Does it Matter When a Power Outage Occurs?
- A Choice Experiment Study on the Willingness to Pay to Avoid Power Outages

Fredrik Carlsson[A]
Peter Martinsson[B]

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Department of Economics
Gothenburg University

Abstract
Using a choice experiment survey, the marginal willingness to pay (WTP) among Swedish households for reductions in power outages is estimated. The results from the random parameter logit estimation indicate that the marginal WTP increases with the duration of the outages, and is higher if the outages occur during weekends and during winter months. The random parameter logit model allows us to estimate a sample distribution of WTP. We find a significant unobserved heterogeneity in some of the outage attributes but not all. Furthermore we show that the sample distribution of WTP does not to any large extent suffer from the problem of reverse sign of the WTP. Therefore, choosing an unconstrained normal distribution might not be as problematic as one would think. Given that households have negative welfare effects from outages, which differ in timing and duration, and are rarely compensated for them, it is important that policy makers consider these negative impacts on households utility when regulating the electricity market.

Keywords: Choice experiment; Power outages; Random parameters; Willingness to pay

JEL-classification: C25, C93, D12, Q41

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[A] Fredrik Carlsson, Department of Economics, Göteborg University, Box 640, 405 30 Göteborg, Sweden; Ph +46 31 773 41 74; Fax +46 31 773 10 43; E-mail fredrik.carlsson@economics.gu.se.
[B] Peter Martinsson, Department of Economics, Göteborg University, Box 640, 405 30 Göteborg, Sweden; Ph +46 31 773 52 55; Fax +46 31 773 10 43; E-mail peter.martinsson@economics.gu.se.

1. Introduction

There are many factors that contribute to the quality of living and one important factor is the supply of electricity. In a time of increasing reliance on electricity among households, we expect that the negative welfare effects on households from power outages have increased. The households have over the years become more and more dependent on electricity because of an increased use of electronic items and also because people work from their homes to a larger extent than before. According to statistics however, a household used approximately the same amount of electricity in 2003 as they did 10 years earlier (Svensk Energi, 2003). During this period, there has been an increased use of electronic items, but this increase in demand has been cancelled out mainly by installments of new and less energy-consuming kitchen equipment in older apartments as well as a transfer away from electric heating to other forms of heating (Svensk Energi, 2003). From a welfare point of view, but also from the point of view of the power companies, there is a trade-off between on the one hand the negative welfare effects from power outages on those affected, and on the other hand the costs of reducing outages by maintenance and investment in the national grid and in regional and local networks, as well as in keeping a reserve capacity for production of electricity in case of insufficient supply from ordinary sources. The experiences of deregulation in many of the states in the USA during the last 10 years also show that it is not evident that the number of outages will remain at a low level, especially not after a deregulation. In the case of the US, it seems that the deregulation per se in connection with congested transmission grids, resulted in an increased number of outages and blackouts in the US (Faruqui et al., 2001; Joskow, 2001). In addition, more extreme weather conditions such as hurricanes have also resulted in more problems with outages. All this taken together, it is of importance for both from the regulators and the grid and power companies to obtain information about the customers' views and valuations of outages.

In this paper, we study the welfare implications of power outages on Swedish households by conducting a stated preference study. Most previous studies have applied some form of stated preference method because this allows for non-monetary effects of outages on the households to be included such as the inconvenience of freezing and not being able to watch TV or cook food during the outage.[1] Both the contingent valuation method and the choice experiment method have been used for valuation of power outages, but the contingent valuation method has been the predominantly applied method (see e.g. Beenstock et al., 1998; Doane et al., 1988b; Layton and Moeltner, 2004; and Svenska Elverksföreningen, 1994). There are several components of a power outage that may affect the valuation, where both the timing of the outage as well as the duration are likely to be important. In this paper we estimate among Swedish households the marginal willingness to pay (WTP) for reducing unplanned power outages by using a choice experiment, and we separate the valuation on several possible characteristics of an outage: the duration of the outage (4, 8 and 24 hours), time of the week (working day and weekend) and the time of the year (winter months and the rest of the year). In a choice experiment, we do not directly observe the marginal WTP, but only the respondents' choices in certain situations. In the econometric analyses we therefore apply a random parameter logit model, which accounts for an unobserved heterogeneity by allowing the parameters of the utility function to have a distribution rather than being fixed, and considers that each respondent makes choices in more than one choice situation. Although we do not observe the WTP, we can estimate the respondents' WTP from the random parameter model. Furthermore, we are able to obtain individual specific parameters and consequently WTP values for each respondent. As shown in the paper this is an interesting strength of the random parameter model; it both allows us to in more detail investigate the sample distribution of WTP and has some implications for the choice of distribution of the random parameters.

The rest of the paper is organized as follows. Section 2 contains a description of the choice experiment and the econometric approach applied. In Section 3 we present the results from the study and finally in Section 4 we conclude the paper.

[1] There are also a number of studies that have asked the respondents to state the hypothetical monetary costs of power outages, see for example Wacker et al. (1985), Doane et al. (1988a) and SINTEF (2003). However, this approach neglects any non-monetary effects of power outages. In principle one could also use revealed preference data to measure the WTP, for example by studying households investments in equipment such as UPS equipment and backup power to reduce the effects of outages. This would require rather detailed information about the extent of the expected power outages that would be avoided in the household during the lifetime of the equipment being bought.

2. The Choice Experiment

In a choice experiment, individuals are asked to make repeated selections of their preferred alternative in the choice sets presented to them.[2] Since power outages affect the whole household, we explicitly stated that the respondents should answer for their entire household. Each choice set consists of several alternatives, and each alternative is described by a number of attributes. We introduced three groups of attributes in the choice experiment: duration of the power outage (4, 8 and 24 hours), the day of the week that the outage occurs (working days and weekends) and the connection fee to a back-up electricity board, which needs to be paid in order to guarantee the number of power outages to the levels stated. This means there are in total seven attributes in each alternative, since for each time of the week there are three different durations in addition to the cost attribute. We focused on unplanned outages, and therefore the number of planned outages remained unaffected.[3] Moreover, each respondent answered two different parts, each containing six choice sets: one part concerned outages during the winter months (November-March) and the other part concerned outages during the rest of the year (April-October). In Table 1 we summarize the attributes and attribute levels used, where the levels refer to the number of outages over the next five years. The reason why we used over the next five years was because we wanted to avoid describing the outages in fractions rather than using integer numbers.[4]

>>> TABLE 1

Given the number of attributes and attribute levels, a large number of choice sets containing two alternatives can be constructed. However, time constraints and cognitive abilities restrict the number of choices a respondent can make, and thus a selection of the choice sets to be included have to be done. The choice sets were selected by using a cyclical design principle (Bunch et al., 1996). A cyclical design is a straightforward

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[2] For overviews on the choice experiment method see for example Alpizar et al. (2003) and Louviere et al. (2000).

[3] There is a possibility of negative correlation between the number of planned and unplanned outages. Therefore we stated that the number of planned outages remained the same during the period.

[4] In Sweden, households located in built-up areas experienced on average 0.08 planned and 0.39 unplanned power outages per year during the period 1998-2001 with an average duration of 12 and 23 minutes respectively (Svenska Kraftnät, 2002). The corresponding figures for power outages in sparsely populated areas of Sweden are 0.60 planned with average durations of 83 minutes and 1.54 unplanned power outages per year with an average of 203 minutes.

extension of the orthogonal approach. First, each of the alternatives from a fractional factorial design is allocated to different choice sets.[5] The attribute level in the new alternative is the next higher attribute level to the one used in the previous alternative. If the highest level is attained, the attribute level is set to its lowest level. Thus, we obtained a set of possible choice sets to use. From this set we deleted all strictly dominating choice sets. Moreover, we wanted to avoid "too" dominating choice sets. This was done by calculating so-called code sums for each alternative (Wiley, 1978). In order to calculate the code sum, we order the levels of the attributes from worst to best case, and the lowest attribute level is assigned the value 0, the next is 1, the following 2 etc.[6] The code sum is the sum of all these values for each alternative. By comparing the code sums, one can get an indication of if an alternative is highly dominating in a choice set.[7] In our case, we deleted all design alternatives with a code sum difference larger than eight; in total there were 78 such design alternatives. From the remaining choice sets, we created 6 blocks of choice sets, which were randomly allocated to the respondents. Before they answered the choice experiment, the respondents were instructed to read a short scenario describing the attributes and some facts regarding power outages. The scenarios presented to them are found in the Appendix. An example of a choice set is presented in Figure 1.

>>> FIGURE 1

In the analysis of the responses we assume a linear random utility function, where we then write the utility for household *i* for alternative *j* as

$$U_{ij} = v_{ij} + \varepsilon_{ij} = \alpha + \beta a_i + \gamma(y_i - c_{ij}) + \varepsilon_{ij}\,, \qquad (1)$$

where α is the status quo utility, a_i is a vector of the attributes in alternative *i*, β is the corresponding parameter vector, y_i is income, c_{ij} is the cost associated with alternative *j*, γ is the marginal utility of income and ε_{ij} is an error term. Since the

[5] A fractional factorial design contains a sub-set of all combinations of levels of attributes. A fractional factorial design has the properties of being balanced and orthogonal.

[6] In our case we assigned a 24 hour outage a code value of 3.

[7] This is obviously a crude approach, and in order for the approach to work fairly well, the utility difference between two levels should not be too different across attributes.

utility function is linear in income, the marginal WTP for an attribute is the ratio between the parameter of the attribute and the cost parameter such that

$$MWTP = \frac{\beta}{\gamma}. \tag{2}$$

In the econometric analysis we wish to explicitly consider unobserved heterogeneity and therefore we apply a random parameter logit model (e.g. Train, 2003). This means that the random parameters are the sum of the population mean, $\overline{\beta}$, and a respondent deviation, $\tilde{\beta}_i$, i.e. $\beta_i = \overline{\beta} + \tilde{\beta}_i$. These deviations are assumed to be normally distributed with mean zero and a standard deviation. A normal distribution is perhaps not the most intuitive distribution in this case, since this model by definition will predict that a share of the population has the reversed sign of the taste parameters. An alternative would therefore be to assume a log-normal distribution or a truncated normal distribution, which both overcome the problems of reversed signs. However, estimations using such distributions are more sensitive, and in particular the log-normal distribution tends to result in WTP estimates that are sensitive to model specification. In addition, the issue of a reversed sign is perhaps not that important, especially if one focuses on the sample distribution of preferences; we will return to this issue later on in the paper.

More formally, we assume that the coefficient vector β varies among the population with density $f(\beta \mid \theta)$, where θ is a vector of the true parameters of the taste distribution. If the $\varepsilon's$ are IID type I extreme value, the conditional probability of alternative *j* for individual *i* in choice situation *t* is

$$L_i(y_{jt} \mid \beta) = \frac{\exp(v_{jt})}{\sum_{k \in \mathbf{A}_t} \exp(\beta v_{kt})}, \tag{3}$$

where $\mathbf{A}_t$ is the choice set. The conditional probability of observing a sequence of choices, denoted y_i, from the choice sets is then the product of the conditional probabilities

$$P(y_i \mid \beta) = \prod_t L_i(y_{it} \mid \beta). \tag{4}$$

The unconditional probability for a sequence of choices that individual *i* makes in the choice experiment is then the integral of the conditional probability in equation (4) over all values of β such that

$$P(y_i \mid \theta) = \int P(y_i \mid \beta) f(\beta \mid \theta) d\beta . \tag{5}$$

In this simple form, the utility coefficients vary among individuals, but are constant between the choice situations for each respondent. This reflects an underlying assumption of stable preference structure for each respondent during the course of making the choices in the choice experiment. Since the integral in equation (5) cannot be evaluated analytically, we have to rely on a simulation method for the probabilities. Here we will use a simulated maximum likelihood estimator, using Halton draws, in order to estimate the models (see Train, 2003). One interesting aspect of random parameter logit models that only recently has been explored is the possibility of retrieving individual-level parameters from the estimated model by using Bayes Theorem (Revelt and Train, 2000). This means that we can obtain an estimate of the location of a specific respondent in the estimated distribution. Train (2003) show that the mean β for an individual *i* is

$$E[\beta_i] = \frac{\int \beta P(y_i \mid \beta) f(\beta \mid \theta) d\beta}{\int P(y_i \mid \beta) f(\beta \mid \theta) d\beta} . \tag{6}$$

This expression does not have a closed form and therefore we again have to rely on simulation methods.

The choice experiment was part of a mail questionnaire on power outages. The questionnaire contained, apart from the experiment, questions about the use of electricity, prevention methods undertaken in order to reduce the effects of power outages, questions related to subjective self-assessed effects of power outages as well as questions about the socio-economic characteristics of the respondents. The questionnaire was developed using both focus groups and pilot tests and discussions with representatives from the industry.

3. Results

The main survey was sent out to 1,200 randomly selected individuals aged 18-74 in Sweden in 2004. Eight of these were returned because of "address unknown".[8] In total 473 individuals returned the questionnaires, which is a response rate of 40%.[9] Due to non-item responses 425 questionnaires are available for the analyses.[10] In Table 2 we present the results from the estimations based on a random parameter logit approach, where we assume cost to be a fixed parameter and the other attributes to be normally distributed.[11] For each random parameter, the estimated mean and standard deviation are reported. The model is estimated with simulated maximum likelihood using Halton draws with 250 replications (see Train, 2003), and the econometric software Limdep was used.

>>> TABLE 2

All attribute parameters are significant at the 5% level and about half of the standard deviations of the random parameters are also significant. Thus, we are able to capture unobserved heterogeneity in the preferences for outages. Based on the estimated parameters, we calculate the marginal WTP for reducing outages of various durations at different times of the week and of the year and the results are reported in Table 3. The standard errors are obtained by using the Delta method.

>>> TABLE 3

The marginal WTP for avoiding an outage is systematically higher for outages during weekends in the winter compared to the rest of the year, and the difference is

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[8] 10 days after the questionnaire was sent out, a reminder was sent out including a copy of the questionnaire.

[9] Comparing the sample statistics with Swedish population statistics (SCB, 2004) shows no statistical difference at the 5% level related to gender composition (p-value=0.76) and geographical representation (based on the postal codes) of the respondents (p-value=0.90). However, there is a significant overrepresentation of older people (95% confidence interval of age is 47.21-48.65 in our sample while the average age in the Swedish population aged 18-75 years is 44.88).

[10] Respondents who answered half or less of the choice sets (for each time of the year) were excluded from the final analysis.

[11] By keeping this parameter fixed we ensure that the distribution of WTP is the distribution of the outage attribute. Furthermore, allowing all parameters to be randomly distributed often leads to problems with convergence and identification (Ruud, 1996).

statistically significant for all outages except from the 8 hour duration. For outages during the weekdays, the difference is only significant between the seasons for 24 hour outages, where the marginal WTP is higher during the winter. As expected, the marginal WTP is systematically higher for weekend outages, when more members of the households are at home, compared to weekday outages, and the marginal WTP increases with the duration of the outage. Consequently, from a welfare point of view, it is of importance to consider these differences.

By using the results from the random parameter logit model and conditioning them with the individual choices, it is also possible to obtain individual level parameters. Thus, we can calculate the marginal WTP for each individual; the results of these calculations are presented below in Table 4.

>>> TABLE 4

The mean individual WTPs are similar to the population means we presented in Table 3. The last two columns in Table 4 report the percentage of reversed signs based on the individual parameters and the population distribution respectively, and the share of negative WTP values is much lower for individual parameters.[12] Similar results are found by Eggert and Olsson (2004) and Sillano and Ortuzar (2003). As discussed by Sillano and Ortuzar (2003), this means that the importance of constraining the distribution in order to rule out reversed signs, such as the log-normal distribution, might not be of great importance. Moreover, it should also be noted that applications of log-normal distributions results in sensitive estimates, which will further result in sensitive calculations of WTP (Train, 2003). In order to further illustrate the richness of information we obtain from the individual parameters, the distribution of some of the marginal WTPs for the attributes is shown in histograms. The largest degree of heterogeneity is found for the 24 hour outages, illustrated below in Figures 2 and 3. The figures show the actual frequency distribution of WTP in our sample. Since the sample is relatively small, the histograms do not resemble a normal distribution.

[12] For the individual parameters, we simply calculate the share of individuals with a negative WTP. For the population distribution we calculate the cumulative mass function evaluated from zero to minus infinity.

>>> FIGURE 2

>>> FIGURE 3

4. Discussion

Power outages have negative welfare effects on households, and many of these effects are non-monetary such as a drop in the indoor temperature and the impossibility of watching TV. In this paper we have applied a choice experiment to investigate the marginal WTP for reducing power outages among Swedish households, which then includes both monetary as well as non-monetary effects. Our results show that the households marginal WTP to reduce power outages increases with duration, and is higher during weekends and the winter months. The random parameter logit model allows us to estimate a sample distribution of WTP. We find a significant unobserved heterogeneity in some of the outage attributes but not in all. Furthermore we show that the sample distribution of WTP dooes not to any large extent suffer from the problem of reverse sign of the WTP. Therefore, choosing an unconstrained normal distribution might not be as problematic as one might think. This is of interest for future applications of the random parameter models, since a normal distribution tends to be much easier to handle with simulated maximum likelihood than say a log-normal or a truncated normal distribution.

Previous surveys on households WTP to reduce power outages in Sweden have applied an open-ended contingent valuation survey describing a power outage starting during an afternoon in January (Svenska Elverksföreningen, 1994). The WTPs for reducing an unplanned power outage for 4 and 8 hours were 21.54 and 60.60 SEK, respectively when expressed in year 2003 price level.[13] The marginal WTPs during winters obtained in our study are in general lower than these values. However, since the former study aimed at obtaining a value for the “worst case” and we estimate the WTP for reducing one unspecified outage, the difference in results is not surprising.

Our results also have policy implications for the regulation of the tariffs charged by the network companies. In 1996, the reformation of the Swedish electricity market began when the electricity sector changed from being a completely regulated domestic

[13] In the survey a power outages of a one hour duration were also included as well as planned outages.

market to a now completely liberalized Nordic-wide market with the major exception being the transmission of electricity. One part of the electricity bill paid by households relates to the tariff for the transmission of electricity, and the level of the tariff is determined by the network companies, since there is no market for transmission of electricity. However, the tariffs charged by the network companies have to be "reasonable" according to Swedish law, and in order to judge whether or not the tariff charged is reasonable, the so-called network performance assessment model has been developed. In cases when the network companies have over-charged their customers, they have to pay back the same amount to their customers. However, the current model only considers the duration of power outages as the relevant dimension to use when evaluating the negative welfare effects (Energimyndigheten, 2004). What we find is that the network performance model should differentiate on the timing of the power outages as well.

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Table 1. Attribute and attribute levels in the choice experiment.

Attribute	Attribute levels
Number of outages of 4 hour duration over 5 years	2,1,0
Number of outages of 8 hour duration over 5 years	2,1,0
Number of outages of 24 hour duration over 5 years	1,0
Cost	125, 200, 225, 275, 375

Table 2. Estimation results from the random parameter logit model.

	November- March		April-October	
Attribute	Coefficient	P-value	Coefficient	P-value
Fixed parameters				
Cost	-0.0082	0.000	-0.0105	0.000
Random parameters				
4 hour weekday	-0.0795	0.001	-0.1049	0.000
8 hour weekday	-0.1883	0.000	-0.2706	0.000
24 hour weekday	-0.8507	0.000	-0.7515	0.000
4 hour weekend	-0.2616	0.000	-0.1941	0.000
8 hour weekend	-0.3205	0.000	-0.3930	0.000
24 hour weekend	-1.1128	0.000	-1.0296	0.000
Standard deviation of random parameters				
4 hour weekday	0.0224	0.411	0.0055	0.843
8 hour weekday	0.0062	0.873	0.0136	0.724
24 hour weekday	0.6939	0.000	0.8185	0.000
4 hour weekend	0.0165	0.552	0.0160	0.559
8 hour weekend	0.4315	0.000	0.0362	0.342
24 hour weekend	0.8095	0.000	0.6006	0.000
Number of observations		2545		2543
Number of individuals		425		424
Pseudo R2		0.03		0.03

Table 3. Marginal WTP in SEK for reducing power outages (standard errors in parentheses obtained with the Delta method).

	November-March Mean marginal WTP	**April-October** Mean marginal WTP	**Test of H_0: No difference in WTP between the season (P-values), t-test**
4 hour weekday	9.64	10.03	
	(2.85)	(2.30)	0.915
8 hour weekday	22.83	25.87	
	(4.04)	(3.17)	0.554
24 hour weekday	103.16	71.83	
	(4.56)	(3.38)	0.000
4 hour weekend	31.73	18.55	
	(3.06)	(2.38)	0.000
8 hour weekend	38.86	37.56	
	(4.06)	(3.14)	0.801
24 hour weekend	134.96	98.42	
	(5.20)	(3.40)	0.000

Table 4. Estimated individual WTP.

		Mean	Std dev	Min	Max	% reverse sign Individual	% reverse sign Population
November-March	4 hour weekday	9.63	0.11	9.19	10.82	0.000	0.000
	8 hour weekday	22.83	0.02	22.72	22.91	0.000	0.000
	24 hour weekday	103.05	42.34	-40.01	218.95	0.008	0.110
	4 hour weekend	31.72	0.09	31.37	32.27	0.000	0.000
	8 hour weekend	38.95	18.10	-34.32	103.15	0.024	0.229
	24 hour weekend	134.93	55.32	-37.11	262.42	0.007	0.085
April - October	4 hour weekday	10.03	0.01	10.00	10.12	0.000	0.000
	8 hour weekday	25.88	0.03	25.74	26.02	0.000	0.000
	24 hour weekday	71.83	45.43	-33.85	195.66	0.052	0.179
	4 hour weekend	18.55	0.05	18.33	18.76	0.000	0.000
	8 hour weekend	37.56	0.16	36.92	38.08	0.000	0.001
	24 hour weekend	98.55	26.29	25.99	199.46	0.000	0.043

Figure 1. Example of a choice set.

Number of outages over 5 years	*Alternative A*	*Alternative B*
Working days: number of outages of 4 hours duration.	0 during 5 year	1 during 5 year
Working days: number of outages of 8 hours duration.	1 during 5 year	0 during 5 year
Working days: number of outages of 24 hours duration.	1 during 5 year	0 during 5 year
Weekends: number of outages of 4 hours duration.	1 during 5 year	2 during 5 year
Weekends: number of outages of 8 hours duration.	0 during 5 year	1 during 5 year
Weekends: number of outages of 24 hours duration.	0 during 5 year	1 during 5 year
Connection fee for your household	200 SEK	225 SEK
Your choice		

Figure 2. Histogram of individual marginal WTP to prevent a 24 hours power outage during weekdays in November-March and April-September.

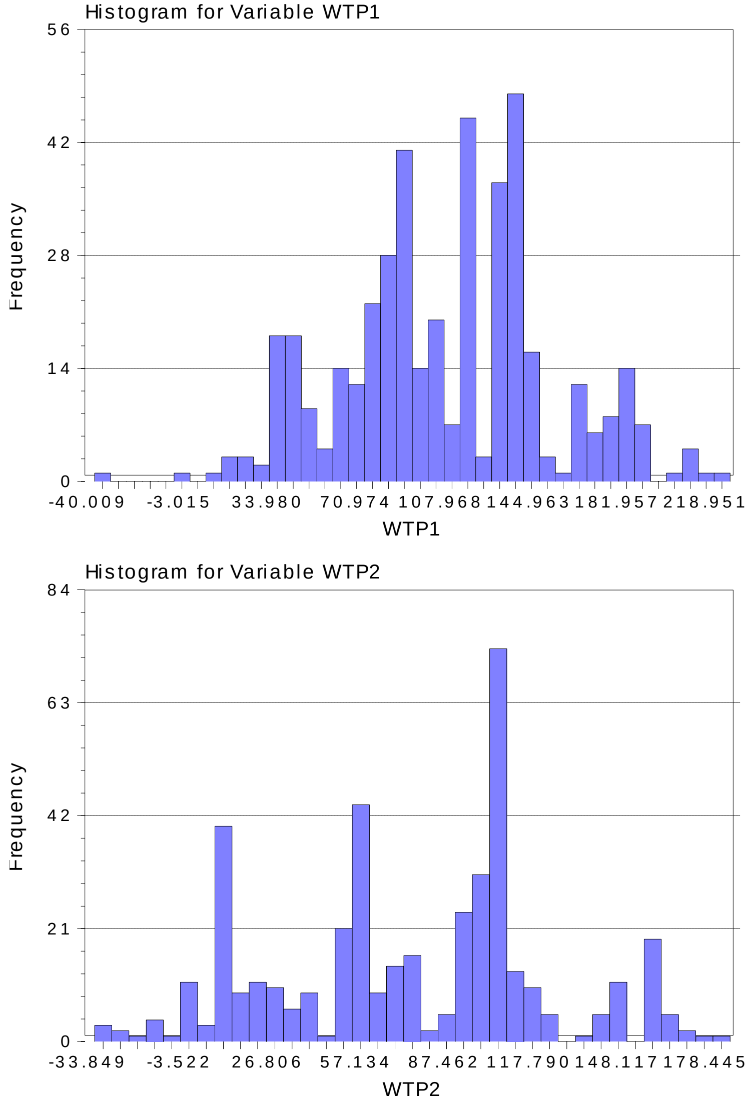
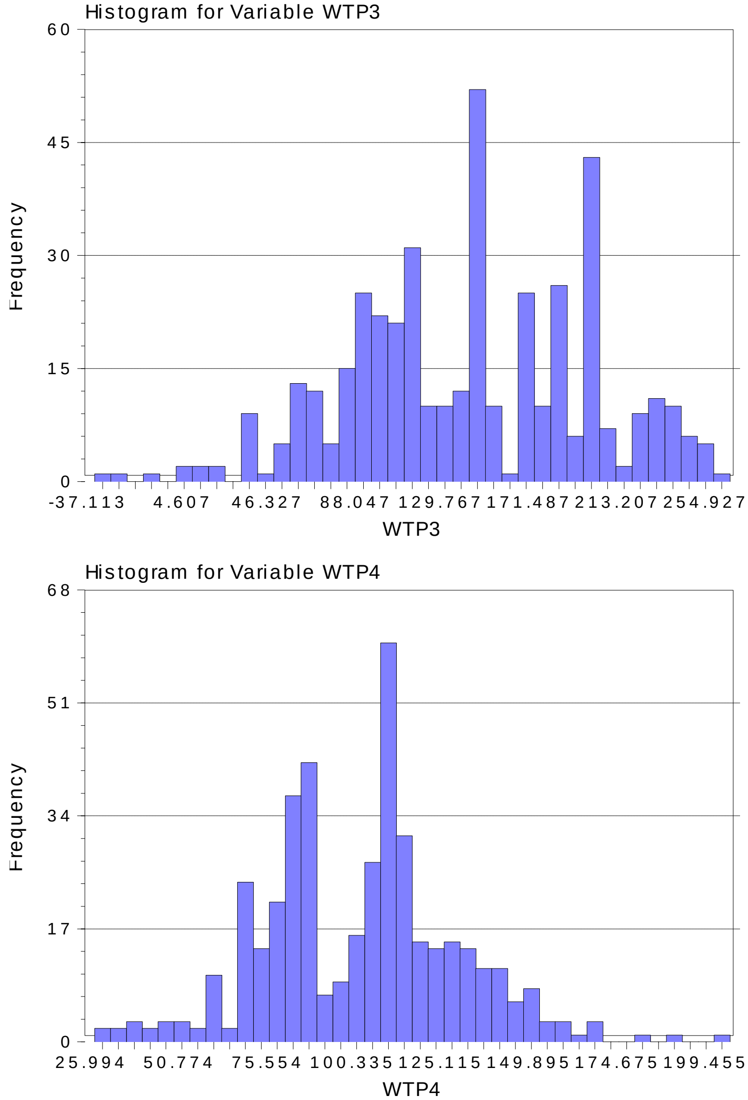


Figure 3. Histogram of individual marginal WTP to prevent a 24 hours power outage during weekends in November-March and April-September.



Appendix. Scenario

We will now ask some questions regarding your household's willingness to avoid power outages. Imagine that there is a possibility to choose between different contracts with your electricity supplier and that a backup electricity board exists that can be used in case of a power outage. By connecting to this backup electricity board you can affect the number of power outages that your household will experience. For connection to this service you have to pay a connection fee to the owner of the network. Apart from the stated power outages there will always be a number of power outages which you know about in advance because maintenance work will always be conducted.

Since power outages are not particularly common we present the number of outages for a 5-year period. For each alternative we will state the number of power outages of different durations on working days (Monday-Friday) and weekends (Saturday–Sunday). The time of the year may impact on your experience of the power outages. We will therefore ask questions both for power outages during the winter and during the rest of the year.

An example of a choice set is shown below. For each set we want you to state which alternative you think is best for you and your household. Note that your choice will not affect anything other than the number of power outages and your fixed tariff - everything else remains as it is today.

[An example of a choice set was shown below].