Energy Research & Social Science xxx (2015) xxx–xxx

Contents lists available at ScienceDirect

Energy Research & Social Science

journal homepage: www.elsevier.com/locate/erss

Original research article

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

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ARTICLE INFO

Article history:
Received 27 February 2015
Received in revised form 18 August 2015
Accepted 20 August 2015
Available online xxx

Keywords:
Demand-side response
Time of use tariffs
Automation
Direct load control
Domestic
Smart grids

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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http://dx.doi.org/10.1016/j.erss.2015.08.023

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 control constructs (as reflected in the items used to measure them)

Please cite this article in press as: M.J. Fell, et al., Public acceptability of domestic demand-side response in Great Britain: The role of automation and direct load control, Energy Res Soc Sci (2015), http://dx.doi.org/10.1016/j.erss.2015.08.023