Making the least active pay: Rewards and penalties for Demand Side Participation programs

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Jacopo Torriti[a,*], Matthew Leach[a]

[a]*Centre for Environmental Strategy, University of Surrey, Guildford, GU2 7XH, UK*

Abstract

The orthodox approach for incentivising Demand Side Participation (DSP) programs is that utility losses from capital costs, installations and planning DSP should be recovered under financial incentive mechanisms such as the Cost Recovery Mechanisms and the Lost Revenue Mechanisms. These mechanims aim to ensure that utilities have the right incentives in place to implement DSP activities. The national smart metering roll-out in the UK means that this approach needs to be reassessed because utilities will already recover the capital costs associated with DSP technology and recoup them through higher bills or upfront fees. This paper introduces a penalty/reward mechanism focusing on consumers. The utility DSP planning costs are still recovered through payments from those consumers who do not react to price signals. In addition, those consumers who react to price signals, hence shifting loads, will be rewarded by paying less for their electricity consumption. Because real-time incentives to residential consumers tend to fail due to the neglictable amounts associated with net gains (and losses) for the individual consumer, in the proposed mechanism the regulator determines cumulative benchmarks which are matched against responses to price signals and caps the level of rewards/penalties to avoid market distortions. The paper presents an overview of existing financial incentive mechanisms for DSP; introduces the penalty/reward mechanism aimed at fostering DSP under the hypothesis of smart metering roll-out; considers the costs faced by utilities for DSP programs; assesses linear rate effects and value

[*] Corresponding author: Tel.: +44(0)1483682174; Fax: +44(0)1483686671; E-mail address: j.torriti@surrey.ac.uk

changes; and introduces compensatory weights for those consumers who have physical or financial impedements.

Keywords

Demand Side Management; Demand Side Participation; Electricity Demand

1. Introduction

High peak demand on the electricity grid creates significant impacts on system costs because of the need for higher marginal cost generation, higher cost system balancing and increasing grid reinforcement investment. Demand Side Management programmes use rates, incentives and other strategies to help better manage electricity use during periods of high peak demand (Bilton et al., 2008). Those Demand Side Management initiatives involving direct participation from the consumer side, which in this paper we call 'Demand Side Participation' (DSP) programs, can in principle bring about significant reductions in electricity prices, as demand-driven shifts of demand during peaks could reduce marginal costs (Faraqui, 2005). In practice, DSP programmes can only work upon two conditions. First, DSP can only operate in the absence of asymmetries of information. A constant exchange of information between the provider and the consumer via two-way communication systems should operate under price sensitive technologies. The roll-out of smart metering technology aims to reduce asymmetries of information by covering large portions of consumer population and ensuring immediate access to information regarding consumption (Torriti et al, 2010). Second, the demand side should respond to the signals inputted by the provider. There are various ways of fostering active demand participation, namely through changes in price structures, information programs and incentives. This paper focuses on the latter, focusing on rewards and penalties for the consumers.

The extensive theoretical literature on Demand Side Management agrees that one major reason why DSP programmes are not effective is because of the absence of electricity providers' incentives to use DSP (Wirl, 1995; Fisher, 2005; Faruqui et al., 2010). The existing literature is based on the concept that providers may see DSP programs as sub-optimal due to the losses associated with reductions in demand which exceed gains associated with marginal decreases in generation costs and imports. The orthodox rationale is that losses from capital costs, installations and planning DSP should be recovered under financial incentive mechanisms such as Cost Recovery Mechanisms, Lost Revenue Mechanisms. The case of massive smart metering roll-out in the UK, means that suppliers have already faced capital costs (about £340 per household) and recouped them from customers through higher bills or upfront fees.

We ensure that planning costs of DSP programs are still recovered so that providers make up for such costs by receiving payments from consumers for not reacting to price signals. In addition, those consumers who proactively engage in shifting their loads and significantly react to price signals will be rewarded by paying less for their electricity consumption. Because real-time rewards to consumers tend to fail due to the neglictable amounts associated with gains (and losses) for a single consumer (Dulleck and S. Kaufmann, 2004), in the approach presented here, the regulator determines cumulative benchmarks which are matched against responses to price signals.

This paper commences with a brief overview of existing financial incentive mechanisms for DSP (Section 2). It presents a price mechamism aimed at fostering DSP programs (Section 3). It considers the costs faced by utitlities for DSP programs (Section 4) and rate effects and value changes (Section 5). Since the objectives should be set in a way that proportionally penalises non-active consumers, the mechanism should guarrantee that consumers who have any sort of impedement to responsiveness will not pay excessively for their performance (Section 6). The conclusion reflect on the implications and challenges associated with the proposed mechanism (Section 7).

2. Financial incentive mechanisms for providers

Existing financial mechanisms by regulators to incentivise DSP programs focus almost exclusively on providers. It is assumed that providers will have to pay for the absence of technological investments in DSP. The idea behind the financial schemes in place in the United States, Canada, Australia and India is that losses from capital costs, installations and planning DSP should be recovered under mechanisms such as cost recovery mechanisms, lost revenue mechanisms and shared savings incentive mechanisms based on performance.

Cost recovery mechanisms are designed to eliminate the business incentive to underspend on DSP programs. They allow providers to recover the capital and installation costs. The utility's costs for DSP are usually "expensed," approved by regulators and sometimes amortised over several years. Interest is charged on under- or over- recoveries. Because under cost recovery mechanisms the providers costs are amortised over several years, the economic significance of load shifting is lost. In other words, the behavioural learning on the consumer side is very limited.

Lost revenue mechanisms pay providers back for the direct losses that they experience due to decreases in electricity sold. Lost revenues associated with reductions in total amounts of sold electricity are partly offset by a reduction or avoidance of variable costs -e.g., the cost of fuel for power plants. These should normally not be included in lost revenue mechanisms. The typology of opportunity costs often included in lost revenue mechanisms include recovery of all of the revenues that providers would have benefited from had they not promoted DSP programs. Lost revenue mechanisms are designed to make DSP revenue-neutral and eliminate the incentive to minimise savings from DSP. This leaves the provider financially indifferent to the level of DSP achieved. A practical example of lost revenue mechanism can be exemplified through the Lost Revenue Adjustment Mechanism, a means to compensate for lost revenues in Canada. In a given year, the provider calculates the amount of volume or kWh losses due to its own DSP programs. This must be calculated net of any efficiency trends occurring independently of DSP, since sales losses due to other factors would have been experienced anyway.

Lost revenue mechanisms are designed to make DSP revenue-neutral and eliminate the incentive to minimise savings from DSP. This leaves the provider financially indifferent as to the level of DSP that is achieved. The provider gets reward for its DSP losses. If services delivered go down as a result of DSP activities, all other things being equal, rates will go up so that costs may be recovered. This means that all consumers pay for lack of responsiveness. Instead, it would be much preferable if only the least responsive consumers had to pay.

Shared Savings Incentive Mechanisms are designed to provide rewards to utilities based on the effectiveness of socially beneficial DSP. These mechanisms can compensate for energy savings associated with DSP by making it possible for the provider to share the consumer net benefits from DSP programs. In principle, penalties for underperformance can also be part of a Shared Savings Incentive Mechanism, but have not been implemented. This creates a business case for sustainable DSP initiatives that promote energy efficiency on an evolving, adaptive, multi-year basis. A pre-condition of Shared Savings Incentive Mechanisms is that the regulator determines DSP target levels on providers. This can represent a forecasting problem under different (e.g. temperature) conditions that might induce peak loads. For instance, a share or percentage of actual DSP net benefits over the target level determined by the regulator can be apportioned to the provider in the form of a positive rate adjustment. In other words the aim of Shared Savings Incentive Mechanisms is to remunerate a provider to achieve more than DSP targets approved by the regulator. However, it is difficult to make incentives dependent upon objective verification.

In addition to the points raised above for each of the mechanisms, at least three common problems can be related to all three mechanisms. First, they all focus on network and generation capacity recovery rather than consumer learning. Incentives concentrate mostly on recuperation of costs on the provider side rather than ensuring that consumers improve their demand participation. Second, for all three mechanisms establishing the level of incentives for providers is challenging the first year. Third, they build on the hypothesis that capital costs associated with technological investment have to be met by providers. The model put forward in this paper transcends these problems by taking into account (i) consumer performance in terms of demand participation; (ii) a mechanism to determine the level of rewards and penalties based on previous period performance; and (iii) the hypothesis of technological investment not being included in the mechanism. The third point is typical of national roll-out plans, where the capital costs of smart meters are recouped from consumers through higher bills or upfront fees. In other words, rewards and penalties can be based on consumer responses to price signals and yet ensure that providers planning costs are recovered.

3. Penalty/reward mechanism

The economic agents involved in the DSP mechanism are consumers, utilities and a regulatory agency. Time runs in a discrete sequence of periods indexed by the period unit t. There are c consumers, producing c different responses to price signals typically under high peak periods. We assume that the market where the mechanism is introduced is competitive, so consumers take prices as given. The regualtory agency has the power to allow changes in prices under DSP programmes.

At the beginning of each period, benchmarks are established according to overall consumers' performance in the previous period. The benchmark (*Bn*) for the time t is obtained as a result of performance for the previous period using level of reward/penalty α:

$$Bn_t = Bn_{t-1} \times (1-\alpha_t)$$

If consumers overall reacted more frequently to price signals at the time $t-1$, than at the time $t-2$, then α will increase for the next periond t.

The level of α, where $0<\alpha<1$, for one period is dependent on performance in the previous period, according to standard incentive model (Ajodhia et al, 2006), based on the following regulator's problem:

$$\alpha_t = \max \left[\beta\%;\ 1 - \left(\frac{Meas_{t-1}}{Bn_{t-1}} \right)^{\frac{1}{t}} \right]$$

t: period

$Meas_{t-1}$: Measured consumer responsiveness for previous period

Bn_{t-1} : benchmark for previous period

β : minimum number of responsive actions that consumers can undertake for the period t

Each consumer will be faced with the choice to respond to price signals more frequently than the benchmark level in order to get rewards. If the consumer responds to price signals less frequently than the benchmark level the consumer will pay penalties.

The level of reward/penalty should be minimum *β%*. The minimum number of responsive actions that one consumer can undertake in one year can be determined as percentage of continuous annual supply. Contingent valuation surveys can help identify how much Brittish consumers are willing to pay and may help refine the parameters for determining the rewards/penalties ratio between for the baseline period. The WTP value can define the maximum number of responsive actions that one consumer can undertake in one year, as percentage of continuous annual supply.

Each period *t* consumers are rewarded or penalised according to their measured performance $Meas_{c,t}$. For instance, if a consumer reacted 7 times to 11 price signals by the provider to reduce or shift loads, then Meas=0.63. Unitary reward/penalty parameters are set *ex ante* at the beginning of the year. Reward and penalty parameters are capped:

$$\text{Min}(\alpha\_cap) \leq \alpha_c \leq \text{Max}(\alpha\_cap)$$

in order to limit volatility of retail prices. For every *t*, the price-cap reflects the changes in rewards and penalties. The incentive system is funded through penalties paid by those consumers whose responsiveness targets are not met, and for the net difference between rewards and penalties, through adding an R-factor in the conventional price-cap formula:

$$\text{price\_cap}_\alpha = \text{RPI} - \text{X} \pm \text{R}_{c,t}$$

where *RPI* represents the Retail Price Index and *X* are the expected efficiency savings. The subtraction *RPI-X* represents the conventional price-cap formula (Sibley, 1989), whereas *R* can be seen as the factor that varies *ex post* for each year *t* based on measured responsiveness:

$$R_t = \sum_{c=1}^{n} (Bn_{c,t} - Meas_{c,t}) \times \left[\frac{C_{gen}}{8760}\right]$$

R_t: responsiveness factor for the period t;

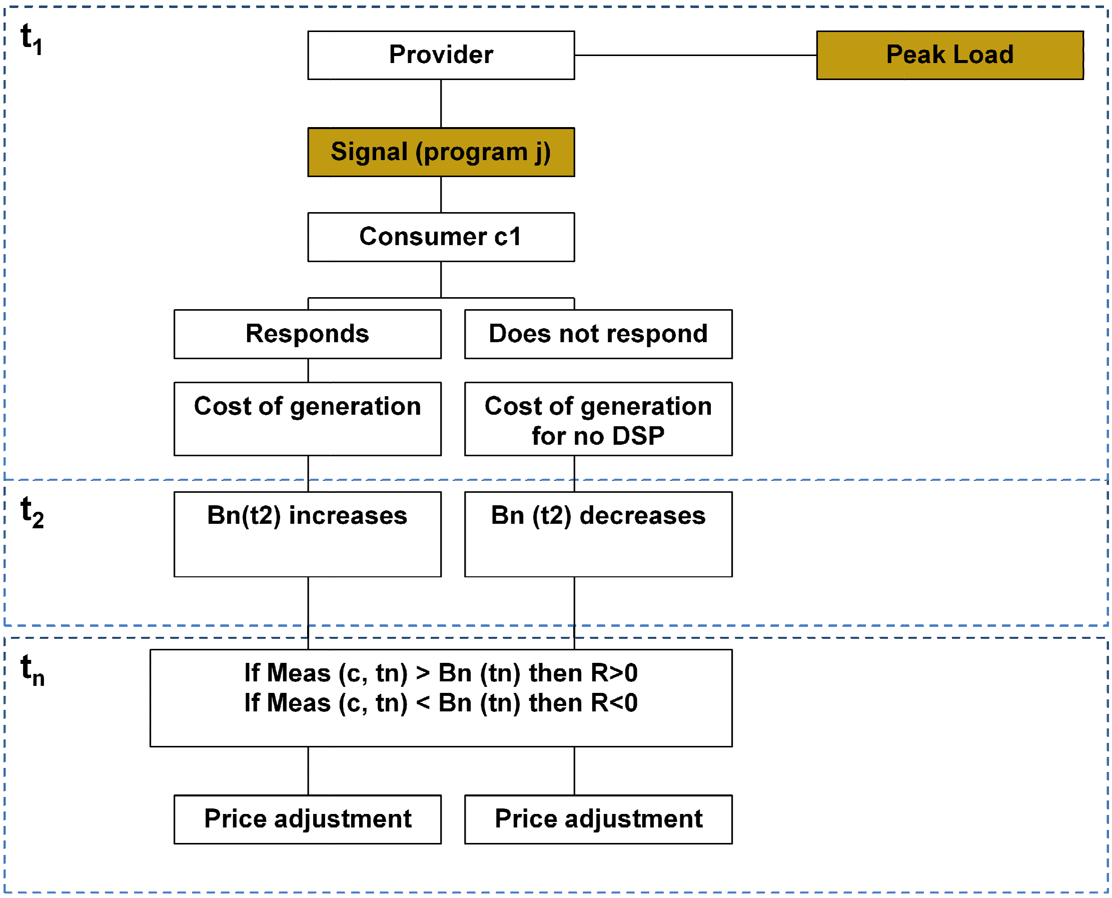
C_{gen}: generation cost (hr/kWh)

$Bn_{c,t}$: active demand participation benchmark set *ex ante* for each type of consumer c for each year t; consumer responsiveness is determined as

$Meas_{c,t}$: measured response activities for each type of consumer c for year t (in minutes)

The R factor for the period t is determined as a result of the sum of all benchmark levels minus measured consumer responsiveness multiplied by the provider cost of generation under DSP programmes.

Figure 1-DSP mechanism



Thus far we have defined the basic equations for determining the objectives of responsivess for individual consumers (benchmarks), levels of rewards (α_c) and cap values (price_cap$_{\alpha}$). The mechanism consists of price signals from the provider in case of peak loads, when C_{gen} is higher than usual at the time t_1. The signal is inputted through the DSP program j to the consumer c who decides whether to respond to it (in which case $Meas_{c,t}$ increases) or not (in which case $Meas_{c,t}$ decreases). Determining C_{gen} is vital in order to assess α_c as well the efficiency of the DSP programme according to the provider.

4. Costs for providers

This section investigates the cost of planning DSP programs attributable to each customer c for not responding to price signals. How much each provider will spend can be determined as non-DSP cost of generation plus cost of DSP values:

$$C_{gen} = \sum_c c_c\, G_c + \sum_j [(1 - \alpha_j) d_{uj}]\, DSP_j$$

G_c: generation for consumer c (MW)
c_c: generation cost, consumer c (£/MWh)
DSP_j: energy savings from DSP program j (MW)
d_{uj}: provider cost for DSP program j (£/MWh)
α_j: percentage of provider cost consisting of rewards (e.g. monetary transfers) to participants in programme j

The formula quantifies the generation cost which becomes necessary for consumer not responding to price signals ($\sum_c c_c\, G_c$, which includes increasing loading cycles, start-up and shut-down costs of power systems), and the avoided savings from DSP with a % of provider costs consisting of rewards to participants ($\sum_j [(1 - \alpha_j) d_{uj}]\, DSP_j$).

The formula provides cost to the provider of generation and DSP actions. It provides a simple and fair characterization of the dynamics for valuing generation. However, it ignores details with regards to temporal variability of loads, costs and generator availability. This is because some of the capital costs necessary for DSP technologies are already met via recouping costs of smart meters. Scale economies in DSP programmes and non-linear heat rates are not taken into account. Complications associated with interaction between different

DSP programmes, energy-limited units and storage are not considered because they are not necessary for the purpose of this model, which is to show how changes in total value can be included in the reward/penalty mechanism.

In terms of generation costs, each provider is disposed to pay according to an α_j percentage to responsive consumers for programme *j*, as follows:

$$\alpha_j = \frac{(\mathrm{Cgen} - \sum_c c_c\ G_c) \sum_j (d_{uj})\ DSP_j}{n}$$

Where n is the number of DSP programmes implemented by the provider. Compared to the estimate of α_c made by the regulatory agency, the provider choice on α_j is characterised by cost minimisation constraints. While the regulator faces an effectiveness problem (i.e. maximising rewards and penalties, while keeping weak consumers safe), providers face an efficiency problem (i.e. finding the right level of rewards to DSP programmes). How can these two different problems be reconciled?

Firstly, the responsiveness factor should include the cost of generation faced by utilities:

$$R_t = \sum_{c=1}^{n} (Bn_{c,t} - Meas_{c,t}) \times \left[\frac{\sum_c c_c\ G_c + \sum_j [(1-\alpha_j) d_{uj}]\ DSPj}{8760} \right]$$

Secondly, the two different levels of rewards should be made equal in order to calculate the appropriate level for the decision variable G_c:

$$\frac{(\mathrm{Cgen} - \sum_c c_c\ G_c) \sum_j (d_{uj})\ DSP_j}{n} = 1 - \left(\frac{Meas_c^{\frac{1}{z}}}{Bn_c} \right)^{\frac{1}{t}}$$

All loads must be met either by normal generating power or additional generating power. Hence, the model includes the following demand constraints and upper bounds on the provider's decision variables G_c and DSP_j:

$D = \sum_j DSPj + \sum_c G_c$

$0 \leq G_c \leq cap \quad \forall\, c$
$0 \leq DSP_j \leq D^* \quad \forall\, j$

Where D is the total demand, i.e. the sum of non participating loads (loads that would not be directly affected by any DSP programme) and potential participants that would not be eliminated by any DSP programme; D^* is MW demand by potentially participating programmes that would be eliminated if DSP measures are implemented. The constraints limit unit generation and the size of the DSP programme and cap is the capacity of generating unit *c*.

5. Rate effects and value changes

The above mechanism does not take into account the effect of costs on rates and loads. The costs estimated by the above model are fed into a financial mechanism that calculates rates according to a penalty/reward mechanism. If the resulting rates differ from those assumed in forecasting the loads in the reward/penalty mechanism, then those loads could be adjusted. Rate determination can be made internal to a model by adding a restriction, e.g. a revenue requirement equation (Braeutigam and Panzar, 1993). This restriction specifies that the revenue received by the provider should cover its cost plus any consumer rewards that might be offered, for example, for pursuing DSP. For simplicity, the complications of multiple customer classes and nonlinear rate schedules will be ignored.

$$P\ (Q - \sum_j DSP_j) = (k + \sum_c c_c G_c + \sum_j d_{u,j}\ DSP_j)$$

P: Price of electricity (£/MWh)
k: capital and fixed operations and maintenance costs to be recovered from rates (£/h)
Q: potential MW load (MW)

The left term is the provider's revenue and the right term is the provider's cost. It means that price times actual MWh load, equal to the potential load Q minus savings due to DSP programmes. Calculations related to rate-induced changes in loads are essential both for accurate estimates of the costs of serving those loads and to understand how these would affect the total value received by consumers.

6. Weights for disadvantaged electricity consumers (physical and mobility disabilities, severe illness, number of dependent children)

The incentive/payment scheme implies that consumers are tasked with the objective of improving the way they respond to price signals year by year. The pressure on active participation would be high on all types of consumers. However, the regulator might want to protect those consumers who for various reasons have limited ability to respond when it comes to shifting loads. Weights should be included in the scheme to compensate the negative distributional impacts associated with the introduction of the incentive/payment scheme, particularly on disadvantaged electricity consumers. One of the criticalities of incentive-payment schemes is that they might increase disparities by penalising those who strive to pay energy bills. Elements of impedement to responsiveness (e.g. physical and mobility disabilities, severe illness, number of dependant children) could be factored into the mechanism:

$$\alpha_t = \max\left[\beta\%;\ 1-\left(\frac{\mathrm{Meas_{t-1}}^{\frac{1}{z+y+x}}}{\mathrm{Bn_{t-1}}}\right)^{\frac{1}{t}}\right]$$

where z is the disability rating; y is the number of days per year of severe illness; and x is the number of children per parent. Although allocative efficiency is less tangible than productive efficiency, the introduction of weights for disadvantaged electricity consumers might be as important for the success of mechanism as rates charged for non-disadvantaged consumers.

7. Conclusions

The paper responds to the double need identified in the existing Demand Side Management literature to create sufficient incentives to providers for planning programmes (Schultz and Lineweber, 2006) and to establish a regulatory framework to optimise the potential of DSP (Strbac, 2008). Unlike other existing rewards/penalty mechanisms which focus on the provider as the agent who should be incentivised to trigger DSP, the proposed mechanism is centred on consumers. It assumes that most of the capital costs associated with DSP have been (or will be) paid for as in the case of the smart metering roll-out in the UK.

Incentives mechanism can only be successful if they combine incentives for cost reductions with freedom on price balancing (Vogelsang, 2002). The effectiveness of the mechanism is likely to depend on the capacity of measuring consumption decreases following a peak signal. Existing models on time of use (see Richardson et al, 2008) suggest that monitoring of domestic consumption in 10 minutes interval might be able to capture responses to signals. Further research is needed to establish what level of peak reduction (in kWh) could be considered a sizeable response to the price signal.

One of the criticalities of the DSP mechanism is the shift in risks both for providers and consumers. Providers will bear additional risks, because if their planning costs rise, their profits will fall because they cannot raise their prices to compensate for the cost increases. Only financially advantaged consumers might be able to benefit from the DSP mechanism and take the risk of paying higher bills for poor performance. One way to prevent the first criticality is to ensure that at consistent intervals (e.g. under the Price Control Review) the regulator reviews the objectives for the levels of rewards and penalties, as it occurs under the Quality of Supply regulation. In order to prevent the second criticality and encourage active demand participation of all residential consumers, while limiting volatility in the market and protecting 'weaker' consumers, objectives should be set so that different benchmarks should be applied to different consumers.

The mechanism presented in this paper assumes a completely new type of consumers. The "responsive" consumers will have their performance measured and will either save or pay depending on the improvements to their active DSP.

Further research in the spheres of environmental psychology and sociology is needed to understand issues of acceptance of such mechanism and behavioural risks from a consumer perspective.

In conclusion, while this paper presented the features of the reward/penalty scheme, further research is planned to apply the model to an occupancy simulation platform. The following research steps will be undertaken in order apply the model to an occupancy simulation platform: (i) taking a sample of households based on real occupancy data; (ii) running occupancy simulation to get time of use profiles for different levels of occupancy aggregate population; (iii) identifying peaks by supposing peak signals are sent at those times; (iv) applying stochastic results from smart metering trials; (v) taking levels of responses (in % of responses by users to peaks) as inputs for reward/penalty scheme; and (vi) running penalty reward scheme for 2-3 periods to see what levels of penalty/reward are reached.

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