Peak Load Habits for Sale? Soft Load Control and Consumer Preferences on the Electricity Market

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ABSTRACT

The main purpose of this paper is to estimate lost consumer values due to various restrictions on household electricity use involving behavior adaptation. To do this, we conduct a choice experiment where households choose between hypothetical electricity contracts including various restrictions on the use of high-power household appliances. In addition, we use a contingent valuation question related to complete blackouts to study a restriction on other types of electricity usage (heating, lighting, TV, etc.). The results indicate a significant difference between the value lost due to the soft control, and the blackouts. Furthermore, policies aiming at stimulating behavioral changes are costly and it is far from obvious that demand response requiring behavioral adaptation is more cost effective than supply response (i.e., increased production of electricity).

Keywords: Value of lost load, Choice experiment, Electricity contracts, Demand response

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1. INTRODUCTION

In Europe, and elsewhere, electricity markets are changing and the transformation is characterized by three key factors: (i) deregulation of electricity markets, (ii) new technologies with respect to generation, distribution and use, and (iii) substantial changes in the production mix as a result of energy and climate policy as well as changes in relative production costs for different technologies. These factors in combination with a rigid demand side characterized by daily and seasonal consumption patterns, and consumers that are not exposed to the time of use marginal generation cost, have raised concerns about security of supply. Because of this concern, there is an ongoing discussion of whether energy-only markets, which are the most common market design, should be complemented with a capacity mechanism to ensure enough generation in peak periods (Joskow, 2008a, 2008b; Eurelectric, 2015; Newbery, 2016). Related to this is also the discussion of demand management and demand flexibility, which can be seen as part of such a capacity mechanism (Strbac, 2008; Broberg and Persson, 2016).

The Swedish electricity generation structure with about 85% hydro- and nuclear power contributes to a relatively flexible and robust power system with modest climate impacts. Nevertheless, the current Swedish interest in demand flexibility is driven by future challenges mainly related to further integration of European electricity markets and the Swedish target of 100% renewable

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electricity production by 2040. The Swedish aim to increase the share of renewable electricity inevitably leads to a large share of intermittent sources such as solar and wind, while the market integration may lead to less control of domestically produced electricity.

In line with these observations, the main objective of this study is to estimate Swedish household's willingness to accept load restrictions for electricity use during peak hours. Two types of load restrictions, or control, are considered: "soft control," which refers to a temporary restriction in the maximum possible load (in watt) for high-power appliances and installations; and "hard control," which refers to a complete loss of power for 30 minutes during peak time. We use a stated preference approach asking electricity consumers to choose between hypothetical electricity (delivery) contracts with different attributes concerning maximum load during a specific time of the day. Each hypothetical contract is appended with a monetary compensation, enabling an estimate of the monetary compensation required for load restrictions. The resulting monetary compensation for the "soft" load control can be interpreted as the value of potential lost load (VoPLL), whereas the monetary compensation for complete loss of load corresponds to the value of lost load (VoLL).

We contribute to the previous literature and the policy discussion in two ways. First, the results of the analysis elicit consumer preferences for demand flexibility, and hence the potential for demand side management (DSM). Second, the analysis gives estimates of VoPLL and VoLL, which is of paramount importance if/when explicit capacity mechanisms are considered. Any capacity mechanism should be designed such that the optimal level of supply security is reached cost-effectively, for which information about the value of lost load is needed (Ovaere et.al. 2019). In addition to these two contributions, we explore households' power consumption for home appliances in the peak hours. A better knowledge of household habits and consumption patterns is important not only for determining the potential for demand response, but also for determining the costs in terms of utility losses associated with curtailment actions. Importantly, this analysis is based on respondents' reported consumption patterns.

The stated preference approach is commonly used in situations where market values do not exist (Johnston et al., 2017). Several applications in the previous literature relate to assessment of the utility loss following a power outage, i.e. estimation of VoLL (e.g. Doane et al., 1988; Beenstock et.al., 1998; Layton and Moeltner, 2004; Carlsson and Martinsson, 2007; Carlsson et al., 2011; and Reichl et al., 2013). Recently, stated preference approach has also been applied to study demand flexibility (Parsons et al., 2014; Broberg and Persson, 2016; Daniel et al., 2018; and Richter and Pollitt, 2018). Despite its documented weaknesses,[1] the stated preference approach is used in these contexts to overcome difficulties in estimating consumer surplus from electricity consumption using price and quantity data.[2]

The reminder of the paper is structured as follows. Section 2 provides an extended background and motivation underlying the research questions in focus, as well as a review of the related literature. Section 3 includes a conceptual framework with explanations of VoLL and VoPLL. Section 4 provides descriptions of the methodological approach and data used in the empirical analyses. The empirical results are presented in Section 5. Section 6, finally, is devoted to a discussion and concluding comments.

1. It is well-known that stated preference results must be carefully interpreted and communicated as they may be subject to hypothetical bias (Ready et al., 2010; Loomis, 2011) and framing effects (Hanemann, 1991).

2. Estimated demand functions are usually only defined in the segment of observed prices. A power outage corresponds to a situation where the price is so high that households do not want to use any electricity. To our knowledge, such high electricity price has not been observed in any country.

2. BACKGROUND AND PREVIOUS RESEARCH

DSM in Sweden has targeted large industrial electricity consumers at moments of imminent power shortages. These moments have typically occurred on days with high power consumption due to exogenous factors, sometimes combined with problems in the power grid or in large-scale nuclear power production. The balancing of intermittent power production, however, requires more adaptable resources that can be activated at short notice during any times of the year. In general, large industrial plants are ill-suited to provide such continuous (dynamic) demand response due to their relatively high start/stop costs. For that reason, interest has shifted towards the household sector (Torriti et al, 2010). The household sector in general, and detached and terrace houses in particular, may have a large potential in this context.

The basic idea is that DSM programs can be used to create timely load shifting/saving among households. Contracts can be designed so that households are financially compensated if they reduce their power demand at moments when the stability of the power system is threatened. Such contracts may be designed in different ways, but ultimately part of the load is controlled remotely by an external actor (Babar et al., 2014).[3] In the contractual context, a central role is given to aggregators that mediate energy services between suppliers, grid owners and end users. The role of the aggregator is to consolidate the fragmented supply of household power services and package it into products that can be sold on the spot market or the regulating markets.

At the household level, demand response can work through automatic response and/or through behavioral changes. Activities related to automatic response can be referred to as efficiency activities, and those related to behavioral changes to curtailment activities (see, e.g., Gardner and Stern, 2008). Examples of the former are electricity and appliances for heating, the refrigerator and the freezer, which to a large extent are regulated automatically. Examples of the latter are high-power appliances like the kitchen stove and the coffee machine, and low-power appliances like lighting and computers. Since many single- and two-dwelling buildings in Sweden are heated by electricity, automatic response of heating systems has a significant potential to help balance fluctuations in the power system (EI, 2016). For demand response through curtailment activities the story may be different because it requires a behavioral change.

Previous research reveals that people demand substantial economic compensation to engage in DSM programs. For example, Broberg and Persson (2016) finds, in a choice-experiment study, that people very much dislike restrictions on the use of household appliances during the evening peak hours. In a related context, there is extensive research related to estimating the value of lost load (VoLL). In general, results from the VoLL literature confirm the findings in Broberg and Persson (2016) that people and firms assign a relatively high value to have access to electricity. In a review, Van der Welle and van der Zwaan (2007) find that the average value for developed countries is in the range 4–40 $/kWh, but also that the value differs substantially between sectors and countries. In a more recent review, Schröder and Kuckshinrich (2015) conclude that VoLL varies substantially within, as well as between, end-user groups, countries and estimation methods. Their reported values range between a few €/kWh to more than 250 €/kWh for non-household end-users and between a few €/kWh and 45 €/kWh for households. Overall, the review reveals that the VoLL

3. Both dynamic pricing schedules and DSM programs can be designed to cost-effectively stimulate demand response. One obstacle for trade with DSM products is that it may be difficult to verify that load curtailment really has taken place. Verification is thus necessary for trade to result in power reductions that are equalized with power production (Borenstein, 2014). On the other hand, DSM programs may be easier for customers to handle, especially if the targeted loads are automatically controlled and the curtailment not noticeable to customers.

is very situation- and time specific, implying that when, where and for how long a blackout occurs are important determinants. The review also reveals that the methodology used to estimate VoLL may explain differences in results. For household end-users, it seems like studies based on the stated preference approach tend to result in lower estimates than indirect approaches, e.g. using a household production function to measure VoLL in terms of the lost value of leisure time (for an example see de Nooij et al., 2007).

The VoLL for Swedish households has been estimated several times using the stated preference approach. Carlsson and Martinsson (2007) and Carlsson et al. (2011) use an open-ended contingent valuation question and estimate that Swedish households on average are willing to pay about € 0.5–22 to avoid an unplanned blackout at 6 pm wintertime with the duration of 1, 4, 8 or 24 hours.[4] These fairly low WTP estimates are to a large extent driven by the large share of respondents stating zero willingness to pay for avoiding a blackout.[5] In a similar study for Sweden, Carlsson and Martinsson (2008) employ a choice experiment approach to elicit the average willingness to pay for avoiding an unplanned power outage that could happen any time of the day on a weekday or a weekend either November-March or April-October. The results show that the WTP differs between weekdays and weekends and that the season only matters for a 24-hour power outage: the WTP for avoiding a 24-hour power outage in the cold and dark season is slightly higher than a power outage in the relatively warm and bright season. Overall, their WTP estimates for avoiding a power outage on a weekday lasting for 4 to 24 hours range between €0.7–10. These estimates may seem surprisingly low but are partly explained by the scenario used in their choice experiment in which power outages with different durations are avoided during a five-year period.

The analyses presented in this paper differ from the above-mentioned literature in several ways. Our hypothetical DSM program is characterized by controlling the maximum level of load at the household level. That is, instead of a strict focus on VoLL, we also report on values of potential lost load (VoPLL). In essence, VoPLL captures the value of a secure and sufficient power supply to the household. From the household perspective, VoPLL is the expected disutility of not being able to use all of their loads as they are used to. The expected disutility stems both from actual load shifting, but also a loss of option value. The option value could be interpreted as the possibility to use an appliance or installation when needed. Note that a given limit in load is not necessarily binding at all times. By definition, or at least by logic, VoPLL must be lower than VoLL, and is thus more relevant for analyzing demand response. Using the method of contingent valuation, we however also estimate the average monetary compensation required to accept five 30-minute blackouts during the winter season. Given the specific design, we estimate VoLL while also assessing the relative importance of different categories of household appliances and installations not covered by our soft control scenarios (VoPLL). In this way, we obtain measures of several levels of restrictions and, in addition, we are able to make comparisons to the related (VoLL) literature.

The hypothetical DSM-program studied in this paper focuses on short restrictions at specific times during the typical peak hours of the day and year: 0.5–3 hours for the soft load control of high-power appliances and 30 minutes for the blackouts. The focus on shorter periods of restrictions is motivated by our expectations on how future DSM programs may function. Based on previous research, we expect people to require compensations for engaging in extended curtailment activities that are substantially higher than the cost associated with supply-side flexibility (Broberg and

4. A relevant comparison can be made to the compensation of at least €90 that the distributors by law must pay each household experiencing a 12–24-hour blackout (https://www.ei.se/sv/for-energikonsument/el/Elnat/elavbrott).

5. 90% of the respondents stated a zero willingness to pay for a one-hour outage, and 40% stated zero for a 24-hour outage (Carlsson and Martinsson, 2011).

Persson, 2016). It is therefore unlikely that there will be a notable market for extended curtailment activities. Another motivation for the set-up here is that we want to relate to the VoLL-literature where it is often assumed that a power outage, or blackout, lasts for several hours, although they often are shorter than one hour, at least in Sweden (see EI, 2016).

Furthermore, our analysis also differs from many previous studies by asking for the willingness to accept a restriction (or blackout) instead of the willingness to pay to avoid a restriction, as in Carlsson and Martinsson (2007, 2008) and Carlsson et.al. (2011). Previous VoLL-related literature comparing WTP and WTA measures using the stated preference approach suggest that the latter measure is significantly higher (see e.g. Doane et al., 1988; Hartman et al., 1991; Beenstock et.al., 1998; Praktiknjo, 2014).[6] We argue that a WTA-framing is logical as the market-based DSM program that we study requires that household's voluntary accept personalized restrictions that cause utility losses. A WTA-framing may also potentially lead to fewer protest answers concerning blackout scenarios, and provide estimates that are more in line with actual preferences. The reason being that a respondent that have signed a contract with the distributor may perceive that the latter has an obligation to deliver, and requiring a payment for avoiding more interruptions in delivery may therefore be provocative (Willis and Garrod, 1997).

3. CONCEPTUAL FRAMEWORK

In our scenario, a household know that their maximum load will be constrained a certain number of days during the winter season at 6 pm, and that the constraints will last for 0.5–3 hours (centered at 6 pm). The exact days when the constraint occur is however not known. The household's electricity use varies over days, due to both deterministic and stochastic factors, and they form expectations about if, and to what extent, the constraints will affect them. Hence, it is the households actual load at the time of the load constraint that is uncertain and not if the constraint will take place or not.

Conceptually, we think of the household's demand for electricity as being a function of the electricity price, living habits/preferences, and various external factors such as e.g. temperature, precipitation, darkness and traffic conditions. Some of these factors are uncertain to the household implying that its demand for electricity during the peak hours is stochastic (uncertain).[7] Given these assumptions, the inverted demand function, or willingness to pay function, for the household can be written as:

$$p = p(q, x, \theta) \tag{1}$$

where p is willingness to pay, q electricity quantity, x household characteristics and other deterministic demand factors, and θ is a stochastic component with a known distribution.

If the price for electricity is p^*, VoLL for the household is defined as the expected change in consumer surplus (CS) that follows from a power outage ($q = 0$) in line with:

6. The issue of WTP vs. WTA has been widely discussed in literature. Standard theory suggest that the two measures should be equivalent in case of small or no income effects (Randal and Stoll, 1980). However, empirical results show that the WTA not having some good tend to be several times higher than the WTP for acquiring the same good, especially if the valued good is far from an ordinary private good (Horowitz and McConnell, 2002). The WTP/WTA disparity has been explained by large income-effects and low complementarity between the valued public good and a composite private good (Hanemann, 1991) and loss-aversion among consumers (Kahneman and Tversky, 1979).

7. Weather conditions, timing of cooking etc. define different states that occur with different probabilities, and therefore, the utility derived from energy usage is state contingent.

$$VoLL = E\left[\int_{q=0}^{k(\theta)} (p(q,x,\theta) - p^*)dq\right] = \int_{\theta=m1}^{m2} CS(q,x,p^*,\theta)\cdot g(\theta)d\theta\,, \tag{2}$$

where k, the upper limit of the unconstrained level of consumption, depends on θ, the stochastic component, and $g(\theta)$ is the density function for θ with limits $m1$ and $m2$. The upper limit, k, is the quantity where marginal willingness to pay, $p(q,x,\theta)$, equals the (certain) consumer price for electricity.

In the questionnaire, we ask households about their willingness to accept a temporary load constraint larger than zero ($\overline{q} > 0$). As the household's demand for electricity in the peak hour is stochastic, we define the potential lost load as the expected loss in consumer surplus because of the load constraint as:

$$VoPLL = E\left[h\cdot\int_{\overline{q}\geq 0}^{k(\theta)} (p(q,x,\theta) - p^*)dq\right] = \int_{\theta=m1}^{m2} CS(q,x,p^*,\theta)\cdot g(\theta)d\theta\,, \tag{3}$$

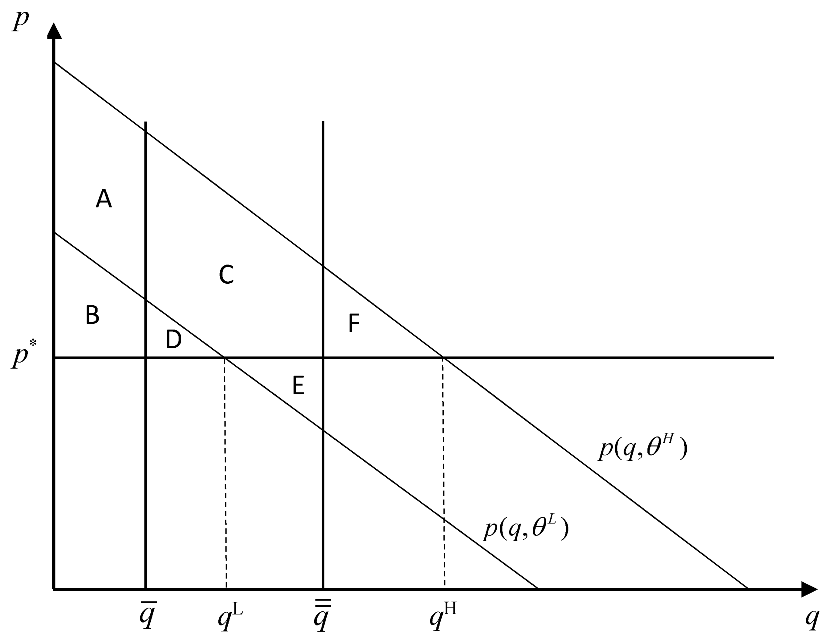
where h is a variable that equals one if $k > \overline{q}$, and zero if $k \leq \overline{q}$. The latter follows from the fact that the constraint is not binding if k lies below the maximum allowed level. Therefore, the loss of consumer surplus is zero.

An illustration is given in Figure 1, where the demand can be in two states: high demand (H) or low demand (L), with probabilities s and (1-s) respectively. Furthermore, as above, if the constraint is not binding there is no loss of consumer surplus. Given a load constraint equal to $\overline{q}$, the expected loss in consumer surplus equals:

$$VoPLL = s\cdot\left[h\cdot\int_{\overline{q}}^{q^H} p(q,\theta^H)dq - p^*(q^H - \overline{q})\right] + (1-s)\cdot\left[h\cdot\int_{\overline{q}}^{q^L} p(q,\theta^L)dq - p^*(q^L - \overline{q})\right], \tag{4}$$

illustrated by the area C+D+F times the probability for the high demand state, plus the area D times the probability for the low demand state. From Figure 1, the expected value of this limited load

Figure 1. VoPLL and VoLL in terms of consumer surplus.



constraint is lower than VoLL, i.e. when consumption is set to zero.[8] If the load constraint is more lenient ($\overline{\overline{q}}$), the term within the second bracket in Eq. 4 equals zero ($h = 0$), and the expected loss of consumer surplus becomes lower.

4. METHODOLOGICAL APPROACH AND DATA

4.1 The choice experiment

To estimate VoPLL, we introduce choice situations with hypothetical contracts for demand side management where at least one contract contains a temporary maximum load restriction, as well as a monetary compensation. A contract involving load restrictions can be defined by many attributes. However, for different reasons the number of attributes must be limited. First, it is important to consider the cognitive limitations of the respondent in respect of the complexity of the issues being investigated. Second, it is important that the suggested contracts are reasonable and realistic from the respondent's point of view. Considering this, our hypothetical contracts center on four attributes related to load control, and one attribute in the form of a monetary compensation. The attributes and their respective levels are described in Table 1. The attributes define the maximum high-power load that the household can use ("load control"), the number of electricity interruptions during the winter season that will occur ("days"), the duration of each interruption ("duration and timing"), whether there is flexibility in which appliances that will be curtailed ("choice of appliances"), and the size of the monetary compensation ("monetary compensation").[9]

Table 1: Contract characteristics.

Attribute	Description	Levels
Load control	Equipment will be installed to monitor and restrict the use of electricity. During the restriction, your household must adapt and consume accordingly. If not, the main fuse will blow. Only the appliances mentioned in the previous questions are considered for the restriction.	Max 2,000 watt Max 3,500 watt Max 5,000 watt
Choice of appliances	During any restriction your household is free to choose which appliances to use within the limit or not. If not, you are bound to use the chosen appliances in the previous question. Irrespectively of whether or not there is flexibility, you still need to adapt to the total load control.	Pre-specified Flexible
Duration and timing	The duration of restriction may vary between contracts. The specific hours are defined in the contract.	5.30pm–6pm 5pm–6.30pm 4.30pm–7.30pm
Days	The restriction on electricity use will occur on a given number of days during December through February. Restrictions will only be on weekdays but may be spread across separate days.	5 days 10 days 20 days
Monetary compensation	Your household will be given a monetary compensation for the given period of load control.	SEK 300 SEK 750 SEK 1,500 SEK 2,500

Importantly, any restriction on electricity use will be communicated the day before at 3pm. In addition to restrictions specified in the contracts, random disruptions (just like today's situation) may still occur.

Prior to the table, the respondents were informed that they were soon to be faced with hypothetical contracts. They were also informed that the purpose of the contracts was to restrict the

8. VoLL is the area A+B+C+D+F times *s*, plus B+D times (1-*s*).
9. The currency used in the survey is Swedish crowns, SEK, and the exchange rate is about SEK/EURO=10.

use of electricity for a given compensation during times when the grid is stressed. It was mentioned that the restricting contracts contribute to a more reliable supply of electricity in general. Moreover, the actual choice of appliances considered for the specific attributes was explicitly linked to the previous questions in the questionnaire. An example of a choice card is given in Figure 2.

The hypothetical contracts were tested in focus groups and two pilot studies (including 100 respondents each). The pilot studies served as inputs in the explicit design of the final versions of the hypothetical contracts.

Figure 2. Example of choice card.

Which of the following A, B or C contracts would you choose if offered to you? Unless otherwise stated in the agreement, everything else works as today, for example, the electricity price you pay and how often it changes.			
	Contract A	Contract B	Contract C – as today
Load control	5000 watt	3500 watt	As today
Choice of appliances	Pre-determined given the load	Flexible given the load	As today
Duration	4.30pm-7.30pm	5pm-6.30pm	-
Number of days	5 days	20 days	-
Compensation	2500	750	-
My choice	[ ]	[ ]	[ ]

By design, each respondent was faced with eight choice sets, where the attribute levels were varied in a statistically efficient way.[10] This implies that the number of choice observations equals the number of respondents times eight. Each choice set implies a discrete choice between two hypothetical contracts and the status quo contract. In the behavioral process, it is assumed that each contract corresponds to a specific utility level and that the respondent chooses the alternative that provides the highest expected level of utility. The data generated translates to the probability of choosing a specific contract, given the attribute levels characterizing the contracts. The analysis of this type of data is typically done within the logit framework. The multinomial logit model (MNL) is based on a rather strong assumption that unobserved factors affecting the choice of alternatives are independent. Unobserved factors affecting the utility of each respective contract may however be correlated with observable factors included as attributes in the experiment and it has become common practice to instead analyze the responses in the random parameter logit (RPL) framework. The RPL model is a more general version of the MNL and allows unobserved factors underlying choices to be random and to follow a pre-specified distribution; see e.g Train (2009).

In general, individual (or household) q's utility from choosing contract (alternative) j can be defined as[11]

$$U_{qj} = \beta_q' X_{qj} + \varepsilon_{qj} \tag{5}$$

10. The total number of different choice sets was 16 and the respondents were divided into two blocks to reduce the cognitive burden. The design of the choice sets was decided by simulating a choice model based on Bayesian priors using the software Ngene. The design with the lowest D-error was chosen.

11. Without loss of generality and for interpretational convenience, the panel structure of the data (repeated choices) has been left out in the model description. The panel structure is however considered in the estimation.

where X_{qj} is a vector of observables related to the alternative and the respondent (including alternative specific constants), β_q is a corresponding vector of parameters representing taste, and ε_{qj} is an error term. Given an assumption of homogenous preferences (taste), i.e. $\beta_q = \beta$, and that the error term is independent and identically distributed extreme value type-1 with variance $\pi^2 / 6$, the probability for choosing alternative i would be of the standard logit type defined as:

$$L_{qi}\left(\beta\right) = \frac{\exp\left(\beta' X_{qi}\right)}{\sum_{j=1}^{J} \exp\left(\beta' X_{qj}\right)} \tag{6}$$

The RPL specification however allows for heterogenous preferences and correlation between unobserved factors influencing choices. This is done by introducing a vector of parameters that instead vary randomly over individuals and is characterized by a joint density function $f\left(\beta|\Omega\right)$, where Ω represents underlying distributional parameters such as the mean and variance. The individual parameters are however unknown and the probability defined by equation (6) is not applicable. The probability is instead defined as the integral of the standard logit probabilities, $L_{qi}\left(\beta\right)$, over all possible values of coefficients:

$$P_{qi} = \int \frac{\exp\left(\beta_q' X_{qi}\right)}{\sum_{j=1}^{J} \exp\left(\beta_q' X_{qj}\right)} f\left(\beta|\Omega\right) d\beta \tag{7}$$

where β_q represents individual taste among the respondents. The distribution for the parameters can take on any form such as normal, lognormal, triangular. In the present study, there is no prior information concerning the distributions and the normal is therefore used.

The output from the RPL model described above gives (i) estimates of the parameters with corresponding standard errors and (ii) the standard deviation of each random parameter reflecting preference heterogeneity. In general, the interpretation of the parameters as such is analogous to the standard logit measuring the effect on the likelihood of choosing an alternative (although the absolute numbers require a transformation to be directly comparable). A statistically significant standard deviation is interpreted such that the parameter actually varies across individuals and preference heterogeneity is present.

By including a monetary compensation in the contracts, it is possible to normalize preferences to willingness to accept (WTA) measures. The marginal WTA is the monetary compensation required to move from the opt in base, or reference, contract to a contract with the specified attribute level. The marginal WTA is calculated as the ratio of the preference for the respective attribute and the compensation attribute. In principle, and by the econometric specification, we allow for negative compensation levels.[12] In the analysis, the models are specified such that all the attribute levels except the monetary compensation are dummy coded. The reference levels are "5,000 watt," "pre-specified appliances," "5.45pm–6.15pm" and "5 days," respectively. This means that the marginal WTA reported for, say, 2,000 watts translates to how much compensation, on average, the respondents require to accept the corresponding one-dimensional move from the reference levels.

The attributes defined in Table 1, and their respective effect on choices, may to some extent be correlated. First, the load control is a prerequisite for the other attributes, which motivates the dummy coding structure defining a reference case as a combination of attribute levels. The other attributes are simply not relevant without the load restriction. Second, it is possible that there is a link, or interaction mechanism, between the attributes. The level of restriction may matter for the

12. Although unlikely, it is possible that households may be willing to pay for a restriction in their use of electricity.

disutility of, say, duration. For example, a longer duration is probably worse if it is combined with a stricter load control. To be more complete in our analysis, we therefore present results from estimation of both a main effects only specification and a specification allowing for interactions between the 2,000 watt restriction and the levels of the other attributes in the contract.

4.2 The contingent valuation scenario

In eliciting preferences related to full blackouts, the contingent valuation method is adopted. [13] The choice experiment approach described above is attractive in its potential to simultaneously cover several dimensions of a hypothetical scenario. As described, it is possible to separate the preferences for the different attributes and their respective levels. If this is not of particular interest, but instead the focus is on the preferences concerning a specific "package" of characteristics, the contingent valuation approach is more appealing, due to its simplicity relative to the choice experiment.

After the choice experiment questions, respondents were faced with a question related to full blackouts. It was explained to the respondent that the household would receive a monetary compensation if they accept that the electricity is cut for 30 minutes, 5 times during the period of December through February. It was made clear that all electricity would be cut, i.e., a blackout, and that it would be at 5.45pm–6.15pm on weekdays. It was also made clear that they would not be notified in advance. The respondents were then faced with seven bids ranging from SEK 100 to SEK 4,000 to accept blackouts as described. Each bid was presented separately, and the respondent did not know how many bids would be offered. The question was designed such that it allowed respondents to express uncertainty when they stated whether to accept the respective bid. In the end, each respondent's answer could be summarized in a matrix as illustrated in Figure 3.[14]

Figure 3. Bid vector for the compensation in the contingent valuation question.

Bid (SEK)	Definitely Yes	Probably Yes	Unsure	Probably No	Definitely No
100	□	□	□	□	□
300	□	□	□	□	□
600	□	□	□	□	□
1 000	□	□	□	□	□
1 500	□	□	□	□	□
2 500	□	□	□	□	□
4 000	□	□	□	□	□

4.3 Data

The data used in the choice experiment and the contingent valuation analysis was collected through a web survey conducted in 2017.

The questionnaire consisted of three parts addressing three different research questions. The first part focused on household use of electricity in general and the use of specific appliances

13. The WTA for a full black-out is an extension of the choice experiment, although not possible to include directly in the design.

14. For a discussion on uncertainty and contingent valuation, see e.g., Broberg and Brännlund, 2008.

during Swedish peak demand hours. The second part concerned households' choices of hypothetical electricity contracts as described above. The third (final) part introduced the contingent valuation question related to blackouts. The order of questions (parts) was discussed during development of the questionnaire. The first part was considered as a warm-up section, while the multidimensional contract choices deserved the main focus given its relatively complex design.

The study population was Swedish households living in single-family homes or duplexes. The main reason for choosing this population is that we expect that more or less all households in the survey pay their own electricity bill and are in control of all major power-consuming appliances in the house. This is not necessarily the case for households living in multi-dwelling houses. For example, the electricity bill may be included in the apartment rent and some households residing in apartments may not have their own laundry appliances.

In total, the questionnaire was answered by 1,007 respondents, sampled from a web-panel managed by Norstat. General characteristics of the respondents are provided in Table 2 and nothing in the descriptive statistics raises fundamental questions about the representativeness of the sample. Males are somewhat overrepresented (52 percent), which also has been the case in other energy related surveys in Sweden (see Broberg and Persson, 2016 and Ek and Söderholm, 2010). The average age in the sample may appear high at first but considering that the population is homeowners and that only people over 18 years old are allowed to answer the questionnaire, the average age is not particularly high.

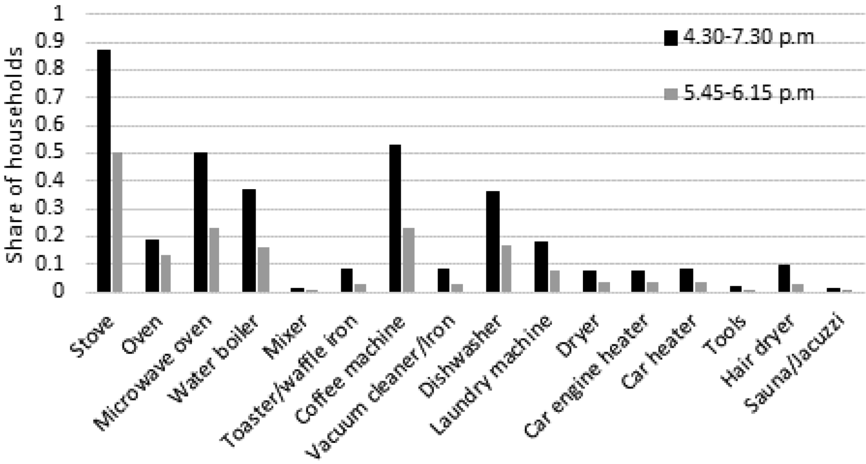
Table 2. Survey sample descriptive statistics.

	Mean/share	Std.dev
Age	53.15	16.78
Male	0.52	0.50
Retired	0.33	0.47
Single household	0.11	0.32
Households with children	0.33	0.47
District heating/Combustion (main or additional source)	0.32	0.47
Upper north counties	0.05	0.22
Stockholm county	0.19	0.39
Highly educated	0.52	0.50
Median monthly household income (SEK) (category variable)	40,000–50,000	

As mentioned, the first part of the questionnaire pertains to use of electricity in general and the use of specific appliances during Swedish peak demand hours in particular. More specifically, we ask about their use of high-power appliances during weekday afternoons in the winter season (December-February). Typical examples of high-power appliances are stoves, ovens, electric kettles, dishwashers, washing- and drying machines (see Broberg et.al., 2018 for details). Low-power appliances include lightbulbs, TV, stereo, computers, toys, hobby equipment. From a pure energy perspective, the aggregate of low power appliances contributes more to total electricity use than high-power appliances, while each of them is less important from a pure power perspective.

Figures 4 and 5 describe households' use of electric appliances/installations during the evening peak load. Figure 4 shows the share of households reporting that they use specific appliances/installations during the peak period for four or five workdays during a typical week. About 90 percent of the households use the stove, and about 25 percent run their laundry machine between 4.30 and 7.30 pm. Between 5.45 and 6.15 pm, about 50 percent of the households use their stove, while less than 10 percent use their laundry machine. A general pattern is that households tend to use kitchen appliances during the power system peak hours.

Figure 4. Share of households routinely using specific high-power appliances/installations at peak hours in the winter season.



To highlight potential heterogeneity in the sample, corresponding statistics were constructed for households with and without children separately. This analysis revealed that households with children more frequently use the dishwasher, laundry machine and dryer from 4.30–7.30 pm and 5.45–6.15 pm respectively. On the other hand, households without children seem to use the coffee machine more frequently. The analysis also shows that households with children seem to engage in kitchen activities more frequently in the half-hour peak.[15]

Figure 5 shows the reported number of appliances that households use during the peak hours 4–5 workdays per week. Almost all households responded that they use one or more electrical appliances during 4.30–7.30 pm, while about 60 percent responded that they use one or more appliances 5.45–6.15 pm. The median household routinely uses four appliances during the three-hour peak and 1–2 appliances during the half-hour peak.

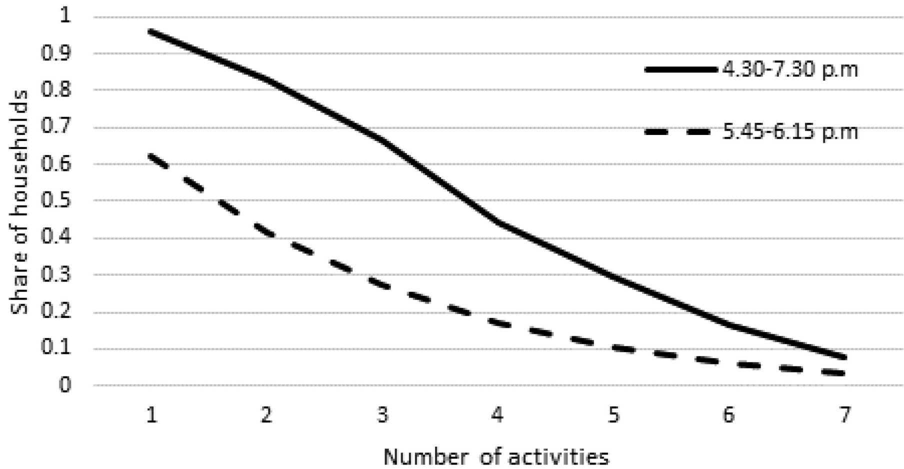
A rough estimate of the households' expected power demand from high power-appliances during workdays at 5.45–6.15pm suggests that the load restrictions of 5,000, 3,500 and 2,000 watts may necessitate curtailment activities in 45, 63 and 81 percent of the sampled households where the average curtailment amounts to 1.4 kW, 2.1 kW and 2.7 kW.[16]

In a separate question, we asked the respondents to choose the high-power appliances that they would prefer to have control over if their maximum load were to be restricted to 2,000 watts during workdays 5.45–6.15pm. As expected, a large fraction chose kitchen appliances; approximately 35 percent the stove, 16 percent the oven, 10 percent the microwave oven, 10 percent the coffee machine, and 6 percent the electric kettle. Only 5 percent chose the dishwasher, 5 percent

15. These descriptive results are in line with the results from a previous study estimating daily load curves for two different types of homeowner households using detailed metering data (Zimmermann, 2009). In this study it is shown that the households electricity consumption peak in the evening between 6 pm and 10 pm for households without children, and 5 pm to 9 pm for families with children. It is also shown that lighting is the most energy consuming activity during peak hours, followed by appliances related to kitchen activities. See also Vesterberg and Krishnamurty (2016) for related results.

16. The expected power demand from high-power appliances was calculated from estimates of the maximum electrical power drawn by specific appliances and the households' expected use of these appliances during workdays. For example, a specific appliance was given the weight 0.9 if used 4–5 workdays, 0.5 if used 2–3 workdays and 0.1 if used 0–1 workdays.

Figure 5. Number of high-power appliances/installations that households routinely use during the peak hours on 4–5 workdays in a typical week. Share of households that use at least a specific number of appliances/installations.



the laundry machine and 1 percent the dryer. Even if some numbers are small, it suggests that these appliances are important to households since they actually use them at the time of the restriction.

To further deepen our understanding of household use of electricity, we asked a set of knowledge-based questions. The answers from these questions reveal that a fairly large fraction of homeowners in Sweden have limited understanding of their power consumption, electricity prices, and contract possibilities. For example, almost 30 percent of the respondents did not know what fuse rate they had, and 77 percent stated no understanding about the relation between the fuse rate and the maximum possible load.

5. RESULTS

This section reports from both the choice experiment and the contingent valuation. The choice experiment covers the hypothesis related to soft load control and VoPLL, while the contingent valuation addresses the issue of a full black out and the VoLL in peak load hours.

5.1 The choice experiment and VoPLL (soft load control)

The estimated models are specified with dummy variables and the parameter estimates for the different attributes of the contracts should be interpreted as changes from the reference level. For example, the parameter estimates for 2,000 watts in Table 3 should be interpreted as the change from 5,000 watts, which is the reference level. Interaction terms between the most stringent load control of 2,000 watts and the other attribute levels are introduced in a second model specification. This is done to capture the potential relationship, or link, between the different attributes of the contracts. Specifically, it is reasonable to believe that how a respondent perceives a load restriction depends on the duration of the restriction and how many days it may be enforced.

All parameter estimates are presented in Table 3. Given the RPL specification, the respective coefficients can be interpreted as the mean preferences (recall that we allow for individual heterogeneity) and are presented along with the standard errors and significance levels. The standard deviations of the distributions and the respective significance levels capture and illustrates the heterogeneity in preferences.[17]

Most of the point estimates in Table 3 have the expected sign. Stricter control in terms of a maximum load of 2,000 watt, duration and occasions are all related to discomfort and disutility, according to the point estimates. Notably, the flexibility attribute representing the possibility to change appliances during the disruption is not statistically significant at any relevant level. Moreover, it is only the interaction between a maximum load of 2,000 watt and the duration that is statistically significant. The sign of this coefficient is interpreted such that a longer duration combined with stricter control means more disutility. Finally, the parameters Alfa A and B reflect "generic" preferences for contract A or B relative to today's contract. In theory, there should be no difference between generic contracts such as A and B in our case, but in practice it is typical to find preferences for one or the other. In our specification, we allow for such differences although the explicit interpretation is of no particular interest.

Table 3. Results from the random parameter logit.

	Without interactions			With attribute interactions		
Attributes	Coeff	Stand. err.	Std. dev.	Coeff	Stand. err.	Std. dev.
3,500 w	–0.070	0.072	0.842***	–0.049	0.074	0.856***
2,000 w	–0.666***	0.094	1.411***	–0.204	0.189	1.441***
Flex	0.080	0.065	0.713***	0.093	0.085	0.751***
90 min	–0.272***	0.074	1.050***	–0.120	0.082	1.103***
180 min	–1.179***	0.102	1.698***	–0.786***	0.133	1.685***
10 days	–0.525***	0.064	0.139	–0.543***	0.075	0.137
20 days	–0.793***	0.086	1.141***	–0.880***	0.115	1.138***
Alfa A	–1.495***	0.136	3.014***	–1.718***	0.156	2.993***
Alfa B	–1.198***	0.132	2.939***	–1.328***	0.138	2.930***
Comp/1,000	1.156***	0.043		1.158***	0.043	
I_dur				–0.564***	0.125	
I_days				0.778	1.102	
I_flex				0.008	0.158	
Log-likelihood		–6,590.419			–6,575.179	
Restricted log-likelihood		–8,850.421			–8,850.421	
McFadden pseudo R2		0.255			0.257	
AIC/N		1.641			1.638	
No of resp		1,007			1,007	
No of obs		8,056			8,056	
No of shuffled uniform vector draws		1,000			1,000	

*** Significance at 1-percent level

By dividing the coefficients for the respective attribute level with the compensation attribute, the results in Table 3 can be used to calculate the mean marginal willingness to accept (WTA) for the various levels of the attributes relative to the respective reference level. These results are presented in Table 4, where estimates of mean WTA are presented along with confidence intervals for interpretational convenience.[18]

17. In all cases, according to log-likelihood ratio tests, the RPL specification is preferred over the MNL specification (not presented in the tables).

18. The Wald procedure in Limdep was used to obtain functions of parameters from the RPL model and to estimate standard errors and confidence intervals for those functions. The procedure was specified to adopt the Krinsky-Robb method with 1,000 draws for simulating the properties of the maximum likelihood estimated coefficients. Since the coefficients reflect average preferences, the marginal WTA will also reflect average preferences.

Table 4. Marginal willingness to accept, SEK.

	Without interactions		With interactions	
	Point estimate	95% confidence interval	Point estimate	95% confidence interval
Compared to a 5,000 watt limit on electricity use, the compensation required for a…				
3,500 watt limit is…	61	–62–184	42	–78–163
2,000 watt limit is…	576***	424–729	176	–138–491
Compared to a pre-determined choice of appliances, the compensation required for flexible choice of appliances is…	–69	–179–41	–80	–224–64
Compared to a duration of 30 minutes, the compensation required for a duration of…				
90 minutes is…	235***	109–362	104	–30–237
180 minutes is…	1,020***	856–1,185	679***	458–900
Compared to 5 days during the period, the compensation required for…				
10 days is…	454***	351–558	469***	346–593
20 days is…	686*	552–821	759***	574–944
Compared to the status quo, the compensation for…				
contract A is…	1,293***	1,059–1,528	1,483***	1,214–1,752
contract B is…	1,036***	812–1,260	1,146***	913–1,380
2,000 watt in combination with…				
duration			4.9***	2.7–7.0
days			–6.7	–25.2–11.8
flexible choice			–7.0	–279–265

*** Significance at 1-percent level

In Table 4 we see that all the statistically significant estimates of marginal WTA have the expected sign. Given that a restriction on the use of electricity is related to discomfort or disutility, the respondents logically require a positive compensation for any of the attributes in the contracts. It can also be seen that stricter restrictions are associated with higher compensation. Starting from the reference contract, characterized by 5,000 watts, 30 minutes and 5 days, we find that among the possible changes of this contract an increase of the duration to 180 minutes is associated with the highest average required compensation, more than SEK 1,000 (€100) for the specification without interaction terms.

The results in Table 4 also show that the average compensation required to accept the reference contract, relative to the status quo contract (including the preference for status quo as such), is in the range of SEK 1,036–1,293 for the model without interactions. The status quo compensation level is low in comparison to the corresponding valuation (keeping the no-restriction contract) found in Broberg and Persson (2016). In that study, the average compensation required to make people consider opting into a new contract was estimated at almost SEK 3,000. The likely reason for this difference is that the contracts in the current study are characterized by more flexibility and, in general, softer load control.

Turning to the specification allowing for interactions between the 2,000 watt restriction and duration, number of days and flexibility, the general findings do not change to any larger extent. The marginal WTA estimates are derived from the results reported in Table 3, meaning that e.g. only the duration interaction is statistically significant. The interaction is interpreted such that each extra minute in duration, given a maximum load of 2,000 watt, corresponds to about SEK 5 extra in compensation. Given the statistical insignificance, any interpretation of the other interaction terms needs to be done with care.

Instead of focusing on the respective attribute level separately, an alternative way to illustrate the results is to calculate the minimum compensation for specific hypothetical contracts. In Table 5, the contracts are designed for the purpose to compare differences in valuation between "hard" and "soft" restrictions on homeowners' electricity use, but also to allow for a test of the hypothesis that shorter, but perhaps more frequent, disruptions may be easier to handle and compensate for. For this, we consider four distinct contracts in which we elaborate on all attributes except the flexible versus predetermined choice of appliances. The reason for the latter is that the parameter estimate for this attribute was not statistically different from zero in any specification. "Hard control" refers to a case with the strictest restrictions for all the attributes—2,000 watt load control and 180-minute disruptions for 20 days. "Hard but short" refers to 2,000 watt and 20 days, but only 30-minute disruptions. "Hard load only" refers to 2,000 watt, 30 minutes and 5 days. Finally, "soft but often" refers to 20 days, but 5,000 watt and 30 minutes. Recall that the calculations are based on the specification including attribute interactions between 2,000 watt, duration and number of days.[19]

All point estimates are statistically significant at the 1 percent level, except for the "hard load only" scenario. Notice also that the scenarios are calculated both with and without the compensation needed to accept the reference DSM contract (the average of the range SEK 1,146 to 1,483). The compensation to accept the DSM-contracts (including the status quo cost) ranges from SEK 1,603 for the "hard load only" to SEK 3,671 for the "hard control". The relatively low average compensation required for the "hard load only" is explained by the negative interaction for 2,000 watts and number of days, which is not part of the control.

Table 5. Willingness to accept, SEK for different pre-specified contracts (confidence intervals within parentheses).

	Without SQ cost	With average SQ cost
Hard control	2,356***	3,671***
	(2,050–2,662)	(3,323–4,019)
Hard but short	947***	2,262***
	(717–1,177)	(2,018–2,506)
Hard load only	289**	1,603***
	(62–516)	(1,364–1,843)
Soft but often	759***	2,074***
	(562–957)	(1,837–2,311)

Hard control = 2,000 watt load control and 180-minute disruptions for 20 days
Hard but short = 2,000 watt load control and 30-minute disruptions for 20 days
Hard load only = 2,000 watt load control and 30 minutes for 5 days
Soft but often = 5,000 watt load control and 30 minutes for 200 days

***, ** Significance at 1-percent and 5-percent level respectively

Part of the motivation for our study was to link the preferences (and the valuation of attributes) to the concepts of VoLL and VoPLL as defined in the introduction and background. Based on the results above, it is not possible to calculate a single value of the potential loss of load (VoPLL) in terms of SEK per kWh, but only a range of values. The reason is that the average compensation required for accepting a DSM-contract may change disproportionally to the change in a numeric attribute, e.g. duration. To illustrate, consider two contracts with 2,000 watt and 20 days restrictions, but with a duration of 30 and 180 minutes respectively. The average compensations for these two

19. The standard errors and confidence intervals were estimated through the Wald procedure in Limdep, using the Krinsky-Robb method with 1,000 draws for the simulation.

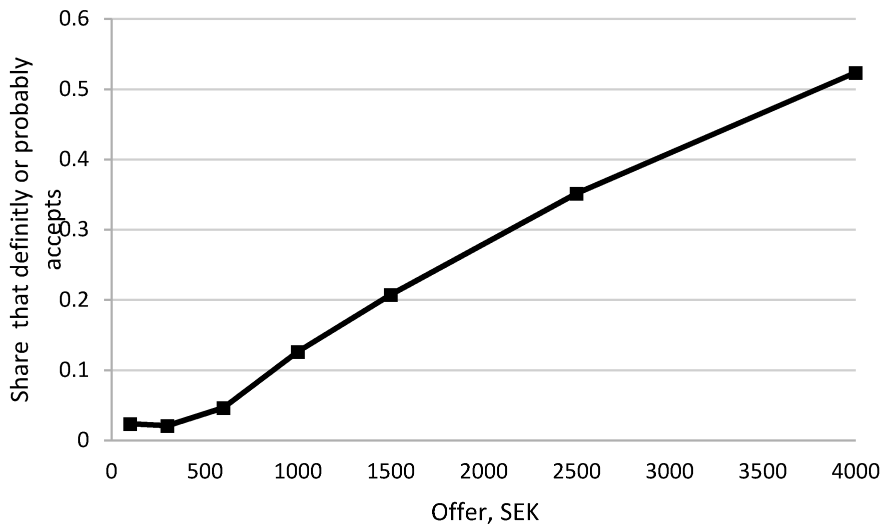
contracts would be SEK 2,262 and SEK 3,671 respectively (see Table 5).[20] That is, the compensation associated with the latter contract is only about 60 percent higher, although the duration is 600 percent longer. As a result, we present an interval for VoPLL based on the difference in compensation between the reference contract and contracts with a load control set to 2,000 watt. A contract with a change from 5,000 to 2,000 watt, 5 to 20 days and 30 to 180 minutes duration implies a difference in time involved equal to 15 days*(180–30) minutes = 2,250 minutes, or 37.5 hours. The 3,000 watt tighter restriction would consequently translate to 113 kWh (3,000*37.5) of potential lost load and a VoPLL equal to SEK 21 per kWh (SEK 2,356/113).[21]

Equivalently, a calculation based on a change from 5,000 to 2,000 watt only would result in a VoPLL equal to SEK 39 per kWh (SEK 289/7.5). This difference motivates the use of an interval, and the value households attach to their unrestricted use of high-power appliances and installations is therefore estimated to between SEK 21 and 39. As mentioned previously, this value captures both the value of appliances and installations used, but also an option value capturing the possibility to use appliances and installations up to the contract-limit without temporary restrictions.

5.2 The contingent valuation approach and VoLL

As described above, the CV method was adopted to elicit preferences related to a full blackout. The responses to the CV question are summarized in figures 6 and 7. Figure 6 illustrates the share of respondents who answered that they definitely or probably would accept the contract containing complete blackouts if given a specific amount. As can be seen, the acceptance rate increases with the size of the compensation, but even at the highest compensation offered (SEK 4,000), about 50 percent of the respondents turned down the offer.

Figure 6. Survival curve for accepting compensation for a blackout.

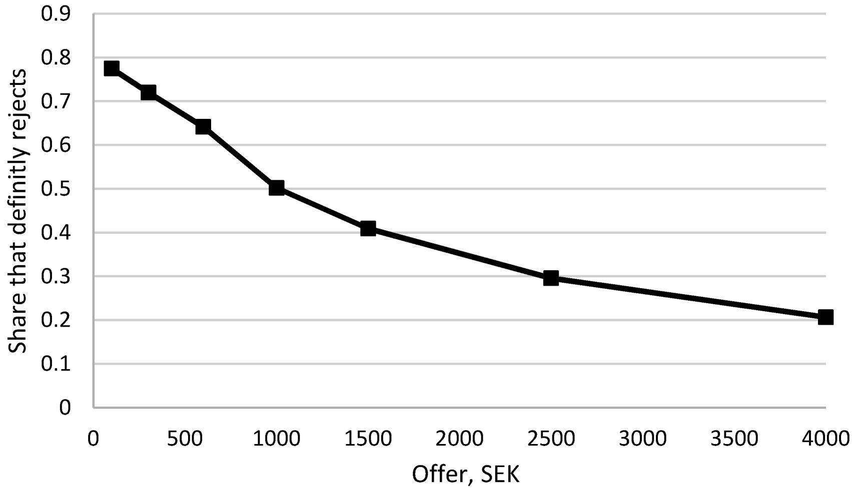


20. These values can in principle be calculated directly from Table 4 by using the formula:
WTA = 1,314.5 + 176 + 679 + 759 + 4.9* *duration*—6.7**days*. Note however that the numbers in table 5 are calculated with the exact point estimates, not the rounded values in table 4.

21. Because that fact that both alternative scenarios presuppose an existing contract, it does not matter if we include the SQ cost or not in these calculations.

A similar story is illustrated in Figure 7, showing the share of respondents definitely turning down specific amounts offered to them. As can be seen, the share of respondents rejecting offers decreases with the level of compensation. At our highest bid, approximately 20 percent answered that they would definitely not accept the contract.

Figure 7. Survival curve for definitely rejecting compensation for blackouts.



The average compensation required to accept blackouts can be estimated statistically. Because a large fraction of the sample did not accept the highest bid offered, it is difficult to estimate the distribution of the compensation levels with perfect accuracy. We simply have too little information about the right-hand-side tail of the distribution, implying that an estimate of the average compensation requires an assumption about the distribution. An alternative approach is to use the median compensation, which equals SEK 4,000. To get an estimate of the average compensation, we non-parametrically calculate an interval for the average compensation level by measuring the area under the curve in Figure 6 using two alternative assumptions: (1) Those who reject SEK 4,000 would accept SEK 4,001, and (2) the accepted compensation among people who reject SEK 4,000 are distributed according to a linear extrapolation of the last segment of the curve in Figure 6. That is, the curve is extrapolated until the share of households equals unity, in this case at SEK 8,200. The latter simply means that the person with the highest compensation demand would accept the blackouts for a compensation of SEK 8,200. Indeed, the second assumption seems to the most reasonable of the two.

The resulting interval for the average compensation is SEK 3,000–4,200 and can be compared with the average compensation required for accepting the scenario "hard but short" in the contract choice analysis in the previous section. The "hard but short" scenario is similar to the blackout scenario with respect to duration and number of days. As expected, the comparison reveals that households on average demand higher compensation to accept the blackout scenario. The difference in compensation levels also implies that people place a high value on being fully flexible in their use of both high- and low-power appliances.

Making similar assumptions as in the discussion of the scenarios in the choice analysis, we can calculate the value of lost load, VoLL, for that particular time of day. Assuming a 5,000 watt loss of load for 30 minutes for 5 days, this implies a total loss of 12.5 kWh. Given a required compensation of SEK 3,000–4,200, the value of lost load would be SEK 240–336 per kWh. However, to estimate VoLL in terms of SEK per kWh, the starting point must be the actual load in use at the highest peak hour, of which we do not have full information. Assuming that the lost load is approximately 1.5 kWh at each blackout (see Vesterberg and Krishnamurthy, 2016, for a motivation), VoLL is calculated to about SEK 400–600. Again, a comparison with the hard and short scenario in the choice analysis reveals that a blackout is perceived as a stricter restriction with more disutility attached to it, which is expected.

To find out more about the drivers for the valuation of blackouts we estimate a regression model where the dependent variable is the lowest bid that the respondents would definitely or probably accept. Because the highest bid offered is lower than what a large share of the respondents would accept, we adopt a Tobit model. In principle, the Tobit specification is a combination of a linear and binary regression model. The Tobit model censors the estimated distribution to a specific number—in our case SEK 4,000—and utilizes the fact that the censored observations are higher than SEK 4,000. In the Tobit model, the variables explain the size of the compensation (WTA), given that it is lower than SEK 4,000 and the likelihood that a respondent has a WTA above SEK 4,000.

Table 6 presents the results from two different model specifications. In both specifications, the dependent variable is the lowest amount the respondents answered that they definitely, or probably, would require to accept the blackouts. Model 1 is estimated on the full sample including all relevant variables except household income, while Model 2 includes household income. In the sample, information about income is missing for 374 respondents, which motivates the two model specifications in Table 6. We here discuss the coefficients based on their sign and statistical significance. A positive (negative) coefficient significantly different from zero means that the variable is positively (negatively) correlated with the compensation level. As was the case in the choice experiment analysis, many of the variables are binary and should be interpreted as an average comparison between two groups of respondents, e.g., males and females.

Table 6: Regression result of minimum compensation for accepting blackouts.[a,b]

	Model 1		Model 2	
	Coef.	Std.err.	Coef.	Std.err.
Age	22***	7	15*	8
Male	197	159	223	178
Retired	–350*	254	39	280
Tight power supply	–497***	166	–491***	184
Single household	–147	263	117	287
District heating/Combustion	–1	170	–28	186
Upper north counties	368	410	–101	430
Stockholm county	612***	213	623***	238
Waste sorter	–344**	168	–444**	184
Labeled electricity	–87	236	–24	252
Fixed price contract	258	164	328*	177
Use >3 appliances during 5.30–6 pm	103	215	223	241
Highly educated	111	159	29	177
Above median household income	N.A	N.A	461**	196
Low effort	343*	208	333	231
Constant	2,329***	356	2,310***	438
NOBS	992		800	
Right-censored	465		370	
Log-likelihood	–5,176.58		–4,209.38	

[a] The dependent variable is the lowest amount the respondents answered that they definitely, or probably, would require to accept the blackouts.
[b] * indicates statistical significance at the 10-percent level, ** at the 5-percent level and ***at the 1-percent level

By comparing the results in Model 1 and Model 2, income acts as a confounding variable in Model 1. Among other things, a relatively low average income among retired households seems to explain why they require lower compensation than others. The same pattern holds for households in the upper north part of Sweden and those buying electricity labeled green. Also, there seems to be a correlation between the low-effort respondents and income.[22] Overall, respondents who report above median household income require higher compensations levels, which is fairly intuitive.

Interestingly, respondents who already adjust their loads to avoid internal power failures ("Tight power supply") require lower compensation on average. This is also true for respondents who stated that they think it is important for them to sort dairy packaging ("Waste sorter").[23] Tentatively, these results suggest that preferences may adapt to new circumstances and that people develop new habits because of experience. The point is that people may perceive the cost of a power failure to be higher than it really is. When exposed to a power failure, people may learn about the true costs and correct their misperceptions.

6. DISCUSSION AND CONCLUSIONS

The overall objective of this paper is to study household preferences for demand response in order to learn more about the balancing potential for demand-side resources. More specifically, we estimate Swedish household's possibilities and willingness to accept load restrictions in electricity use during peak hours. The analysis reveals consumer preferences for various load restrictions at different hours of the day, and hence the potential for load shifting and demand side management. The analysis also contributes with explicit values of partial (VoPLL) and complete load restrictions (VoLL), which is of paramount importance when it comes to balance demand and supply side measures to meet potential effect challenges.

We apply a survey approach to elicit preferences concerning a hypothetical DSM program. The DSM program includes load control on a number of occasions during the peak hours in the winter season. The load controls, or attributes, in the program are: (i) maximum high-power loads, (ii) duration of load control, (iii) number of occasions of load control and (iv) flexibility in the choice of high-power appliances within the control. By varying these attributes, we elicit household's preferences for the attributes and place a monetary value on them.

To estimate the relative value of having full access to high-power loads compared to other loads (e.g., heating, lighting and TV), we use a contingent valuation scenario involving a complete blackout. The difference between the compensation required for a blackout and a DSM program with a softer load control, but with similar duration and number of occasions, then reveals information about the relative value of different loads.

The overall conclusion from our empirical analyses is that demand response relying on behavioral change is expensive in the sense that households require a high compensation for accepting restrictions. The required compensation can in this case be interpreted as the opportunity cost of time, e.g. the risk of not being able to make dinner at the usual time may be disruptive for the household. According to our results, such disruptions are very costly.

22. Such correlation may result if some respondents systematically have chosen answers such as "I don't know," "Status quo" and "I don't want to answer".

23. The reason why we included "waste sorter" in the regression model was that it may serve as a "marker" for people who have an environmental awareness or in a broader sense have a pro-environmental behavior, which may influence there stated WTA.

The results reveal that households would require a minimum compensation ranging between about SEK 2,000 and SEK 3,700, depending on how stringent the control is with respect to maximum load, duration, and number of days. This is a significant amount of money, considering that the yearly electricity bill for a homeowner household is approximately SEK 15,000 on average. Another way to illustrate the economic significance of the compensation they require is to relate it to the VoLL, i.e. a blackout. Households value, on average, the VoPLL to SEK 21–39 per kWh, which should be compared to the actual electricity consumer price of about SEK 1 per kWh. This means that the value households attach to secure access to electricity in the afternoon peak hour greatly exceeds the marginal cost of providing electricity.

Looking more specifically at the minimum compensation for accepting five 30-minute blackouts in the afternoon peak hour reveals an even higher value than the less restricted load control, which is expected. According to the results, an average compensation of at least SEK 3,000 is needed. More likely however, is that the average compensation exceeds this amount considering that the median is SEK 4,000. These amounts correspond to a VoLL of approximately SEK 400–600 per kWh and indicate a rather big difference between the value of the load that was controlled in the choice experiment and the remaining load (e.g. lighting and TV).

Compared to previous literature on VoLL our estimates are placed in the higher range. For example, Carlsson and Martinsson (2008) estimate VoLL for Swedish households, conditioned on a scenario with one additional power failure in a five-year period lasting for 24 hours. Translated to one power failure per year, their results point at a VoLL of about SEK 30–40 per kWh (assuming an average annual power consumption of 6,000 kWh for all households in Sweden). One explanation for the high values of VoLL in our case, is the scenario they are conditioned on. Compared to today's rather safe power supply, the scenario of five random blackouts in the peak hour winter period mirrors a highly unstable power system. Another explanation is the WTA approach, which typically results in higher values than approaches asking people to state their willingness to pay for avoiding a power failure. As we argued in Section 2, a WTA-framing is highly justified in our case as the market-based DSM programs that we study require households to voluntary accept personalized restrictions that cause utility losses.

The load restrictions studied in this paper would significantly reduce the use of electrical power in peak hours. As an example, if the average household's use of high-power appliances where restricted to 2,000 watt during 5.45–6.15 pm workdays, it may necessitate curtailment activities of about 2.7 kW, which is equivalent to replacing 56 incandescent lamps (60 watt) with led lamps (8 watt). According to our results, specific policies aiming at behavioral changes would however be very costly. This implies that demand response through curtailment actions may be less cost-effective than supply response or demand response through automation and passive response. In a Swedish household context, electricity used for heating probably has the largest potential for automated or passive response as it on average counts for more than 50 percent of the annual electricity use. Therefore, one important area for future research is to investigate to what extent households accept external control of their heating systems if such control implies small but still noticeable changes in their indoor temperature.

To conclude, households cannot be expected to actively change their load profiles in the absence of very strong incentives. Apart from facilitate trade with demand flexibility based on active response, policies should target automatization and passive response. A relatively large share of households use of electricity is related to passive use, such as heating, refrigerators, ventilation, etc. The load that can be subject to passive response is therefore relatively large, implying a large potential for load-shifting without large negative effects on well-being. The results also imply that it is far from obvious that demand response is more cost effective than supply response, i.e., increasing production of electricity. A combination of policies that facilitate trade with demand flexibility, stimulates active response, and that removes price ceilings and other price regulations is therefore motivated. Such a combination results in a more cost-effective balance between curtailment activities, passive response and investments in new generation capacity.

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