs, so that it could be assumed that they were not altering their consumption patterns in response to other influences outside the trial.

The former assumption was met by conducting the trial from May to early September, so that the temperatures and daylight conditions when reference loads were produced (May 10 to June 19) were similar to those when events were held (June 20 to September 3). The latter assumption was met by ensuring that participating households were not on legacy time-varying electricity tariffs such as Economy 7 or Economy 10, which might have biased their response.

Reference consumption (RC_{hk}) values were calculated for each household (h) for each event period (k), where the latter is defined as the day of the week and the time of day of the corresponding event. This involved measuring electricity consumption in each household during each period during the monitoring stage that corresponded with the events (i=1,…N_{hk}), and taking the mean:

$$RC_{hk} = \left(\frac{1}{N_{hk}}\right)\left(\sum_{i=1,N_{hk}} RC_{hki}\right) \qquad (1)$$

The resulting RC_{hk} values provided estimates of the counterfactual: in other words, what electricity consumption in each household would have been during the events had it not been exposed to the treatment.

As household routines which influence electricity consumption are more likely to recur at similar times (Cetin *et al*, 2014; Powells *et al*, 2014), RC_{hk} values were calculated using consumption data collected over the same hours and on the same days of the week as the events themselves. This increased the likelihood that the values would reflect the typical electricity consumption of the households for these periods.

Stage 3 – Validate reference load model

Before within-subjects designs are used to estimate changes in electricity consumption, it is helpful to assess the accuracy of the load model in predicting actual loads (Cappers *et al*, 2013). In this case, four tests were performed to examine how accurately the model predicted the total electricity consumption of all households during different periods on different days of the week. To this end, reference consumption values for each household were created for each test period.

The reference consumption values for all households were then combined and compared with the actual consumption of all households during the test periods.

For example, for Test 1, the total electricity consumed by all households between 4:00pm and 8:00pm on May 13, May 20, May 27, June 3 and June 10 was calculated and then divided by five (the number of reference periods for which consumption data was collected). This resulted in a predicted total consumption on Wednesdays between 4:00pm and 8:00pm of 78.58 kWh. This was then compared with the actual consumption of the households between 4:00pm and 8:00pm during the test period on June 17 (77.49 kWh). The results of the four tests are reported in Table 14.

Table 14. Model load prediction tests

	Date	Day	Time	Predicted consumption (kWh)	Actual consumption (kWh)	Load difference (kWh)	Percentage difference
1	17.06.15	Wednesday	4:00pm-8:00pm	78.58	77.49	-1.09	-1.39%
2	19.06.25	Friday	8:00pm-12:00am	74.61	74.26	-0.35	-0.47%
3	20.06.15	Saturday	12:00pm-2:00pm	32.60	34.01	1.41	4.33%
4	22.06.15	Monday	7:00am-10:00am	53.78	56.03	2.25	4.18%

As expected, there was some variance between the model's predictions and actual consumption during the test periods: sometimes the model overestimated consumption (Tests 1 and 2), and sometimes it underestimated consumption (Tests 3 and 4). Across the four tests, the model predicted electricity consumption with an average deviation of 2.6% from actual consumption during the test periods.

Paired sample t-tests were carried out on predicted and actual consumption values for each test. The null hypothesis in each case was that there was no difference between predicted and actual consumption during the test period. As none of the tests was statistically significant, the null hypothesis was accepted, providing additional confidence that the model would produce viable reference loads.

The combined electricity consumption of all households was also compared on two Saturdays and two Thursdays while reference consumption data was being collected. This made it possible to explore whether consumption followed a similar pattern on the same days of the week (see Figure 23 and Figure 24).

As can be seen from Figure 23 and Figure 24, electricity consumption in all households followed a similar pattern on the same days of the week. For instance, on both Thursdays depicted in Figure 24, combined consumption was less than 3.5kWh between 12:00am and 6:30am, before increasing to a morning peak of between 5.5kWh and 6.2 kWh at 7:30am. Electricity consumption also peaked at 6.2kWh and 6.5kWh on both Thursdays at 7:30pm.

Figure 23. Total electricity consumption for all households on Saturday June 13 and 20

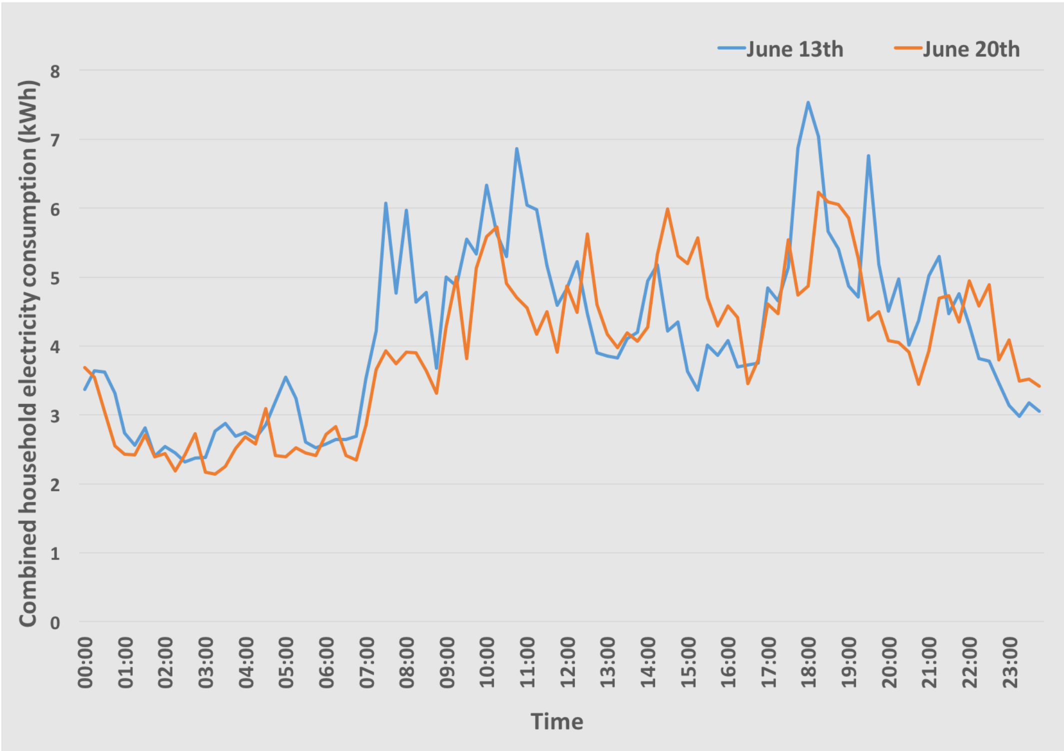
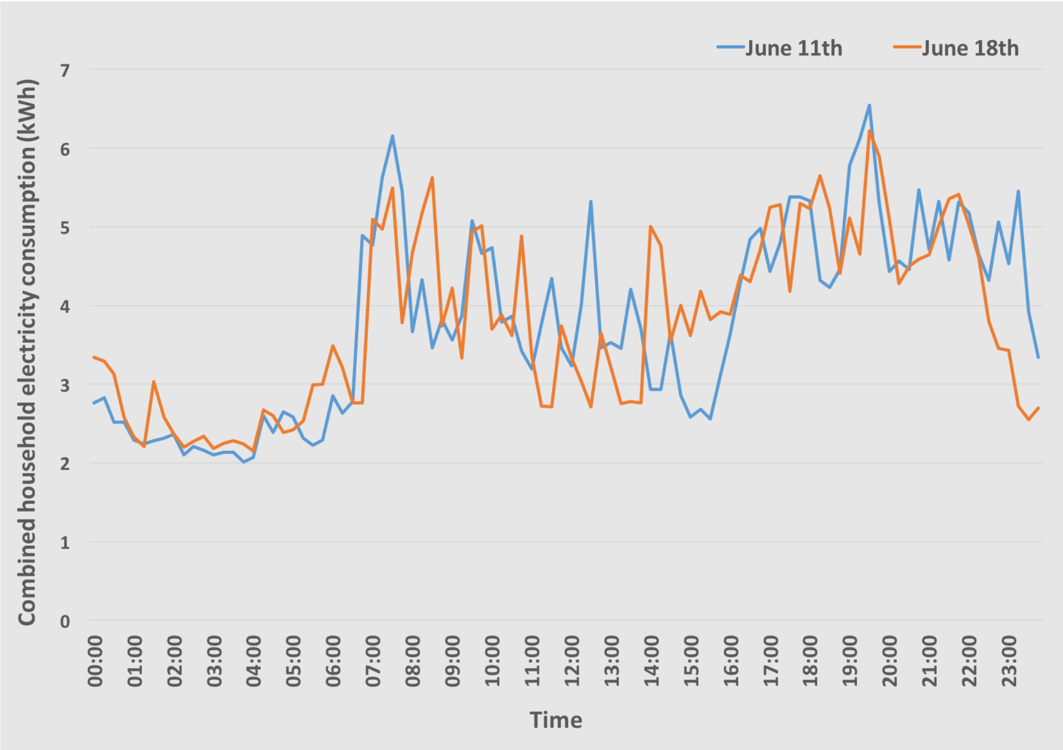


Figure 24. Total electricity consumption for all households on Thursday June 11 and 18



Stage 4 – Estimate load impacts

To examine whether electricity consumption during events in each household differed from typical consumption, the difference in consumption for each household during event periods (EC_{hk}) and corresponding reference consumption periods (RC_{hk}) was calculated. This was expressed in absolute terms (Δ_{hk}) and as a percentage (P_{hk}) of the reference consumption:

$$\Delta_{hk} = EC_{hk} - RC_{hk} \qquad (2)$$

$$P_{hk} = \frac{(EC_{hk} - RC_{hk})}{RC_{hk}} * 100 \qquad (3)$$

To examine whether the total electricity consumption of all households during events differed from typical consumption, two further values were calculated. The first was the total combined electricity consumption of the households for each event:

$$EC_k = \sum_h EC_{hk} \qquad (4)$$

The second was the corresponding combined total reference electricity consumption of the households for each event:

$$RC_k = \sum_h RC_{hk} \qquad (5)$$

The percentage change in consumption between EC_k and RC_k for each event was then calculated:

$$P_k = \left[\frac{\sum_h \Delta_{hk}}{\sum_h RC_{hk}} \right] * 100 \qquad (6)$$

6.4 Event response

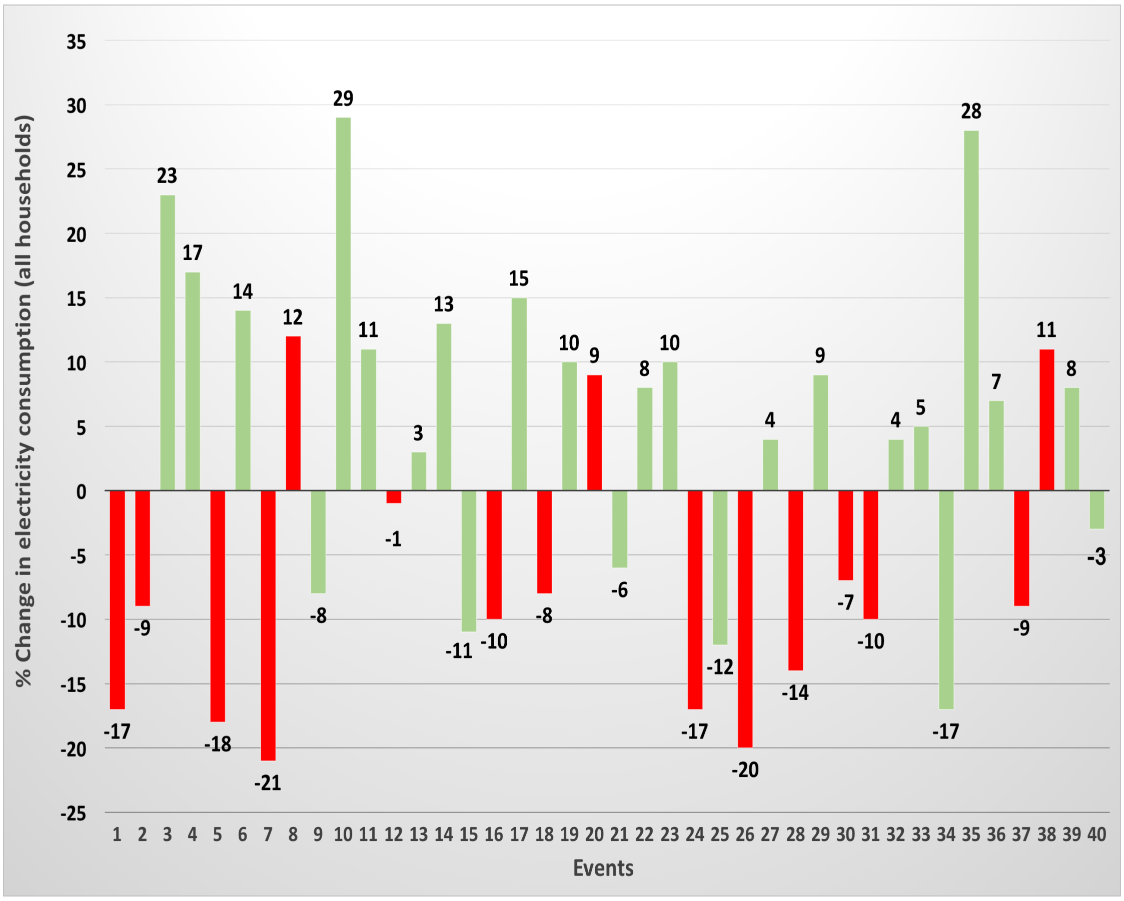
In line with recommended practice for evaluating and reporting the results of electricity trials (Cappers *et al*, 2013), and to facilitate comparison of the response recorded in this trial with other DSR studies, two measurements of response are reported:

- Average kWh change per event hour – the mean household response per hour during turn-up events was +18W and the mean household response per hour during turn-down events was -44W. The mean household response per hour considering both turn-up and turn-down events was +/-30W.
- Average percentage change in energy use per event hour – this was an average increase in electricity usage of 4.4% for turn-up events and an average decrease in electricity usage of 9.9% per hour for turn-down events. The mean household percentage change in consumption per event hour considering both turn-up and turn-down events was 6.8%.

During 14 out of 16 turn-down events, the total electricity consumption of the households (EC_k) was lower than their total reference consumption (RC_k); while during 19 out of 24 turn-up events, EC_k was higher than RC_k.

Figure 25 shows the percentage difference between the total electricity consumption during each event and the corresponding total reference load (Equation 6). Turn-down events are shown in red and turn-up events are shown in green.

Figure 25. Percentage difference between electricity consumption during events and reference load (all households)



The greatest response occurred during Event 10 (a turn-up event from 1:00pm to 4:00pm on Monday July 6): households used 29% more electricity than during the corresponding reference period (13.4 kWh more electricity). The lowest response occurred during Event 34 (a turn-up event from 10:00am to 9:00pm on Sunday August 23): households used 17% less electricity (44.5 kWh), despite having been asked to try to use more.

In the case of Event 34 and four other anomalous turn-up events (Events 15, 21, 25 and 40), complementarity (cf Greene *et al*, 1989 and Chapter 4) – achieved by analysing household electricity consumption data alongside the interview data – made it possible to explore why EC_k was lower than RC_k, even though the events had called for increased consumption. The analysis revealed that certain larger households that usually consumed more electricity than average for the trial group had been empty during these events. To explore whether this had caused the anomalous results, EC_k and RC_k values were recalculated after removing the RC_{hk} and EC_{hk} values of these households; the results are shown in Table 15.

Table 15. Anomalous turn-up events before and after adjusting for households identified as empty

Event	RC_k KwH	EC_k KwH	% change in consumption	Empty households[92]	Adjusted RC_k KwH	Adjusted EC_k	% change in consumption
15	111.9	99.6	-11.05	1	108.6	98.2	-9.58
21	125.4	117.2	-6.53	3	109.9	110.9	+0.91
25	105.6	93.3	-11.65	4	91.9	90.0	-2.07
34	268.7	224.1	-16.59	4	231.1	214.8	-7.05
40	89.5	86.7	-3.08	3	84.8	85.7	+1.06

After these adjustments, two of the turn-up events showed a positive overall response (Events 21 and 40), and the difference between EC_k and RC_k values for the other events was considerably lower (Events 15, 21 and 34). It was thus confirmed that the larger households identified as unoccupied during the events had contributed significantly to the anomalous results: in the case of at least two of the events, the reduced consumption in these households had more than offset any increase in consumption in the other households, leading to an overall anomalous result.

Further analysis of the events – including comparisons between EC_k and RC_k for each event and the results of the statistical tests used to explore the differences between these values – are provided in Table 16 (turn-down events) and Table 17 (turn-up events).

6.4.1 Individual household response

As has been seen in other UK residential DSR trials (Bulkeley *et al*, 2014; Schofield *et al*, 2014), response varied considerably between households: the average percentage change in consumption across all events ranged from -16% for the least responsive household to +52% for the most responsive household.[93]

Figure 26 shows the average percentage change in electricity consumption in each household across all events (relative to reference consumption).[94] In cases where households show a

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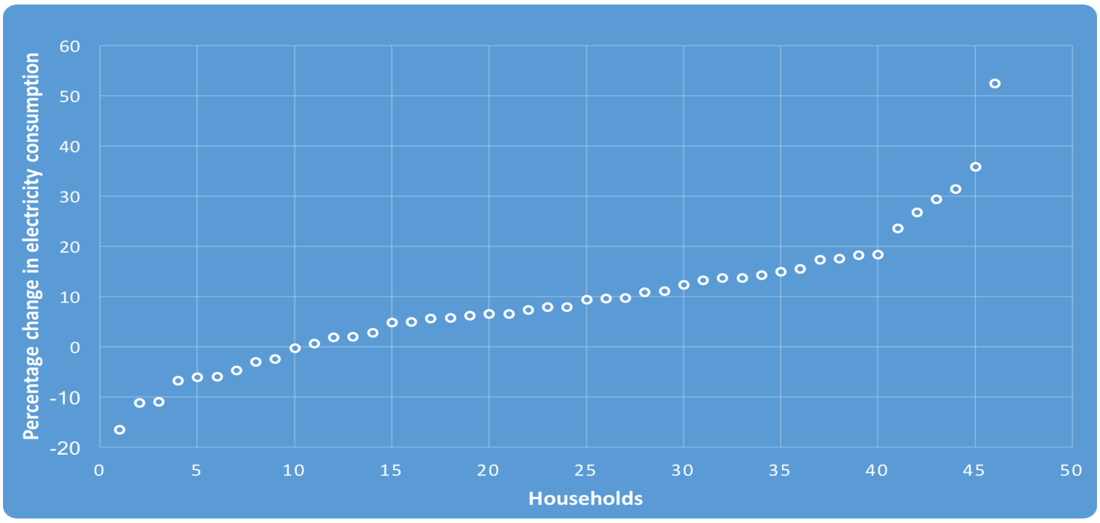
[92] This was the number of households identified as having been empty through the interviews and analysis of electricity consumption data. The actual number of empty households during these events may have exceeded this number.

[93] Household response was also analysed in terms of load shifted (in kWh/event hour). This likewise revealed considerable variation in response: the response from the top 25% of households was three times greater (approximately +\-100W) than the average response.

[94] The data has been converted so that response to both turn-up and turn-down events can be shown simultaneously. To do this, in cases where households consumed less electricity during turn-down events, this was counted as a positive response.

negative consumption change – those shown below the 0 in Figure 26 – this was because the household consumed more electricity than its reference consumption during turn-down events and/or less electricity than its reference consumption during turn-up events.

Figure 26. Average percentage change in electricity consumption by household



Once again, complementarity – achieved through analysing the electricity consumption data alongside the interview data – made it possible to explore why some households had consistently failed to respond. Lead participants from two of these households – represented by data points 3 and 5 in Figure 26 – explained that their households had given up attempting to respond very early in the trial because they found this too difficult with children (discussed further in Chapter 7).

Another lead participant, from the second least responsive household – represented by data point 2 in Figure 26 – explained that for much of the trial she had moved out of her household to care for her partner, who was unwell, making it impossible to respond during turn-up events.

The average +\-30W response per hour during events equates to approximately 3.5% of the average winter peak household load (Carmichael *et al*, 2014). This was lower than the average response of 0.05 KW per hour achieved by households on the LCL dynamic ToU trial (ibid). While the financial incentives in the latter trial may well have encouraged greater response, other contextual differences between the two may also have contributed.

First, the frequency of events on the information-only trial was greater – at around four per week – than the maximum three events per week permitted on the LCL trial (ibid); a lower response might be expected when participants are asked to respond more frequently. This supposition was also supported by the interview comments of one lead participant: “There was a phase when you were sending a lot of alerts very frequently one after another, and after that when you slowed it down again I was fatigued – I mean, still fatigued even though you had slowed it down again.”

Second, on the LCL trial event notifications were sent through participants’ in-home displays as well as by text message, which may have increased their immediacy, making it more likely that household members would respond. This supposition is supported by previous dynamic DSR studies which found that response is usually greater when participants are notified of events via in-home displays (Stromback *et al,* 2011).

6.4.2 Statistical analysis of event response

Paired samples t-tests were carried out using EC_k and RC_k for each event to determine whether the changes in electricity demand during the events were statistically significant. For events which asked participating households to reduce consumption, the hypothesis tested was that households had reduced consumption during the events relative to their corresponding reference consumption value and vice versa.

The tests were statistically significant at the 5% confidence level ($P<0.05$) for six of the turn-down events (38%) and for four of the turn-up events (17%). A further four turn-down events (25%) and three turn-up events (13%) were significant at the 10% confidence level ($P<0.1$). The difference between $\mathrm{EC_k}$ and $\mathrm{RC_k}$ is reported for all events in Table 16 and Table 17, along with 95% confidence intervals and significance values. Events during which consumption differed significantly from reference consumption at the 5% confidence level are indicated with ** in the final column, while events during which consumption differed significantly from reference consumption at the 10% confidence level are indicated with * in the final column.

As the difference between event and reference consumption was not statistically significant for all events, an additional paired samples t-test was conducted, using EC_k and RC_k data for all events. The null hypothesis for the test was that the total electricity consumption of all households during the events was no different from the total reference consumption of all households for the events. Before proceeding with the test, the data was transformed so that all turn-up and turn-down events could be tested simultaneously.[95]

The test revealed that RC_k was 102.75 kWh and EC_k was 110.13 kWh. The difference between RC_k and EC_k was 7.38 kWh, with a 95% confidence interval between 2.33 kWh and 12.43 kWh; the t-test statistic was 2.957, with 39 degrees of freedom, and was statistically significant (P=0.00). As such, the null hypothesis was strongly rejected: the combined electricity consumption of the trial households during events was statistically different from their consumption during the reference periods.

[95] The transformation treated reduced demand during turn-down events in the households as a positive response.

Table 16. Turn-down events

Event	Date	Day	Event time	Hrs	RC_k (kWh)	EC_k (kWh)	Difference (kWh)	% change	Mean difference/ household (kWh)	95% confidence interval of the difference		Sig. (1-tailed)
										Lower	Upper	
1	23.6.15	Tue	5pm-10pm	5	118.01	98.19	-19.82	-16.79	-.48	-.87	-.12	.005**
2	25.6.15	Thu	7am-10am	3	57.54	52.32	-5.22	-9.07	-.12	-.25	.01	.032**
5	29.6.15	Mon	6am-9am	3	50.46	41.44	-9.02	-17.87	-.21	-.36	-.07	.002**
7	3.7.15	Fri	7am-11am	4	75.65	59.63	-16.02	-21.18	-.37	-.58	-.17	.000**
9	5.7.15	Sun	6am–9am	3	42.98	39.57	-3.41	-7.93	-.08	-.17	.02	.050*
12	9.7.15	Thu	4pm-10pm	6	121.03	120.41	-0.51	-0.62	-.01	-.36	.33	.466
16	19.7.15	Sun	9pm-12am	3	54.44	48.96	-5.48	-10.07	-.13	-.30	.03	.050*
18	22.7.15	Wed	8am-10am	2	34.82	32.09	-2.73	-7.84	-.07	-.28	.14	.258
20	24.7.15	Fri	7am-2pm	7	122.60	133.22	+10.62	+8.66	.26	-.24	.77	.853
24	31.7.15	Fri	1am-8am	7	76.79	63.84	-12.95	-16.86	-.32	-.52	-.12	.001**
26	7.8.15	Fri	6am-12am	18	324.69	260.34	-64.35	-19.82	-1.61	-2.47	-.74	.000**
28	11.8.15	Tue	4pm-10pm	6	146.04	125.5	-20.54	-14.06	-.47	-1.06	.12	.061*
30	15.8.15	Sat	4pm-12am	8	165.50	153.07	-12.43	-7.51	-.29	-.80	.22	.131
31	17.8.15	Mon	6am-12am	18	341.64	308.67	-32.97	-9.65	-.77	-1.70	.16	.052*
37	28.8.15	Fri	6am-10am	4	72.40	65.97	-6.43	-8.88	-.15	-.40	.10	.121
38	29.8.15	Sat	7pm-12am	5	102.08	113.76	+11.68	+11.44	.26	-.14	.67	.905

*Significant at the 10% confidence level ** Significant at the 5% confidence level

Table 17. Turn-up events

Event	Date	Day	Event time	Hrs	RC_k (kWh)	EC_k (kWh)	Difference (kWh)	% change	Mean difference/ household (kWh)	95% confidence interval of the difference		Sig (1-tailed)
										Lower	Upper	
3	26.6.15	Fri	8pm-10pm	2	47.58	58.53	+10.95	+23.01	.26	-.03	.55	.038**
4	28.6.15	Sun	7am-12pm	5	89.09	104.63	+15.54	+17.46	.38	-.23	.99	.107
6	1.7.15	Wed	10am-3pm	5	74.97	85.28	+10.31	+13.75	.24	-.11	.59	.085*
8	4.7.15	Sat	1am-7am	6	59.67	67.03	+7.36	+12.33	.17	-.09	.44	.094*
10	6.7.17	Mon	1pm-4pm	3	46.83	60.25	+13.42	+28.66	.31	.00	.62	.025**
11	7.7.15	Tue	8pm-12am	4	80.68	89.52	+8.84	+10.96	.21	-.09	.51	.081*
13	11.7.15	Sat	6pm-11pm	5	105.49	108.69	+3.2	+3.03	.08	-.39	.54	.372
14	16.7.15	Thu	8pm-12am	4	74.87	84.80	+9.93	+13.26	.24	-.02	.51	.035**
15	17.7.15	Fri	9am-4pm	7	111.92	99.55	-12.37	-11.05	-.31	-.65	.03	.963
17	21.7.15	Tue	10am-3pm	5	81.93	94.30	+12.37	+15.10	.30	-.29	.89	.155
19	23.7.15	Thu	9am-4pm	7	104.43	115.18	+10.75	+10.29	.27	-.21	.75	.134
21	25.7.15	Sat	7am-2pm	7	125.37	117.18	-8.19	-6.53	-.21	-.66	.23	.834
22	27.7.15	Mon	9am-3pm	6	94.27	101.66	+7.39	+7.84	.19	-.27	.66	.200
23	29.7.15	Wed	10am-3pm	5	71.58	78.72	+7.14	+9.97	.18	-.22	.59	.184
25	4.8.15	Tue	3pm-8pm	5	105.58	93.28	-12.3	-11.65	-.31	-.74	.12	.921
27	8.8.15	Sat	4pm-12am	8	156.16	161.72	+5.56	+3.56	.14	-.77	1.05	.379
29	13.8.15	Thu	8pm-12am	4	78.83	85.9	+7.07	+8.97	.16	-.14	.46	.146
32	19.8.15	Wed	7pm-12am	5	102.76	106.97	+4.21	+4.10	.10	-.45	.66	.356
33	20.8.15	Thu	8pm-4am	8	113.85	119.33	+5.48	+4.81	.13	-.23	.49	.237
34	23.8.15	Sun	10am-9pm	11	268.65	224.08	-44.57	-16.59	-1.01	-1.91	-.11	.986
35	26.8.15	Wed	9am-4pm	7	107.82	138.56	+30.74	+28.50	.71	-.00	1.43	.025**
36	27.8.15	Thu	9am-4pm	7	108.32	115.93	+7.61	+7.02	.18	- .20	.56	.178
39	3.9.15	Thu	10am-4pm	6	93.09	100.97	+7.88	+8.46	.17	-.36	.71	.256
40	5.9.15	Sat	9am-1pm	4	89.44	86.68	-2.76	-3.08	-.06	-.40	.28	.641

*Significant at the 10% confidence level ** Significant at the 5% confidence level

6.5 Discussion

6.5.1 Potential benefits of dynamic information-only DSR programmes

Overall, most households successfully changed their consumption patterns in response to the event notifications, consuming 9.9% less electricity on average during turn-down events and 4.4% more electricity on average during turn-up events.

This finding is especially noteworthy when considered alongside the results of the switching survey, which revealed that approximately 8% of respondents would be willing to participate in dynamic information-only DSR programmes based on available wind generation. Taken together, the results of the trial and the switching survey suggest that such programmes could provide a valuable but overlooked resource for suppliers, helping them to balance supply and demand in a future system in which a greater share of electricity comes from renewables.

However, some consumers may be reluctant to participate in information-only DSR programmes because, while their efforts may result in reduced costs for suppliers, they themselves will not benefit financially from responding. This point was expressed in the interviews: one lead participant suggested that because of this inequity, he would be unwilling to sign up to such programmes. His comments echo those of residential consumers in the DSR study conducted by Buchanan *et al* (2016), who expected to be compensated financially for their efforts: "Given that their actions were providing a financial benefit to suppliers, they expected a fair exchange for their part in the transaction (i.e., retribution in the same metric-financial" (ibid, p.93).

Within this context, it is helpful to consider whether other electricity stakeholders than suppliers might benefit from implementing dynamic information-only DSR programmes. DNOs, for example, might be able to leverage such programmes to reduce network constraints, thus deferring costly network upgrades and increasing asset utilisation. A similar programme – albeit using a dynamic ToU tariff – was explored by the LCL trial (Schofield *et al*, 2014), although the study concluded that the tariff could not serve as a cost-competitive alternative to traditional network reinforcement.[96] However, an information-only programme might be more viable, as it would avoid some of the costs of price-based DSR programmes, such as those associated with providing financial incentives and changing customer billing arrangements.[97]

Perhaps aware of these advantages, DNO Electricity North West pioneered a similar programme – the Power Saver Challenge – in Heaton Moor and Heaton Norris, Stockport, in Winter 2014/15. Residents successfully reduced their electricity consumption at times of peak load, deferring the need to build a costly new substation to cope with growing demand (Power Saver Challenge, 2015).

Dynamic information-only DSR programmes could also help to balance electricity flows in network areas with high levels of local generation. As highlighted by Work Stream Six[98] (2014), community schemes could be developed to encourage electricity use at certain times close to sources of generation, thereby avoiding thermal or voltage issues. Work Stream Six also suggested that instead of rewarding individual customers financially for responding, benefits could "be directed towards sources of value to the whole community affected by the network constraint and prepared to provide an appropriate response" (ibid, p.18)

The scepticism expressed towards suppliers further suggests that certain non-conventional players, which operate what Ofgem refers to as 'non-traditional business models' (Ofgem, 2015), may be well placed to implement dynamic information-only DSR programmes. Examples include Bristol Energy and Robin Hood Energy, the not-for-profit energy supply companies established by Bristol and Nottingham Councils, respectively. Given their not-for-profit status, some consumers might be more willing to participate on programmes offered by such bodies.

6.5.2 Potential alternative models for information-only programmes

Although the trial event notifications were based on prevailing wind generation, other factors might also prove effective in eliciting response. For instance, the signal for consumers to

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[96] EDF Energy, which administered the LCL dynamic ToU trial, incurred costs which were estimated at £350 per customer, with around one-third of these costs expected to apply on an annual basis (Schofield *et al*, 2014).
[97] The principal costs on an information-only DSR programme would arise from recruiting consumers to participate and providing event notifications.
[98] Work Stream Six was a working group of the Smart Grid Forum tasked with investigating the commercial and regulatory challenges of implementing the smart grid in Great Britain. It was chaired by Ofgem and included representatives from DNOs, electricity suppliers, consumer groups and other industry stakeholders (Ofgem, 2017b).

respond could be based on threats to electricity supply arising from spikes in demand (Gyamfi and Krumdieck, 2011). Alternatively, DSR programmes could be designed to reduce carbon emissions, using the carbon intensity of electricity generation at different times of day as the basis for event notifications (see GridCarbon's carbon dioxide tracking website – GridCarbon, 2017).

The burgeoning applications for information-only DSR were highlighted by one of the programme managers working on the CITYOPT information-only DSR programme, part of an EU project to promote efficient planning, design and operation of energy systems in urban areas (Power Technology, 2017):

> I can see that, in the future, these kinds of applications could be a reality in many initiatives. You are getting the information about the community's level of electricity use and then the electricity companies can communicate with the end users. They can give them the indication that they may have a problem with peak demand in the next couple of hours, so please do your best to take part in helping the community cope with the situation.

6.6 Conclusions and limitations

This chapter describes one of the few dynamic information-only DSR trials and – to the author's knowledge – the first to explore how such programmes could help to balance residential demand with fluctuating supply from wind generation.

As these programmes circumvent a key barrier to uptake of traditional ToU tariffs – financial loss aversion (Bradley *et al*, 2016; Nicolson *et al*, 2016 and Chapter 2) – they may attract consumers who might otherwise be unwilling to participate and thus help to optimise the impact of residential DSR.

In combination, the electricity consumption data and qualitative interview data revealed that most participating households successfully rescheduled their electricity use in response to notifications (see also Chapter 8). However, overall response was not as high as that on the LCL dynamic ToU trial, which – while similar in many respects – was financially incentivised (Schofield *et al*, 2014). This suggests that alternative incentives may need to be leveraged to elicit comparable response on information-only programmes. The interviews discussed in the following chapter aimed to explore further the question of how response on residential DSR programmes – in particular, information-only programmes – might be maximised.

Certain limitations of the trial must be acknowledged. The first relates to the small sample size (N=46): it has been argued that when small-scale studies are scaled up, the response per household may be smaller (Pollitt and Shaorshadze, 2011). This is also supported by a meta-analysis of DSR programmes conducted by Stromback *et al* (2011), which found that response on a per-household basis on non-automated DSR programmes is usually lower when these involve larger numbers of participants.

The second relates to the short duration of the trial, which ran for four months only. This raises two questions. First, although many households successfully responded by changing their consumption patterns, it is unknown whether response would have become weaker or stronger over time. Had the trial lasted longer, 'response fatigue' (Kim and Shcherbakova, 2013) might have led some participants to respond less often or cease responding altogether. On the other hand, response might actually have increased: some energy scholars suggest that response increases over time as new ways of responding become embedded in everyday routines (Breukers and Mourik, 2013; Filippini, 2011; Sexton *et al*, 1987; Thorsnes, 2012).

Second, patterns of electricity demand vary throughout the year, and a trial conducted in summer reveals nothing about whether response at other times of year – for example, in winter – might be higher or lower (Hu *et al*, 2015). In this regard, however, evidence from other DSR studies suggests that the response might have been greater had the trial taken place in winter: a meta-analysis of DSR programmes in Stromback *et al* (2011) and the results of the LCL dynamic ToU trial (Schofield *et al*, 2014) both indicate that response on non-automated dynamic DSR programmes is greater in winter than at other times of the year.

Finally, it is possible that response might have been biased because participants were aware that they were taking part in an experiment – sometimes referred to as the 'Hawthorne effect' (Benson, 2000). This could have influenced response and is often more pronounced in shorter experiments such as that described here, as participants have less time to grow accustomed to the intervention (Darby, 2011).

These considerations suggest it may be imprudent to assume that the response recorded on this trial would necessarily be replicated in a real-world context. As such, further studies exploring consumer response to dynamic information-only DSR programmes would be valuable. Ideally, these should involve larger samples and be conducted over longer timeframes, making it possible to determine whether the response recorded in this trial could be replicated across a larger cohort of households and whether response would be sustained over time.

7. Trial interviews

7.1 Introduction

Once the dynamic information-only trial had ended, participants were invited to be interviewed to explore their experiences and develop insights that might inform future residential DSR strategies – particularly in relation to how response on such programmes might be maximised. Specifically, the interviews aimed to:

- identify factors that affected interviewees' ability to respond;
- identify factors that affected their motivation to respond;
- determine how feedback affected their motivation to respond;
- determine how and why response varied between different households; and
- develop practical recommendations for the design of future DSR programmes.

Section 7.2 of this chapter describes how interviewees were recruited, the socio-demographic characteristics of the sample and the structure of the interviews. Section 7.3 identifies the appliances that participants used to respond on the trial. Section 7.4 highlights the themes that were identified through analysis of the interview data, while Section 7.5 explores interviewees' experiences through the prism of the FBM. Section 7.6 draws on this analysis to provide suggestions for how these findings might inform future DSR strategies, and Section 7.7 presents conclusions.

7.2 Interview methodology

At the end of the trial, the 46 lead participants were invited to discuss their experiences in interviews with the author; 24 of them agreed to do so. Although these individuals self-selected for interview, the socio-economic range was nonetheless diverse, including single occupancy households, multiple occupancy households, households containing children under the age of five, households containing students and households containing retirees. Further details of the interview sample are provided in Table 18.

Table 18. Socio-demographic details of interview sample

Characteristics		Number of interviewees
Age	25-34	8
	35-44	10
	45-54	2
	55-64	3
	65+	1
Gender	Male	9
	Female	15
Household ownership	Owner	18
	Renter	6
Household size	1	3
	2	10
	3	2
	4	8
	5+	1
Weekly household income	£200-£299	1
	£300-£399	1
	£500-£599	1
	£700-£799	1
	£800-£899	3
	£900-£999	2
	£1,000+	10
	Don't know/prefer not to say	5

Interviewing individuals with first-hand experience of a DSR programme – rather than, for instance, DSR experts or DSR programme managers – allowed for factors that influenced their ability and motivation to respond to be identified. Exploring these enablers and constraints alongside the triggers used to prompt response – the event notifications – made it possible to identify measures which could help to maximise response. As Grünewald (2015) explains: "Greater emphasis in research on the dynamics that enable and inhibit flexibility, grounded in a more activity centred perspective, rather than focusing on the responses observed in load profiles alone, may therefore yield valuable insights into the potential for demand side flexibility." (p.16)

The interviews were conducted by telephone between September 2015 and October 2015. Each lasted approximately 45 minutes and followed a semi-structured format, allowing initial questions to be prepared in advance and points of interest that emerged during the interviews to be explored in greater depth. The interviews included questions on:

- the appliances that participants used to respond;
- the factors that influenced their motivation or ability to respond;
- the effectiveness of the event notifications in triggering response; and
- the feedback that interviewees received about their response.

The interviews were recorded and subsequently transcribed. Transcription is conducive to an interpretative qualitative methodology, as it helps to facilitate "the close attention and the interpretive thinking that is needed to make sense of the data" (Lapadat and Lindsay, 1999, p.82). Transcribed scripts were imported into qualitative analysis software (NVivo) and coded using thematic analysis using the five-stage process described by Braun and Clarke (2006), in which analysts:

- familiarise themselves with the data;
- code the data;
- identify initial themes;
- review the themes; and
- define and name the themes.

Themes that provided insight into the enablers and constraints of response were identified where they were mentioned in at least three interviews. These themes were then mapped to the FBM to conceptualise them through this framework. At the same time, the interview data was used to refine and develop the FBM as a framework for understanding response.

7.3 Response during trial events

While previous DSR studies have examined whether consumers on DSR programmes successfully change consumption patterns, they often fail to address the question of how this is achieved (Breukers and Mourik, 2013). To arrive at a more nuanced understanding of how consumers respond on DSR programmes, it is important to identify both the appliances that are most commonly used to respond and the different behaviours involved in responding.

To this end, the eight DSR mechanisms identified by Grünewald (2015) were used to categorise response from interviewees, as follows:

- Reduce load – reducing load by using more efficient appliances or smart automated features.
- Substitute energy vector or location – switching to an alternative form of energy or relocating the use of energy (eg, using a gas hob to boil water rather than an electric kettle).
- Shift load forward in time – delaying the use of an appliance (eg, by using a timer to start a wash cycle at a future point in time).
- Shift load backward in time – shifting the energy use of an appliance to an earlier point in time (eg, by heating water with an immersion heater in advance of when it is needed).
- Shift a practice in time – performing an activity (eg, watching television, cooking or using a computer) at a different time.
- Substitute the practice – using a different practice to achieve a similar outcome (eg, preparing a cold meal instead of a hot one).
- Substitute service provision to metabolic energy – carrying out a practice manually rather than using an appliance (eg, washing clothes by hand or mixing ingredients with a hand beater rather than an electric mixer).
- Change the practitioner – carrying out the practice outside of the consumer's household (eg, going out to eat instead of cooking at home or going to the cinema instead of watching television).

Interviewees used washing machines and dishwashers most frequently to respond – either by delaying the use of these appliances so that they were not used during turn-down events (shifting forward) or by advancing their use to take advantage of a turn-up event (shifting backward). The various appliances used to respond are shown in Table 19.

Table 19. Appliances that interviewees used to respond

	Washing machine	Dishwasher	Oven	Hob	Vacuum	Laptop	Immersion heater	Shower	Tumble dryer	Other
P1	1	1	1					1	1	
P2	1	1								
P3	1									1*
P4	1	1	1	1		1		1		
P5										
P6			1	1		1		1		
P7	1									
P8	1									
P9			1							
P10	1	1								1**
P11	1						1			
P12	1	1					1			
P13	1	1								
P14	1	1			1					1***
P15	1	1								
P16	1			1	1					
P17	1	1				1				1****
P18	1	1							1	
P19			1							
P20	1		1	1			1			
P21	1		1	1						
P22										
P23	1		1							
P24	1		1		1					
Total	19	10	9	5	3	3	3	3	2	4

*Kettle **Dehumidifier ***Hairdryer ****Mobile phone charger

Although some interviewees (n=5) explained that their households had not changed how food was prepared or consumed in order to respond – normally because mealtimes were governed by routines dictated by school or work – somewhat surprisingly, nearly half of the interviewees (n=11) reported that their households had in fact done so, including by:

- preparing food during turn-up events for consumption later (shifting the practice in time);
- waiting until a turn-down event had finished before preparing hot food or drinks (shifting the practice in time);
- using a microwave rather than an electric hob or oven to reheat food during turn-down events (reducing load);
- not using appliances to cook or reheat food during turn-down events (eg, by preparing cold meals instead of hot meals) (substituting the practice); and
- using gas rather than electricity during turn-down events (eg, boiling water using a gas hob rather than a kettle) (substituting energy vector).

That so many interviewees demonstrated flexibility in the preparation and consumption of food is a significant finding, as although some studies have found a degree of response in the form of rescheduled cooking times (Bulkeley *et al*, 2015; Carmichael *et al*, 2014) kitchen practices are not generally considered to offer much promise for DSR (Bird, 2015; Darby and McKenna, 2012; Parrish *et al*, 2015).

Meanwhile, all interviewees who owned immersion heaters (n=3) indicated that they had used these appliances to respond on the trial, either by refraining from using them during turn-down events (shifting load forward in time) (P11, P20), or by switching them on manually or setting timers to coincide with turn-up events (shifting load backward in time) (P12).

The significance of the flexibility shown in relation to kitchen practices and the use of immersion heaters is discussed in Section 7.6.

7.4 Themes

Twelve themes were identified from the thematic coding of the interview transcripts:

- Themes 1 to 7 relate to ability to respond;
- Themes 7 to 10 relate to motivations for responding; and
- Themes 11 and 12 relate to the triggers used to prompt response.

7.4.1 Ability themes

Theme 1 – A greater understanding of appliance consumption and functionality would facilitate response

Before the trial began, lead participants' understanding of appliance consumption was tested by analysing their responses to a question in the enrolment questionnaire which asked them to rank six common household activities in order of energy intensiveness (see Appendix II, Question 16). Table 20 shows the percentage of participants who incorrectly ranked each activity.

Table 20. Percentage of lead participants who incorrectly ranked each household activity

Activity	Percentage of participants who incorrectly ranked the activity (N=46)
Washing a laundry load at 40 degrees Celsius	70%
Running a dishwasher at 65 degrees Celsius	59%
Ironing for 20 minutes	56%
Fully charging a laptop	22%
Fully charging a smartphone	15%
Using a tumble dryer for 60 minutes (on high heat)	13%

Overall, only 15% of participants ranked all activities correctly, with 41% ranking two activities incorrectly and 44% ranking three or more activities incorrectly.

Although all trial interviewees were aware that washing machines, dishwashers and tumble dryers are energy intensive, some were uncertain as to how much electricity is needed to run other appliances (P2, P4, P22), making it more difficult for them to prioritise which appliances to use to respond. As P4 explained: "I think there's a lack of information – or at least, I lack general information – about how much products consume... In order to use other appliances to respond, I would need to know how much energy they take up."

P2 likewise suggested that tables and graphs illustrating the typical consumption of common appliances would have helped him to "focus more on, 'Okay, now is a high power usage time – let's use that,' or, 'It's going to be a low power usage time – let's make sure that's not running'".

Other interviewees remarked that it would have facilitated response if their in-home displays showed real-time information about how much electricity different appliances were using (P7, P12). As P12 commented: "If you knew what different appliances were using more precisely, then that would have made it easier."[99]

The interviews further revealed that sometimes participants lacked other knowledge that would have facilitated response. For example, P9 and P23 had timers on certain appliances, but did not

[99] The interest that these interviewees expressed in receiving appliance specific consumption information echoes similar comments made by focus group participants in "Consumer views of smart metering" (Ofgem, 2010).

know how to use them, which prevented them from programming the appliances to start during turn-up events. P23 explained: "I was considering learning how to use the timer on my washing machine, because it would have been fun to turn it on at work with some of the alerts that you sent. However, there's no manual with it and I haven't found the manual online, so I don't know how to set it." Similarly, P9 only discovered towards the end of the trial that her dishwasher had a delay cycle: "Had I known that and known how to use it, I might have had that set up so that if we were going out and were asked to use more, then that could have been something that we could have done."

Some interviewees believed that had they purchased smart plugs[100] and connected these to specific appliances – in P11's case, a hot water tank; in P17's, a dishwasher – they would have been able to respond when they were not at home. However, P11's hot water tank was hardwired into the wall, so could not have easily been fitted with a smart plug; while P17 was unaware that remotely switching on an electrical socket would not initiate a wash cycle. In each case, specialist expertise or appliances would have been required to achieve the desired goal.

Theme 2 – Inflexible routines can prevent response

Many interviewees reported that they had found it difficult to respond because the times at which appliances were used were governed by fixed routines.[101] For instance, P13 – a retiree – explained that dinner in his household always took place at a specific time: "It was difficult if you wanted us to use electricity between 8:00pm and midnight to say, 'Well, we'll have our dinner at 8 o'clock' – two hours later than we normally have it. These were difficult things."

Similarly, P24 found that her partner's routines sometimes prevented their household from responding: "If you said, 'Use less at the weekend,' it would be difficult because the tumble dryer and the ironing tend to happen together. He just likes to do it all in one block; he doesn't like to spread it out over the weekend. He'll have the TV on and be doing the ironing and running the tumble dryer all at the same time."

The lives of some families in particular were often structured around routines that occurred at specific times – such as before and after school, and at bath time and mealtimes – making

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[100] Smart plugs connect home appliances and other electronic devices to WiFi networks, enabling them to be switched on or off remotely (Elzabadini *et al*, 2005).
[101] That household routines can make it more difficult for consumers to respond has also been found in other DSR studies (Nicholls and Strengers, 2015; Pollitt and Shaorshadze, 2011; Powells *et al*, 2014).

response especially difficult (P5, P7, P19). As P5 explained: “When you’ve got children who need clothes for school and a husband who needs shirts for work, things have to be done by a certain time and they aren’t that moveable.” Similarly, P19 admitted: “It was hard because it didn’t really fit around my lifestyle – that’s the truth of it. You know, family… It’s quite rigorous timings, and it just wasn’t very easy to start changing things at the last minute or even with preparation the day before. There’s just certain things that happen at certain times.” Interviewees from these households explained that they had quickly disengaged from the trial altogether, as they realised that their day-to-day routines made it too difficult to respond.[102]

Other residential DSR studies have likewise found that family households often find response especially challenging (Bulkeley *et al,* 2015; Nicholls and Strengers, 2015). On the CLNR ToU trial, households with children under the age of five were less responsive to peak prices than other households; the qualitative data revealed that this was often due to daily cooking and bathing routines (Bulkeley *et al*, 2015). Similarly, from their study of Australian family households, Nicholls and Strengers (2015) concluded that “the family peak is tightly coordinated and routinised…. [and] TOU tariffs are unlikely to effectively reduce peak period electricity consumption in households with children” (p.1).

Although many interviewees reported that their routines had made response more difficult, for some the events came to supplant previous routines and instead determine the timing of household practices (P6, P11, P16, P20, P23, P24). P11 explained that the events had “governed when I would put the washing on”; while P6 found that once the notifications stopped, members of his household “were sort of at a loss to know how to plan our meals”. Similarly, P20 described how she felt once the trial had ended: “‘Well, we haven’t had an alert, so what energy should I be using?’… Now it’s stopped, I keep feeling like, ‘Well, I got really used to these alerts and responding to them.’”

When asked about his thoughts once the trial had ended, P2 likewise said:

> I didn’t have a guide as to when would be a beneficial or non-beneficial time [to use electricity] and my attitude towards consumption of electricity laxed…because I didn’t have a reminder saying, ‘Oops you are using electricity.’ Because when the reminder comes in, it’s a reminder to use or not use more electricity; but it’s also a reminder that you are using electricity full stop. So without it, it’s not in the forefront of our minds.

[102] These individuals gave up on attempting to respond during the events rather than formally withdrawing from the trial.

These comments are interesting given that many DSR programmes have been found to lead to lower overall electricity consumption (Stromback *et al*, 2011). This has been attributed to improved energy literacy from the additional educational measures and feedback that are often features of such programmes (ibid; Breukers and Mourik, 2013). P2's comments, however, suggest that an additional impetus may be at play: their experiences on the DSR programme may make participants more conscious not only of when they are using electricity, but also of the fact that they are using electricity at all. The implications of this enhanced energy consciousness are discussed further in Theme 10 and Section 7.6.3(b).

Theme 3 – Immediate need for appliance use can prevent response

Several interviewees described how sometimes an immediate need to use appliances had prevented them from responding (P2, P7, P9, P12, P15, P17). For example, P9 explained that if his child had an accident in bed during the night, he would wash the sheets straight away; while P2 said that he washed his gym kit immediately after returning home from training. Similarly, P7 stated: "Vacuuming just has to be done when it has to be done. I am quite inflexible about that because of the busy lives we lead, but also when there's a mess it has to be cleared up – you can't just walk around it."

P15 described her need to use certain appliances at specific times as "non-negotiable": "I was not willing to move what I call my 'essential usage', so having the lamp on in the kitchen while I am cooking, you know – those kinds of things that you still want at peak time."

This tendency to prioritise an immediate need to use appliances over response has also been found in other studies (Bourgeois *et al*, 2014; Buchanan *et al*, 2016; Parrish *et al,* 2015).

Theme 4 - Time pressures and fatigue can prevent response

Response usually takes time – even if only to turn an appliance on or off. Several interviewees observed that when time pressures were particularly acute, they were much less likely to respond (P5, P8, P9, P18, P19). Indeed, some of these individuals (P5, P8, P19) – who once again tended to be from family households – felt these time pressures so intensely that they did not respond at all. As P19 admitted: "I didn't feel there was much scope for us to change, because we are pretty busy with our lives. You just do the washing when you do it – you know, you just fit it in. There just wasn't any room in the day to start shifting things around – too tight, time was too tight."

Others found that when they were preoccupied with other activities – such as work or childcare – they often ended up ignoring event notifications (P8, P9, P18). In the words of P18: "Very often with the texts, I look at them and if I am in the middle of something, that's it – it's gone from my brain immediately and I don't look back through my texts at the end of the day." Similarly, P21 recalled that she had sometimes failed to take the final steps necessary to respond: "On one or two occasions, I actually forgot. I woke up, I loaded [the washing machine] on purpose and then I started doing other things and then I left the house. Then on the way to work, I remembered that I forgot to press the button."

Interviewees further reported that they had sometimes wanted to respond, but had been too tired to do so (P1, P9). As P1 explained: "You asked us to use more [electricity] one evening, so I deliberately saved up my ironing to do in the evening. But I had physically run out of steam, so I didn't have the energy; so it had to be done when it was a normal time."

While physical fatigue was occasionally a constraint for some, for others response fatigue (Kim and Shcherbakova, 2011) proved problematic as the trial progressed and the cumulative effect of the notifications became increasingly draining. P23 recalled:

> I had a moment where I got the alert and it said, 'Please use less electricity,' and I was just looking at it and thinking, 'No, I'm sorry – not today'… There was a phase when you were sending a lot of alerts very frequently, and after that when you slowed it down again, I was fatigued – I mean, still fatigued, even though you did slow it down again.

Theme 5 – Active occupancy is a necessary requirement for response, in the absence of smart appliances or appliances with timers

All interviewees reported that there had been times – such as while they were absent or asleep – when they had been unable to respond. As P23 explained: "I would get the alert and it would be when I was off either for work for a couple of days or for a holiday somewhere, and I would think, 'Oh well, can't do anything about that.'"

Some interviewees suggested that if they had owned appliances with timers or appliances that could be controlled remotely, they might have sometimes been able to respond when they were absent or asleep (P10, P14, P20). Others felt that smart appliances which could start automatically during turn-up events would have facilitated response (P3, P5, P7, P9, P15). In the words of P3: "I think that would be the trick – to automate it somehow. Automate it with the appliances, so I can press a button on my washing machine to say, 'Come on when renewable energy is at its highest.'"

Interviewees were predominantly accepting of smart appliances, viewing them as a natural complement to DSR programmes as they help to facilitate response when households are not actively occupied. Some even suggested that some form of automation would be necessary before they would consider participating in future DSR programmes (P4, P8). As P4 stated: "I don't think I could do it if it involved a decision by me; I think things would have to happen automatically."

Theme 6 – Third-party control can prevent response

Several interviewees reported that often the use of certain appliances in their households was scheduled not by household members, but rather by other individuals (P1, P4, P6, P7, P11, P12, P18). For instance, some said that it was not usually possible to schedule the use of vacuum cleaners, irons and washing machines for turn-up events because these appliances were primarily used by their cleaners (P1, P7, P11). Similarly, P12 was disabled and had carers who came to help her with ironing and vacuuming, which meant that these activities could not be synchronised with trial events. Meanwhile, P4 and P18 explained that they had tenants living in their households during the trial and did not feel it would be appropriate to prevail on them to respond by asking them to reschedule appliance use.

Even electric heating systems sometimes could not be used to respond since the times when these came on were controlled by third parties – as was the case for P11's communal underfloor heating system.

7.4.2 Motivation themes

Theme 7 - Concerns about social rejection can prevent response

Interviewees explained that sometimes they had not used certain appliances to respond because they were concerned that this would inconvenience others. For instance, two interviewees reported that they had not used their washing machines during some of the turn-up events that occurred early in the morning or late at night (P21, P14). As P21 elaborated: "I didn't want to wake up the neighbours and I was particularly conscious of the fact that the neighbours are underneath me, so can hear the washing machine, and I had been asked to use it at unsocial hours."

Interviewees also mentioned other concerns about social rejection which sometimes prevented them from rescheduling the use of appliances. P1, for example, reported that on occasion she had been unwilling to delay vacuuming until the next turn-up event because she was expecting guests and did not want her home to appear dirty.

Theme 8 – Performance feedback can facilitate response

During the trial participants received regular feedback on both their own household's response and the response of all households. This was provided every three weeks[103] and included positive or negative emoticons (😀 or 😔), depending on whether the household(s) had successfully changed their consumption patterns during trial events.

For most interviewees, this feedback was welcome and increased their motivation to respond. P20's comment was typical: "Getting that feedback, the very first one, made me think, 'Well, it is actually doing something – my energy consumption has changed as a result of these alerts, so that's good and let's keep doing it.'"

Similarly, for P24, receiving the feedback "felt good, to be honest with you, because you said that we were doing well"; while P17 reported: "Obviously, everyone likes a little bit of a pat on the back. When it I got it, I said to my partner, 'Ooh look, we've done better this week.'"

Some interviewees also indicated that the emoticons had strengthened their motivation to respond (P2, P9, P17). As P9 explained: "When you sent that first feedback text, for the days immediately afterwards we made more effort because we didn't want there to be another sad face. We were trying to get a smiley face the next time – or at least, we were trying not to get a sad face."

However, the feedback did not universally increase motivation to respond. Recalling how she had felt after receiving feedback indicating that her household had consumed more electricity than normal during several turn-down events, P8 explained:

> I don't think it put me off altogether, but I think that it was slightly demotivating – I think especially the realisation that because we had a few people staying over and because the house had been quite full, there wasn't really a lot we could have done

[103] All participants received the feedback by text, while those who chose to receive notifications via email also received it via this medium.

> anyway. I think that was a bit demotivating because it made it feel as if my personal level of agency wasn't really that significant.

In one case, even positive feedback negatively influenced an interviewee's motivation to respond. Reflecting on feedback showing that his household had reduced consumption during turn-down events, P22 commented: "I don't know – maybe perhaps subtly it made me try less hard because I had thought I did better than expected. And I seem to remember in the second feedback we did less well, so maybe that's borne out."

A growing body of literature suggests that peer comparisons of electricity use can be an effective way to promote energy conservation (Allcott, 2011; Arvola *et al*, 1993; Dolan and Metcalf, 2015; Steg, 2008). This was reflected in the comments of several trial interviewees, who felt that peer comparisons provided as part of the feedback would have increased their motivation to respond (P1, P4, P16, P23). As P1 suggested: "I suppose if you had been able to compare how you are doing with how an average group are doing, then that for me would have been a motivator."

More negatively, however, there is also evidence that motivation can be adversely affected where individuals who receive peer comparisons have performed better than average – a phenomenon referred to as the "destructive boomerang effect" (Schultz *et al*, 2007). That said, P22's earlier comments suggest that sometimes even an individual's own positive performance can have a similar effect and reduce motivation to respond, so the value of peer comparisons should not be discounted on this ground.

One way in which feedback in the form of descriptive norms can motivate behaviour is by setting a standard from which individuals are reluctant to deviate (Schultz *et al*, 2007). The interviews revealed that for those participants who were in a position to make their own peer comparisons, the feedback served this purpose. P6 explained: "My manager, who I sit next to, and someone else in my team [P3 and P17] – we all did the trial together because we all saw the same advert, so we all got the texts and the feedback at the same time, and so we compared notes and I said, 'Ahh, I've only changed by 7%.' So I basically used them as a benchmark." They also reminded each other of the timing of events and discussed the different actions they were taking to respond – as did P1, P7, P18 and P24, with members of their own households.

P3 likewise recognised the benefits of peer comparisons and highlighted another potent motivator in doing so – competition: "[Perhaps] it's more about what everyone else is doing?

So, being motivated by the fact that other people are doing it or your neighbours are doing it or other people on your street are doing it – by that competitive element.”

The potential to unlock greater response by harnessing the competitive spirit of some participants was further emphasised by other interviewees, who suggested that being able to compare themselves against other households in their region or of their size (P4), or against the household with the greatest response (P23), would have introduced “a bit of friendly anonymous competition” (P23) and made them “want to try to do better, or try to do better than the others” (P4).

Theme 9 – Feedback on environmental benefits could facilitate response

The interviews – along with data from the enrolment questionnaire – revealed that many (n=13) participants had signed up to the trial at least in part because they wanted to reduce the environmental impact of their electricity use and help to combat climate change. To this end, several interviewees said that they would have welcomed information about the environmental benefits realised through their efforts as the trial progressed (P10, P16, P17, P21, P23). Although they were informed at the outset of the environmental benefits of response, these interviewees indicated that they would also have liked to receive feedback on how their own efforts were affecting their carbon footprint during the trial. As P10 explained:

> I think maybe some sort of statistics around how much carbon dioxide you are not creating or how much wind power you have been able to use. Or where it’s gone AWOL, where you’ve produced more carbon dioxide because you have operated appliances outside of the specified times – in which case, here’s potentially how much you could have saved. I think that kind of information is something I would be interested in – your kind of carbon score.

Theme 10 – Counter-motivations can prevent response

For some interviewees, the environmental commitment evident in Theme 9 meant that requests to respond during turn-up events were uneasily received, as apparently running counter to their philosophy and habits (P2, P16, P19). Even those who successfully responded expressed some discomfort with the phrasing of the notifications. As P19 elaborated: “It felt wrong, to be encouraging people to use more energy, so I didn’t really like that… I think the wording was kind of a bit misleading. What you are trying to do presumably is trying to get people to shift, rather than use more.”

P2 echoed this concern, while acknowledging the inherent tension where an action which itself appears innately counter to environmental principles in fact serves a crucial purpose in the broader environmental context:

> It's phrased funnily in the messages, cos you've used more and that's kind of a bad thing; but because you've done it in a period when it would have been more windy, it's actually a positive thing… It's a strange way of conceptualising energy consumption, but it felt positive because we had actually achieved what we were supposed to achieve.

In some cases, this tension actively served as a counter-motivation to response. For example, P7 sometimes did not respond by running his dishwasher or washing machine because he did not have a full load and did not want to waste electricity. Likewise, when it came to turn-down events, some interviewees were unwilling to delay doing a wash cycle because they preferred to avail of outdoor drying (P9, P10, P12, P14, P16).

Taking this one step further, P4 reported that their experiences on the trial prompted individuals in her household to consider not only how they could change their consumption patterns to respond, but also how they could minimise their overall energy use. As a result, they sometimes used certain appliances during turn-down events even though this was contraindicated. For instance, she had sometimes used her electric shower rather than having a bath – which would have used gas to heat the water – because she thought that doing so would use less energy overall. This represents a substitution of energy vector (Grünewald, 2015) for a different purpose: to reduce overall consumption, rather than to load shift. As she explained: "I suppose we made our own decisions based on, not just, 'Yes, we are going to be using or not using energy according to the availability of wind-generated energy,' but actually looking at our overall energy consumption and looking at what's going to use the least energy of any source." The potential implications of this approach are discussed in Section 7.6.3(c).

7.4.3 Trigger themes

Theme 11 – Multi-modal event notifications can facilitate response

When enrolling on the trial, participants opted to receive event notifications either by text message only or by text message and email. Some interviewees who had chosen to receive notifications via both channels reported that this increased the likelihood that they would receive the messages and would therefore be well placed to respond (P1, P7, P11). As P11 explained: "It was probably quite good because it was belt and braces; so if I missed one, I would have spotted the other, because I tend to look at my messages on my phone when I am out and about and emails on my computer when I am in." Similarly, P1 stated that this ensured she received all notifications regardless of whether she happened to be without either internet or mobile coverage.

Conversely, in a few cases where interviewees had opted to receive text message notifications only, this ended up preventing response (P8, P18, P13). For instance, a member of P8's household lost his phone a week into the trial and so did not receive any notifications; while P18 opted out of receiving text message notifications when she went on holiday and then forgot to switch them back on once she returned home.

Some interviewees suggested that had they received notifications through alternative channels, this would have helped to increase response; messages would have been received in a manner and at a time that would have made it more likely that they would have been acted upon (P2, P8, P17, P18, P21). Suggestions included social media notifications, calendar alerts and 'push' notifications on smartphone apps. For example, P21 felt that calendar alerts would have worked especially well because they are harder to dismiss than texts and would appear automatically on all her various devices. Similarly, P18 thought that Facebook notifications would be particularly effective for her:

> If I was part of a group and there was a post on my wall, then in among photographs of my daughter and kids riding their bikes and macaroni cheese recipes, I would get a little reminder: 'If you've got a wash upstairs sitting in the basket, go and do it tonight.'… It would catch me at the right time.

Theme 12 – The effectiveness of in-home displays and other devices in triggering response

Event notifications could not be sent through the in-home displays used on the trial because participants did not have smart meters in their households. However, most interviewees (n=14) suggested that this would have made it easier for them to respond and could help to promote continued response over the longer term: when household members checked how much electricity was being used in their households, they would also be reminded of the timing of upcoming events (P2, P21). As P14 observed: "You would put the two together – it would all be in one place… That would remind you that the wind is blowing now, so it's a good time to do stuff."

When asked what might have facilitated response, several interviewees thought that it would have been helpful if their in-home displays could change colour to indicate when events were taking place (P3, P13, P17, P18, P20). As P18 stated: "If you could have a different-coloured light or some sort of indication that now is a good time, that would be useful, because it's just all built into a central space and you'd have it somewhere that's visual, like under the telly…You'd think, 'Oh, the light's gone green – it's time to get the wash on.'"

P4 even wondered whether event notifications could be linked, via the in-home displays, with household appliances to create a network that could trigger response through appliances themselves: "We are meant to be living in the 21st century. If the device was hooked up to the appliances, so that when you tried to put them on, you got a message that, 'You are in an alert – are you sure you want to put it on? You are meant to be using less,' it might make you think twice."

7.5 Response and the FBM

This section explores how the various enablers and constraints of response identified through the interviews can be conceptualised through the prism of the FBM.

7.5.1 Ability

The interview data revealed that, of the FBM's six 'ability' elements (see Chapter 3), the physical effort, brain cycles, time and non-routine elements all served as constraints to response on the trial. For instance, having to perform non-routine behaviours – such as washing clothes outside existing household schedules or changing mealtimes – sometimes prevented response (see Theme 2). The fact that response was at times either physically or cognitively challenging also served as a constraint: on occasion, some interviewees were too tired to respond, or forgot to do so because they were distracted by other tasks or had not registered the details of events (Theme 4). Time pressures also prevented response (Theme 4), with the demands of family life proving particularly detrimental for some households.

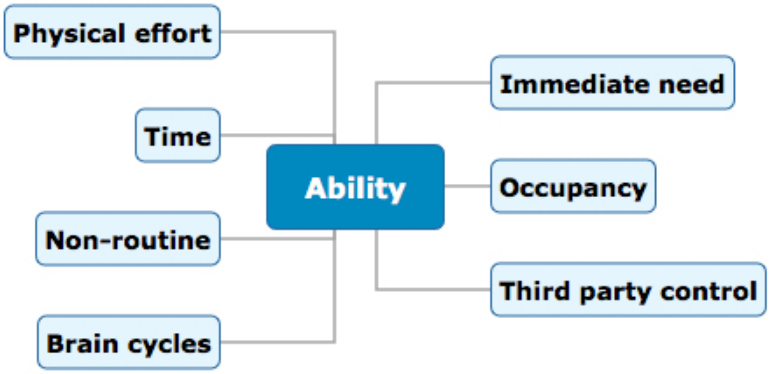
While these constraints all mapped readily to the FBM, three additional factors were identified which did not fit the model so easily:

- Immediate need – where an immediate need to use a specific appliance arose (Theme 3);
- Third-party control – where someone from outside the household determined the use times of appliances (Theme 5); and

- Active occupancy – where response was difficult or impossible because household members were away from the home or asleep (Theme 6).

The ability component of the FBM was thus expanded to include these additional factors (see Figure 27).

Figure 27. Revised ability component of the FBM



7.5.2 Motivation

Analysis of the interview data revealed close correlations with the FBM's three core motivators (see Chapter 3). The feedback provided on the trial – in particular, the personal feedback – appears to have successfully tapped into the pleasure/pain motivator. This was evident in the language that interviewees used to describe their reactions to the feedback: they spoke of being "chuffed", said that "it felt good" and observed, "We've done well, which felt good." Their input suggests that the pleasure which this feedback elicited helped to promote continued response throughout the trial (see Theme 7). The considerable enthusiasm expressed for peer comparisons suggests that this motivator could be leveraged further by providing a benchmark against which some participants could measure themselves and even a source of competition for others.

Meanwhile, concerns expressed about disturbing neighbours by using certain appliances late at night or appearing untidy to visitors by delaying vacuuming clearly map to the social acceptance/rejection motivator of the FBM.

Regarding the hope/fear motivator, some interviewees suggested that details of the specific environmental benefits realised through their efforts would have increased their motivation to respond (P1, P7, P10, P21) (Theme 9); this would tap into fears about climate change and hopes that individual response could help to mitigate its effects. Communicating these benefits is further recommended by Fischer *et al* (2013), who suggest that programmes should “convey to consumers the environmental benefits of load shifting (eg, avoiding peak demand and thus reducing carbon emissions)… and reward consent not just with money, but also with game like rewards or environmental praise” (p.10).

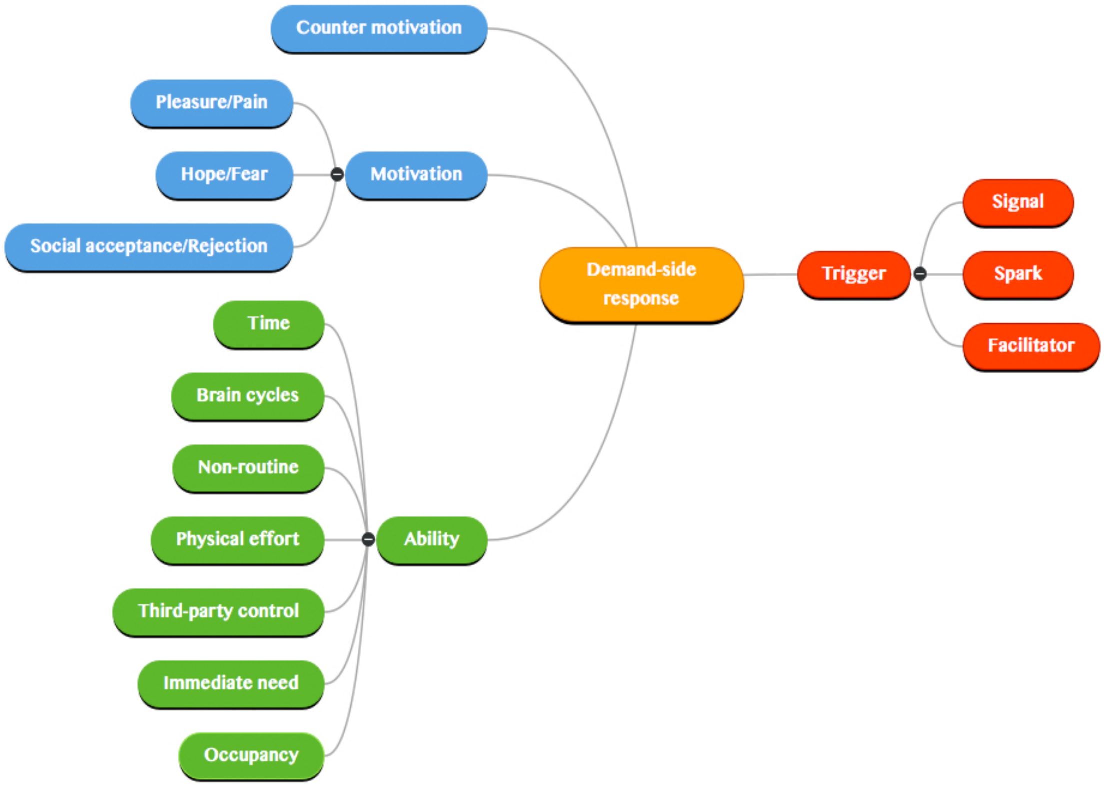
However, the interview data also revealed a tension between how some interviewees prefer to use their appliances and how they might need to in order to respond. In those cases, the desire to conserve energy proved a powerful counter-motivation, with interviewees refraining from using certain appliances to respond to avoid increasing overall consumption – for example, by not running partial laundry or dishwasher loads during turn-up events, and by doing laundry during turn-down events to avail of outdoor drying. One interviewee (P4) even reframed her energy decisions around what would use less energy overall, rather than specifically around response. The concept of counter-motivation is therefore included in the extended version of the FBM presented in this chapter (see Figure 28).

7.5.3 Trigger

Most of the interviewees suggested that event notifications sent through their in-home displays would have helped to facilitate response (n=13). Within the framework of the FBM, the in-home display would complement the text message and email notifications by acting as an additional ‘signal trigger’, which would be visible to everyone in the household and would further prompt response at appropriate times.

One interviewee suggested that devices indicating when appliances should be used should be placed close to, or even incorporated within, energy-intensive appliances (P17). They could thus help to increase response by serving as “in-the-moment, localised awareness mechanisms that are visible as a decision is being made” (Sugarman, 2014, p.47). From the perspective of the FBM, such devices would act as facilitator triggers, making it easier to respond by reminding consumers whether it was an appropriate time to use their appliances at the precise moment that they were about to use them.

Figure 28. Adapted FBM model for DSR



7.6 Lessons for shaping DSR strategies

This section draws on the findings from the interviews – read together with the wider energy literature – to explore how these might inform future DSR strategies.

7.6.1 Promoting acceptance of DSR programme models

While the interviews primarily explored the enablers and constraints of response, they also provided an opportunity to seek qualitative feedback on how interviewees' experiences on the trial might inform their preferences for different potential DSR programme models, to complement the quantitative data from the switching survey (see Chapter 5).

To this end, interviewees were asked whether they would prefer to participate in similar programmes which were price based or information-only. Perhaps unsurprisingly, most (n=14) indicated that they would be more motivated to respond if their efforts could translate into savings on their electricity bills. This is in line with the findings of the switching survey, which revealed that financial incentives were powerful motivators for participation in DSR programmes: around 84% of respondents who opted to switch to one of the DSR tariffs cited the opportunity to save money as either “Very important” or “Extremely important” in their choice of programme.

Two interviewees stated that their experiences on the trial had made them more likely to switch to price-based programmes should these become available (P11, P23). P11 reported that the trial had made her realise that a financially incentivised tariff might suit her household: “Your study showed that I can change my behaviour – maybe not in huge ways, but a bit; so actually, a tariff that both rewarded me for it and reinforced that tendency would be good, I think.”

P15 suggested that financial incentives might also help to prevent response fatigue: “If there was no price incentive and I was doing this year in, year out, I don’t think you would get the same response from me... In the long term, there is a risk that I would become disengaged.”

However, other interviewees indicated a preference for information-only programmes (P8, P14, P21, P22). As P14 explained: “I don’t need a financial incentive to change my ways and it was very interesting to feel that you are in tune with the weather… I think I would probably respond to your methods better than a sort of midnight tariff or whatever they might come up with.”

Considering the types of communications from suppliers that might encourage her to switch to a DSR programme, P8 suggested: “If they sent me a message saying, ‘If you switch to this tariff, it would probably help to promote renewables,’ then I would be more likely to switch, because we’ve already switched electricity supplier to be with a green electricity supplier. If that was the kind of sales pitch they used, I think I would be more likely to at least consider it.”

The interview data thus confirmed that in deciding whether to switch to DSR programmes, some consumers are motivated more by non-financial considerations – such as the desire to promote renewables or protect the environment – than by the opportunity to save money on their electricity bills. In fact, P21 wondered whether a programme that financially incentivised response might even have perverse effects: “If we monetised this and I could actually afford the more expensive price, then I would just use things whenever it’s easiest for me… In a way, that gives me a green light to act irresponsibly because I can afford to.” The fact that financial incentives might sometimes negatively affect response is supported by research in other contexts which has shown that pro-social motivations can be ‘crowded out’ by financial incentives (see Chapter 2).

Meanwhile, comments made by P13 and P18 suggest that some consumers might be reluctant to switch to information-only DSR if suppliers are ultimately the sole financial beneficiaries of their efforts. In the words of P13: "If people used electricity when there is more available and didn't receive any reward for doing that, the only people who would gain would be the suppliers." Similarly, P18 suggested that receiving a financial reward for responding would "feel kind of fairer, because I guess whoever owns the turbine is able to make their money when the winds are high".[104]

7.6.2 Promoting penetration of smart appliances

The interview data revealed that the most common constraint that interviewees experienced in responding related to active occupancy: if the house was empty or everyone was asleep, they generally could not run appliances during turn-up events. Many interviewees mentioned that had they owned smart appliances that could self-start at times of high renewable generation or could be activated remotely upon receipt of notifications, this would have facilitated response.

Their feedback suggests that greater market penetration of smart appliances would help to increase response. However, achieving this is not necessarily straightforward. Some scholars have characterised it as a classic "chicken and egg problem" (Vanthournout, 2015): on one hand, few residential DSR programmes are currently available because consumers have limited capacity to respond, given that most do not own smart appliances; but on the other, the market for smart appliances is underdeveloped, since consumers have limited interest in investing in this new technology in the absence of financial incentives to do so.

In this context, regulation may be needed to ensure a minimum level of smart functionality for new household appliances. This has already been introduced in other countries: for example, Australia's Department of Climate Change and Energy Efficiency concluded that "Government action is necessary to create the conditions for the appliance market to introduce smart appliances…and to ensure that they are sold in sufficient quantities for the electricity distributors to be able to cost-effectively implement demand response strategies" (Department of Climate Change and Energy Efficiency, 2011, p.4). This led to the introduction of Standard AS/NZS 4755 – "Demand response capabilities and supporting technologies for electrical

[104] These comments are in line with the findings of Buchanan *et al* (2016): residential consumers in this study felt that since their response helped to provide financial value for the grid and suppliers, they should share in the financial benefits.

products" – which was designed to facilitate the roll-out of smart appliances. To comply with the standard, appliances must at a minimum be able to switch off automatically or operate at minimal load for the duration of DSR events (ibid).

The UK government has recently taken a first step in this direction. Ofgem's Smart Systems and Flexibility Plan (Ofgem, 2017) acknowledges that the "limited availability of smart appliances means consumers cannot realise bill savings by providing demand response", and states that "the Government intends to consult on seeking powers to set standards for smart appliances" (p.25).[105] However, although regulation should help to increase penetration of smart appliances, it will still take some time before these are commonly found in consumer households, given the lifespan of appliances. In the meantime, additional strategies such as those outlined below will be necessary to maximise consumer response.

7.6.3 Promoting the development of DSR know-how

Burchell *et al* (2015) use the term 'energy know-how' to refer to "the things that it is helpful for householders to know if they want to reduce their energy consumption" (p.1987). The term encompasses knowledge of alternative ways of doing things that would consume less energy, the practical skills needed to implement these alternatives, and an understanding of any materials that may be required and where to obtain them (ibid).

The interview data suggests that helping consumers to develop similar knowledge would increase response on DSR programmes. This is supported by a meta-analysis of DSR programmes by Stromback *et al* (2011), which found that consumer education – including information about how to save energy and tips and advice on potential response – has a significant impact on programme outcomes (see Chapter 2): consumers reduced peak consumption by 50% more on ToU programmes that included these types of educational measures than those on programmes that did not (a 6% versus 4% decrease).

The knowledge that is likely to be helpful when it comes to increasing response on DSR programmes is referred to in this thesis as 'DSR know-how'. This in turn consists of three elements: appliance consumption knowledge, appliance know-how and practice know-how (see Figure 29).

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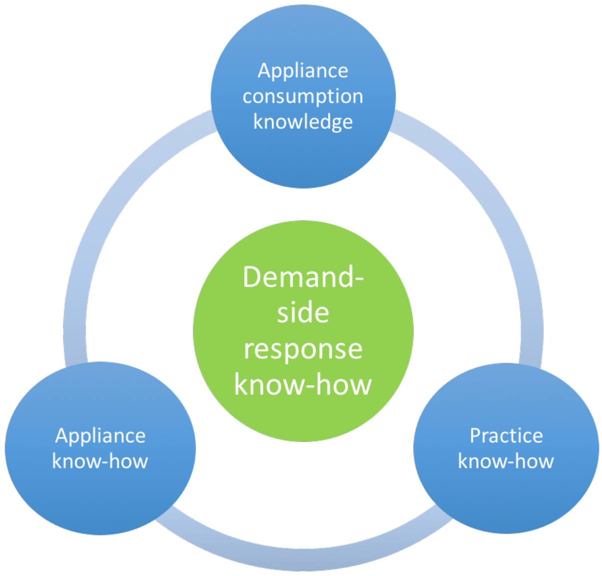
[105] The government plans to focus on appliances which can be communications enabled and can thus adjust their energy consumption in response to signals. These would initially include cold and wet appliances, heating, ventilation and battery storage (Ofgem, 2017).

Figure 29. DSR know-how



(a) Appliance consumption knowledge

For consumers to change their consumption patterns effectively, they first need to know how much electricity is required for specific end uses (Fischer, 2008). However, as highlighted in Theme 1, the enrolment questionnaire and interview data revealed that many trial participants had a poor understanding of how much electricity different appliances consume. This echoes the results of previous studies: Kempton and Montgomery (1982), for instance, found that consumers frequently estimate how much energy appliances use according to their perceptual salience (eg, they often overestimate the electricity consumption of televisions and lighting), and overestimate how much energy is used by appliances that replace tasks which previously involved manual labour. Similarly, in a more recent US study, Chen *et al* (2014) found that consumers frequently misestimated the amount of electricity required to run overhead lighting, heating and cooling systems, and various electrical items.

Thus, helping to develop consumers' appliance consumption knowledge should facilitate response by enabling them to identify the most appropriate appliances to use when acting on notifications (Ofgem, 2010).

(b) Appliance know-how

The interview data revealed that interviewees often lacked specific knowledge about their own appliances which would have facilitated response (Theme 1). For instance, some were unaware that their appliances had timers or did not know how to set them. Others were interested in retrofitting specific appliances with plugs that would facilitate remote control (eg, immersion heaters), but did not know how to do so. In each case, this lack of appliance know-how prevented response when households were not actively occupied.

These findings suggest that helping participants to develop a better understanding of how their own appliances operate should increase response.[106] As others have argued, the information provided on DSR programmes "needs to extend beyond an explanation of the tariffs to also include interaction with heating systems or digital control devices and appliances. Information on how to use devices or timers without affecting functionality will be important" (Owen *et al*, 2013, p.57).

Feedback from P17 further highlighted this point: "The alerts were very helpful and told you when to use more or less. But what I did think would be good would be some additional tips – say, for example, 'Did you know that it was more economical using X, Y or Z?'" Such suggestions could relate, for example, to rescheduling a load using a timer, using a half-load setting where this function is available or using eco-settings instead of standard cycles. Meanwhile, to prompt response from participants (like P23) who may be unsure of how their appliances operate and have no manual to hand, notifications could include a tip to search for an online version or contact the manufacturer.

Under the FBM, such notifications – combining a message about when to take action with tips on how to do so – would be considered 'facilitator' triggers, since they prompt response while simultaneously making response easier.

[106] This is also suggested by the qualitative study of consumer response on the CLNR ToU trial, which found that consumers with greater appliance know-how find it easier to be flexible about their energy use (Bulkeley *et al*, 2014).

(c) Practice know-how

The final component of DSR know-how involves adjusting various household practices in order to respond and is informed by the concept of practice-led approaches presented by Grünewald (2015). Grünewald defines 'practice-led approaches' as those that lead to "a change in load which is brought about by people doing things differently".

Many interviewees explained how they had adopted such approaches in order to respond during the trial. For example, during turn-down events, P24 had sometimes risen earlier and left the house with her daughter to avoid using electricity at home (changing the practitioner). Likewise, P17 demonstrated practice know-how when staying with his mother – a fellow trial participant – by using her standard shower rather than her power shower to consume less electricity during turn-down events (substituting the practice).

The comments of P17's mother in this regard confirm that helping participants to think about the different ways in which they can adjust household practices could facilitate response: "My son was participating as well and he was staying in my house during some of the alerts. I have a power shower and a non-power shower, and he showered without using the power shower. It would not have occurred to me to do that."

The interview data revealed that one area in which many interviewees already possessed advanced practice know-how, and drew on this to positive effect, concerned kitchen practices. Interviewees reported that they had responded by reheating food in microwaves rather than using an electric hob or oven (load reduction) or cooking on a gas hob rather than in an electric oven (substituting energy vector) during turn-down events, and by preparing food in advance for consumption later during turn-up events (shifting backwards). Helping consumers to develop their practice know-how in this space might be especially beneficial given that electricity used for cooking represents a significant proportion of residential demand (17.5% in 2014) (DECC, 2015) and around 20% of the evening peak (Element Energy, 2014); changes in such behaviour could thus unlock significant response on DSR programmes.

Similarly, all three interviewees with immersion heaters exhibited advanced practice know-how in relation to their use and had used them during trial events in order to respond – either by refraining from use during turn-down events (shifting load forward in time) or by switching them on manually or setting timers to coincide with turn-up events (shifting load backward in time). This likewise suggests that helping to develop practice know-how in this regard should facilitate response – for example, by promoting greater awareness of the fact that the energy intensiveness of immersion heaters makes heating water off peak a highly effective way to respond, and providing details of how long water is likely to remain hot once pre-heated.

Practice know-how should also encompass an understanding of when response might be contraindicated so that overall load is not accidentally increased on DSR programmes. For instance, participants should understand that in general, washing machines, tumble dryers and dishwashers should not be run with partial loads in order to respond. An OECD study involving 10,000 EU households showed that some DSR programmes resulted in increased overall consumption, in part because participants chose to run partial loads during low-priced periods (Breukers and Mourik, 2013). Similarly, although doing laundry when outdoor drying is possible might sometimes mean that participants cannot respond by using their washing machine during turn-up events, it is still important to encourage such behaviour to avoid the additional electrical loads associated with tumble dryer use (see Theme 10).

That said, a fine line must be negotiated between preventing increases in overall consumption and ensuring that response is still sufficient to achieve the goals of DSR, which – as some participants may not appreciate – are distinct from those of energy conservation. As the discussion in Theme 10 illustrates, energy use decisions can be informed by competing motivations and objectives. Consumers – particularly the environmentally committed individuals who are more likely to switch to information-only DSR programmes (see Chapter 5), and those whose energy consciousness is further heightened through participation (see Theme 2) – may be unaware that a focus on reducing consumption above all else could, perhaps counterintuitively, at times be antithetical to the purposes of DSR. For example, while what many consumers would understand as the accepted rules of energy use (eg, running full loads, utilising natural power whenever available, avoiding unnecessary use) are usually compatible with the demands of DSR, there may be occasions when wind generation is so abundant that any response at all will assist in balancing the system and avoiding the need to spill excess output.

In developing practice know-how, it would thus be helpful to promote a wider understanding of the differences between load shifting and load reduction, and to provide concrete suggestions on how different types of response in different scenarios might best achieve the goals of DSR (eg, in cases of exceptional generation such as those outlined above, even partial loads or tumble drying could represent an acceptable response).

7.6.4 Linking event notifications to in-home displays

Consumers on DSR programmes whose households have smart meters could receive additional notifications of DSR events through their in-home displays. While the interview data suggests that this should help to increase event visibility and thus facilitate response, the interviews also yielded additional findings about the potential use of in-home displays on DSR programmes.

First, many interviewees recommended that in-house displays use different colours to indicate peak and off-peak periods. ‘Traffic light’ systems – with red indicating peak, amber regular and green off-peak – have been used with positive results on previous DSR programmes. For example, in a critical peak pricing pilot conducted by US utility Baltimore Gas and Electric Company, customers provided with Energy Orbs (a type of ambient in-home display) shifted loads off-peak by between 23% and 27%, compared to a control group which shifted loads by between 18% and 21% (DECC, 2012b).

The LCL dynamic ToU trial likewise informed participants of electricity consumption in their households in real time through a traffic light system on their in-home displays (Carmichael *et al*, 2014). However, this particular application of the system could potentially cause confusion and thus hinder response: participants might attempt to use more electricity during turn-down events if the in-home display were green or reduce consumption during turn-up events on seeing the in-home display turn red. The consensus expressed in the post-trial interviews was that to avoid confusion, the traffic light system should relate to the different price periods, rather than to household electricity consumption (Carmichael *et al*, 2014).

This approach was supported by the interview data, as P17 observed: “But if it was red, red, red… You’d think, ‘Oh God…’ Well, red is stop, at the end of the day; green is positive.”

7.6.5 Multi-modal event notifications

While in-home displays are a natural channel for event notifications, the interview data suggests that the potential impact of other channels – such as social media, mobile phone apps and calendar messages – should not be ignored. For some individuals, these might work better by “catch[ing] their attention at just the right time”, in the words of one interviewee – *kairos* in action, in Fogg’s terminology.

This is supported by a meta-analysis of response on DSR trials conducted by Stromback *et al* (2011), which found a positive correlation between response on critical peak pricing, critical peak rebate and real-time pricing programmes and the number of different channels used to notify participants about events. A qualitative study of EnergyAustralia's dynamic peak pricing trial likewise revealed that when households were provided with event notifications in several different ways, this "heightened the sense of urgency" around impending dynamic peak pricing events for participants (Strengers, 2010).

While this 'heightened sense of urgency' may be one reason why multiple event notifications increase response, the interview data suggests other, more prosaic reasons. Interviewees observed that where they had opted to receive text notifications only, they sometimes missed these messages – for example, if they were outside network coverage or did not have their phones to hand – and were thus unaware of the timing of upcoming events. The notifications were also sometimes ignored when they arrived at inconvenient times. Multi-modal event notifications may thus help to facilitate response on DSR programmes by making it more likely that participants will both receive notifications and register the details of events.[107]

7.6.6 Feedback lessons

Although the feedback strengthened motivation to respond for most interviewees, several observed that they would have also welcomed information on the environmental benefits realised through their efforts. This form of feedback will likely be particularly important on information-only programmes, given the absence of other incentives to respond. On price-based programmes, the pricing mechanism itself serves as an incentive: participants who succeed in load shifting can see their efforts translate directly into savings. However, this kind of tangible benefit is absent from information-only programmes, making alternative incentives even more necessary.

Similarly, the recommendations that peer comparisons be incorporated into the feedback suggest that benchmarking and competition could both serve as additional motivators which would help to promote response in the absence of financial incentives.

[107] This approach may not be as beneficial in the case of static ToU programmes, since consumers on these programmes may begin to develop new consumption patterns based around peak and off-peak periods which occur at the same times each day.

That several interviewees voluntarily chose to compare feedback, share details of how they responded and remind each other about events is also a significant finding: it confirms the potential for creating a community of users, which can be an effective way to encourage behaviour change (Petersen *et al*, 2007). One way to achieve this would be to establish forums which enable participants on DSR programmes to exchange experiences and discuss different ways of responding; for example, Salt River Project Power and Water in Central Arizona introduced a platform through which customers can share their experiences of its ToU tariffs (SRP, 2017). This approach is further supported by research showing that participants in energy demand programmes are often interested in learning about alternative routines and ways of doing things from their peers (Hitchings and Day 2011; Simcock *et al*, 2014), which in turn can help them to identify new ways of responding (Boardman and Darby, 2000).

7.6.7 Towards a tailored DSR system

The interview data confirms that when it comes to DSR, one size cannot and does not fit all. As the preceding discussion highlights, the potential utility of a personalised approach is apparent from an analysis of interviewee input on all aspects of the trial – from the frequency and content of event notifications to the channels through which they were sent and the format and content of the feedback provided. In fact, such an approach was expressly advocated by P2, who ventured suggestions on what an ideal real-world DSR system might look like: "You could build the application for the user when they sign up. They would actually fill in their likes, dislikes and requirements…You would then be able to provide enhancement, advice, information, notifications, all in relation to specific lifestyle circumstances and events."

The value of this tailored approach – "persuasion through customization", in Fogg's words (Fogg, 2002) – is supported by the literature. While tailoring has traditionally been used for health interventions, studies have also confirmed it as a potent tool for effecting behavioural change in the energy context (Abrahamse *et al*, 2007; Fogg, 2002). These confirm that a tailored programme is likely to have significantly greater effect than more generic models, as people tend to assign disproportionate weight to information that is highly concrete and personalised (Borgida and Nisbett, 1977), and are more likely to make consumption changes when information is tailored to their lives and contexts (Boardman and Darby, 2000; Green *et al*, 1998; Henryson *et al,* 2000; Steg, 2008).[108]

[108] Providing personalised hints and tips of this kind to consumers on DSR programmes has been found to increase response (Lewis *et al*, 2012).

A tailored DSR system would afford several advantages.[109] First, by submitting details of the specific appliances they own,[110] users could be provided with more accurate information on the amount of electricity that each consumes and the different ways in which it might be used to respond. An example of the kind of personalised appliance information that could be used to help facilitate response on DSR programmes is shown in Table 21.

Table 21. Personalised response information (Source: adapted from Fischer *et al*, 2013)

What can I do?

Save by shifting loads. Shift the use of your **washing machine, dishwasher** or **tumble dryer** from day to night time. We predict that the yearly use of these kinds of appliances (438 kWh) accounts for 13% of your overall electricity consumption. From your profile, we have detected you typically use those kind of appliances at least **24 times per month**.

Inspecting the times when you typically use those appliances, we predict their use would cost you at least **£72 per year**. It appears that 100% of the time you would use these appliances during the day rate hours of the selected tariff. As a result, you would spend at least **£72 for day time use**, and **£0 for night time use** of your washing machine, dishwasher, and tumble dryer.

How much could I save by shifting loads?

From your profile, we have calculated how much you could save on the selected tariff.	**Potential Annual Savings**
Save **£13** by shifting a quarter of your day time use of washing machine, dishwasher or tumble dryer to night times.	£13
Save **£25** by shifting a half of your day time use of washing machine, dishwasher or tumble dryer to night times.	£25
Save **£38** by shifting three quarters of your day time use of washing machine, dishwasher or tumble dryer to night times.	£38
Save **£51** by shifting all of your day time use of washing machine, dishwasher or tumble dryer to night times.	£51

A tailored system could also help users to identify the most appropriate appliances to use to respond on an event-by-event basis by including personalised suggestions in event notifications. Appliances that users might not have previously considered using could be highlighted, as well as those whose use involves the strongest behavioural component, such as space and water heating (see Chen *et al*, 2014).[111]

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[109] Although such an approach would require more complex back-end systems to administer, the increasing power of data analytics means that more sophisticated segmentation is becoming cheaper and easier (The Behavioural Insights Team, 2014).
[110] This information could also be obtained using non-intrusive load monitoring subject to participant consent (see Zoha *et al*, 2012).
[111] The latter is important because the behavioural component of electricity consumption varies by appliance so appliance level information policies are most effective when they target appliances with the largest behavioural component (ibid).

The system could further provide customised tips on ways in which various household practices could be adjusted to use the minimum electricity possible. This would be especially helpful in highlighting alternative approaches in case of immediate need: for example, notifications might point out that laundry could be washed at a lower heat setting or draw users' attention to eco-settings which they may be unaware of (reduce load). As P4 observed, this sort of information might "help you to make those judgement calls when you know you can't respond completely, but at least to use a bit less than you would otherwise".

A tailored system would additionally allow users to set preferences for the channels through which event notifications are received (eg, text messages, emails, calendar alerts, Facebook posts) [112] and the frequency with which they are sent. This would help to ensure that response is triggered in the ways which resonate most with users and at times when they may be best placed to take action. Users could also update their preferences with time and experience to ensure continued response. For instance, as lead participant on the trial, P3 took responsibility for receiving all notifications, but soon realised that he was not always remembering to forward them on to family members. A tailored system would have allowed him to add those family members as additional recipients, thus increasing his household's ability to respond.

Similarly, users could also specify their preferences for the frequency and types of feedback sent (eg, own household performance, peer comparisons, carbon savings). This would enhance the motivational resonance of this feedback – as Lewis *et al* (2012) argue: "Feedback should furthermore be personalised…supported by tips and advice (and wherever possible also solutions), not based on kWh, available in both ambient and more direct form, and available real-time, but ultimately delivered by request, both in its timing, content, quantity and style." (p.3)

Despite the benefits, however, a tailored DSR system such as that discussed above would be significantly more costly than existing models for electricity stakeholders to implement, and would require greater time and resources to maintain. A detailed discussion of these increased transaction costs is beyond the scope of this thesis.

[112] Baltimore Gas & Electric's Smart Energy Rewards Programme offers such a differentiated notification system with participants able to choose from calls, texts and email notifications of DSR events (Greentech Media, 2017).

7.7 Conclusions

This chapter presents the findings from interviews with 24 of the 46 lead participants who participated in the information-only DSR trial. Thematic coding of the interview data yielded 12 themes which provide insight into the various enablers and constraints of response on the trial. These themes were then examined through the prism of the FBM to identify measures which could inform future DSR strategies to help to increase response.

Although these measures were derived from feedback from a relatively small sample (n=24), it is notable that other DSR studies support their value in facilitating response. Table 22 summarises the main findings from the interviews, together with references to supporting literature and implications for future DSR strategies.

Meanwhile, analysis of the interview data also made it possible to refine and develop the FBM as a framework for exploring the factors that influence response on DSR programmes. Additional ability elements – immediate need, third-party control and occupancy – were identified which impacted participants' ability to respond (Figure 27). The analysis also highlighted that in some cases participants were unwilling to use their appliances to respond because a specific 'counter-motivation' – the desire to conserve energy – trumped their desire to respond. Counter-motivations were thus included alongside the new ability elements in the revised FBM, depicted in Figure 28.

The following chapter draws on the findings from the research to present the main conclusions of this thesis, discusses the contribution made to knowledge in the field and provides several suggestions for further research which would build on the work presented.

Table 22. Summary of main interview findings

Interview findings	Relationship to FBM	Implications for DSR strategies	Supporting literature
Participants often had a limited understanding of how much electricity household appliances consume	Ability: brain cycles	Promote DSR know-how	Attari *et al*, 2010; Chen *et al*, 2014; Kim and Shcherbakova 2011; Lyndhurst, 2007; Neuberg, 2013; Stromback *et al*, 2011
Household routines can prevent response	Ability: non-routine	Promote DSR know-how so participants learn different ways of carrying out practices and lower energy options	Mourik and Breukers, 2013; Neuberg, 2013; Nicholls and Strengers, 2015; Pollitt and Shaorshadze 2011
Personalised messages about consumption and appliances were preferred	Ability: brain cycles	Use a tailored approach to provide personalised messages and information	The Behavioural Insights Team, 2014; Kjeldskov *et al*, 2012; Lewis *et al*, 2012
Immediate need for appliances can prevent response	Ability: non-negotiable need	Promote DSR know-how so participants learn different ways of doing things and lower energy options	Bourgeois *et al*, 2014; Buchanan *et al*, 2016; Parrish *et al*, 2015; Mourik and Breukers 2013
Participants were interested in learning about alternative ways of doing things from their peers	Ability: brain cycles	Facilitate conditions for participants to share DSR know-how	Catney *et al*, 2013, Hitchings and Day, 2011; Simcock *et al*, 2014
Participants lacked specific knowledge – such as how to set timers on appliances – that would have facilitated response	Ability: brain cycles	Promote DSR know-how so participants understand alternative or less energy-intensive ways of doing things	Neuberg, 2013; Simcock *et al*, 2014
Active occupancy was usually required for participants to respond	Ability: occupancy	Regulate to increase the penetration of smart appliances in consumer households	Abi Ghanem, 2014; Neuberg, 2013; Thorsnes *et al*, 2012; Torriti, 2013
Participants were interested in receiving information about the environmental benefits of their response	Motivation: hope/fear	Provide this type of feedback or, where a tailored approach is used, provide it as one of the options	Fischer *et al*, 2013; Gyamfi and Krumdieck 2011; Ofgem, 2010 Shuling Chen Lillemo, 2014
Peer comparisons can be an effective way to increase response	Motivation: pleasure/pain	Provide this type of feedback or, where a tailored approach is used, provide it as one of the options	Allcott, 2011; Arvola, 1993; Dolan and Metcalf, 2015; Steg, 2008
Willingness to use certain appliances to respond can be reduced by noise considerations	Motivation: social acceptance/rejection	More stringent appliance regulations governing appliance sound levels	Butler *et al*, 2013; Mert *et al,* 2008; Ofgem, 2010
Offering consumers financial incentives to participate in DSR can crowd out other motivations	Motivation	Offer consumers the option of participating in information-only programmes	Curtius et al, 2012; The Behavioural Insights Team, 2014; Gneezy et al, 2011
Providing multi-modal notifications facilitated response	Trigger	Use multi-modal notification to inform participants about DSR	Strengers, 2010; Stromback *et al*, 2011
Providing notifications at appropriate times can facilitate response	Trigger	Use a tailored approach which allows users to choose when they receive notifications	The Behavioural Insights Team, 2014; Fogg, 2009
In-home displays using a 'traffic light system' which is linked to the timing of DSR events may facilitate response	Trigger	Provide consumers on dynamic DSR programmes with in-home displays which indicate the timing of events using a traffic light system	Carmichael, 2014; Martinez and Geltz, 2005; Ofgem, 2010

8. Conclusions

8.1 Introduction

This chapter presents the main conclusions of this thesis and its contribution to knowledge. The research aimed to identify how to optimise the impact of residential DSR in the UK by examining two central questions:

- What measures could electricity stakeholders implement to maximise uptake of residential DSR programmes?
- What measures could electricity stakeholders implement to maximise response on such programmes?

This chapter draws on the findings from the switching survey, the dynamic information-only DSR trial and the interviews with trial participants to answer these questions.

Section 8.2 summarises the main findings of the research relating to uptake and response. Section 8.3 explains how this thesis proposes a robust theoretical framework for understanding DSR behaviours and has further contributed to the knowledge on residential DSR. Section 8.4 outlines practical recommendations for increasing uptake and response. Section 8.5 concludes by highlighting some limitations of the research and provides suggestions for further study to build on the work presented.

8.2 Summary of research

8.2.1 Switching survey and dynamic information-only trial

This thesis aimed to explore how to optimise the impact of residential DSR in the UK. As a starting point, a representative sample of UK consumers was surveyed to examine preferences for three different DSR programme models which are well suited either to the current UK electricity system or to conditions which are likely to prevail as renewables become an increasingly important part of the UK energy mix:

- a static ToU tariff that could help to reduce peak demand; and
- two dynamic programmes that could help to balance fluctuating supply and demand in a renewables-rich electricity system:
    - a dynamic ToU tariff; and
    - a dynamic information-only programme.

Detailed analysis of the survey data revealed that around 23% of respondents would be willing to switch to the static ToU tariff, 9% would be willing to switch to the dynamic ToU tariff and 8% would be willing to switch to the dynamic information-only programme.[113]

While UK consumer response to static and dynamic ToU tariffs has been examined in two previous large-scale projects,[114] no studies have hitherto explored whether UK consumers would successfully modify their consumption patterns in line with available renewable generation in the absence of a financial incentive. As 20% of all survey respondents who indicated WTS to one of the three DSR programme models presented in the survey indicated a preference for the dynamic information-only model, a four-month trial was conducted in Summer 2015 to test how consumers might respond on such a programme in practice. Over the course of the trial, participants were sent 40 event notifications based on available generation from UK wind farms, asking them to adjust their consumption accordingly for specified periods.

Detailed analysis of the electricity consumption data from participating households and qualitative data from post-trial interviews revealed that approximately 75% of trial households successfully changed their consumption patterns during the trial. On average, they used 9.9% less electricity during 'turn-down events' (which asked them to reduce consumption) and 4.4% more electricity during 'turn-up events' (which asked them to increase consumption).

The finding that most of these households proved willing and able to vary their consumption based on available wind generation in the absence of a financial incentive is especially significant when considered in the context of the UK electricity system. Generation capacity from wind is growing year on year (DUKES, 2015; DUKES, 2016; DUKES, 2017), and the falling cost of offshore wind generation means that this trend is only likely to accelerate (Carbon Brief, 2017a). As more wind power comes online, the potential savings to be made from

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[113] These are the percentages post-certainty correction (see Chapter 4 and Chapter 5).
[114] The CLNR ToU trial (Bulkeley *et al*, 2015) and the LCL dynamic ToU trial (Carmichael *et al*, 2015), both of which were supported by the Low Carbon Networks Fund.

dynamic DSR are likely to increase substantially (Hesmondhalgh, 2014). The promising findings from the dynamic information-only trial suggest that such programmes could represent a valuable resource for electricity stakeholders seeking to balance supply and demand as renewables are increasingly integrated into the energy mix.[115]

8.3 Contribution to knowledge

This thesis makes a threefold contribution to knowledge, as follows:

- It contributes to the FBM by refining and developing the model as a framework for understanding DSR behaviours.
- It contributes to the DSR literature by estimating the size of the resource represented by dynamic information-only residential DSR, examining the environmental and pro-social considerations that motivate participation in such programmes and testing potential response on such programmes.
- It applies a novel methodological approach for validating the results of statistical models that are produced using stated preference data.

8.3.1 Developing the FBM as a framework to understand DSR behaviours

In applying the FBM to examine the factors that influence WTS and response – the key DSR behaviours studied in this thesis – two new conceptual elements were added to the model: perceived ability to respond[116] and counter-motivations.

Perceived ability to respond encompasses three factors – perceived consumption knowledge, perceived ease of rescheduling energy-intensive appliance use and perceived ability to use electric heating systems to respond – which were all found to increase WTS. This finding not only develops the FBM as a framework for understanding switching behaviour, but also has practical implications, since it highlights the role that certain measures which should help to increase ability to respond (and thus, as an anticipated corollary, perceived ability) could play in maximising programme uptake. Two such measures are outlined in Sections 8.4.2(a) and 8.4.3(a).

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[115] Potential applications of dynamic information-only DSR are not limited to wind generation, but could also be designed to help to integrate other renewable sources, such as solar.
[116] By its nature, perceived ability to respond is relevant only in regard to WTS, not in relation to response.

The FBM was further developed as a framework for exploring WTS and response by incorporating the conceptual element of counter-motivations. According to the FBM, as motivation and ability increase, a behaviour becomes more likely. However, the empirical data collected for this thesis revealed that certain counter-motivations can serve to reduce WTS, while others can prevent response. For example, safety concerns relating to the unattended use of appliances and a desire to maximise benefits from existing solar installations can reduce WTS; while an overarching desire to reduce energy consumption[117] can reduce response.

Here again, this theoretical insight has practical implications. Fogg (2009a) contends that "the goal in designing for motivation is, conceptually, to move a user to a higher position in the FBM landscape. In other words… to have motivation increased so they cross the behavior activation threshold" (p.4). However, the inclusion of counter-motivations in the model highlights that when devising strategies to increase WTS or response, it is also essential to consider how the influence of these countervailing factors can be mitigated.

The research further develops the FBM as a framework for understanding response by refining Fogg's 'ability' elements, which influence performance of a target behaviour, and incorporating three additional elements – third-party control, active occupancy and immediate need – identified in the post-trial interviews which served as further constraints to response. The inclusion of these factors in the FBM, alongside the additional concept of counter-motivations, has produced a more robust framework that better reflects the diverse range of factors that influence DSR behaviours.

8.3.2 The value of dynamic information-only DSR programmes

This thesis also makes a significant contribution to the DSR literature on information-only DSR (Gyamfi and Krumdieck, 2011; Gyamfi *et al*, 2013; Thorsnes *et al*, 2012; Onzo, 2011; Strengers, 2010). It is the first study to estimate the size of the potential resource represented by dynamic information-only residential DSR in the UK and to examine the environmental and pro-social considerations that motivate participation in these programmes. To the author's knowledge, the dynamic information-only DSR trial is also the first to examine how UK

[117] The motivations to use less electricity and to use less energy overall (ie, including both electricity and gas) were both found to conflict with response on the DSR trial.

consumers might respond in practice to requests to vary their electricity consumption depending on available wind generation.

The findings of this thesis challenge the prevailing assumption – both in much of the DSR literature and in the industry's current approach to residential DSR – "that there is no better signal than price" (Gyamfi *et al*, 2013, p.76). Instead, the results show that while many consumers who are interested in DSR might favour price-based programmes, a significant proportion would prefer to participate on an information-only basis. In this regard, the research revealed that 8% of UK consumers[118] would favour information-only models which allowed them to contribute towards the environmental and pro-social goals of DSR without exposing them to the financial risks inherent in price-based programmes. Programmes which take advantage of this resource could thus play an important role in optimising the impact of residential DSR in the UK electricity system.

8.3.3 Validation of statistical models produced using stated preference data

A final contribution of this work is in its application of a novel methodological approach for validating the results of statistical models produced using stated preference data. Although certainty correction has previously been applied to address hypothetical bias, its application in the analysis of the switching survey data was novel and could have equal utility in other domains beyond DSR. While previous research has used certainty correction techniques in contingent valuation studies to refine estimates of willingness to pay (Champ *et al*, 2009; Fifer, 2011), in this thesis certainty corrected data was also used to estimate an additional statistical model to cross-validate the results from the initial model produced using uncorrected data. This represents a promising methodological approach for generating further insights when using statistical methods to analyse data from stated choice experiments.

[118] 20% of all consumers who chose to switch to one or other of the DSR programmes in the switching survey.

8.4 Practical recommendations to maximise uptake and response

8.4.1 Maximising uptake

(a) Promote awareness of the non-financial benefits of DSR

Respondents who were more environmentally motivated – as measured using the "Commitment to environmental sustainability" measure – had greater WTS to all three DSR programme models presented in the switching survey. This confirms that, as other commentators have suggested (Buryk *et al*, 2015; Darby and Pisica, 2013; Faruqui *et al*, 2010b), uptake of DSR programmes could be increased by highlighting the environmental benefits of DSR to the wider public.

The research also revealed that other pro-social considerations may additionally influence WTS. More than half of the respondents who indicated WTS to one of the three DSR programme models presented in the survey stated that the fact that DSR would help to improve the efficiency of the electricity system, promote the integration of renewables into the energy mix and prevent power cuts was either "Very important" or "Extremely important" in their decision to switch. This suggests that highlighting these potential electricity system benefits alongside the environmental benefits of DSR should further help to maximise uptake.

However, as discussed in Chapter 2, the way in which such information is disseminated may significantly affect its impact, given the prevailing scepticism towards suppliers revealed in previous studies (Accenture, 2011; Fell, 2015b). As such, careful consideration should be given to which organisations are best placed to provide this information. Ofgem and Smart Energy GB would both appear viable candidates to spearhead national campaigns: as non-commercial organisations, they are more likely to engender trust in consumers and could thus play a vital role in securing public buy-in by communicating the non-financial benefits of residential DSR. At a local level, suppliers might benefit from working with 'trusted third-party intermediaries' to convey such information, as Owen *et al* (2013) suggest:

> Working with trusted third party intermediaries, such as Citizens Advice and the Money Advice Service, local councils and social housing providers, is one way in which suppliers can get their messages more effectively across... These sorts of organisation are often adept at using local champions to promote behaviour change and facilitating peer to peer networks to provide advice and support. (p.56).

(b) Offer information-only DSR programmes

To date, financial incentives have been the primary drivers used to prompt consumers to switch to DSR programmes and to respond once enrolled. However, the sizeable dynamic information-only DSR resource revealed through the switching survey, together with the promising response recorded from trial participants, suggests that providing consumers with opportunities to participate on an information-only basis would help to optimise the impact of residential DSR. Indeed, the research shows that if price-based programmes are the only model available, this could marginalise many consumers who would be prepared to engage in DSR, but not on specifically financial terms.

At the same time, the fact that their experiences on the trial made many interviewees more accepting of DSR suggests that information-only programmes could serve as a potent catalyst in the transition towards dynamic pricing. While Darby and McKenna suggest that static ToU tariffs could function as "a staging post on the road to RTP [real time pricing]" (2012, p.767), dynamic information-only programmes would arguably prove even more effective in this regard. Consumers would have the opportunity to test out different ways of responding to fluctuations in supply which more closely resemble the anticipated conditions of a renewables-rich future electricity system, without any attendant financial pressures or risks. As McKenna *et al* (2016) observe:

> It is reasonable to expect demand response to change over time – in scale, type and duration – as they [consumers] grow accustomed to the concept, the tariffs and the activities involved and as the technologies involved change and develop. Hence the importance attached to customer education and experimentation in demand response programmes. (p.8)

The interview data further suggests that were information-only DSR programmes commercially available, some consumers may be reluctant to sign up if electricity stakeholders would be the exclusive financial beneficiaries of their efforts (see Chapter 7). Thus, to maximise uptake, suppliers may need to share some of the attendant financial benefits with community organisations or charities. This approach is recommended by Work Stream Six and has already been implemented on two information-only DSR pilots: the Power Saver Challenge and the CITYOPT DSR programme (CITYOPT, 2017; Power Saver Challenge, 2015; Work Stream Six, 2014).

8.4.2 Maximising response

(a) Promote the development of DSR know-how

The interviews revealed that consumers often lack specific knowledge that would facilitate response on DSR programmes. Given that other studies have shown that DSR programmes incorporating educational measures tend to see greatest response (Stromback *et al*, 2013), this finding suggests that electricity stakeholders should take steps to help consumers develop such knowledge so that they are better positioned to respond.

Referred to in this thesis as 'DSR know-how', this encompasses:

- appliance consumption knowledge – an understanding of how much electricity different appliances consume;
- appliance know-how – an understanding of the features of specific appliances and how they operate; and
- practice know-how – an understanding of how different household practices can be modified in order to respond.

In this regard, helping consumers to develop appliance consumption knowledge may prove especially advantageous. While the switching survey showed that respondents with greater perceived appliance consumption knowledge had greater WTS to the static ToU tariff and the dynamic information-only tariff, the survey, trial enrolment questionnaire and subsequent interviews revealed that many UK consumers in fact have a poor understanding of the relative consumption of different appliances. Together, these findings make a compelling case for advancing appliance consumption knowledge among the UK public, given that this should both increase WTS to DSR programmes and promote greater response once enrolled.

Once again, however, careful consideration should be given to how DSR know-how would best be cultivated. Given the traditionally low success rate of mass information campaigns (Simcock *et al*, 2013; Catney *et al*, 2013), alternative channels for promoting this knowledge may prove more effective. One potential method highlighted by this research would be to establish forums which allow consumers to develop this know-how organically by exchanging experiences, tips and suggestions – as several participants on the DSR trial spontaneously chose to do.[119]

(b) Provide multi-modal event notifications on dynamic DSR programmes

Previous studies of dynamic DSR programmes have found that response is normally greater when participants are provided with event notifications through more than one communication channel (Stromback *et al*, 2011). The interview data suggests that this is because participants are more likely both to receive notifications when they are delivered through more than one medium and to receive them at a time when they well placed to register the details of events. These findings confirm the importance of using multiple channels – such as text messages, email and in-home displays – to notify consumers on dynamic DSR programmes of events.

(c) Provide tailored DSR programmes

The interviews highlighted the important role that tailoring could play in personalising the DSR experience to the needs, preferences and circumstances of individual households (see Chapter 7). Ultimately, this approach could not only help to promote sustained response, but also potentially capture a wider user base than has hitherto been possible.

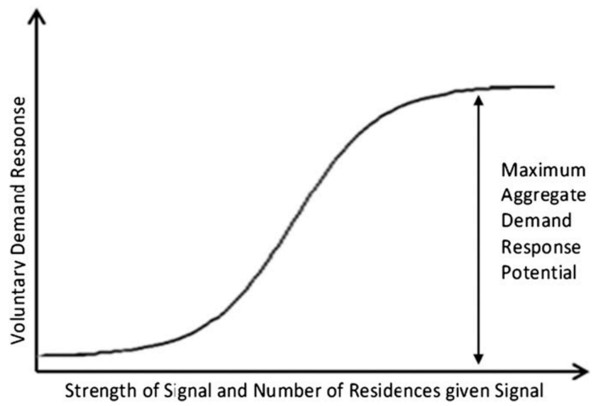
For example, both the DSR literature and the interview data indicate that, while they may be sympathetic to its goals, families tend to struggle with the demands of DSR in practice. However, Nicholls and Strengers (2014) have also observed that family households which may be reluctant to adapt their routines to the vicissitudes of DSR may be more amenable to infrequent 'peak alerts' inviting them to "'do their bit' for the ongoing security and affordable supply of electricity for all" (see Chapter 2). This suggests that an interactive programme that provided a unique experience for each household could potentially harness the resource represented by this elusive cohort by allowing them to set the parameters of their engagement on viable terms.

The "advanced signal design and multi-mode signalling" proposed by Gyamfi and Krumdieck (2011) to facilitate "effective, time critical demand response" (p.2995) illustrates how this

[119] Simcock *et al* (2013) also argue that to encourage learning it is valuable to support strategies that encourage and create opportunities for the exchange of 'informal' knowledge between peers.

additional resource could be integrated into the DSR matrix. Under this model, smart meter signals based on “cost (increased price), environment (increased CO_2 foot-print) [or] security (risk of blackout)” (ibid) would be deployed to an increasing number of households, with the strength of the signal increasing concomitantly, until the requisite response was achieved (see Figure 30).

Figure 30. Aggregate DSR based on signal and signal strength (Source: Gyamfi and Krumdieck, 2011)



In a similar way, a tailored DSR system such as that proposed in Chapter 7 could build profiles of individual households based on their circumstances, inputs, preferences and other interactions, and stratify them according to likelihood of response. Targeted notifications could then be scheduled and released to each stratum in waves, depending on the urgency of the event, with the frequency, content and message tailored accordingly. Those users who were most engaged in the programme would represent the first wave of response and would be notified of events most frequently; at the other end of the spectrum, those least engaged would be called on to act only in the most urgent cases, where an excessive or unpredicted change in generation or demand required the greatest possible response.

By giving them “room to act on voluntary bases, based on their capacity to respond” (Gyamfi *et al*, 2013, p.76), households could thus participate flexibly on terms which are compatible with their circumstances, needs and expectations. In this way, a tailored system would circumvent the restrictions of existing one-size-fits-all programmes and could thus expand the resource represented by residential DSR.

8.4.3 Maximising both uptake and response

(a) Promote penetration of smart appliances

The switching survey revealed that respondents who had greater perceived ability to reschedule the use of common energy-intensive appliances[120] had greater WTS to both DSR tariffs. This suggests, as argued in Chapter 7, that measures which make it easier to reschedule appliance use could increase WTS – at least to price-based DSR programmes. Meanwhile, the trial interviews revealed that the most common constraint that participants experienced in responding was a lack of 'active occupancy' – that is, response was not possible when they were either not at home or asleep. This likewise suggests that measures which make it easier to operate appliances remotely or which facilitate autonomous operation could help to facilitate response.

These findings highlight the role that increased market penetration of smart appliances could play in maximising both uptake and response on DSR programmes. In this regard, the proposals in Ofgem's Smart Systems and Flexibility Plan (2017) to establish new standards for smart appliances in partnership with industry – which would "allow consumers to provide flexibility and benefit from DSR, whilst ensuring cyber security and avoiding proprietary standards which could limit interoperability and consumer choice" – are particularly welcome, as these should help to promote the advancement and adoption of this burgeoning technology.

There is also a case to be made for including immersion heaters in these new standards: although these are not mentioned in the Smart Systems and Flexibility Plan, the interview data complements evidence from previous DSR research (Deasley *et al*, 2014) in suggesting that more flexible use of such appliances could play a significant role in facilitating response.

(b) Target higher-income households

The switching survey revealed that higher-income households had greater WTS to both the dynamic DSR tariff and the dynamic information-only programme. As such, suppliers could increase the number of households that switch through targeted marketing directed towards such households. This could represent a double win for suppliers, as such households also tend to be more responsive overall than lower-income households once enrolled, shifting more electrical

[120] That is, washing machines, tumble dryers, dishwashers, immersions, irons and vacuum cleaners.

load from peak to off-peak periods (Bulkeley *et al*, 2015; CER, 2011; Harding and Lamarche, 2016).

(c) Target consumers with electric central heating

The results of the switching survey further suggest that uptake could be increased through targeted marketing directed towards households with electric central heating systems (excluding storage heating), as these households had greater WTS to both the static ToU tariff and the dynamic information-only programme. Once again, therefore, targeted marketing could provide benefits in terms of both switching and response, given that such households would be more likely to switch to these programme models in the survey and may also be able to respond by rescheduling use of their heating systems (Mountain and Lawson, 1995).

However, as noted in Chapter 5, although consumers with electric central heating may have greater WTS to certain DSR programmes, the use of these systems to respond will be contingent on whether these households have sufficient thermal inertia. In this regard, as Deasley *et al* (2014) observe, building insulation "is another important factor in determining the practicality and customer acceptability of demand side response capability." (p.89) Therefore, measures to improve the thermal efficiency of residential buildings may additionally be needed to realise the full potential of the DSR resource represented by such households.

8.5 Limitations and future research

This section highlights certain limitations of the research for this thesis and identifies some promising avenues for future research which should help to overcome them, while at the same time extending the work presented in this thesis.

8.5.1 Switching survey

Approximately 40% of respondents indicated WTS to one of the three DSR programme models presented in the switching survey.[121] However, the hypothetical nature of the stated choice experiment means that although certainty correction was used to produce more realistic switching estimates, these may not necessarily reflect the number of consumers that ultimately

[121] According to the more conservative estimates produced after the switching data was subjected to the certainty correction.

switch. As new programmes are rolled out, this will present an opportunity to build on the research presented in this thesis by exploring real-world preferences for different models – in terms of both their relative popularity and the factors that might influence switching to each. This would produce a more accurate estimate of predicted uptake for the different programme models and could also yield additional insights regarding consumer and household characteristics which influence WTS.

8.5.2 Dynamic information-only trial

Further limitations of this research relate to the short duration of the dynamic information-only trial, which took place over four months, and the small convenience sample (N=46) which self-selected to participate. This raises three important questions:

- Would the results scale up if the same trial were implemented with a larger number of consumers?
- Would response increase or decrease over time if the trial continued over a longer timeframe?
- Since the households that participated were recruited through channels that may have predisposed them to have a greater than average interest in energy issues, could response be matched in a commercial application of the programme?[122]

These questions highlight the risks in presuming that the trial results could be replicated if the model were rolled out on a commercial basis. Once again, this suggests avenues for further research: the results could be supported by repeating the trial for a longer duration with a larger sample of consumers recruited as they would be in a real-world setting – that is, through a supplier or other electricity stakeholder (as was initially intended for this thesis). At the same time, this approach might also allow households with smart meters to be recruited, to explore how these might affect response (eg, whether linking event notifications to in-home displays led to greater response).

A second point relates to the accuracy of event notifications. Although approximately 75% of trial households responded by making consumption changes in response to day-ahead event notifications, supplemented by reminders one hour in advance of each event, this model may have adverse consequences in cases where forecasts change unexpectedly in the meantime:

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[122] Ham *et al* (1997) and Aubin *et al* (1995) discuss the bias which can be induced by voluntary participation in programmes and the importance of accounting for selection when using experimental data.

participants could end up responding in a manner which does not reflect actual generation during events.[123] This has led scholars to suggest that participants in dynamic DSR programmes based on renewable generation might also need to be sent event updates to ensure that response is aligned with actual rather than predicted supply conditions (Peacock and Owens, 2013). Future research would thus be valuable to examine whether consumers on dynamic information-only programmes can successfully act on such updates, to prevent any "negative economic and environmental outcomes" (ibid, p.10) from inadvertent response to outdated information.

Although the event notifications on the trial were based on predicted output from UK wind farms, there may also be scope for using other system conditions – such as periods of supply instability or the carbon intensity of generation – as an alternative basis for seeking response on information-only DSR programmes (Gyamfi *et al*, 2013). Future research could thus explore how consumers respond to such alternative bases, facilitating a more nuanced understanding of which particular pro-social aims – for example, preventing power cuts, responding to generation levels from renewables or responding to the carbon intensity of generation – are most effective in facilitating response.

Finally, further research into the different ways in which response triggers can be delivered would be valuable, to identify those which resonate best with consumers. For example, several trial interviewees saw potential in a colour-coded traffic light system which could complement the event notifications by serving as an immediate signal trigger – a proposal which supports the findings from the LCL dynamic ToU trial that such a system could increase ability to respond. Some interviewees also expressed unease at the wording of turn-up event notifications, suggesting that requests to use more electricity seemed antithetical to environmental principles; there may thus be value in investigating how turn-up messages could be best framed to address this disconnect, and how a greater understanding of the functions and goals of residential DSR could be promoted. Ultimately, as the UK transitions to a renewables-rich energy system, realising the full potential afforded by residential DSR may require a sea change in consumer perceptions, with the 'accepted' rules of energy use supplanted by a new conception of energy as a mutable resource which ebbs and flows, and which must be harnessed and used accordingly.

[123] Errors for single wind farms reportedly range from 6.9% (normalised mean absolute percentage error) for a one-hour-ahead forecast to 23.7 % for a 24-hour-ahead forecast (De Giorgi *et al*, 2011).

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Appendix I – Methodology for literature identification

Most of the literature for this review was identified through online searches carried out using Scopus – the world's largest database of peer-reviewed literature, which includes scientific journals, books and conference papers. The following search terms were used to identify relevant literature on consumer preferences for DSR programmes and studies on WTS:

- "Demand side response";
- "Demand response";
- "Residential demand side response"; and
- "Switching electricity tariff"

The following search terms were used to identify relevant literature on response:

- "Feedback";
- "Load shifting";
- "In-home displays";
- "Demand response"; and
- "Demand side response".

To complement the literature and ensure that policy-oriented papers and reports were also captured by the review, Google searches were also carried out. The following search terms were used:

- "Demand response";
- "Demand side response"; and
- "Preferences for demand side response".

Citation snowballing was also used to identify additional literature as well as 'backward snowballing', whereby the reference lists of journal articles are used to identify additional material (Wohlin, 2014).

Appendix II – Switching survey

Household electricity survey

This survey is about your electricity use and tariff preferences. It aims to find out about the electrical appliances in your home, how these are used and your thoughts on new electricity tariffs that might be available in the future.

The survey – which is completely anonymous – will be used in a University of Sussex study on household energy use. By completing it, you are consenting for the University of Sussex to use the fully anonymised results in data analysis, publications and other research output.

Please note that if you complete this survey using a PC or Mac, definitions of certain terms can be seen if you hover your cursor over them (these are highlighted in blue). Many thanks for taking the time to complete this survey.

1. Do you decide which electricity supplier/tariff your household uses?

- ○ Yes
- ○ Yes, together with someone else
- ○ No

2. What is your gender?

- ○ Male
- ○ Female

3. How old are you?

- ○ 18-24
- ○ 25-34
- ○ 35-44
- ○ 45-54
- ○ 55-64
- ○ 65+

4. In which country do you live?

- ○ England
- ○ Scotland
- ○ Wales
- ○ Northern Ireland

5. Does your household own or rent?

- ○ Owns outright
- ○ Owns with a mortgage or a loan
- ○ Part owns and part rents (shared ownership)
- ○ Rents (with or without housing benefit)
- ○ Lives rent free

6. Please estimate your household's total income from all sources over the last 12 months.

Count income from every person included in the household. Include: all earnings (include overtime, tips, bonuses, self-employment); all pensions; all student grants and bursaries (but not loans); all benefits and tax credits (such as child benefit, income support or pension credit); all interest from savings or investments; all rent from property; other income (such as maintenance or grants). Do not deduct: taxes, national insurance contributions, health insurance payments, pension payments.

Per week/per year

- ○ Less than £100/Less than £5,200
- ○ £100 to £199/£5,200 to £10,399
- ○ £200 to £299/£10,400 to £15,599
- ○ £300 to £399/£15,600 to £20,799
- ○ £400 to £499/£20,800 to £25,999
- ○ £500 to £599/£26,000 to £31,199
- ○ £600 to £699/£31,200 to £36,399
- ○ £700 to £799/£36,400 to £41,599
- ○ £800 to £899/£41,600 to £46,799
- ○ £900 to £999/£46,800 to £51,999
- ○ £1,000 to £1,499/£52,000 to £77,999
- ○ £1,500 to £1,999/£78,000 to £103,999
- ○ £2,000+/£104,000+
- ○ Don’t know/prefer not to say

7. How many people normally live in your household?

- ○ 1
- ○ 2
- ○ 3
- ○ 4
- ○ 5
- ○ 6
- ○ 7
- ○ 8+

8. How many children aged between 0 and 5 years old normally live in your household?

- ○ None
- ○ 1
- ○ 2
- ○ 3
- ○ 4
- ○ 5+

9. How many children aged between 6 and 14 years old normally live in your household?

- ○ None
- ○ 1
- ○ 2
- ○ 3
- ○ 4
- ○ 5+

10. Do you have an Economy 7 or Economy 10 electricity tariff (which provides lower-priced off-peak electricity at certain times)?

- ○ Yes
- ○ No
- ○ Don’t know

11. Some electricity customers are on variable electricity tariffs, where their suppliers can change the price they pay per unit at any time. Other customers are on fixed-price tariffs, which guarantee that the price per unit will stay the same until a certain date in the future. Is your household on a fixed tariff?

○ Yes

○ No

○ Don't know

12. How do you heat your home? Please select all that apply.

☐ Gas

☐ Plug-in electric heaters

☐ Electric central heating (not storage heaters)

☐ Storage heaters

☐ Oil

☐ Solid fuel (eg, wood, coal)

☐ Other (Please specify) ______________________

13. How much is your average combined electricity and gas bill per month? (If you pay your bills quarterly or on a meter, please think about how much this would cost per month.)

○ Less than £25

○ £25-£49

○ £50-£74

○ £75-£99

○ £100-£124

○ £125-£149

○ £150+

○ Don't know, because my electricity and gas are included in my rent

○ Don't know

14. How much is your average electricity bill per month? (If you pay your bills quarterly or on a meter, please think about how much this would cost per month.)

- ○ Less than £25
- ○ £25-£49
- ○ £50-£74
- ○ £75-£99
- ○ £100-£124
- ○ £125-£149
- ○ £150+
- ○ Don’t know, because my electricity is included in my rent
- ○ Don’t know how much my electricity bill is, because I pay for my electricity and gas together
- ○ Don’t know

15. How knowledgeable do you think you are about the amount of electricity used by different appliances in your home?

- ○ Not at all
- ○ Slightly
- ○ Moderately
- ○ Very
- ○ Extremely

16. Please rank the following activities to show which you think use the most electricity and which use the least.

	Uses the most electricity	Uses the 2nd most electricity	Uses the 3rd most electricity	Uses the 4th most electricity	Uses the 5th most electricity	Uses the least electricity
Fully charging a laptop	○	○	○	○	○	○
Ironing for 20 minutes (average temperature)	○	○	○	○	○	○
Washing one load of dishes in a dishwasher (at 65 degrees)	○	○	○	○	○	○
Drying clothes in a tumble dryer for 60 minutes (on the high temperature setting)	○	○	○	○	○	○
Fully charging a smartphone	○	○	○	○	○	○
Doing one load of washing in a washing machine (at 40 degrees)	○	○	○	○	○	○

17. Which of the following appliances do you have in your home?

Combined washer dryer	○
Washing machine	○
Tumble dryer	○
Dishwasher	○
Electric water heater/immersion	○
Iron	○
Vacuum cleaner	○

18. How often is the electric water heater or immersion in your household used?

○ Never

○ Occasionally

○ Often

19. Please consider for a moment the times when the appliances below are normally used in your household. Please indicate how easy/difficult it would be in your household to change the times at which these appliances are used (for example, if using them at certain times was better for the environment or would make your electricity bills cheaper).

	Very difficult	Difficult	Neither easy nor difficult	Easy	Very easy
Combined washer dryer	○	○	○	○	○
Washing machine	○	○	○	○	○
Tumble dryer	○	○	○	○	○
Dishwasher	○	○	○	○	○
Vacuum cleaner	○	○	○	○	○
Iron	○	○	○	○	○
Electric water heater or immersion	○	○	○	○	○

20. Which of the appliances in your household listed below have timers which can be used to set a time in the future to start the appliance?

	Yes	No	Don't know
Washer dryer	○	○	○
Washing machine	○	○	○
Tumble dryer	○	○	○
Dishwasher	○	○	○
Electric water heater/immersion	○	○	○

21. Does anyone in your household know how to set the timers on the appliances below?

	Yes	No	Don't know
Washer dryer	○	○	○
Washing machine	○	○	○
Tumble dryer	○	○	○
Dishwasher	○	○	○
Electric water heater or immersion	○	○	○

22. Would it be acceptable to use your washing machine when everyone in your household was asleep?

○ Yes

○ No (please say why) ______________________

23. Would it be acceptable to use your washing machine when no one was at home?

- ○ Yes
- ○ No (please say why) ______________________

24. Would it be acceptable to use your tumble dryer when everyone in your household was asleep?

- ○ Yes
- ○ No (please say why) ______________________

25. Would it be acceptable to use your tumble dryer when no one was at home?

- ○ Yes
- ○ No (please say why) ______________________

26. Would it be acceptable to use your washer dryer when everyone in your household was asleep?

- ○ Yes
- ○ No (please say why) ______________________

27. Would it be acceptable to use your washer dryer when no one was at home?

- ○ Yes
- ○ No (please say why) ______________________

28. Would it be acceptable to use your dishwasher when everyone in your household was asleep?

- ○ Yes
- ○ No (please say why) ______________________

29. Would it be acceptable to use your dishwasher when no one was at home?

- ○ Yes
- ○ No (please say why) ______________________

30. On how many weekdays (Monday to Friday, 9:00am-5:00pm) is there someone at home who could do household tasks that require the use of electrical appliances, such as ironing, laundry, vacuuming or running the dishwasher?

- ○ None
- ○ One day
- ○ Two days
- ○ Three days
- ○ Four days
- ○ Five days

31. On how many weekdays (Monday to Friday) is there no one at home from 5:00pm-8:00pm?

- ○ None
- ○ One day
- ○ Two days
- ○ Three days
- ○ Four days
- ○ Five days

Please say to what extent you agree or disagree with the following statements.

32. It takes too much time and effort to do things that are environmentally friendly.

- ○ Disagree strongly
- ○ Disagree
- ○ Neither agree nor disagree
- ○ Agree
- ○ Agree strongly

33. The environment is a low priority for me compared with a lot of other things in my life.

- ○ Disagree strongly
- ○ Disagree
- ○ Neither agree nor disagree
- ○ Agree
- ○ Agree strongly

34. I am environmentally friendly in most things that I do.

- ○ Disagree strongly
- ○ Disagree
- ○ Neither agree nor disagree
- ○ Agree
- ○ Agree strongly

35. The need to reduce carbon emissions frequently influences what I do - for example, by choosing to drive less or to turn lights off when I can.

- ○ Disagree strongly
- ○ Disagree
- ○ Neither agree nor disagree
- ○ Agree
- ○ Agree strongly

36. Most people in the UK will have to make big changes to their way of life to help to solve climate change.

- ○ Disagree strongly
- ○ Disagree
- ○ Neither agree nor disagree
- ○ Agree
- ○ Agree strongly

37. Most people in the UK need to change their way of life so that future generations can enjoy a good quality of life and environment.

- ○ Disagree strongly
- ○ Disagree
- ○ Neither agree nor disagree
- ○ Agree
- ○ Agree strongly

38. I need to change my way of life so that future generations can enjoy a good quality of life and environment.

- ○ Disagree strongly
- ○ Disagree
- ○ Neither agree nor disagree
- ○ Agree
- ○ Agree strongly
- ○ Already changed

The following questions are about your household's electricity tariff.

39. When choosing your electricity tariff, how important is it that you get the cheapest deal available?

- ○ Not at all important
- ○ Slightly important
- ○ Moderately important
- ○ Very important
- ○ Extremely important

40. How much effort would you be willing to put into comparing electricity tariffs to get the cheapest deal?

- ○ None
- ○ A small amount
- ○ A moderate amount
- ○ A large amount
- ○ As much effort as possible

41. How worried are you about the cost of electricity rising in the future?

- ○ Not at all worried
- ○ Slightly worried
- ○ Moderately worried
- ○ Very worried
- ○ Extremely worried

Future electricity tariffs

Although the cost of producing electricity varies at different times of day, most UK households pay the same price for their electricity at all times. Some future electricity tariffs will encourage customers to use appliances which use a lot of electricity – such as washing machines, tumble dryers and dishwashers – at certain times when there is less overall demand. This will make the electricity system more efficient, help to prevent pollution, delay climate change and make power cuts less likely. Three possible future tariffs for you to consider are described on the next page.

Future electricity tariffs[124]

Daily time of use

On this tariff, your electricity would be more expensive between 7:00am and 9:00am and between 4:00pm and 8:00pm, but would be cheaper at other times, as well as all weekend. You would know the price you were paying, as this would be shown on an in-home display. By using household appliances that use a lot of electricity at the cheaper times, households would save an average of 2% per year on this tariff. Households that used lots of electricity at the expensive times would pay more than they do now.

Day-ahead alert

On this tariff, you would pay three different rates for your electricity. Most of the time, your electricity would be charged at a standard rate. However, on half the days of the year, there would be a period of between one and six hours when you would be charged at either a more expensive rate or a cheaper rate, depending on electricity demand and availability. You would be informed of these periods a day in advance by a message on an in-home display. By using household appliances that use a lot of electricity at the standard and cheaper times, households would save an average of 4% per year on this tariff. Households that used lots of electricity at the expensive times would pay more than they do now. Choosing this tariff would help the UK's share of renewable energy to grow, as customers would be encouraged to use more electricity at times when lots of renewable energy was being produced (eg, windy days).

Environmental alert

On this tariff, you would be charged the same price for a unit of electricity at all times so your electricity bill would not vary depending on when you used your appliances. However, although the price of electricity would not vary, you would still be encouraged by messages on an in-home display to use more or less electricity, depending on the level of demand and the amount of electricity being produced from renewable sources at certain times. Choosing this tariff would help the UK's share of renewable energy to grow, as customers would be encouraged to use more electricity at times when lots of renewable energy was being produced (eg, windy days).

42a. If you were offered these tariffs which would you choose? (Hover over the tariffs for a brief summary of each)

- ○ Daily time of use
- ○ Day-ahead alert
- ○ Environmental alert
- ○ Remain on your current tariff
- ○ Don't know

[124] The order in which the tariffs was presented so that approximately an equal number of respondents received each possible permutation.

Future electricity tariffs

Daily time of use

On this tariff, your electricity would be more expensive between 7:00am and 9:00am and between 4:00pm and 8:00pm, but would be cheaper at other times, as well as all weekend. You would know the price you were paying, as this would be shown on an in-home display. By using household appliances that use a lot of electricity at the cheaper times, households would save an average of 4% per year on this tariff. Households that used lots of electricity at the expensive times would pay more than they do now.

Day-ahead alert

On this tariff, you would pay three different rates for your electricity. Most of the time, your electricity would be charged at a standard rate. However, on half the days of the year, there would be a period of between one and six hours when you would be charged at either a more expensive rate or a cheaper rate, depending on electricity demand and availability. You would be informed of these periods a day in advance by a message on an in-home display. By using household appliances that use a lot of electricity at the standard and cheaper times, households would save an average of 8% per year on this tariff. Households that used lots of electricity at the expensive times would pay more than they do now. Choosing this tariff would help the UK's share of renewable energy to grow, as customers would be encouraged to use more electricity at times when lots of renewable energy was being produced (eg, windy days).

Environmental alert

On this tariff, you would be charged the same price for a unit of electricity at all times so your electricity bill would not vary depending on when you used your appliances. However, although the price of electricity would not vary, you would still be encouraged by messages on an in-home display to use more or less electricity depending on the level of demand and the amount of electricity being produced from renewable sources at certain times. Choosing this tariff would help the UK's share of renewable energy to grow, as customers would be encouraged to use more electricity at times when lots of renewable energy was being produced (eg, windy days).

42b. If you were offered these tariffs, which would you choose? (Hover over the tariffs for a brief summary of each)

- ○ Daily time of use
- ○ Day-ahead alert
- ○ Environmental alert
- ○ Remain on your current tariff
- ○ Don't know

Future electricity tariffs

Daily time of use

On this tariff, your electricity would be more expensive between 7:00am and 9:00am and between 4:00pm and 8:00pm, but would be cheaper at other times, as well as all weekend. You would know the price you were paying, as this would be shown on an in-home display. By using household appliances that use a lot of electricity at the cheaper times, households would save an average of 2% per year on this tariff. Households that used lots of electricity at the expensive times would pay more than they do now. To help you decide whether this tariff would work for your household, it would come with a price guarantee. If, after the first three months, your bill was higher than it would have been on your previous tariff, you would be refunded the difference and allowed to switch to another tariff without penalty.

Day-ahead alert

On this tariff, you would pay three different rates for your electricity. Most of the time, your electricity would be charged at a standard rate. However, on half the days of the year, there would be a period of between one and six hours when you would be charged at either a more expensive rate or a cheaper rate, depending on electricity demand and availability. You would be informed of these periods a day in advance by a message on an in-home display. By using household appliances that use a lot of electricity at the standard and cheaper times, households would save an average of 4% per year on this tariff. Households that used lots of electricity at the expensive times would pay more than they do now. Choosing this tariff would help the UK's share of renewable energy to grow, as customers would be encouraged to use more electricity at times when lots of renewable energy was being produced (eg, windy days). To help you decide whether this tariff would work for your household, it would come with a price guarantee. If, after the first three months, your bill was higher than it would have been on your previous tariff, you would be refunded the difference and allowed to switch to another tariff without penalty.

Environmental alert

On this tariff, you would be charged the same price for a unit of electricity at all times so your electricity bill would not vary depending on when you used your appliances. However, although the price of electricity would not vary, you would still be encouraged by messages on an in-home display to use more or less electricity depending on the level of demand and the amount of electricity being produced from renewable sources at certain times. Choosing this tariff would help the UK's share of renewable energy to grow, as customers would be encouraged to use more electricity at times when lots of renewable energy was being produced (eg, windy days).

42c. If you were offered these tariffs, which would you choose? (Hover over the tariffs for a brief summary of each)

- ○ Daily time of use
- ○ Day-ahead alert
- ○ Environmental alert
- ○ Remain on your current tariff
- ○ Don't know

Future electricity tariffs

Daily time of use

On this tariff, your electricity would be more expensive between 7:00am and 9:00am and between 4:00pm and 8:00pm, but would be cheaper at other times, as well as all weekend. You would know the price you were paying, as this would be shown on an in-home display. By using household appliances that use a lot of electricity at the cheaper times, households would save an average of 4% per year on this tariff. Households that used lots of electricity at the expensive times would pay more than they do now. To help you decide whether this tariff would work for your household, it would come with a price guarantee. If, after the first three months, your bill was higher than it would have been on your previous tariff, you would be refunded the difference and allowed to switch to another tariff without penalty.

Day-ahead alert

On this tariff, you would pay three different rates for your electricity. Most of the time, your electricity would be charged at a standard rate. However, on half the days of the year, there would be a period of between one and six hours when you would be charged at either a more expensive rate or a cheaper rate, depending on electricity demand and availability. You would be informed of these periods a day in advance by a message on an in-home display. By using household appliances that use a lot of electricity at the standard and cheaper times, households would save an average of 8% per year on this tariff. Households that used lots of electricity at the expensive times would pay more than they do now. Choosing this tariff would help the UK's share of renewable energy to grow, as customers would be encouraged to use more electricity at times when lots of renewable energy was being produced (eg, windy days). To help you decide whether this tariff would work for your household, it would come with a price guarantee. If, after the first three months, your bill was higher than it would have been on your previous tariff, you would be refunded the difference and allowed to switch to another tariff without penalty.

Environmental alert

On this tariff, you would be charged the same price for a unit of electricity at all times so your electricity bill would not vary depending on when you used your appliances. However, although the price of electricity would not vary, you would still be encouraged by messages on an in-home display to use more or less electricity depending on the level of demand and the amount of electricity being produced from renewable sources at certain times. Choosing this tariff would help the UK's share of renewable energy to grow, as customers would be encouraged to use more electricity at times when lots of renewable energy was being produced (eg, windy days).

42d. If you were offered these tariffs, which would you choose? (Hover over the tariffs for a brief summary of each)

- ○ daily time of use
- ○ Day-ahead alert
- ○ environmental alert
- ○ to remain on your current tariff
- ○ don't know

43. You have said that if it were available, you would switch to the X tariff. Please indicate below how sure you are that you would switch to this tariff (where 1 is "not very sure" and 10 is "very sure").

- ○ 1
- ○ 2
- ○ 3
- ○ 4
- ○ 5
- ○ 6
- ○ 7
- ○ 8
- ○ 9
- ○ 10

44. Please say how important the following factors were in your decision to switch from your current tariff to the X tariff.

	Not at all important	Slightly important	Moderately important	Very important	Extremely important
It would be better for the environment	○	○	○	○	○
It would be easy to be flexible about when appliances were used in your household	○	○	○	○	○
It would help to reduce the risk of power cuts	○	○	○	○	○
It would help you to save money	○	○	○	○	○
It would help to increase the share of renewable energy in the UK	○	○	○	○	○
It would help to make the UK electricity system more efficient	○	○	○	○	○
You would be guaranteed not to pay more than you do now for the first three months	○	○	○	○	○
You would pay the same price for a unit of electricity at all times	○	○	○	○	○
You would be able to switch to another tariff without paying a penalty for the first three months	○	○	○	○	○

45. What was the most important reason why you chose the X tariff? (Your answer could be one of the reasons above or something else which has not been mentioned)

46. If the tariff you chose became available, how would you like to hear about it? (Please select as many of the following options as you want)

- ☐ Email from supplier
- ☐ Letter from supplier
- ☐ Text (SMS) from supplier
- ☐ Electricity supplier's website
- ☐ On the internet when checking or paying an energy bill
- ☐ On a price comparison website
- ☐ Through the media

47. You have said that you would not be interested in, or are unsure about, switching to any of the future tariffs. Please say how important the following factors were in your decision.

	Not at all important	Slightly important	Moderately important	Very important	Extremely important
I don't have many appliances with timers	○	○	○	○	○
I would not have been able to save enough money to make it worthwhile	○	○	○	○	○
Changing the times when household appliances are used would have been inconvenient	○	○	○	○	○
Using appliances during the night or when no one was at home might not have been safe	○	○	○	○	○
Using appliances at certain times would have been too noisy	○	○	○	○	○
I might have ended up paying more on the tariff	○	○	○	○	○
It would have been too much hassle to switch tariffs	○	○	○	○	○
I do not trust energy suppliers	○	○	○	○	○
I am content with the tariff that I am on	○	○	○	○	○

48. What was the most important reason why you chose not to switch to one of the tariffs? (Your answer could be one of the reasons above or something else which has not been mentioned)

49. Which of the following best describes your ethnic group?

○ White

○ Mixed / multiple ethnic groups

○ Asian/Asian British

○ Black/African/Caribbean/Black British

○ Other ethnic group

50. Please tick every box that applies if you have any of the qualifications listed. If your UK qualification is not listed, tick the box that contains the nearest qualification. If you have qualifications gained outside the UK, tick the 'Foreign qualifications' box and the nearest UK equivalents (if known).

☐ 1-4 O levels/CSEs/GCSEs (any grades). Entry Level, Foundation Diploma

☐ NVQ Level 1, Foundation GNVQ, Basic Skills

☐ 5+ O levels (passes)/CSEs (grade 1)/GCSEs (grades A*-C), School Certificate, 1 A level/2-3 AS levels/VCEs, Higher Diploma

☐ NVQ Level 2, Intermediate GNVQ, City and Guilds Craft, BTEC First/General Diploma, RSA Diploma

☐ Apprenticeship

☐ 2+ A levels/VCEs, 4+ AS levels, Higher School Certificate, Progression/Advanced Diploma

☐ NVQ Level 3, Advanced GNVQ, City & Guilds Advanced Craft, ONC, OND, BTEC National, RSA Advanced Diploma

☐ Degree (for example BA, BSc), Higher Degree (for example MA, PhD, PGCE)

☐ NVQ Level 4-5, HNC, HND, RSA Higher Diploma, BTEC Higher Level

☐ Professional qualifications (for example teaching, nursing, accountancy)

☐ Other vocational/work related qualifications

☐ Foreign qualifications

☐ No qualifications

Appendix III – Survey design

Survey bias

Ordering bias occurs when the sequence in which text or questions are presented influences response (Krosnick and Presser, 2009). In the case of the switching survey, if the order in which the tariffs were presented to respondents systematically influenced their stated tariff preferences, this would represent a significant threat to the validity of the results. To mitigate this risk, the order in which the tariffs were presented was randomised, so that approximately the same number of respondents were presented with the tariffs in each of the six possible permutations in which they could appear.

Certain questions were also deliberately positioned before others in the survey, because earlier questions can sometimes serve as an interpretive framework for subsequent questions, affecting how respondents construe their meaning (Ryan *et al*, 2012). For instance, the questions asking respondents how easy they would find it to reschedule appliance use were presented before those asking whether they would be prepared to operate those appliances unattended. This made it less likely that when answering the former questions, respondents' reflections on the factors which might influence their ability to reschedule appliances use would be dominated by considerations associated with unattended use.

Another form of survey bias can arise due to divergent subjective interpretations of the wording of surveys (Kitchenham and Pfleeger, 2002). To mitigate this risk, specific terms such as 'climate change' and 'in-home display' were defined, to ensure that all respondents were "working with the same understanding of vocabulary" (Kitchenham and Pfleeger, 2002, p.22). These items were highlighted in blue and definitions appeared onscreen when respondents hovered their cursors over the terms while completing the survey.

Optimising rating scales

There is a substantial body of literature examining how rating scale questions can be designed to minimise bias. Considerations include the ideal number of response options for rating scales (Beckstead, 2014; Krosnick and Tahk, 2015; Revilla *et al*, 2014); whether a middle response option should be provided (Kalton *et al*, 1980; O'Muircheartaigh *et al*, 2001); and how question sequencing can be used to improve data quality (Krosnick and Presser, 2009; Lietz, 2010).

Regarding the optimal number of response options for rating scales, the central issue is that "While a rating scale with too few response options may not allow the respondent to make full use of his/her capacity to discriminate, a scale with too many options may exceed the respondent's capacity to discriminate, and so contribute measurement error" (Beckstead, 2014, p.811).

In this regard, a meta-analysis by Krosnick and Tahk (2008) found that the optimal length for rating scales is normally five-point for unipolar scales and seven-point for bipolar scales.[125] In line with these findings, five-point scales were used for the unipolar scales which explored the influence of various factors on respondents' tariff switching decisions. This approach was supported by studies which have shown that the modifiers 'somewhat' and 'moderately', which are frequently used together in seven-point scales, are often misplaced by respondents along the response continuum (Bass *et al*, 1974; Boote, 1981).

Although Krosnick and Tahk (2015) recommend the use of seven-point scales for most bipolar continua, Krosnick also co-authored a study which concluded that agree/disagree scales should always be presented using five-point scales (Revilla *et al*, 2014). The authors explain that: "Regardless of the country, regardless of the topic, and despite what the information theory states, there is no gain in information when an agree disagree scale with more than five categories is used. There is, instead, a loss of quality." (*ibid*, p.90).

For this reason, the agree/disagree questions in the survey all used five-point response scales, notwithstanding the general recommendation to use seven-point scales for bipolar continua.

Scale labels

When selecting the response options for scale questions, the intervals between scale points should be approximately equal (Kitchenham and Pfleeger, 2002). Questions asking respondents to indicate the influence of various factors on their tariff switching decisions used the following scale options: 'not at all important', 'slightly important', 'moderately important', 'very important' and 'extremely important'. Rohrmann (2003) explored the measurement features of words and expressions commonly used in rating scales to identify optimal scale point labels. The results of the study support the use of the scale labels used in the survey with the average

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[125] Unipolar continua are those that extend in only one direction – for example, 'not at all important' to 'extremely important'; whereas bipolar continua are those defined by favourable and unfavourable extremes – for example, 'strongly disagree' to 'strongly agree' (Beckstead, 2014).

scores for the scale points used either at or very close to the optimal interval positions of 0.0, 2.5, 5.0, 7.5 and 10.0. In Rohrmann's analysis, 'not at all' was 0.0, 'slightly' was 2.5, 'moderately' was 5.0, 'very' was 7.9 and 'extremely' was 9.6 (ibid).[126]

Pre-testing and piloting the survey

Before administering surveys, it is good practice to carry out testing to refine questions and identify design issues (Krosnick and Presser 2009). In this case five tests were conducted: a small group pre-test (N=5), a set of cognitive interviews (N=8), two pre-tests (N=17 and N=50) and a larger pilot (N=93).

The small group pre-test and the cognitive interviews were used to explore how respondents understood specific questions and to identify any which were not interpreted as intended. The first pre-test examined how well respondents understood the tariff explanations, while the larger pre-test and pilot (N=50 and N=93 respectively) made it possible to perform principal component analysis on responses to the attitudinal questions.

The various online tests were also used to check that automatic survey branching was functioning correctly. This revealed that the survey software had a bug which was affecting the routing of respondents to different pages, which was fixed before the final version of the survey went live.

Survey revisions

Cognitive interviews produce qualitative data that can be used to improve surveys. They normally involve asking respondents to think out loud when answering questions and to elaborate on certain responses (Krosnick and Presser, 2010).

During the cognitive interviews, interviewees were asked to comment on the factors that influenced their response to the following question: "Please indicate how easy/difficult it would be in your household to change the times at which the following appliances were used (for example, if using them at certain times would be better for the environment or would make your electricity bills cheaper)."

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[126] The use of the labels 'not at all', 'slightly', 'moderately', 'very' and 'extremely' was also supported by a meta-analysis of the value of scale labels (Beckstead, 2014).

Interviewees were encouraged to vocalise their thoughts when answering this question to determine whether it captured a range of contextual factors that influence whether consumers find it easy to reschedule appliance use. The diversity of the responses provided gave confidence that this was indeed the case. For example, one interviewee explained that ironing would be difficult to reschedule as items were ironed immediately before use, rather than in advance; another indicated that laundry was done on weekends, as household members were normally busy with other activities on weekdays when they came home from work; and another suggested that it would be difficult to change the times when vacuuming was done, because this was scheduled so that other household members would not be disturbed.

The cognitive interviews also informed changes to the questions used to establish the measure "Commitment to environmental sustainability". One of the agree/disagree questions from Alcock (2012) – "Scientists will find a solution to climate change without people having to make big changes to their lifestyle" – was revised for the final survey. In cognitive pre-tests, one respondent reported that the negation ('without') in the sentence was confusing. The use of questions which include negations is inadvisable, as they can be cognitively burdensome, leading to measurement error and respondent fatigue (Krosnick and Presser, 2009). Two further interviewees indicated that they had wanted to answer 'Don't know' to this question because they were unsure whether scientists would find solutions to climate change, but that this response option had not been available.

As a result of this feedback, the question was rephrased as: "Most people will have to make big changes to their way of life to help to solve climate change." As well as avoiding the use of the negation 'without', this removed the reference to scientists which some interviewees had found problematic. The changes were supported by the principal component analysis on the revised question, which showed the revised question loaded onto one of the identified components at 0.63, compared to the loading of 0.46 for the previous iteration.[127] The same question also originally lacked a middle 'neither agree nor disagree' response option, as presented in Alcock (2012). However, scales without middle points have lower validity, as well as higher random error variance, suggesting that respondents randomly choose other response options which are available when the middle option is lacking (O'Muircheartaigh *et al*, 2001).[128] As such, a middle

[127] The rotated component score for this question was also higher, at 0.81, compared with the previous score for the question of 0.41.
[128] Further evidence that having a neutral middle point increases the reliability and validity of response scales is provided by a meta-analysis of 87 experiments of question design by Saris and Galhofer (2007).

point was added to improve data quality and standardise all the items used to create the "Commitment to environmental sustainability" measure.

One further change was made to the questions used by Alcock (2012) to create the measure. One question (Q35) originally provided response options of 'frequently', 'sometimes', 'rarely' and 'never'. This question was reformulated as an agree/disagree to standardise the questions used to create the measure, and because research has shown that certain modifiers – including 'frequently' – are often interpreted differently by different individuals, leading to increased measurement error (Lietz, 2010).

A final important change to the survey was made after one of the pre-tests (N=50). In this, all but one of the respondents indicated that they would switch to the DSR programmes. The fact that nearly all respondents indicated that they were willing to switch strongly suggested that hypothetical bias was influencing the responses provided. This led to the inclusion of the certainty question in subsequent iterations of the survey, which made it possible to produce more conservative estimates of WTS. As Loomis (2014) cautions, "stated preference surveys would be wise to include a question asking respondents to indicate their level of certainty for their response" (p.42).

Data cleaning

Strikes

Respondents sometimes complete surveys without making the cognitive effort necessary to choose the optimal responses that truly reflect their views (Krosnick and Presser, 2010). One indication that this might be the case is where respondents provide answers to sets of closed questions in vertical, horizontal or diagonal lines, known as 'straight-lining' (Cole *et al*, 2012).

However, sometimes responses may appear in these patterns because they represent respondents' considered choices (ibid). Since a single instance of straight lining might plausibly be down to chance, a 'three strikes' rule was adopted, whereby any survey response with straight-lining through three sets of questions was discarded.[129]

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[129] The question sets which were evaluated for this purpose contained an average of seven questions.

In addition to straight-lining, two further question responses were considered ‘strikes’ which, when combined with one or more instances of straight-lining, led to the rejection of a survey response. These included instances where respondents indicated that:

- the number of children living in their household was greater than the total number of household members; or
- their gas and electricity bill was lower than their electricity bill alone.

Speeding

Data quality can also be compromised when respondents complete surveys very quickly (Zhang and Conrad, 2013). The average time taken to complete the pre-test and pilot versions of the survey was 12 minutes and 57 seconds. Respondents who completed the questionnaire much faster than this were thought unlikely to have provided considered responses.

To determine whether the quality of the data collected was inferior when respondents completed the survey quickly, the quality of responses which were provided in between five and seven minutes (N=58) was compared with those provided in between seven and nine minutes (N=97) by examining the number of ‘strikes’ in each set of responses.

Responses were awarded one point for each of the ‘strikes’ described above, as well as for each instance of straight-lining. The mean number of strikes per response was 0.71 for the seven to nine-minute group and 1.2 for the five to seven-minute group. An independent samples t-test revealed a statistically significant difference in the mean number of strikes for these groups (P=0.00), and that the difference in the number of strikes between the two groups was between -0.84 and -0.17 with a 95% confidence interval. This confirmed that data quality declined in responses completed in under seven minutes and supported the rejection of these responses.

Respondents who completed the surveys very quickly might also have been more prone to defaulting to a ‘Don’t know’ response to the tariff choice question. However, although a larger proportion of respondents who completed the survey in between five and seven minutes answered ‘Don’t know’ to this question than those who completed the survey in between seven and nine minutes (26% versus 18%), a chi square test found that this difference was not statistically significant (P=0.28).

In some cases, respondents took a long time to complete the survey: nine respondents on the pilot (N=93) took over 30 minutes to do so. These responses were retained because long completion times may reflect the fact that subjects were distracted while answering, which might also occur when people choose an energy contract in real life (Momsen and Stoerk, 2014).

Appendix IV – Rationale for switch/remain survey questions

When deciding which factors to include in Questions 44 and 47 of the switching survey, particular reference was made to the findings of the UK Energy Research Council project “Transforming the UK energy system – Public values, attitudes and acceptability” (Parkhill *et al*, 2013), which developed a comprehensive picture of public perspectives and acceptability with regard to energy system change.

Factors influencing the decision to switch

The survey found a “set of clear preferences for particular energy system elements that people feel should be integral to energy system change” (ibid, p3). These included a strong commitment to renewable forms of energy production and the importance of efficiency in minimising waste and overall energy usage. The survey also found a strong preference for an energy system that protects the environment. As DSR programmes would contribute towards electricity system efficiency, environmental protection and, in the case of the two dynamic DSR programmes, the growth of renewables, respondents who opted to switch were asked to rate the importance of each benefit in their decision.

Other factors were included due to the importance that they are afforded in the DSR literature. For example, flexibility in scheduling appliance use is often cited by consumers and experts as a necessary requirement for participation in DSR (Ofgem, 2009; Powells *et al*, 2014; Salies, 2013). Likewise, saving money is often an important consideration for consumers in making purchasing decisions (Leijten *et al*, 2014; Whitehead and Cherry 2007), with lower electricity bills often cited as an important reason for choosing to switch to DSR tariffs (Dütschke and Paetz, 2013; Namerikawae *et al*, 2015). At the same time, a number of studies have highlighted consumer concerns about electricity blackouts (Gyamfi and Krumdieck, 2011; Ipsos Mori, 2012; Parkhill *et al*, 2013) and 49% of people interviewed in an opinion tracker poll expressed concern about power cuts becoming more frequent in future (DECC, 2014b).

Factors influencing the decision not to switch

The factors that respondents who opted to remain on their current tariff were asked to rate were likewise informed by a review of the DSR literature. For example, UK consumer mistrust of energy suppliers is well documented (Energy and Climate Change Committee, 2013; Fell *et al*, 2015a; Parkhill *et al*, 2013), and trust is regarded as an important influence on consumer interest in new energy-related products. As Smart Grid GB (2013) explains: “The level of trust between consumer and energy provider is a factor that can either act as barrier or enabler to consumers’ interest in either participating in schemes, or simply in listening to what is on offer” (p.24).

Concerns about the risk of increased electricity bills was also presented as one of the factors, as such concerns are often raised when consumers are asked whether they would be interested in switching to DSR tariffs (Darby and Pisica, 2013; Pollitt and Shaorshadze, 2011). Similarly, the inability to make sufficient savings was included as it has also been recognised that the modest savings which might be realised from DSR for the foreseeable future may discourage some consumers from participating (Owen *et al*, 2013; Kim and Shcherbakova, 2011).

Respondents were also asked to indicate the extent to which contentment with their existing tariff had influenced their decision not to switch, because in survey pre-testing respondents frequently cited this reason in an open-ended question asking whether any additional factors had influenced their decision.

Appendix V – Ethical approval for DSR trial

University of Sussex

Certificate of Approval	
Reference Number:	ER/MJG29/3
Title Of Project:	In-home-display pilot (COPY)
Principal Investigator (PI):	Matthew Gross
Student:	Matthew Gross
Collaborators:	
Duration Of Approval:	n/a
Expected Start Date:	06-Apr-2015
Date Of Approval:	27-Mar-2015
Approval Expiry Date:	06-Jul-2015
Approved By:	Jayne Paulin
Name of Authorised Signatory:	Janet Boddy
Date:	27-Mar-2015

*NB. If the actual project start date is delayed beyond 12 months of the expected start date, this Certificate of Approval will lapse and the project will need to be reviewed again to take account of changed circumstances such as legislation, sponsor requirements and University procedures.

Please note and follow the requirements for approved submissions:

Amendments to protocol

* Any changes or amendments to approved protocols must be submitted to the C-REC for authorisation prior to implementation.

Feedback regarding the status and conduct of approved projects

* Any incidents with ethical implications that occur during the implementation of the project must be reported immediately to the Chair of the C-REC.

Feedback regarding any adverse and unexpected events

* Any adverse (undesirable and unintended) and unexpected events that occur during the implementation of the project must be reported to the Chair of the Social Sciences C-REC. In the event of a serious adverse event, research must be stopped immediately and the Chair alerted within 24 hours of the occurrence.

Appendix VI – Invitation to participate in DSR trial

Environmental alert trial

You are invited to take part in a research study. Before you decide whether to take part, it is important to understand why the research is being done and what it will involve. Please take the time to read the following information carefully.

The purpose of the study is to learn whether electricity customers are able to use more or less electricity in their homes at certain times of day, depending on the amount of renewable energy available from wind. This is important since renewable electricity generated from wind needs to be used at the time it is produced; otherwise it often goes to waste, as it cannot be stored.

Why have I been invited to take part?

You have been invited to take part because you have asked to receive more information about the trial. The study will involve 60 households and will take place between April 2015 and July 2015.

Do I have to take part?

It is up to you to decide whether to take part and you are free to withdraw at any time without giving a reason. If you decide to participate, please keep this information and sign and return the attached consent form.

What will happen if I take part?

If you decide to take part, you will first be sent a short online questionnaire which will take around 10 minutes to complete. The questionnaire includes questions about your home and the people who live there. It also includes questions about your electrical appliances and heating.

After completing the questionnaire, you will be sent a free electricity monitor, which will tell you how much electricity you are using in your home. In the first month of the trial, you will set up and get used to your new electricity monitor. This will involve plugging in the device and setting it up so that your electricity consumption data can be accessed via the internet. Only members of your household and the lead researcher responsible for the trial will have access to this data.

Over the next two months, you will receive a maximum of one text message a day – to encourage you to use more or less electricity at certain times – on the mobile phone numbers you have provided (you can also choose to receive emails if you wish). On around half of the days during the trial, you will not receive any text messages.

At the end of the trial, participants will be contacted to see whether they would be willing to take part in a 45-minute telephone interview. Interviewees will be asked about their experience of the trial and what things made it easier or more difficult to make changes to the appliances they used at certain times. These interviews will be recorded and it is entirely up to you whether you would like to participate.

What are the benefits of taking part?

Through using their electricity monitors, participants will have a better understanding of how they are using electricity in their households, which should help them to reduce their electricity bills. The electricity monitor will be theirs to keep at the end of the trial. The trial will also help to develop a wider understanding of how residential customers can help to promote the use of renewable sources of electricity by changing the times at which they use household appliances.

What should I do if I want to take part?

If you would like to take part in the study, please return your completed consent form by email to M.J.Gross@sussex.ac.uk by April 22 2015 to register for the trial. Please be aware that the trial is only open to 60 households and these will be selected on a first come, first served basis.

Will my information in this study be kept confidential?

All information collected about you and other members of your household, as well as your electricity consumption data, will be kept strictly confidential. In order to protect the confidentiality, privacy and anonymity of participants, only the principal researcher (Matthew Gross) will have access to electricity consumption data and interview recordings. Individuals will be assigned a number which will be used instead of their name in all publications and outputs generated as part of the study.

What will happen to the results of the research study?

The results of this trial will contribute to doctoral research being carried out at the University of Sussex. A copy of this research can be obtained by contacting Matthew Gross at M.J.Gross@sussex.ac.uk.

Who is organising and funding the research?

Matthew Gross is conducting this research as a student at the University of Sussex within the Science Policy Research Unit. The research is funded by the Engineering and Physical Sciences Research Council (EPSRC).

Who has approved this study?

The research has been approved by the Cross-Schools Research Ethics Committee (C-REC).

Further information

If you would like any further information about the trial, please contact Matthew Gross at M.J.Gross@sussex.ac.uk. If you have any concerns about the way in which the study is being conducted while participating, please contact Dr Steve Sorrell, who is responsible for supervising this project (S.R.Sorrell@sussex.ac.uk).

Appendix VII – DSR Trial consent form

CONSENT FORM

Project title: Environmental alert trial

Project Approval Reference: ER/MJG29/3

I agree to take part in the above University of Sussex research project. I have read and understood the Information Sheet, which I have kept for my records. I understand that agreeing to take part means that I am willing to:

- Complete a short survey about my household and the electrical appliances it contains before the trial starts
- Receive a free electricity monitor and keep this connected in my home for the three-month trial period
- Allow the principal researcher from the University of Sussex access to my electricity consumption data during the trial
- Receive up to one text per day in the final two months of the trial on all mobile phones that I register informing me of periods to try to use more or less electricity
- Take part in a 45 minute recorded telephone interview with the researcher at the end of the trial (optional)

I understand that my name and all identifying details will remain anonymous in the report of the project and in any related publications.

I understand that my participation is voluntary, that I can choose not to participate in part or all of the project, and that I can withdraw at any stage of the project without being penalised or disadvantaged in any way.

I consent to the processing of my personal information for the purposes of this research study. I understand that such information will be treated as strictly confidential and handled in accordance with the Data Protection Act 1998.

Please enter the mobile numbers on which you would like to receive messages during the trial below. A minimum of one number is required – however, the more mobile phones that are registered, the more your household will be able to engage with the trial. Before entering any additional numbers below please ensure that you have shown the owners of the phones the information and consent forms, and have obtained their consent.

Please note that you can stop receiving messages on any numbers that you provide below by replying 'stop' from that phone to any message received.

Main trial mobile telephone number:__ ________________
2nd mobile telephone number:________________________
3rd mobile telephone number:________________________
4th mobile telephone number:________________________

Full name: _____________________

Date: _____________________

Completing this form and returning it to M.J.Gross@sussex.ac.uk constitutes acceptance of the trial as described here, as well as in the accompanying information form.

Appendix VIII – DSR trial information form

University of Sussex

Environmental alert trial

The environmental alert trial is due to start soon. It aims to examine whether households can vary the amount of electricity they use at certain times, depending on the amount of wind power available. This information sheet answers some of the questions you may have about how the trial will work.

Why are the members of my household being asked to try to use more or less electricity at certain times?

When you are sent messages asking you to try to use more electricity at certain times, this is because more renewable electricity will be available from wind at those times. When you are sent messages asking you to try to use less electricity at certain times, this is because not much electricity will be available from wind at those times.

Since electricity produced from wind is very difficult to store, it is important that this electricity is used at times when there is lots available, so that it does not go to waste. At the same time, if households can use less electricity when less wind power is available, this will mean that not as much electricity needs to be produced from non-renewable fossil fuels to meet demand at those times.

If you are sent a message asking you to try to use less electricity during a certain period, please try to avoid using appliances that use a lot of electricity at these times – for example, washing machines, tumble dryers, dishwashers, vacuum cleaners and irons.

On the other hand, if you are sent a message asking you to try to use more electricity during a certain period, this is a good time to use those electrical appliances. At these times, it is good if your electricity monitor shows that you are using a lot of electricity carrying out your household tasks – the bar on your monitor will turn red and the display will indicate that you are using more electricity than normal. Remember, however, that the aim is only to carry out household tasks that you would have to do at some point anyway – not to increase your electricity use unnecessarily! This is because you are only trying to change when you use electricity, not to increase the amount of electricity that you use overall.

When will I receive messages by text message or email?

This week you will start receiving messages asking you to try to use more or less electricity at certain times. You will receive text messages on most days on the mobile phone numbers that you provided on your consent form, as well as emails if you asked to receive these when you completed the registration survey. Don't worry if on some days you don't receive a message: this will be because neither especially windy weather nor especially still weather is forecast for the following day.

How will I know how well I am doing at changing the amount of electricity I use during the alert periods?

Over the first few weeks that your energy monitor has been connected, information about your electricity use has been saved to your Energynote account. This will be compared against the amount of electricity that you use during the alert periods, to measure whether your household has been able to change its electricity use in response to the alerts.

So that you know whether you have succeeded in using more or less electricity during a particular alert period, you will also receive messages letting you know whether the amount of electricity used during the last alert period was more or less than the average for your household at that time.

Smart plugs

Smart plugs can be used with your Geo Solo II monitor to learn more about how much electricity individual appliances in your home are using. They can also be used to turn appliances on and off remotely from your Energynote account; it might help you to save energy by turning appliances on and off when you are not at home. These appliances are available online if you search for "Geo Solo II smart plugs".

Your broadband connection

If possible, please keep your broadband switched on while the trial is taking place (your router does not use much electricity). However, do not worry too much if your broadband is switched off briefly, as the Geo Solo II will store your electricity data for short periods. Similarly, if you want to move your Geo Solo II, don't worry - just unplug it and plug it in again at the new location.

If you experience any problems with your Geo Solo II or Energynote account, you can contact Geo's technical support number on 01223 850210 during normal office hours and from 9:00am to 12:30pm on Saturdays. Alternatively, please feel free to contact me at M.J.Gross@sussex.ac.uk with any questions you may have about your involvement in the trial.

Thank you very much for taking part in the University of Sussex environmental alert trial.
Kind regards
Matthew Gross
Sussex Energy Group