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Public acceptability of domestic demand-side response in Great Britain: The role of automation and direct load control

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ABSTRACT

Domestic demand-side response (DSR), if widely adopted, could help make electricity more secure, clean and affordable. However, little is known about consumer demand for different approaches to achieving DSR. This study aimed to gauge the acceptability of a range of DSR tariffs, and explore factors affecting it. An online between-subjects survey experiment was deployed to a representative sample of bill payers in Great Britain ($N = 2002$), testing five tariffs including static/dynamic time of use (TOU) pricing (with/without automated response to price changes) and direct load control (DLC) of heating on a below-average flat rate.

The tariff permitting limited DLC of heating was significantly ($p < .01$) more popular than the TOU tariffs. This was surprising given evidence for concern around loss of control in DLC, and suggests that for many people DLC is acceptable in principle (within tight bounds and with override ability). The option of automated response made dynamic TOU (otherwise the least popular tariff) as acceptable as static TOU. This is important because dynamic TOU offers additional network benefits, while automation can improve duration and reliability of response. The TOU tariffs were rated highly for giving people control over spending on electricity, but other factors were more associated with overall acceptance.

1. Introduction

For many countries, the challenge of meeting people's individual demand for electricity while maintaining an electricity system that functions affordably, securely and cleanly is becoming increasingly acute. In the UK, legislation is driving the closure of older coal-fired power plants, and the proportion of variable supply such as wind power is increasing [13]. Faced with anticipated growth in electricity demand, especially for heating and transport [11], there is consensus that a reliable electricity system will require more coordination of how electricity is used, for example through time of use (TOU) pricing and direct load control (DLC) by third parties of technologies in people's homes.

While a reliable grid is in the interest of wider society, it is not clear that individuals' interests would be enhanced by accepting influence over how and when they use electricity. Indeed, research into the acceptability of demand-side response (DSR) suggests that people have many concerns. A key worry is expressed around loss of personal control, especially in relation to DLC (e.g., [27]). Yet set against this is the fact that people routinely accept automation and outside influence in many aspects of their lives. It is important to understand the extent and focus of people's concerns in relation to DSR because, unless programmes can be designed in such a way as to be acceptable, people will not participate, leading to insufficient influence over load and ultimately ineffectiveness of DSR.

The current study builds on work by Fell et al. [17] which explored what it means to people to be in control in relation to energy, and how their expectations of control differed with various approaches to DSR. The study presented here drew on qualitative findings from that work to inform the design of a nationally representative survey experiment which aimed to quantify people's acceptance of, and control expectations in, a range of DSR offerings (static and dynamic TOU pricing, with and without automated response, and DLC). The next section provides an overview of the previous work, and theory that has been applied, in this area. Model and survey development and approach are subsequently described, and the results presented and discussed. The overall aim is to determine the relative acceptability of different approaches to implementing DSR in Great Britain, the extent to which perceptions of control are related to stated acceptance, and what aspects of the design of DSR offerings are associated with expectations of control. Finally, the implications of findings for policy and industry are considered.

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2. Control and acceptance of demand-side response

2.1. Background

Demand-side response can be simply defined as 'change in electricity consumption patterns in response to a signal' ([16]: 9). It is used to provide a number of services for electricity system suppliers and network operators, outlined by He et al. [23] as: portfolio optimization; structural congestion management; occasional physical congestion management; balancing; and other ancillary services. These services require different levels of speed, duration and reliability of response. These characteristics of response can be expected to vary depending on the nature of the signal used to influence consumption patterns, and for this reason it is important to understand what the relative uptake of the different approaches might be. The main types of signal are:

- Price (e.g., in static or dynamic TOU pricing).
- Volume (e.g., in load capping, or limiting the amount of power that can be used at a given time).
- Direct (e.g., in DLC, in which loads such as electrical appliances are remotely switched by DSR operators).

Direct control signals should allow more rapid and reliable responses, followed by volume and pricing [23], although level of automation in response to price signals can affect this Frontier Economics and Sustainability First [21]. However, DLC programmes may also entail some loss of personal control or autonomy for users. As perceived control has been demonstrated to have an effect on acceptance of certain products and services (see next Section), this could have consequences for participation in different kinds of DSR programmes and subsequently their effectiveness.

2.2. Importance of perceived control

Subjective (or perceived) control is defined by Skinner ([36]: 551) as 'an individual's beliefs about how much control is available'. Concerns around loss of control have been emphasized in qualitative research into the acceptability of DSR. Mert [27], in a European study of smart appliances which can be controlled remotely by third parties for the purposes of DSR, found that: 'A . . . major concern for consumers is an anticipated loss of control' (p32). Rodden et al. [32] also encountered fears in this area in the context of automated response to dynamic TOU pricing: 'users expressed a strong [negative] initial reaction about the loss of autonomy and control within their own home' (p6). A similar finding was identified by Darby and Pisica [9] in a focus group study of the acceptability of a range of DSR tariffs including direct load control: 'The other main anxiety was about privacy ("Big Brother") and loss of control' (p2329). This was echoed by Parkhill et al. [30], but they add that the ability to override automation or external control appeared to make DLC more acceptable.

Quantitative research has also detected the importance of the control construct in the context of DSR. A representative UK survey by Downing and iCaro Consulting [15] revealed that 30% of people would be concerned about 'loss of individual control' in an area with sustainable community infrastructure which involves external control of appliances with the aim of system balancing. Another survey in Belgium by Stragier et al. [39] found that people rated the level of personal control that smart appliances would give them as relatively low (i.e., mean of 2.9 on a five-point scale) in comparison to the level of comfort (mean of 3.9) and ease of use (mean of 3.3). Work by Kranz et al. [26] in relation to acceptance of smart meters also found subjective control to be a significant predictor of acceptance.

The current programme of study aimed to build on this prior work in two main ways. Firstly, there has until now been little exploration of what motivates and constitutes feelings of control in relation to energy use. In response to this, [18], based on a series of focus groups, identified four main motivations for control:

- Comfort (such as being able to obtain desired thermal conditions in the home).
- Timing (control over when people do things, such as running appliances like dishwashers).
- Spending (having a sense of control over how much money is spent on energy).
- Autonomy (a more general sense of directing events in one's life, free of outside influence).

Hereafter these constructs are referred to as 'comfort control' 'timing control', 'spending control' and 'autonomy'. Being a small-scale qualitative study; however, this work was not able to say anything generalizable about the relative importance of these facets of control to acceptance of different approaches to DSR. The second stage of work, therefore, has been to use these findings to inform the design of a nationally representative survey experiment.

2.3. Model selection and extension

Control has previously been included in a number of models of human behaviour. The *Theory of Planned Behaviour* suggests that intention to act results from people's attitudes, norms and perceived behavioural control [2]. However, the perceived behavioural control construct refers to people's assessment of their ability to perform actions or achieve goals, rather than their expectations of how much control they would subsequently have if they took an action (e.g., signing up to a new electricity tariff). For this reason it would be inappropriate to apply it in this study. Control is included in a more objective sense in Stern's *Attitude–Behaviour–Context* model [38] (in the form of context) and Triandis' *Theory of Interpersonal Behaviour* [41] where the concept of 'facilitating conditions' may be understood to mean whether an action or event is within someone's control. Again, these control concepts would not be appropriately applied here since the main interest is not in whether people are objectively able to sign up to a DSR tariff but on their subjective control expectations once they are on it.

As well as having been shown to be a concern in relation to DSR (see previous Section), perceived control has been shown to be statistically significantly associated with acceptance of a number of products and services, such as smart meters [25], smart appliances [40] and radio-frequency identification [37]. To explore the role of perceived control, these studies employed extended versions of the *Technology Acceptance Model* (TAM) [10], which has been widely used to study the uptake of new products and services. Applying the *Theory of Reasoned Action* [3], it is highly parsimonious, relying on two variables (perceived usefulness and perceived ease of use) to predict people's attitude towards use and behavioural intention to use technology. The model has been adjusted many times since its original formulation. It has often been extended to explore the importance of other constructs such as social influence [43], which also omits the 'attitude' construct), trust and risk in e-commerce [45] and perceived control in the examples of [25] and [37] above. Often in parallel with such extensions it has been simplified so that so that perceived usefulness, ease of use and other constructs are related directly to the principal outcome variable of interest (i.e., intention to use or actual use) without the inclusion of the attitude construct (e.g., [1,5,43]).

While demonstrating an increase in explanatory power through extending the model with perceived control, the specific con-

trol constructs (as reflected in the items used to measure them) employed in the studies by Kranz [25] and Spiekermann [37] were not considered directly transferrable in the context of a study on DSR. They both focus on a specific information and communications technologies (smart meters in the case of Kranz [25] and radio-frequency identification in the case of Spiekermann [37], and as such conceptualize control principally in relation to the sharing of information (which is the primary role of these technologies). This study therefore extended the TAM with the four newly theorized control constructs outlined above. It set out to test the hypotheses that perceived usefulness, perceived ease of use, comfort control, timing control, spending control and autonomy are separate constructs that are all positively associated with behavioural intention to use a DSR tariff. It was not possible to explore how this is reflected in actual system use since the DSR tariffs investigated are not currently available on the market. The analysis also explored how the constructs vary depending on the approach taken to implementing DSR.

3. Method

3.1. Research population

The study research population was that of Great Britain (GB—the countries of England, Scotland and Wales). Although, the British electricity system has interconnections with those of Ireland and mainland Europe, most DSR activity would need to take place locally (e.g., if they are to be of benefit to local distribution systems [23]. The unit of analysis is individuals who are partly or fully responsible for paying their household energy bills. This group were selected as they represent consumers who would ultimately make tariff switching decisions.

3.2. Survey

The study used an online survey experiment (between-subjects) conducted in August 2014 to allow measurement of the concepts of interest (in this case behavioural intention to use, attitude towards use, perceived usefulness, perceived ease of use, and perceived control over comfort/timing/spending/autonomy). The experimental design permitted differences between groups to be attributed to differences between the tariffs presented. The following sections describe the design of the survey and sample, and how the survey was administered and the results analysed.

3.3. Sample

The research agency Populus was commissioned to administer the survey. They retain a panel of members of the British public whom they invite to respond to online surveys in return for an incentive. They also promote surveys through online advertisement on a range of websites. Invitation recipients and advert viewers together constituted the sampling frame. Representative quotas are set for the research population on the basis of gender, age, social grade and region. Once quotas have filled up, further potential participants are screened out. The survey was positioned at the beginning of an omnibus survey which also contained questions on other topics, so respondents did not know the subject of this study in advance of deciding to participate. A total of 2302 people completed the omnibus. Of these 2178 described themselves as main/joint energy bill payers in GB. Only these 2178 progressed to the study survey, with the remainder skipping straight to the next section of the omnibus.

The data were checked for unengaged participants by calculating the standard deviation of their responses to a 21-item extended TAM scale (see next sub-Section). In total, 176 people showed no variation in their responses. As certain items intended to measure the same constructs were negatively worded, this means they either provided self-contradictory responses or selected the 'neither agree nor disagree' option for all items. Such responses were not considered to contribute useful information to the study and these participants were therefore excluded from the analysis, yielding a final valid participation of $N = 2002$.

Table 1
Weighting factors used in the data analysis.

Age	Males	Females
18–24	1.72	0.82
25–34	1.30	1.23
35–44	1.04	1.30
45–54	0.91	1.13
55–64	0.82	1.04
65+	0.62	1.02

In spite of the use of quota sampling, gender and age variation in the sample was different to that found in census data for the population of Great Britain ONS, 2012. As such, a weighting factor was calculated based on these variables and applied in the analysis (Table 1). The weighting factors bring the age and gender distribution of the sample in line with that of the population, with values above 1.00 boosting the weight given to data collected from participants in relevant age/gender groups, and vice versa. For example, in this survey, men aged 18–24 were underrepresented relative to the population, so their data received a higher weighting. A table summarizing the demographic variables for each experimental group is available in Appendix C. Data collected on other quota factors (education level and social grade, using default categories supplied by Populus) were not directly comparable with census data so it was not considered justifiable to further weight the data to adjust for them.

3.4. Survey design

Participants proceeding to the survey were first asked to identify their electricity supplier, allowing this data to be collected but also ensuring that people had their supplier's identity in mind when they completed the remainder of the survey. Participants were then assigned into one of five groups via simple randomization. Each group was presented with a short outline of the rationale for DSR, giving simple details on cost per unit of electricity (and what this roughly equates to in usage terms) and asking them to imagine that their heating system works exactly as it does at present but is powered by electricity (see Appendix A).

The DSR offerings were presented in the context of home heating for a number of reasons. Electrification of heating is a key part of the UK's plans for decarbonization, and as such heating is expected to be an increasingly important constituent of electrical load [12]. It currently accounts for the majority of household energy use in the UK [29]. It also often already has an element of automation. Finally, electric heating systems provide promising opportunities for DSR because electricity consumption can be lowered for a short time with only a small impact on room temperature.

Each group was then shown a description of one of the following DSR product offerings (see Appendix A for the full descriptions), presented as being offered by their present electricity supplier and accompanied by the offer of a 'smart' thermostat allowing online and smartphone control of heating[1]:

[1] The smart thermostat would facilitate automation and DLC for the relevant tariffs, but was offered in all groups for consistency.

- Static time of use tariff (hereafter *sTOU*) with price bands: weekend/weeknight (8pm–7am) 10p/unit; weekday (7am–4pm) 14p/unit; weekday peak (4pm–8pm) 30p/unit.
- Static TOU with automated response to price changes, e.g., by pre-heating the home when prices are lower (*automated sTOU*).
- Dynamic TOU (with price band alerts 24 h in advance, prices as for sTOU) (*dTOU*).
- Dynamic TOU with automated response to price changes (with price band alerts 24 h in advance) (*automated dTOU*).
- A lower than average (12p/unit) flat rate tariff with direct load control of heating (cycling of heating off and on at times of high demand, unlimited override, effect on temperature capped to 1 °C) (DLC).

The TOU tariffs were based on existing offerings that have been trialled for use in the UK (for prices/bands for the static tariff see Frontier Economics [20] and for general structure of the dynamic tariff see Carmichael et al. [6]. The direct load control tariff was adapted from similar products on the market elsewhere in the world.[2] It was of particular interest to understand the interaction, if any, between the predictability of price changes (i.e., predictable for sTOU contrasted with the unpredictable dTOU) and the option of an automated response.

Directly below the tariff description, participants were asked to respond to a series of items designed to measure their perceptions of control, ease of use, usefulness and overall attitude towards and behavioural intention to use the offering. These items were selected from a larger item pool generated through a combination of reviewing previous research including similar constructs [10,25,37,44], and supplementing this with new items based on language used in the preparatory focus groups described in Fell et al. [18]. In a process described in more detail by Fell et al. [17] and based on a procedure described by Bhattacherjee [4], this item pool was refined through a combination of a sorting exercise and pilot survey ($N = 63$) followed by exploratory and confirmatory factor analysis. The final list of 21 items (see Appendix B) showed provisionally acceptable validity and reliability. Overall acceptance of the tariff was assessed by an item asking whether, if it was offered to the participant now, they would sign up to the tariff.

The items appeared over three separate screens, each accompanied by the tariff description, and the order of the items on each screen was varied at random for each participant. There followed a range of other questions, including items designed to measure their trust in their electricity supplier, their privacy concern, their locus of control in relation to energy and their level of concern about future climate change, affordability of electricity and security of supply (see Appendix B). Socio-demographic data were also collected in a separate section of the omnibus survey.

3.5. Analysis

Data analysis was conducted in IBM SPSS Statistics 22 and IBM SPSS Amos 22. Harmann's single factor test and confirmatory factor analysis were employed to check for multicollinearity between the extended TAM constructs, while the latter also permitted assessment of how well individual items loaded onto their intended constructs. One-way analysis of variance (ANOVA) was used to test for significant differences between the groups in behavioural intention to use the tariffs and attitude, perceived usefulness and ease of use. Because the control constructs are theoretically closely aligned, multivariate analysis of variance (MANOVA) was also employed here to protect against inflated error rates that can be associated with multiple univariate analyses [22]. Two-way ANOVA was used to test for interaction effects between predictability (i.e., whether prices changed at fixed, known times as for sTOU or unpredictably as for dTOU) and automation (the DLC group was excluded from this analysis). Multiple regression was employed to identify associations between the extended TAM constructs and acceptance of the different DSR offerings.

4. Results

4.1. Pre-analysis

Chi square tests and one-way ANOVA were conducted for socio-demographic and attitudinal variables (excluding the perceived control and acceptance scale) to check that the experimental groups did not differ significantly from each other in these respects. For the variables included in the analysis presented here (see list in Section 4.4 below), none of the groups differed significantly from each other at the level $p < .05$.

Harman's single factor test was conducted in SPSS to determine whether the items of the extended TAM scale were best explained by the constructs they were intended to measure or by a single underlying construct [31]. This was done by running an exploratory factor analysis without rotation and extracting a single factor only. Because this single factor explained more than 50% of the variance between the items, the test was failed, meaning that any subsequent analysis based on the individual constructs would likely be susceptible to problems associated with high multicollinearity (see below in this sub-Section). The possible reasons for this are discussed in Section 5. Confirmatory factor analysis was performed using IBM SPSS Amos 22 to assess how well individual items loaded onto their theorized latent constructs (e.g., perceived usefulness, perceived control over spending, etc.). Items with factor loadings lower than 0.7 were excluded (see Appendix B), and the means of the remaining items calculated to yield a mean value for each construct. Confirmatory factor analysis (without the excluded items) also showed high multicollinearity between all the constructs measured, with interfactor correlations ranging from .81 to 1.00 (Fig. 1).

The highest correlations (all >.95) were between the control over comfort, timing and autonomy variables. The correlations between perceived usefulness and perceived ease of use, and between these constructs and control over spending, were all <.90. The extreme multicollinearity in the comfort, timing and autonomy variables suggested that the items measuring these constructs may have been perceived by participants as conceptually very close to each other.

Because high multicollinearity can be problematic for analysis (making it difficult to determine the relative influence of each construct), the decision was taken to treat the three highly collinear constructs (comfort control, timing control and autonomy) as a single construct for the purposes of all further analysis presented here. This new construct is referred to as 'general control'. The number of items for this construct was also reduced to three (to bring it in line with the other constructs) by selecting the one item for each of the comfort, timing and autonomy that loaded most strongly on the new general control factor. A new confirmatory factor analysis revealed that interfactor correlations now ranged from .82 to .91, with the highest correlation (.91) between the general control construct and perceived ease of use (and .82 between general control and spending control). Acknowledging the potential problems associated with such high multicollinearity (discussed further in section 5), analysis proceeded on this basis.

[2] For example, the Summer Advantage Program (http://bit.ly/1Ht4JPY) offered by Entergy in the US. For reasons of consistency and to improve comparability with the TOU tariffs, a reduced price per unit was used in this study rather than a bill rebate. For an extensive listing of such products in the US – and therefore principally applied to air-conditioning – please visit http://bit.ly/1IPuJGC.

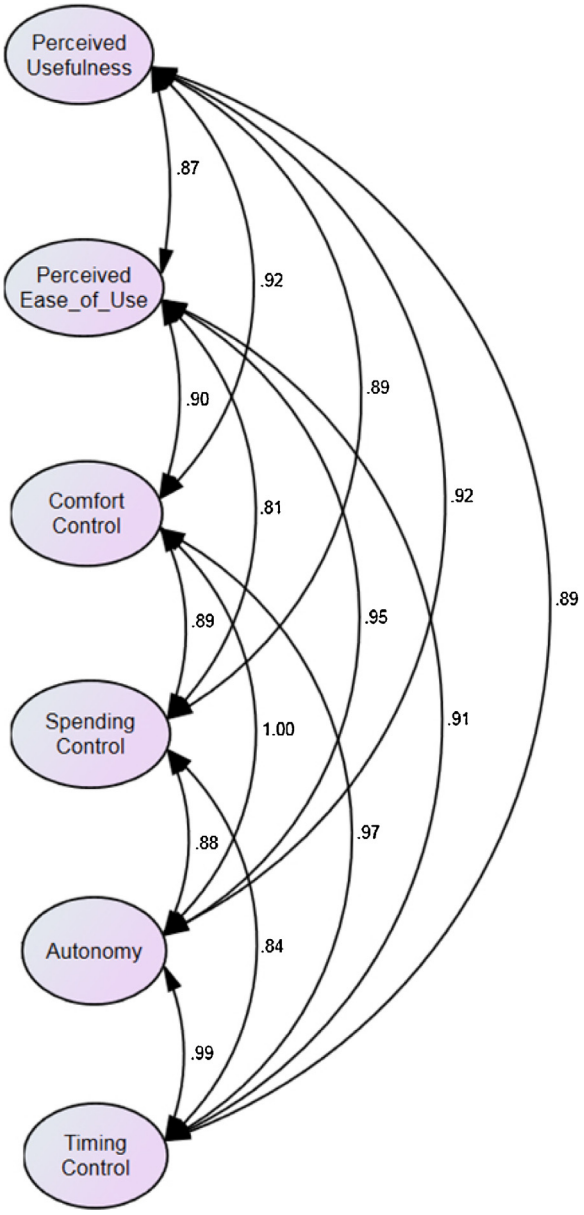

Fig. 1. Interfactor correlations between the extended TAM constructs.

The next sub-Section presents the overall acceptance of the tariffs and the results of one-way ANOVA and MANOVA to compare the extended TAM constructs between experimental groups. The results of two-way ANOVA for tariff predictability/automation are then given, followed by the results of multiple regression to show the relative contribution of the extended TAM constructs to overall acceptance.

4.2. Tariff acceptability

Fig. 2 shows the breakdown of responses to the item asking whether people would sign up to the tariff presented (reflecting their behavioural intention to use it). DLC provoked the most positive response, and was the only tariff for which more people gave a positive (37% strongly or slightly agreed they would sign up) than a negative (30% strongly or slighted disagreed) response. Strongly or slightly positive responses for the TOU tariffs ranged from 25% for dTOU to 30% for sTOU, while strongly or slightly negative responses showed a greater range across the tariffs, from 33 to 43%. For the TOU tariffs, at least twice as many people were strongly negative as were strongly positive in each case.

One-way ANOVA was used to test for differences in each of the extended TAM constructs between the experimental groups, and post hoc tests with Bonferroni correction were employed to test for pairwise differences. It showed that reported behavioural intention to use the tariffs differed significantly ($F[4,1976] = 7.534$, $p < .0005$). Post hoc tests revealed that behavioural intention to use DLC was significantly higher than the other tariffs (sTOU $p = .006$, automated sTOU $p = .001$, dTOU $p < .0005$) except for automated dTOU, where it neared significance ($p = .060$). There was no significant difference between the intention to use any of the TOU tariffs (interaction effects were observed however—see next sub-Section). Attitudes towards the tariffs (measured by asking participants whether they thought the tariff was a good idea, and whether they had a positive attitude towards it) also differed significantly ($F[4,1976] = 16.810$, $p < .0005$). DLC was viewed significantly more positively than all the other tariffs (for sTOU, automated sTOU and dTOU all $p < .0005$, automated dTOU $p = .003$). Indeed, only 13% of people strongly/somewhat disagreed with the item stating that the DLC tariff was a good idea. Automated dTOU was viewed significantly more positively than dTOU ($p < .0005$), as was automated sTOU ($p = .020$). No other significant differences were identified between people's attitudes towards the tariffs.

Fig. 3 shows the mean value for each tariff for the original TAM constructs perceived usefulness and perceived ease of use.

One way ANOVA again revealed significant differences between the groups:

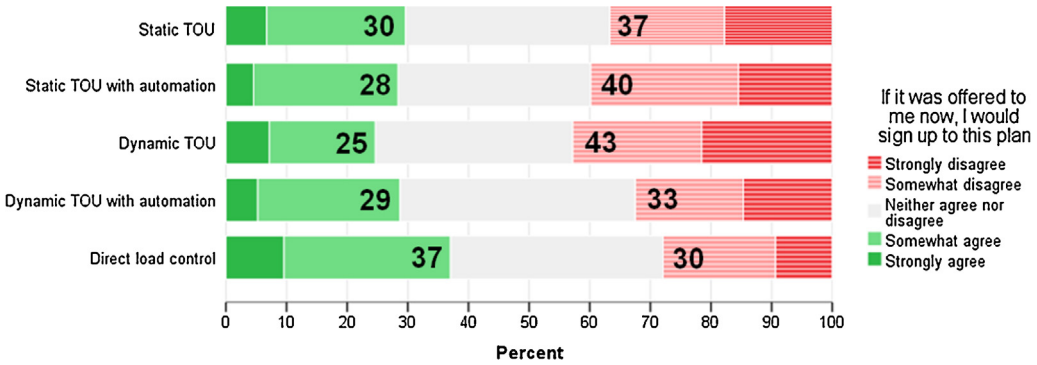

Fig. 2. Responses to the item measuring behavioural intention to use each tariff. The numbers of the chart represent the percentage of participants either strongly or somewhat in favor of, or strongly or somewhat against, switching to the tariff in question.

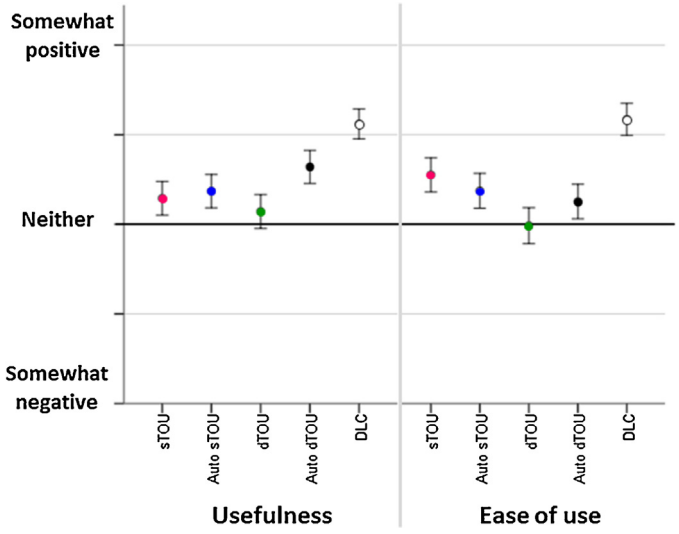

Fig. 3. Mean values for perceived usefulness and perceived ease of use for each tariff. Error bars represent 95% confidence intervals.

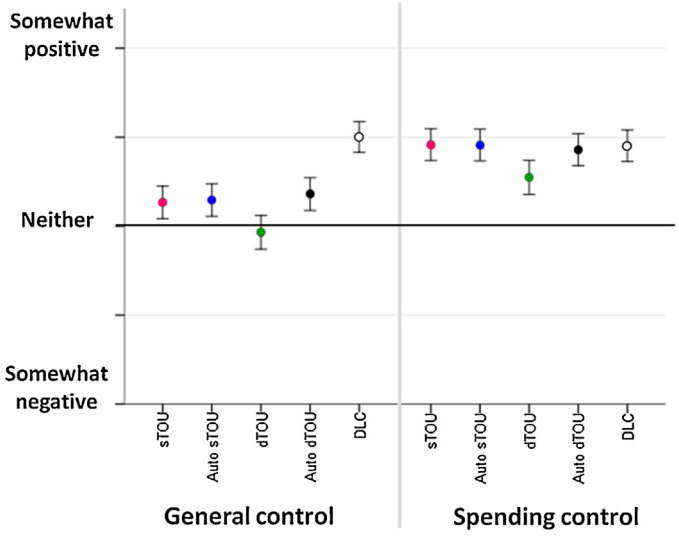

Fig. 4. Mean values for general control and spending control for each tariff. Error bars represent 95% confidence intervals.

- *Perceived usefulness*: $F(4,1976) = 18.385$, $p < .0005$. Post hoc tests showed DLC was viewed as more useful than all of the other tariffs (all $p < .0005$ for sTOU, automated sTOU and dTOU, and $p = .007$ for automated dTOU). Automated dTOU was viewed as significantly more useful than dTOU ($p = .001$), with no other significant differences between the tariffs.
- *Perceived ease of use*: $F(4,1976) = 21.112$, $p < .0005$. DLC is viewed as easier to use than all the other tariffs ($p < .0005$ in all cases). The sTOU tariff is seen as significantly easier to use than dTOU ($p < .0005$). No other significant differences were detected between the groups, although automated sTOU was close to being viewed as significantly easier to use than dTOU ($p = .051$).

Fig. 4 shows the results for the new control constructs: general control and spending control.

Because the general and spending control constructs are theoretically closely related, one-way MANOVA was employed to control for the possibility of inflated error rates. It included both control constructs as dependent variables. As multicollinearity can be problematic for MANOVA the Pearson correlation was calculated for the mean responses to general control and spending control items. Pearson correlation was .688, which is lower than a range of proposed thresholds[3] and was therefore considered acceptable. MANOVA showed significant differences between groups on the combined control variables, $F(8,4084) = 14.783$, $p < .0005$, Wilks' $\Lambda = .945$, partial $\eta 2 = .028$. Univariate analyses with Tukey post hoc tests showed the following significant differences for the individual control constructs:

- *Spending control*: $F(4,2043) = 2.444$, $p = .045$, partial $\eta 2 = .005$. Tukey post hoc tests did not show any significant pairwise differences between the experimental groups.
- *General control*: $F(4,2043) = 18.158$, $p < .0005$, partial $\eta 2 = .034$. Tukey post hoc tests revealed that DLC was viewed as giving significantly more general control than all the other tariffs ($p < .0005$). sTOU ($p = .046$), automated sTOU ($p = .041$) and automated dTOU ($p = .006$) were all viewed as giving significantly more general control than dTOU. No other significant differences between tariffs were found.

4.3. Interaction between predictability and automation

Two-way ANOVA was employed to test whether there was interaction between the predictability of the tariff (i.e., whether prices changed at fixed, known times as for sTOU or unpredictably as for dTOU) and having the option of automation. Data are mean ± standard error, unless otherwise stated. There was found to be a statistically significant interaction between predictability and automation for behavioural intention to use, $F(1,1627) = 4.593$, $p = .032$, partial $\eta 2 = .003$. People were statistically significantly more likely to say they would switch to the unpredictable dTOU tariff where there was the option of automation (0.21 ± 0.08) than where there was not, $F(1,1627) = 6.731$, $p = .010$, partial $\eta 2 = .004$. Neither a main effect of predictability nor of automation was significant. Significant interactions were also revealed for the following constructs:

- *Attitude towards use*: $F(1,1627) = 6.653$, $p = .010$, partial $\eta 2 = .004$. The option of automation significantly improved people's attitude towards the unpredictable dTOU, $F(1,1627) = 18.720$, $p < .0005$, partial $\eta 2 = .011$. Where automation was not offered, its predictability improved people's attitude towards sTOU, $F(1,1627) = 6.219$, $p = .013$, partial $\eta 2 = .004$.
- *Perceived usefulness*: $F(1,1627) = 5.062$, $p = .025$, partial $\eta 2 = .003$. The option of automation significantly increased people's perceived usefulness of the unpredictable dTOU, $F(1,1627) = 13.754$, $p < .0005$, partial $\eta 2 = .008$.
- *Perceived ease of use*: $F(1,1627) = 5.615$, $p = .018$, partial $\eta 2 = .003$. The option of automation made the unpredictable dTOU appear significantly easier to use, $F(1,1627) = 4.508$, $p = .034$, partial $\eta 2 = .003$. Where automation was not offered, the predictable sTOU was perceived as significantly easier to use, $F(1,1627) = 17.280$, $p < .0005$, partial $\eta 2 = .011$.
- *General control*: $F(1,1627) = 5.292$, $p = .022$, partial $\eta 2 = .003$. The option of automation led to people expecting to have significantly more general control for the unpredictable dTOU, $F(1,1627) = 6.188$, $p = .013$, partial $\eta 2 = .004$.

No significant interaction between automation and predictability was shown for spending control, but where there was no

[3] Proposed thresholds include .90 (https://statistics.laerd.com/spss-tutorials/one-way-manova-using-spss-statistics.php, accessed 17.06.15.) and .80 (http://www.statisticssolutions.com/checking-the-additional-assumptions-of-a-manova/, accessed 17.06.15.).

automation, the predictable sTOU tariff was viewed as giving significantly more spending control than unpredictable dTOU, $F(1,1627) = 4.030$, $p = .045$, partial $\eta 2 = .002$. In summary, having the option of automation made people more willing to switch to the dTOU tariff, improved people's attitudes towards it (this was the largest effect), and increased people's perceived usefulness, ease of use and general control on the tariff. Where the option of automation was not offered, the predictable sTOU tariff was viewed more positively (attitude towards use) than dTOU, and as being easier to use (the largest effect) and giving more control over spending. Overall, it should be noted that the effect sizes of these interactions as shown by the partial $\eta 2$ were small.

4.4. Relative contribution of the constructs

A multiple linear regression was run to identify associations between behavioural intention to use each tariff (outcome variable) and the predictor variables: perceived usefulness; perceived ease of use; spending control; and general control for the different tariffs. The following factors were controlled for by including them in the regression model (dummy variables are listed for each, with reference category in italics, see Appendix B for attitudinal items):

- Age (18–24, 25–44, 45–64, 75–74, 75+).
- Gender (female and *male*).
- Housing tenure (*home owner*, social tenant, private tenant, and other tenure).
- Employment status (*employed full-time*, employed part-time, not in paid employment, retired).
- Highest education level (*secondary school*, undergraduate degree, postgraduate degree, and other/refused).
- Annual household income (less than £14 k, £14 k to less than 28 k, £28 k to *less than* 48 k, £48 k+, income not disclosed).
- Presence in the household of children aged 15 or under (*not present* and present).
- Whether the participant lived alone (*does not live alone* and lives alone).
- Whether the participant was already on a TOU tariff (*not on TOU tariff* and on TOU tariff).
- Whether they had ever, or in the last year, switched energy supplier (*never switched*, switched but not in last year, and switched in last year).
- Their assessment of how easy their home was to heat (two items and five-point response scale).
- Their stated level of trust in their current electricity supplier (four items and five-point response scale).
- Their perceived locus of control in relation to energy use (three items and five point response scale).
- Their stated level of concern about future climate change, and reliability and affordability of energy (five-point response scale).
- Their level of privacy concern (three items and binary response).

The results are reported in Table 2 (detailed results are only included for the four main constructs of interest—for discussion of the results regarding trust, privacy concern and locus of control please see Fell et al. [19]. The issue of multicollinearity has been discussed in the pre-analysis section above. A standard collinearity metric is the variance inflation factor (VIF). A range of tolerances have been proposed for an acceptable VIF threshold, usually ranging from 5 (e.g., [33] to 10 (e.g. [24]. In this case the VIFs for the four constructs of interest ranged from 2.56 to 4.68.

For all tariffs the explained variation in intention to use was statistically significantly ($p < .0005$) higher for model 3 (where the perceived control variables were included) than for model 2 (where only the original TAM variables were included), which in turn was significantly ($p < .0005$) higher than for model 1 (including only basic socio-demographic and attitudinal variables). The measured variables in model 3 (including all socio-demographic, attitudinal and extended TAM variables) explained most variation in willingness to switch (as evidenced by the adjusted R^2) for dTOU (adjusted $R^2 = .771$) and sTOU, followed by automated sTOU and automated dTOU, which least variation explained for DLC (adjusted $R^2 = .607$).

Perceived usefulness was significantly positively associated with willingness to switch to all of the tariffs. It was the most important variable in terms of effect size for all the tariffs except automated sTOU, where general control was slightly more important. Perceived ease of use was also significantly positively associated with willingness to switch to all of the tariffs, as was general control. The latter was second to perceived usefulness in effect size for all the tariffs, except automated sTOU. Control over spending was significantly associated with willingness to switch only in the case of sTOU, where the relationship was negative.

5. Discussion

5.1. The acceptability of direct load control

The finding that a DLC tariff (with lower than average flat rate for electricity) was most acceptable was surprising given previous evidence of significant concerns around loss of control on such tariffs (see Section 2 above). Indeed, the results indicated that people expected to have more control in all of the dimensions measured on the DLC tariff compared to the TOU tariffs, except in relation to spending on electricity. There are a number of possible explanations for this.

Firstly, it is important to note that this is the first assessment of demand for various DSR tariffs, including time of use pricing and direct load control, to be conducted for a representative sample of the population of Great Britain. Previously voiced concerns around loss of control in DLC programmes have mainly been raised in smaller scale qualitative studies or in other contexts, for example, that look at the energy system as a whole. The previous findings regarding such concerns in small groups are not necessarily inconsistent with the findings of this study at the national scale. In this study, 37% of participants were favourable towards switching to a tariff involving DLC, with 63% somewhat or strongly agreeing that the tariff presented was a good idea. Thirty per cent of people were found to be strongly or somewhat against switching to the DLC tariff, which is in line with the finding by Downing and iCaro Consulting [15] that the same proportion of people were concerned by loss of individual control in sustainable community infrastructure involving remote control of appliances. The strength with which concerns around loss of control have been expressed (e.g., as quoted in Rodden et al. [32]: 6): '... we should have the choice of how we use energy in our home, at least that! Our home for crying out loud!') may have contributed to a sense that such concerns are more of a barrier to acceptance than the results of this study would suggest. It is pertinent to consider that a form of DLC has actually been in use in the UK for decades through the radio teleswitch for electric storage heaters with no outcry, although it is impossible to know how many people would choose to adopt such a system if it were offered to them (rather than inheriting it as a legacy product).

The DLC tariff presented to participants in this study was intentionally quite benign, allowing only a small ('less than 1 °C') impact on internal temperature. Concerns expressed previously sometimes related to different or stronger forms of direct control. In focus groups conducted by Fell et al. [17], for example, bounds in which temperature might change under DLC were not as tightly delimited (referred to in terms of 'a small amount' rather than a value in degrees Celsius). Other studies such as Mert [27] and Rodden et al. [32] included discussion of control of smart appliances such

Table 2
Multiple regression results showing association of the four constructs of interest with behavioural intention to use each of the DSR tariffs. Adjusted R^2 values are given for model 1 (basic socio-demographic and attitudinal variables only), model 2 (model 1 plus original TAM variables) and model 3 (model 2 plus perceived control variables).

	Model 1	Model 2			Model 3			
Tariff	Adj. R^2	Adj. R^2	Adj. R^2	F	Variable	B	Std. Error	Beta
sTOU	.172	.711	.736	$F(32,390) = 37.721^{***}$	Perceived usefulness	.583	.063	0.486^{***}
					Perceived ease of use	.298	.051	0.253^{***}
					Spending control	−.231	.058	-0.177^{***}
					General control	.330	.061	0.269^{***}
Automated sTOU	.100	.620	.656	$F(32,340) = 23.186^{***}$	Perceived usefulness	.358	.063	0.297^{***}
					Perceived ease of use	.282	.057	0.243^{***}
					Spending control	.014	.071	0.010
					General control	.399	.070	0.321^{***}
dTOU	.174	.742	.771	$F(32,380) = 14.555^{***}$	Perceived usefulness	.536	.062	0.437^{***}
					Perceived ease of use	.274	.049	0.237^{***}
					Spending control	−.071	.054	−0.057
					General control	.374	.052	0.306^{***}
Automated dTOU	.141	.623	.641	$F(32,337) = 21.611^{***}$	Perceived usefulness	.614	.075	0.508^{***}
					Perceived ease of use	.205	.059	0.177^{***}
					Spending control	−.116	.073	−0.092
					General control	.295	.068	0.244^{***}
DLC	.102	.590	.607	$F(32,369) = 20.382^{***}$	Perceived usefulness	.469	.079	0.359^{***}
					Perceived ease of use	.268	.069	0.223^{***}
					Spending control	−.057	.081	−0.043
					General control	.342	.081	0.272^{***}

B = unstandardized regression coefficient; Beta = standardized coefficient. $^{*} = p < .05$, $^{**} = p < .01$, $^{***} = p < .001$. The reported F, R^2 and p values include the other socio-demographic and attitudinal variables that were included in the regression for model 3, but for clarity the detailed significance and effect size information is only provided for the four main constructs of interest.

as washing machines, where other fears such as flooding, fire and noise (as highlighted by Mert) could be associated with concerns around loss of control. Related to this, there is clear prior evidence (cited in Section 2 above) that having an override function made, for some people, the unacceptable acceptable. It may be that inclusion of unlimited overrides meant that people perceived themselves to retain sufficient 'human supervisory control' – of which the ability to intervene in automated action is an important part [35] – for the idea of external control to become acceptable.

Part of the aim of this study was to explore the acceptability of DLC in principle—that is, the direct influence by an external party on the action of technology within the home. Choosing a form of external control that would have limited direct impact on consumers was important in isolating the issue of third party control in itself from concerns that may follow directly from it (such as noise of running a washing machine overnight). What this study has shown is 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. Further work could usefully test how varying the bounds of control and override potential affect acceptance.

Another factor that could help explain the contrast between the findings of the present study and previous results is psychological distance. In this survey, participants were asked to take a relatively quick decision based on the available information about whether they would actually sign up to a tariff. Much of the previous research cited has asked in more general terms what people think about the idea of DLC taking place in a general future period. Construal level theory holds that in making decision which will have temporally nearer outcomes, people focus more on detailed contextual factors (such as value for money and the precise terms of the tariff deal), while for more temporally distant outcomes more high-level and abstract factors (such as values and attitudes) come into play [42]. It may be that when people consider DLC in the abstract, concerns about loss of control and autonomy are more salient than when faced with a tariff decision which (hypothetically at least) has a more immediate outcome. In the latter case, more immediate concerns such as cost and whether people think they will get the energy services they need may take precedence.

The preceding paragraphs have dealt mainly with the absolute acceptability of the principle of DLC in Great Britain. It is also useful to explore its relative acceptability compared to the TOU tariffs, since this may also shed light on the relatively high ratings DLC received for the control variables which were measured. One clear difference between the DLC and TOU tariffs was that the TOU tariffs would affect all electricity use, while the DLC only applied to heating. It is perhaps not surprising that people would report an expectation of lower control over comfort, the timing of when they do things and their lives in general when activities such as cooking and watching television are affected in one case (TOU) and not in another (DLC). The implication is that concerns around who is doing the controlling (e.g., a DSR operator in DLC) are subsidiary to fears that control will be lost over people's ability to do things that use electricity to the extent and at the times they want. However, trust is likely to be an important factor in this (see Fell et al. [19].

Other structural differences between the DLC and TOU tariffs may have contributed to the relative acceptability of the former. Pricing information was prominent in the tariff descriptions used here, and could therefore be expected to be quite salient when participants were making decisions about willingness to switch. Because it was based on a lower than average flat rate, the DLC tariff offers a guaranteed saving and no prospect of losing money compared to being on a standard flat rate tariff. On the contrary, while there is the potential to save money by exploiting low off-peak rates on TOU tariffs, there is also the possibility of being worse off if people find they are unable to do so. This lower risk of losses may have contributed to the relatively high perceived usefulness rating of the DLC tariff, two items for which specifically focused on whether people thought they would save money on the tariff (and perceived usefulness was the strongest predictor of willingness to switch to the DLC tariff).

5.2. The acceptability of time of use tariffs

A range of 25–30% of participants were strongly or somewhat in favor of switching to TOU tariffs. The most consistent difference between these tariffs was the comparatively negative perception of the dTOU tariff. It was rated significantly lower than automated

dTOU for attitude, perceived usefulness and general control; significantly lower than sTOU for perceived ease of use and general control; and significantly lower than automated sTOU for attitude and general control. There were no significant differences in main effects between sTOU, automated sTOU and automated dTOU for any of the constructs measured. However, there was an interaction between predictability of the tariff and automation, and giving the option of automated response to the dynamic tariff made it significantly more acceptable. Automation gave people a greater sense of general control on the dTOU tariff, made it seem easier to use and people felt they were more likely to save money on electricity.

Where the option of having an automated response to the dTOU tariff is made explicit, the dTOU tariff becomes as acceptable to people as sTOU and automated sTOU. This is an important finding for two reasons. Firstly, as established in Section 2, different approaches to DSR can achieve different benefits for the network. While static tariffs allow regular peaks to be managed, they cannot incentivize demand that follows variable supply (such as from wind generation) or a response to unexpected peaks or faults. Dynamic tariffs, on the other hand, do permit such flexibility and are therefore potentially more valuable to networks. If by highlighting the possibility of automation the dynamic option becomes as attractive as the static, this bodes well for acceptance of the more valuable dynamic tariff. Secondly, having an automated response to DSR signals has consistently been found to deliver the greatest and most persistent demand response (see review by Frontier Economics and Sustainability First [21]). The finding that automation makes the dynamic tariff more attractive is therefore doubly encouraging in terms of their potential contribution to the energy system.

It is interesting to contrast the findings of this study with those of a recent large-scale trial where participants actually spent time living with a dynamic time of use tariff—the Low Carbon London project [6]. In that trial, 77% of the 708 people who completed the final survey (out of a total participation of 1044) said that they would like to remain on the tariff if they had the chance, suggesting it was very popular. There are several possible explanations for the difference between this and the result of the current study. Firstly, participants had to opt in to take part in Low Carbon London (and the final survey), so may already have been more interested than average in the products being tested. Secondly, while the structure of the tariff used was similar, the prices were different (with greater differences between price bands in the Low Carbon London trial). The possibility of exceptionally high savings may have proved attractive. Thirdly, unlike in the current study, participants in the Low Carbon London trial actually had experience of living with the tariff. Our survey participants responded only on the basis of their expectations. This may suggest that people find dynamic time of use tariffs better to live with than they might expect. If this were the case, offering people the opportunity to experience a tariff before they commit to it (such as through a trial period) could help increase uptake. Further work by the authors which is currently underway aims to explore the differences between people's expectations and experiences for DSR, and how this relates to their intention to participate in it.

5.3. The value of extending TAM with perceived control constructs

Part of the aim of this study was to test whether, as well as the existing TAM constructs of perceived usefulness and perceived ease of use, four control constructs (comfort control, timing control, spending control and autonomy) were also positively associated with intention to use a DSR tariff and increased the explanatory power of the model. Because factor analysis did not provide evidence for four distinct control constructs, only two were used in regression analysis—general control and spending control. The general control construct was shown to be positively associated with intention to use all tariffs, but spending control was found not to be significantly associated with intention when controlling for the other extended TAM variables (except for the sTOU tariff, where it was negatively associated with acceptance). There was a small but significant increase in adjusted R^2 on addition of the perceived control constructs to the model for all experimental groups, demonstrating an increase in explanatory power. The findings on the role of these control constructs in acceptance should be tempered with caution due to the existence of fairly high levels of multicollinearity. While regression analysis proceeded on the basis that VIF scores were below quite widely used thresholds (i.e., 2.56–4.68 against thresholds of 5–10), some have argued for lower thresholds to be used (e.g., 3.3 [14] or 2.5 [8]). The high observed interfactor correlations could have had a number of causes.

Common method variance (CMV) is a potential cause of multicollinearity (e.g., [7]. This can arise 'if the respondents have a propensity to provide consistent answers to survey questions that are otherwise not related' [7]: 178). For example, a survey respondent may favor one end of a response scale in a list of items, perhaps reflecting a general view rather than a considered response to each item. There is some evidence that this was the case in this study. The negatively framed items did not load well onto their target constructs (e.g., 'Being on this plan would require a lot of mental effort' did not load well with positively framed items onto the target construct of perceived ease of use). This may be because people who were otherwise answering 'strongly agree' or 'strongly disagree' were more likely to tend towards that end of the scale than go to the other end to strongly or somewhat disagree. If this were the case overall, responses may have reflected a generally positive or negative view of the tariffs, rather than specially addressing each item.

There is reason to believe that CMV has only blurred the results, rather than obscured them entirely. For example, [18] found that where people felt time of use tariffs increased their control in relation to energy, it was specifically with regard to spending. In this study, the time use tariffs were rated highest for the spending control construct. If people were just clicking through the survey without considering the items, this construct in particular would not be expect to rate higher than any of the others. It is possible that people who form part of a retained panel of respondents, and therefore are called to answer many questionnaires, may be more inclined to click through surveys as quickly as possible. However, it should be noted that agencies such as Populus, who administered this survey, do have controls in place to prevent this (such as by comparing actual to expected completion times).

Another possible reason for high multicollinearity is that the constructs were indeed highly related and interdependent, such that big differences would not be expected to distinguish them. In the same way that perceived usefulness is partly dependent on perceived ease of use in the original TAM, it is likely that perceived usefulness and perceived ease of use are closely linked to people's perceptions of control. If someone feels they would not have much control over when they do activities, and this is unacceptable to them, they are also unlikely to think they are going to save money with a TOU tariff, or that it will be easy for them to use.

The finding that that spending control was not related to acceptance when controlling for the other extended TAM variables (or was even negatively associated with it in the case of sTOU), if reliable (bearing in mind the possibility of problems due to multicollinearity), is potentially important. Firstly, the regression result does not appear to be obviously misleading when considering that, while all of the tariffs (except dTOU) were rated quite highly for spending control, and without significant differences between them, this did not translate into equivalently high acceptance for all the tariffs. Other control variables, along with perceived usefulness and perceived ease of use, more closely mirror ultimate acceptance.

While this result does not contradict the finding by [18] that spending was the area where people feel most additional control on TOU tariffs, it does suggest that this may not be the most effective area for DSR operators to appeal to when promoting such tariffs since it does not show a clear association with acceptance. Instead, it is more important that operators design tariffs that people consider to give them a general sense of control over comfort, timing and a feeling of autonomy, and that are easy to use. The preceding discussion shows that, in the example of dynamic time of use pricing, for example, this sense of control can be achieved by offering the option of automated response. While emphasizing the spending control benefits of DSR may not in most cases be off-putting, the results indicate the foregrounding aspects of the design which promote feelings of control in other areas, ease of use, etc., could be more effective.

5.4. Study limitations

Several limitations of the study have already been outlined. CMV (discussed above) may have been avoided by varying the scale end-points for the (hypothesized) predictor and dependent variables. Using a scale with fewer items, and with a more even balance of negatively framed items, may also have reduced its effects, although the scale was developed according to a prescribed method and already had a low number of items for each construct.

It is known that stated behavioural intention to act (which this study measured) does not closely relate to actual behaviour. A review by [34] found that, on average, 28% of variance in behaviour was explained by intention. The results presented here should therefore be viewed as indicative rather than predictive of likely tariff acceptance. However, at a time when DSR tariffs are not widely offered, they can provide a useful insight into the factors that might ultimately affect adoption.

The tariffs were designed to be realistic. However, requesting that people imagine they have electric heating (while justified by the reasons provided in the methods section) may have been confusing for some. The tariffs were presented in an intentionally neutral tone, while it is likely that people will ultimately encounter such offerings through adverts which would make a more positive case for signing up. Finally, people who take part in online panel surveys may differ consistently from the general population, introducing bias. However, other sampling approaches make it more difficult to obtain a representative sample of the target population.

6. Conclusion

This study investigated what the possible acceptance might be of a range of demand-side response tariffs in Great Britain, and the extent to which this was associated with various dimensions of perceived control in relation to energy. Results of a representative survey experiment indicated that a direct load control tariff (allowing electricity suppliers to cycle people's heating of and on for short periods in return for a lower flat rate cost per unit) was more acceptable than the time of use tariffs presented (static and dynamic, with and without automated response). People rated it higher than the time of use tariffs in terms of giving a general sense of control (over comfort, timing of when they do things, and autonomy), control over spending, usefulness and ease of use. This was surprising because of concerns about loss of control highlighted by previous research. It suggests that the idea of direct load control is acceptable in principle to many (possibly the majority of) people, at least when operated within tightly defined bounds and with the option to override it. The implication of this is that firms should feel confident to innovate in this area.

Having the option of an automated response to price changes led to people expressing significantly greater intention to use the dynamic time of use tariff. This finding, combined with the acceptability in principle of direct load control, should be encouraging for DSR operators because automatic responses to DSR signals have been shown to be more reliable and durable. It suggests that firms could offer the option of automated response to price changes to encourage the uptake of dynamic time of use tariffs. Overall, 25–30% of people expressed a strongly or somewhat favourable intention to use time of use tariffs. While it is difficult to infer from this what actual uptake may be, this is not inconsistent with UK Government's business case for the introduction of smart meters which is predicated on 20% uptake of static time of use tariffs by 2030 [12].

Integrating perceived control constructs into the Technology Acceptance Model for application to DSR tariff acceptance yielded a small but significant increase in explanatory power. The TAM constructs on their own explained on average 52% of variability across the tariffs (on top of that associated with socio-demographic and other attitudinal variables), while the control constructs added on average 3% to that. The findings of this analysis should be treated with some caution due to high multicollinearity between the constructs. This multicollinearity may have been caused by method-related issues such as common method variance, or to the constructs being naturally very highly correlated. However, measuring the control constructs still provided useful insights. While most of the TOU tariffs were rated highly for control over spending, this was not associated with higher intention to use. This suggests that the emphasis in product design and communications should be on assuring a general sense of control (taking in considerations such as comfort and timing), rather than control over spending. It also helped highlight the areas where adding automation was most valued (again, in general control rather than spending control), which may inform communication of the benefits of automation.

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Appendix A.

The following introduction was included for each tariff, followed by one of five plan descriptions:

Some electricity tariffs try to encourage people to use electricity at times of day when it is cheaper and cleaner to produce.

The next three pages ask for your thoughts on one such tariff. Please read the description and imagine that **it is being offered to you by your present electricity supplier**. A couple of points to note:

- People on standard flat-rate tariffs pay on average **14p per unit of electricity** (one unit is enough to run a fridge-freezer for a day, a PC for three hours or half a cycle of a washing machine).
- More people are expected to use electric heating in future. If you have a non-electric heating system, please imagine that **your heating system works exactly as it does now except that it runs on electricity**.

Static time of use

On this plan you have **three different rates** for your electricity—low, medium and high. They apply for **fixed times** of the day and week. Here are the rates:

Weekend (all day)—Low rate (10p/unit)
Weeknight (8pm–7am)—Low rate (10p/unit)
Week day (7am–4pm)—Medium rate (14p/unit)
Weekday peak (4pm–8pm)—High rate (30p/unit)

If you sign up your electricity supplier will give you a smart thermostat which allows you to monitor and change the temperature in your home remotely online or with a smartphone app.

Static time of use with automation

On this plan you have **three different rates** for your electricity—low, medium and high. They apply for **fixed times** of the day and week. Here are the rates:

Weekend (all day)—Low rate (10p/unit)
Weeknight (8pm–7am)—Low rate (10p/unit)
Week day (7am–4pm)—Medium rate (14p/unit)
Weekday peak (4pm–8pm)—High rate (30p/unit)

If you sign up your electricity supplier will give you a smart thermostat which allows you to monitor and change the temperature in your home remotely online or with a smartphone app. You can also set it to **respond automatically** to price changes so that you have heat and hot water when you need them but at the lowest cost (e.g., by pre-heating your home when prices are lower).

Dynamic time of use

On this plan you have **three different rates** for your electricity—low, medium and high. The times when these rates apply **change** depending on predicted amounts of wind power and national electricity demand. Your electricity supplier will send you an alert (by text message, email or an in-home energy monitor) the day before, letting you know when each rate applies. Here are the rates:

Low rate 10p/unit
Medium rate 14p/unit
High rate 30p/unit

If you sign up your electricity supplier will give you a smart thermostat which allows you to monitor and change the temperature in your home remotely online or with a smartphone app.

Dynamic time of use with automation

On this plan you have **three different rates** for your electricity – low, medium and high. The times when these rates apply **change** depending on predicted amounts of wind power and national electricity demand. Your electricity supplier will send you an alert (by text message, email or an in-home energy monitor) the day before, letting you know when each rate applies. Here are the rates:

Low rate 10p/unit
Medium rate 14p/unit
High rate 30p/unit

If you sign up your electricity supplier will give you a smart thermostat which allows you to monitor and change the temperature in your home remotely online or with a smartphone app. You can also set it to **respond automatically** to price alerts so that you have heat and hot water when you need them but at the lowest cost (e.g., by pre-heating your home when prices are lower).

Direct load control

On this plan you pay a **lower than average flat rate** for your electricity—**12p/unit**.

If you sign up your electricity supplier will give you a smart thermostat which allows you to monitor and change the temperature in your home remotely online or with a smartphone app.

While you are on this plan, the thermostat also allows your electricity supplier to **cycle your heating off and on** for short periods at times when there is high demand for electricity, but this will only have a small (less than 1 °C) effect on the temperature of your home. Your thermostat will show when this is happening, and you have the option to override it.

Appendix B.

The items used to measure the extended TAM constructs. The following introduction was included: 'How much do you agree or disagree with the following statements?' All used a five-point response scale as follows: strongly disagree; somewhat disagree; neither agree nor disagree; somewhat agree; strongly agree.

Construct	Item
Comfort control	With this plan I could make sure my home is warm enough.**
	With this plan I would have enough control over the comfort of my home.
	With this plan I could be sure of a pleasant environment in my home.
Spending control	With this plan I would have enough control over my spending on electricity.
	With this plan I would be in direct control of how much I spend on energy.
	With this plan I would be in charge of my spending on electricity.
Timing control	With this plan I would be able to do things when I want to do them.**
	With this plan I would be able to heat my home at the times I want to heat it.
	This plan would make it hard for me to do things when I want to do them.*
Autonomy	With this plan I would have enough control over my life.**
	With this plan I would be too dependent on automation.*
	With this plan I would be free to live as I choose.
Perceived ease of use	Learning to live with this plan would be easy for me.
	Being on this plan would require a lot of mental effort.*
	I would find this plan easy to use.
Perceived usefulness	This plan would be beneficial for me.
	I could see myself saving money with this plan.
	Being on this plan would save me money.
Attitude	Generally, I have a positive attitude towards this plan.
	I think that this plan is a good idea.
Behavioral intention to use	If it was offered to me now, I would sign up to this plan.

*These items did not load well with their target constructs and were removed for the final analysis.

**These items were used as a measure for the 'general control' construct.

Other attitudinal constructs were measured as follows:

Construct	Introduction	Item	Response
Trust	To what extent do you think your electricity supplier is trustworthy or untrustworthy with regard to the following. . .	• Ensuring you always have a reliable electricity supply • Providing information that you can easily understand • Charging a fair price for your electricity • Acting in your best interest	Very trustworthy, fairly trustworthy, neither trustworthy nor untrustworthy, fairly untrustworthy, very untrustworthy
Privacy concern	Please indicate if each of the following statements apply to you:	• I have refused to give information to a company because I thought that information was too personal • I have signed up to TPS [telephone preference service, which allows people to opt out of receiving sales or marketing calls] • I have asked an organization to take my name off of a mailing or email list	Yes and No
Locus of control	How much do you agree or disagree with the following statements?	• The amount of money my household spends on energy is largely out of my control • There are external factors that make it difficult for me to take actions to reduce my energy bills • It is hard to reduce your energy bills even if you want to	Strongly agree, somewhat agree, neither agree nor disagree, somewhat disagree, strongly agree
Climate/affordability/security concern	How concerned or not concerned are you about each of the following:	• About climate change, sometimes referred to as 'global warming'? • That in the future, electricity will become unaffordable? • That in the future there will be power cuts?	Very concerned, fairly concerned, neither concerned nor unconcerned, not very concerned, not at all concerned
Perceived ease of home heating	How much do you agree or disagree with the following statements?	• On cold winter days it is easy to heat my home up to the temperature I want • On cold winter days, once my home is at the temperature I want, it is easy to keep it warm	Strongly agree, somewhat agree, neither agree nor disagree, somewhat disagree, strongly agree

Appendix C.

Summary of demographic variables for the experimental groups.

		sTOU	Automated sTOU	dTOU	Automated dTOU	DLC	Total
Age	18–24	30	25	27	39	37	158
	25–44	111	106	116	103	105	541
	45–64	154	145	167	131	160	757
	65–74	119	89	96	76	90	470
	75+	19	15	10	16	16	76
Gender	Male	231	214	212	195	212	1064
	Female	202	166	204	170	196	938
Tenure	Homeowner	304	242	277	249	281	1353
	Social tenant	64	58	71	60	78	331
	Private tenant	61	76	64	55	45	301
	Other tenure	4	4	4	1	4	17
Education	Secondary school	232	197	228	194	206	1057
	Undergraduate degree	150	147	142	128	135	702
	Postgraduate degree	36	29	31	35	46	177
	Other education	18	8	16	10	26	78
Household income	<£14 k	84	61	79	68	85	377
	£14 < 28 k	162	157	159	145	147	770
	£28 < 48 k	132	124	123	97	132	608
	£48 k+	32	25	33	28	26	144
	Income not declared	23	13	22	27	18	103
Households with children 15 and under		76	89	88	84	91	428
Single-person households		109	81	86	76	99	451
Households on a TOU tariff		81	73	79	66	75	374
Switching energy supplier	Switched in last year	96	87	103	96	96	478
	Switched, not in last year	254	210	231	206	228	1129
	Never switched	83	83	82	63	84	395

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