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Testing for non-linear acceptance costs for controlled electricity switch-offs using choice experiments

Abstract

With a higher share of renewable energy in the energy production mix, the need for a flexible electricity production, storage and demand increases. At household level, flexibility in the electricity consumption has the potential to mitigate unexpected drastic shortages of electricity in the system. The efficiency of household flexibility depends on the level of compensation needed to make households accept restrictions in their electricity consumption. The present paper contributes to a growing literature estimating the compensation requirements. Using the economic valuation methods choice experiments, we estimate the amount of compensation needed for households to accept contracts, which allow the energy company to remotely switch off the washing machine, laundry dryer and dishwasher in the household. The contracts vary with the number of times the appliances can be switched off in a year and the duration of each switch off event. Households are willing to accept contracts that allow the energy company to turn off individual devices and charge compensation ranging between 4.8-99.0 €/year, depending on the type of contract. The compensation level is found to increase exponentially with the number of annual switch-offs and a linearly with the duration of each switch-off.

Keywords: choice experiment; consumer contracts; controlled switch-off; willingness to accept; certainty in choice; transitivity

1. Introduction

The global demand for renewable energy is increasing. However, compared to non-renewable energy sources, the electricity production from renewable sources is less stable and difficult to ramp up and down in response to changes in demand. This has a potentially negative impact on the reliability of the electricity production and thus on the service level of electricity supply to consumers. Consequently, demand and supply flexibility has become a key element for the reliable operation of the power systems [1]. On the flexibility supply side, PV-battery storage systems for households in particular are increasingly being installed in many EU countries and other regions of the world [2]. On the one hand, these systems enable a higher share of self-produced PV electricity for self-consumption [3]. On the other hand, they provide flexibility to the energy system enabling the use of PV electricity in the evening hours. In addition to providing flexibility at household level, their flexibility is aggregated by market actors who offer their flexibility to distribution grid operators [4] and to wholesale spot and balancing markets [5,6]. Depending on their operation strategy, they can help to flatten the aggregate residual load curve of households. However, flexibility provided only by household battery storages is not sufficient to significantly reduce the need for backup capacities required at system level, see Fett et al [7]. Therefore, demand flexibility, such as load shifting and shedding, has gained increasing attention, as demand flexibility could be a tool to reduce expensive backup capacity installations and reduce investments in costly grid connections, among other benefits.

One tool that increases the flexibility of consumer demand is electricity price incentives. Wolak [8] finds that consumers with time-of-use electricity pricing reduce their electricity consumption in equal response to signals about a short or long period of price increase. Friis and Christensen [9] find that providing household with a free electrical vehicle and offering static time-of-use pricing caused the households to change consumption from high-tariff to low-tariff hours in relation to three consumption areas: dishwashing, laundering and charging of electric vehicles. In another study Tjørring et al. [10] test if text messages and economic incentives can induce households to shift electricity consumption to the period between 20.00-23.00. The results demonstrated a positive but also gender-specific effect. Just recently, Bejan et al. [11] found that consumers are more responsive to a fixed (plan ahead) price change relative to a dynamic price change in terms of reducing electricity consumption. The authors argue that this finding supports the development of automated response technologies that can reduce consumer costs of manually reacting to electricity price incentives. The consumer response to changes in electricity prices is reviewed by Kessel et al. [12]. The study concludes that in order to secure an efficient consumer response, dynamic electricity prices should be easy for consumers to understand, with timely notifications of price changes and a non-trivial effect on their electricity bills. If the tariff and pricing system is too complex, Kessel et al. [12] argue that the burden on consumers could be eased by introducing an automated control. Accordingly, smart meters and smart devices that can take advantage of static time-of-use pricing are a promising tool to balance demand and supply of energy. However, a drawback of this solution is that it relies on consumer behaviour and manual response to price changes. As such, it does not specifically address the need for abrupt supply reductions of utility companies. This strongly advocates for a controlled measure to ensure a more efficient flexibility on consumer level, which can lead to a better balancing of supply and demand.

In the past 5 years, a couple of studies have specifically analysed the potential demand flexibility at household level as a function of the power company having control over electricity consumption [13,14]. The two studies give valuable insight into the demand flexibility potential and the associated costs of having control over household electricity for periods of three hours or more. However, the studies do not explore whether consumers' disutility and ultimately the compensation required to make contracts with consumers vary with regard to the duration and number of flexible hours. If the compensation is non-linear with regard to the number of days with controlled hours and/or the durations of controlled hours, this will influence the optimal design of such contracts. More specifically, if the compensation costs per "controlled" hour are smaller for contracts with few and short controlled periods than many and longer controlled periods, such results would advocate for making contracts with many households for few and short controlled periods.

Using the economic valuation method choice experiments, (CE), the present study contributes by testing for non-linear levels of households' Willingness To Accept compensation (WTA) for contracts with an energy company. The contracts allow the company to shut off specific electricity devices in the household a specified number of times during the year and with specified durations. In the following the term "controlled switch-off" will be used as a synonym for energy company shutting off the electricity devices. Our results produce new evidence on households' non-linear WTA for controlled switch-offs. Compared to the studies by Broberg and Persson [13] and Ruomako et al. [14], we show that, on average, households value the compensation required for the number of switch-offs as a quadratic function, which exponentially increases the WTA for the number of controlled switch-offs. Broberg and Persson [13] and Ruomako et al. [14] do not test for variation in the WTA and the number of times the energy company have the control of the electricity consumption.

The paper is organised as follows. Section 2 gives a summary of previous studies and emphasises the specific contribution of this paper. Section 3 and 4 describe the survey design and the applied econometric model. The results are presented in Section 5. Section 6 discusses the results and section 7 concludes the paper.

2. Review of past studies

In the recent 5-10 years, the energy economic literature has focused on consumers demand for/accepting regulation of the electricity consumption on household level. The studies have applied different economic methodologies and sources of data. Using CE, Richter & Pollitt [15] estimate the need for compensation, when the control of the electricity devices in the household is handed over to the energy company. The study does not specifically test the level of compensation required as a function of when and how many hours the energy company has the control. The results denote that consumers require a monthly compensation of 3.0 €[1]for handing over the control of the electricity devices to the energy company. Pepermans [16] estimates preferences and Willingness To Pay (WTP) for smart meters that can control the electronic devices in the household. In the case that the shutdown is associated with a reduction in the comfort, such as turning down the heat in residence, the respondents have a WTP of €153/year to avoid such a discomfort. In addition to these studies, there is a relatively large literature finding a significant demand for electricity reliability i.e. WTP to avoid power outages/brown outs [17–20].

The two main studies estimating the relation between WTA and the energy company having the control of the energy consumption in specified hours during weekdays and in weekends are Broberg and Persson [13] and Ruokamo et al. [14]. Both studies use the economic valuation method CE. Broberg and Person [13] estimate preferences and WTA in the case of that the energy company has the control of the household's electricity consumption in the hours 7-10 am, 5-8 pm and in extreme cases between 7 am and 8 pm. The CE also includes an attribute that allows the energy company to

[1] 2.19 £ is reported in the original study. The 2015 average exchange rate between British pound and Euros is 1.379. [28]

control the heat in the household and an attribute that gives the energy company the right to share the household's consumption data. The study estimates an annual average level of compensation for electricity control of 91.6 € (7-10 am), 155.0 € (5-8 pm) and 4.8 €/day (7 am-8 pm), respectively[2]. The paper also tests how individual characteristics influence preferences for accepting a contract with the electricity control or not. The variation in preferences is analysed with regard to gender, age, educational level and income of the respondents, the number of children and adults in the household and type of residence. The study finds that older respondents, respondents with a higher income and respondents living in apartments are less likely to accept a contract. Interestingly, and in contrast to the income findings, the study find that respondents with a higher education attainment are more prone to accept a contract. With reference to the status quo bias literature [21], the authors argue that better educated respondents might have an easier task of making the trade-offs between the different attributes and thereby might be better in seeing the value of opting in for a contract.

Ruokamo et al. [14] estimate preferences and WTA for different contracts with the energy company. The contracts are characterised by a combination of different pricing schemes and attributes, which relate to the energy company having control of the electricity consumption in the household. The energy company can have control of the electricity consumption in the hours 7-10 am and 5-8 pm. The annual WTAs for allowing the energy company to have the control of the electricity in the evening and morning are 199 €/year and 54 €/year, respectively. As in Broberg and Persson [13], they analyse how individual and housing characteristics influence the preferences for accepting a contract with the energy company. The study reports no differences in preferences for accepting a flexible contract between genders, income groups, living environment and housing characteristics. They find that people with a higher education attainment and younger respondents are more prone to accept a contract. As mentioned above, both studies estimated the WTA for a fixed number of hours - in both cases three hours.

3. Data

This study's elicitation of preferences and WTA for controlled electricity switch-offs is based on a CE [19,22–24]. The CE methodology builds on Lancaster’s theory, according to which it is not a good per se, but rather the bundle of the good's attributes, that gives utility to the consumer [25,26].

[2] 833 SEK, 1409 SEK and 44 SEK are reported in the original study. The 2014 average exchange rate Swedish Kroner and Euros is 0.110 [28].

To identify the utility that individuals derive from the attributes, respondents in a CE are presented with a set of alternatives [27] and asked to choose the preferred alternative. The alternatives represent the good or service in focus by terms of the key attributes. Different alternatives are created by varying levels of the attributes. By examining the trade-offs between attributes and attribute levels that are implicitly made by the respondent's choices, it is possible to derive an estimate of the utility associated with the different attributes.

In our CE, members of households were asked to state their preferences and WTA for making electricity switch-off contracts with their energy company. In the description of the contracts, the respondents were told to imagine that the energy company remotely could shut off the washing machine, laundry dryer and dishwasher in the house. It was emphasised to the respondents, that no other electrical devices in the household would be shut off and that the washing machine, laundry dryer or dishwasher nor their content would be harmed by being turned off. With regard to the washing machine, it was specifically addressed, that the washing machine would not be turned off, if the washing machine was running a program for sensible clothes, such as silk or wool. The contracts varied with regard the maximum annual number of controlled switch-offs the electricity company could make, the maximum length of each switch-off and the level of compensation to the household (DKK/year). The attribute levels are in Table 1. The development of the survey and the CE was done using interviews of different researchers in the energy economics field and two focus group interviews.

Table 1: Attributes and attribute levels

Attributes	Levels	Variable name
Maximum number of controlled switch-offs each year	2 12 30	No. Switch-offs/year
Maximum duration of each controlled switch-off	15 minutes 1 hour 3 hours	Duration
Compensation level (€/DKK/Year)[a]	0 €/ 0 DKK (no contract) 3.4 €/ 25 DKK 13.4 €/ 100 DKK	Compensation

33.5 €/ 250 DKK
67.1 €/ 500 DKK
107.4 €/ 800 DKK
134.2 €/ 1000 DKK

Notes: a) exchange rates between € and DKK in 2005 were 100€ = 745.19 DKK and 100$US = 600.34 DKK [28]

A simple D-efficient fractional factorial main effect design with 18 alternatives was constructed using SAS [29]. Clearly, since 2005 when the study was carried out, methods to create more efficient CE designs have been developed, see for example Ferrini and Scarpa [30] or Vermeulen et al. [31]. In this perspective, the collected data might look outdated. However, if one considers that the survey was about WTA for basic energy services (electricity for washing machine, laundry dryer and dishwasher and these services are demanded by households at almost the same level as they were asked for in 2005, the data source is still a valid source for investigating the shape of WTA. The age of the data is elaborated on in details in the discussion part of the paper.

The SAS macros in Kuhfeld [29] were used to divide the 18 alternatives into three blocks with three choice sets, each consisting of two D-efficiently designed alternatives and an opt-out alternative (no contract). Each respondent thus evaluated three choice sets with two contract alternatives. Each respondent answered two additional choice sets as a part of a transitivity tests. As we will come back to in the discussion part of the paper, the transitivity tests show strong validation properties in the choices of the respondents. The two additional choice sets are not included in the preference analysis. Preferences for controlled switch-off contracts were obtained by using a paper questionnaire, which was sent by mail to a randomly drawn sample of 300 respondents. The sample consisted of private households in a large Danish municipality with an annual electricity consumption between 5,000 and 6,000 kWh. It was also a requirement that the sampled household did not use electricity as their main heating resource. In total, 85 respondents answered the survey, equal to a response rate of 28.33 percentages.

4. Econometric model

The choices, preferences and WTA for controlled switch-offs are estimated using McFadden's Random Utility Model RUM [32]. The utility U individual n in choice situation t receives from contract i is a function of the observable non-economic contract attributes x and the economic attribute p. In our case p is the level of compensation. This can be formulated as:

$$U_{nit} = -\alpha_n p_{nit} + \beta_n x_{nit} + \varepsilon_{nit} \quad [1]$$

Where α_n and β_n can vary randomly over individuals. As we will come back to, not all non-economic attributes are allowed to vary over individuals. It is assumed that $\varepsilon_{nit}$is IID extreme distributed. The variance is different between the different individuals, Var(ε_{nit})= $\mu_n^2(\pi^2/6)$, where μ_n is the individual scale parameter. To normalise the variance to $\pi^2/6$, equation [1] can be divided with the scale parameter, without changing the behavioural properties of the model:

$$U_{nit} = -\alpha_n/\mu_n\, p_{nit} + \beta_n/\mu_n x_{nit} + \varepsilon_{nit}/\mu_n \quad [2]$$

This model is also known as the preference space model [33] and can be rewritten to:

$$U_{nit} = -\gamma_n\, p_{nit} + \delta_n x_{nit} + \varepsilon_{nit}/\mu_n \quad [3]$$

Where $\gamma_n = \alpha_n/\mu_n$ and $\delta_n = \beta_n/\mu_n$. However, in policy or cost benefit analysis we are not interested in scale confounded preferences estimates, but are interested in the ratios between the non-economic attribute preference estimates and the economic attribute estimate – i.e. the Willingness To Accept compensation (WTA): $WTA_n = \delta_n/\gamma_n$. Inserting this into [3] gives

$$U_{nit} = -\gamma_n\, p_{nit} + (WTA_n\gamma_n)x_{nit} + \varepsilon_{nit}/\mu_n \quad [4]$$

Model [4] is known as utility in WTP - or in our case - WTA space. The respondents are presented with three alternatives in each choice situation; Contract A, Contract B and no contract (C). As shown in Table 1, the non-economic attributes are the maximum number (N) of controlled switch-offs and the maximum duration (D) of each controlled switch-off. The economic attribute is the compensation (Comp) given. This changes [4] into:

$$U_{ntj} = -\gamma_n Comp_{ntj} + (WTA_n\gamma_n)N_{ntj} + \ (WTA_n\gamma_n)D_{ntj} + (WTA_n\gamma_n)ASC\_AB_{ntj} + \ \varepsilon_{ntj}/\mu_n \quad [5]$$

Where ASC_AB is an alternative specific constant, which is included to account for the utility the respondents associate with choosing a contract (alternative A and B) relative to no contract (alternative C). The alternative specific constant represents the WTA, the respondents have for a contract, when accounting for the model specification of the number of controlled switch-offs, the duration of each switch-off and the compensation. As the only non-economic variable ASC_AB varies over individuals. None of the other non-economic attributes varied significantly in the estimated models, which likely is due to the low number, three, of choices per respondent. The WTA space model is estimated by using maximum simulated likelihood [34–36] with the mixlogitwtp command in STATA [37][3]. As it will be clear from the results, the estimated standard deviation of the compensation attribute is not significant. Again, this likely is due to the low number of choices each respondent makes.

5. Results

5.1. The sample

The characteristics of the sample are in Table 2. For validating the representability of the sample, Table 2 includes specific municipality statistics based on data from Statistic Denmark. Municipality statistics are presented for gender, age, education, household income level and if there are children in the household. Unless something else is mentioned, the municipality statistics are drawn for the year 2005. For each characteristic, we have tried to obtain statistics that are as close to the sample definition as possible. The sample is defined by homeowners between 28-81 years of age (cut of years in the effective sample). It has not possible to conditional the statistics on the household electricity consumption. Except for the income level, we are not able to distinguish between homeowners and people renting their residence.

Table 2: Sample Characteristics, N=85.

Characteristics	Mean	S.D.	Number of respondents	Statistics Denmark
Female	0.55	0.50	85	0.50[a]
Age	50.31	10.51	65	52.12[b]
Highest educational attainment				
Master	0.11	0.30	85	0.03[c]
Bachelor	0.31	0.46	85	0.15

[3] When estimating the model in STATA, the sign of the compensation attribute is not changed, as the models is in WTA space and not WTP space.

Shorter secondary education	0.11	0.30	85	0.04
Vocational	0.24	0.42	85	0.42
High school	0.01	0.11	85	0.04
Elementary school	0.24	0.43	85	0.33
Household income level (1,000 €)	65.8	27.2	85	62.4[d,e]
Children in the household	0.49	0.50	83	0.61[f]
Attitude to saving electricity[g]	1.81	0.67		-
Perception of renewable in the energy mix[h]	0.77	0.42		-

Notes: a) For gender, we are not able to obtain statistics for our specific age groups (21-81 years) [38]. b) For age, we can obtain the statistics in the relevant age distribution (21-81 years), though only for the year 2008, three years after the survey was carried out [39]. c) In the case of the education statistics, data on the highest educational attainment among people between 25 and 69 has been drawn [40]. d) Exchange rate between € and DKK in 2005 was 100€ = 745.19 DKK [28]. e) The household income estimate is conditional on being an owner of the residence, the family lives in. It is not possible to conditional on the age distribution of the respondents in the survey [41]. f) The statistics of the number of children in the household are conditional on age distribution (21-81 years) of the respondents in the survey[39]. g) Equal to 0, 1, 2 and 3 if the respondent; does not think, thinks a little, thinks relatively much and thinks a lot on saving power, respectively. h) Equal to 1 if the respondent finds it important that the electricity is produced by renewable energy, else equal to 0.

The sample's average age is 50.31 years and is 52.12 years in the population statistic. The population numbers point towards that the sample is overrepresented by respondents with a master degree, bachelor degree or a shorter secondary education. These respondents constitute 53 percentages in the sample, but only 22 percentages in the population. A bias in the comparison might be that the population statistics only have people younger than 70 years. However, even if we condition our sample statistics on respondents being younger than 70, the respondents with a longer education are still overrepresented. Moving on to the household income level, the average income level in the sample is 65,800 €. The population average is 62,400 €. The final statistical comparison variable is the share of households with children. In the sample, 49 percentages of the households have a child living at home, which is lower when compared to the sample statistics of 61 percentages. Finally, we have two variables controlling for the subjective perception of saving energy and the importance of having renewable energy in the energy mix. With regard to the first perception measure, the respondents were asked, how often they think about saving the consumption of electricity. They could answer on four levels scale equal to 0, 1, 2 and 3 if the respondent; does not think, thinks a little, thinks relatively much and thinks a lot on saving power, respectively. The mean perception of electricity savings is 1.81. In the second case, the respondents were asked how important they find it that the electricity is produced by renewable energy renewable. The respondents could answer important (equal to 1) and not important (equal to 0). The mean level of importance is 0.77. It has not been possible to find comparing statistics with regard to the two subjective measures.

Accounting for that it has not been possible to draw complete matching population statistics, the sample appears to have a higher share of females and respondents with a master degree, bachelor degree or a shorter secondary education. Respondents with a vocational education are highly underrepresented. On the other hand, there seems to be an under representation of respondents in sample from a household with children living at home.

5.2. Preferences and Willingness to Accept

The estimated WTAs for the number of controlled switch-offs and the duration of each switch-off are presented in Table 3. We estimate three models. The first model assumes a linear relationship between the number of controlled switch-offs, the duration and WTA. Model 2 is a more flexible model and allows for a quadratic relation between the number of controlled switch-offs, the duration and WTA. Model 3 includes the linear and quadratic WTA relations, which give the best model fit, i.e. “Best fit” Model.

Table 3: WTA-space models (€)[a]

	Linear Model Estimate	Quadratic Model Estimate	“Best fit” Model Estimate
Mean			
No. Switch-offs/year	-1.60^{***}	0.71	
	[0.45]	[1.50]	
No. Switch-offs/year^2		-0.07^{+}	-0.05^{***}
		[0.04]	[0.01]
Duration/switch-off	-18.81^{***}	7.81	-18.36^{***}
	[4.56]	[18.92]	[4.31]
Duration/ switch-off ^2		-7.50	
		[5.22]	

ASC_AB	39.12	18.03	31.36
	[26.07]	[26.56]	[25.04]
Compensation	-3.492***	-3.447 ***	-3.452 ***
	[0.159]	[0.155]	[0.159]
Random Parameters Standard Deviation			
ASC_AB	137.22***	139.20***	135.67***
	[33.33]	[33.21]	[32.49]
Compensation	0.000429	0.0000046	0.000177
	[0.429]	[0.238]	[0.328]
N		85	
LL(0)		-226.96	
LL(β)	-170.86	-167.95	-169.32
McFadden R2	0.247	0.260	0.254

Standard errors in brackets. The level of parameter significance is marked by $^{+}$ $p < 0.10$, * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$. [a)] Exchange rate between € and DKK in 2005 was 100€ = 745.19 DKK [28].

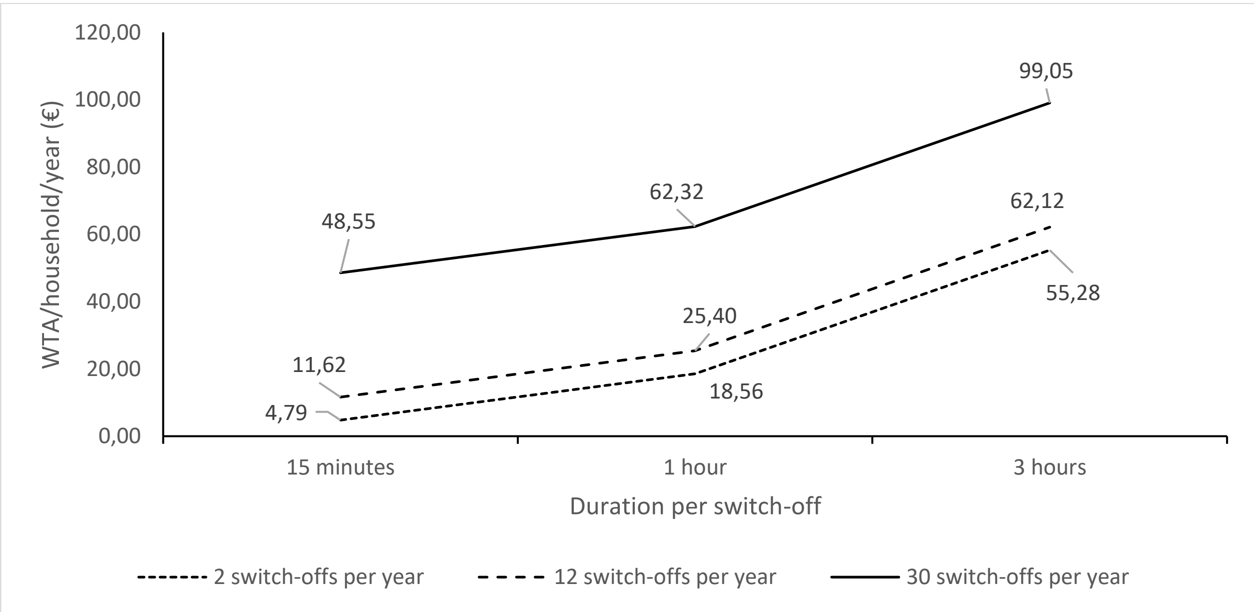
The results from the linear model denote a significant linear relation between WTA and the number of controlled switch-offs and the duration of each switch-off. Each switch-off requires a compensation of 1.60 €/year and every hour of power switch-offs requires a compensation of 18.81 €/year. The estimate of the alternative specific constant for contract A or B is positive. This suggests that the respondents on average have a tendency to choose an alternative (a contract) , which the model specification[4] does not capture. The estimate is not significant. The inclusion of the quadratic variables for the number of controlled switch-offs and the duration of each switch-off increases the loglikelihood value from -170.86 to -167.95. With two degrees of freedom (two more variables are added to the model), a LR test denotes a significant improvement of the model. The improvement is though only significant on a 90 percentages level of confidence. In Model 2 both linear estimates are insignificant and only one of the quadratic estimates is significant on a 90 percentages level of confidence. In the “best fit” model, we keep the quadratic term for the number of power switch-offs. The estimate of 0.05 € per number of switch-offs^2 is significant on a 99.9

[4] If we exclude both controlled switch-offs terms in the model, the associated WTAs are being captured by the alternative specific constant. The WTA for the alternative specific constant now drops to – 16.51 €.

percentages level of confidence. The linear duration variable is kept in the model and the estimate is significant on a 99.9 percentages level of confidence. The estimated WTA is 18.36 € per hour of switch-off. A LR test comparing the "Best Fit" Model with Model 2 (with more parameters) denotes no significant differences in model fit on a 90 percentages level of confidence. The linear model and the "best fit" models are not nested. It is therefore not possible to determine, which model that is correct. The non-economic variables are not significant in Model 2 on a 95 percentages level of confidence and due to the better fit of "Best Fit" model (compared to Model 1), the "Best Fit" model will be used in the following analysis.

The WTA estimates above can be combined in different contract types, which vary in number and duration of the switch-offs. In Figure 1, the WTA levels for different combinations of the number of controlled switch-offs and the duration per switch-off are estimated.

Figure 1: WTA (€) for different combinations of number of controlled switch-offs and the duration per switch-off. Based on the "Best Fit" model.

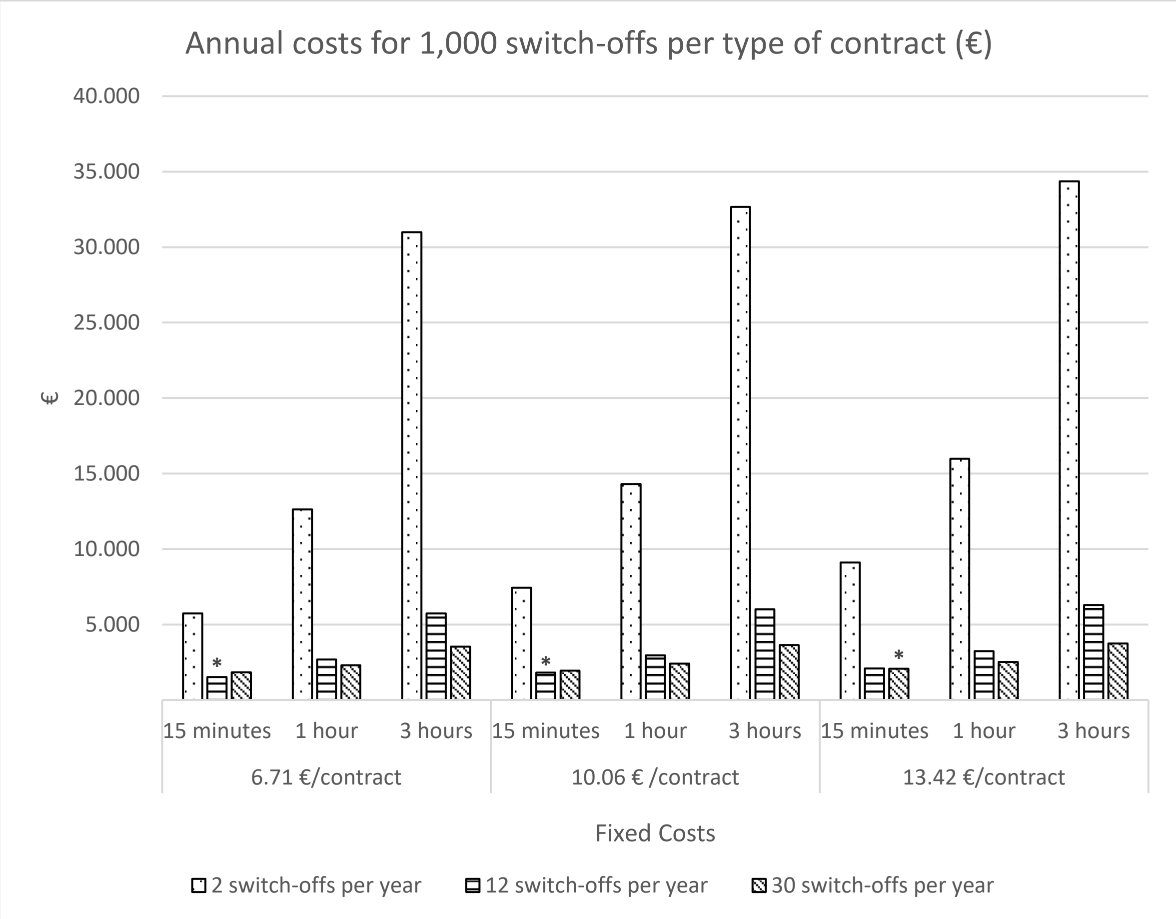


As shown in Figure 1, the WTA strongly correlates with the number of controlled switch-offs due to the quadratic term in the WTA-space model. If the duration of each controlled switch-off is 15 minutes, the WTA levels are 4.8 €/year, 18.6 €/year and 55.3 €/year for 2, 12 and 30 switch-offs per year, respectively. In the case that the duration per controlled switch-off is one hour, the annual

WTA levels are 11.6 €, 25.4 € and 62.1 €. Finally, the WTA levels are 48.6€/year, 62.3 €/year and 99.0 €/year, if the duration of the controlled switch-off is three hours.

The differences in WTA across types of contracts influence the type of contracts worth making from the energy companies' point of view. In a simple framework, the type of contract, which minimises costs of the energy companies, is function of the characteristics of the annual balancing needs in terms of the number and duration of switch-offs and the annual fixed costs of making a contract. To illustrate this, let us assume that an energy company needs to minimise the costs of 1,000 switch-offs or minimise the costs of 1,000 switch-off hours.

We start with the goal to minimise the costs of 1,000 switch-offs. In Figure 2, the costs of the different types of contracts based on the estimates from Table 3 and Figure 1 are shown for varying levels of annual fixed contract costs. We assume the following three levels of annual fixed costs: 6.71€ /contract, 10.06 € /contract and 13.42 €/contract[5]. The columns marked by * denote the contract with the least costs.



[5] This is equal to fixed contract costs of 50 DKK/year, 75 DKK/year and 100 DKK/year with an exchange rate between € and DKK in 2005 of 745.19 DKK for 100 € [28].

Figure 2: Annual costs (€) per type of contract and per level of fixed costs per contract to obtain 1,000 switch-offs.

As seen in Figure 2, the costs increase uniformly with the duration of each switch-off. The longer duration, the higher costs. Accordingly, the least costs are obtained by making contracts with 15 minutes duration of each switch-off. The least costs within this type of contract then depend on the annual fixed costs per contract. If the annual fixed costs are relatively small (6.71 €/contract/year), contracts with 12 annual switch-offs are the cost-minimising for the energy company. The total annual costs in that case are 1,528 €. If the annual fixed costs per contract are 10.06 €, contracts with 12 annual switch-offs are still cost minimising (1,807 €), though contracts with 30 annual switch-offs become more attractive (1,954 €). If the annual costs increase to 13.42 € per contract, contracts with 30 annual switch-offs become the least costs solution for the energy company. The annual costs are 2.066 € relative to 2,087 € for contracts with 12 annual switch-offs. Clearly, if the annual fixed costs per contract increase beyond 100 DKK, contracts with 30 annual switch-offs become even more costs minimising relative to contracts with 12 annual switch-offs.

We now move on to the case, in which the energy company wish to make contracts worth of 1,000 hours of switch-offs. The costs per type of contract with varying annual fixed contract costs are in Figure 3. Columns marked by * denote the contract with the least costs.

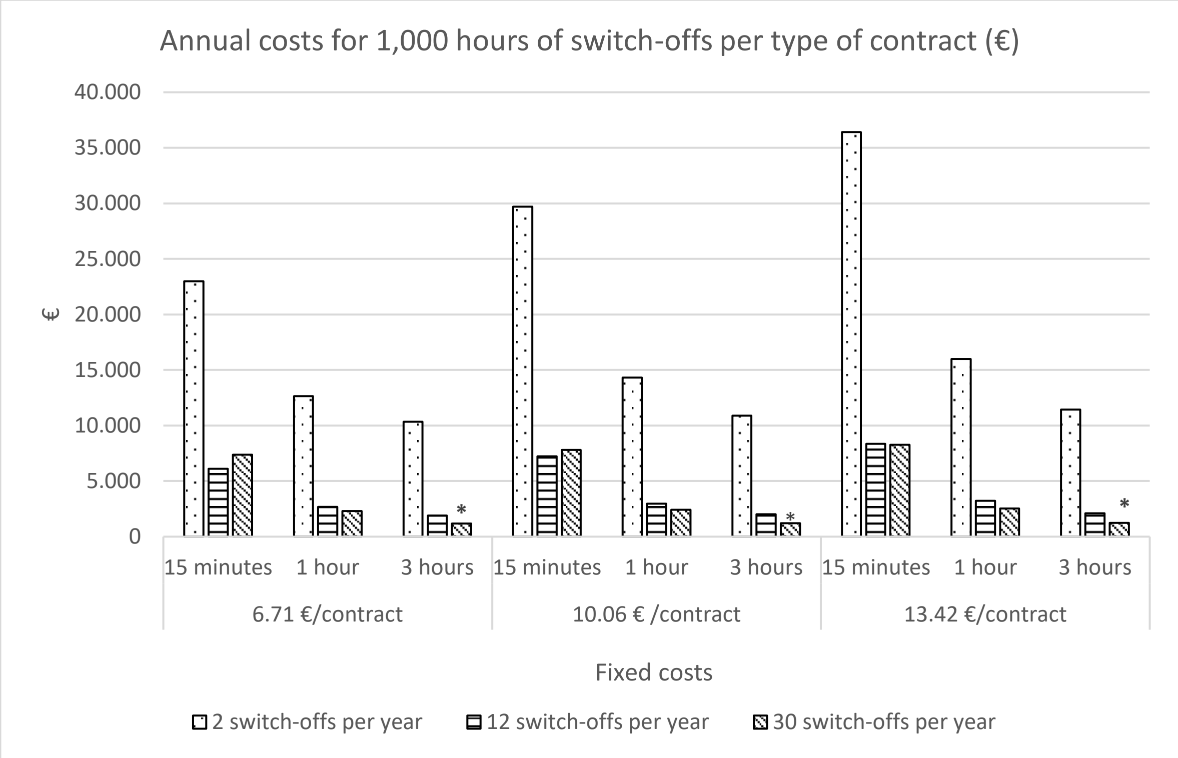


Figure 3: Annual cost (€) per type of contract and per level of fixed costs per contract to obtain 1,000 hours of switch-offs.

Except for contracts of 15 minutes of switch-offs, costs of obtaining 1,000 hours of switch-offs uniformly decrease with the duration of each switch-off. The longer duration, the lower are the total contract costs. Accordingly, the contracts with the least costs are obtained by making contracts of 3 hours switch-off durations. This is independent of the annual fixed contract costs. If the annual fixed contract costs are 6.71€ /contract, 10.06 € /contract or 13.42 €/contract, the total annual costs sum to 1,175 €, 1,212 € and 1,250 €, respectively.

As a final comment, our cost estimates might be in the low end, if the energy company have to install smart technologies, which can switch off the electrical devices in the household. On the other hand, such devices could be send by delivery and just be plugged in by the consumers with a minimum of effort. Our results though demonstrate that for annual fixed cost beyond 13.42 €, the cost minimising contracts will be 15 minutes contracts with 30 annual switch-offs if the goal is to obtain 1,000 annual switch-offs. If the goal is to obtain 1000 hours of switch-off, the cost minimising contracts will be contracts with 30 annual switch-offs with 3 hours of duration.

6. Discussion

6.1. Sample size

In the sections above, the WTAs for controlled switch-offs in a sample of families owning their own residence have been presented. The estimated WTAs are highly significant and show substantial variation over types of controlled switch-off contracts. This is despite that the sample only includes 85 respondents. The low number of respondents is clearly a limitation of the study and makes it difficult to make precise inferences of the potential compensation levels on a national level. However, the aim of the study was never to estimate national level of compensation, but to test whether households/consumers of electricity are willing to make controlled switch-off contracts with power companies. It was also an aim to test if the WTA was non-linear in the dimensions of number of switch-offs and duration of each switch-off. With these results and with the increasing use of smart technologies, the potential for further research in this area seems to be grounded.

6.2.Validation of the study

One of the weakness of the paper is the low number of respondents. This naturally raises the concern if the stated preferences and estimated WTAs have the expected economic properties and are valid. We will address these concerns from different angles and give support of the validity of the estimated WTAs in the following sections.

6.2.1. Certainty in choice

One way to analyse the validity of the stated choices is to explore the respondents certainty in choice [42]. Several studies have explored the relation between certainty and choice validity. The studies find evidence of that certain respondents may be less subject to hypothetical bias and that their choices are more consistent [43–45]. In the questionnaire, the respondents were asked to state the level of certainty in their choices after the three choice tasks. The certainty levels were; difficult (1), somewhat difficult (2), neither difficult nor easy (3), somewhat easy (4) and easy (5). Of the 85 respondents, 23.5 percentages stated that the choice tasks were difficult or somewhat difficult, 17.3 percentages stated that the choice tasks were neither difficult nor easy and 56.0 percentages stated that the choice tasks were somewhat easy or easy. Among the respondents, 3.3 percentages did not report a certainty level. The median value is “somewhat easy”. This is comparable to a median value of 7 or higher found in studies using a 10 point scale [43,45] and a median value of 4 or higher found in studies using a five point scale [46,47]. Comparing our study’s levels of certainty in choice with other studies’ level of certainty is not a specific test of validity. However, we interpret the matching levels of certainties relative to other studies as a positive indicator of the validity in choices in our data.

6.2.2. Transitivity in choices

In addition to the three CE designed choice sets (CS1, CS2 and CS3), the respondents were also given two transitivity choice sets (CS4 and CS5). The transitivity design was based on alternative A and B in CS3. In CS4, alternative B in CS3 (B_{CS3}) was paired with a new alternative (D), not being part of the CE design and a no contract option (Alternative C). In CS5, alternative A in CS3 (A_{CS3}) was paired with alternative D from CS4 and a no contract option (Alternative C). With this setup, four types of intransitive preferences can be identified.

A) Respondents choosing no contract (Alternative C) relative to alternatives A_{CS3} and B_{CS3} in the CS3, should not choose alternative B_{CS3} in CS4 or alternative A_{CS3} in CS5.
B) Respondents choosing alternative A_{CS3} in CS3, should not choose no contract (Alternative C) in CS5 and respondents choosing B_{CS3} in alternative CS3, should not choose no contract (Alternative C) in CS4.
C) Respondents choosing alternative A_{CS3} in CS3, and alternative B_{CS3} relative to alternative D in CS4 should not choose alternative D relative to alternative A_{CS3} in CS5.
D) Respondents choosing alternative B_{CS3} in CS3, and alternative A_{CS3} relative to alternative D in CS5 should not choose alternative D relative to alternative B_{CS3} in CS4.

In the data, we only find three respondents out of 85 respondents (3.7 percentages) that are intransitive. This is in the low end compared to other studies. In three CE studies with binary choices: Carlson and Martinsson [48] find less than six percentages of the respondents to be intransitive, McIntosh and Ryan [49] find six percentages of the respondents to be intransitive and Van der Pol and Cairns [50] find 9-11 percentages to be intransitive. In an Contingent Ranking study with four alternatives and thus having a more complex choice/rank structure compared to the binary choices studies mentioned, Foster and Mourato [51] find 13 percentages of the respondents to be intransitive.

6.2.3. Income effects

One of the validation criteria in stated preferences studies is significant relations between income and WTP or WTA for a change in the good in focus [52]. Though not always observed in stated preference studies [53,54], significant relations between income and preferences are seen as a positive indicator of that the respondents have made hypothetical choices based on the content of their valet. As a validation test, we have tested whether WTA varies significantly over two income groups. The median annual household income level in the sample is 53.667 € (400,000 DKK). There are 45 respondents with an income below 53.667 € and 40 respondents with an income equal to or above 53.667 €. The WTA levels of the two subgroups are presented in Table 4. The differences in WTAs between the two income groups are compared and the significance of the WTA differences is estimated using the Poe-test [55,56]. The presented WTAs are from the "Best fit" model for each of the two income groups. The estimated "Best Fit" models are in Appendix A.

Table 4 WTA (€) across respondents with a household income ≥ or < than 53.667 €

Income <53.667 €	0.25 hours/switch-off	1 hour/switch-off	3 hours/switch-off	ASC_AB
2 switch-offs/year	10.73 [2.95] ***	21.34 [5.90] ***	63.47 [17.85] ***	-79.58[50.46]
12 switch-offs/year	16,91 [2.95] ***	39.45 [5.50] ***	69.65 [17.04] ***	
30 switch-offs/year	50.19 [14.22] ***	69.66 [13.96] ***	102.93 [18.12] ***	
Income≥53.667 €	**0.25 hours/switch-off**	**1 hour/switch-off**	**3 hours/switch-off**	**ASC_AB**
2 switch-offs/year	4.83 [1.21]***	8.45 [1.88] ***	48.31 [15.83] **	9.53 [25.77]
12 switch-offs/year	21.07 [7.11] **	26.17 [6.84] ***	66.03 [15.57] ***	
30 switch-offs/year	54.08 [17.85] **	57.84 [17.58] **	97.69 [20.26] ***	
WTA Difference	**0.25 hours/switch-off**	**1 hour/switch-off**	**3 hours/switch-off**	**ASC_AB**
2 switch-offs/year	5.90 (0.0599)	12.75 (0.0187)	15.16 (0.2600)	89.10 (0.0569)
12 switch-offs/year	-5.50 (0.7609)	1.34 (0.4431)	3.62 (0.4336)	
30 switch-offs/year	-4.03 (0.5650)	2.82 (0.2526)	5.10 (0.4109)	

Standard errors in brackets $^{+}$ $p < 0.10$, * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$. The numbers in parentheses (0.xxxx) denote the Poe-tests levels for significant differences in WTA between the two income groups.

Taking into account the few observations in each income group, the results in Table 4 indicate that respondents from a household with an income below 53.667 €, except for the case of contracts with 12 or 30 switch-offs and 15 minutes duration, have a higher WTA compared to the respondents from a higher income household. The differences are though small (1.34-15.15 €) and are only significant on a 0.05 level in the case of a contract with 2 switch-offs per year with a maximum duration of 1 hour. On the other hand, lower income households have lower WTA for a contract (WTA_{ASC_AB}) than higher income households. Despite that the WTA_{ASC_AB} estimates for lower and higher income groups are insignificant, the difference of 89.10 € is significant on a 0.057 level using the Poe test.

6.3. Comparison of means from other studies

Relative to Broberg and Persson [13] and Ruomako et al. [14], we estimate WTA for a varying number of controlled switch-offs with different switch-off durations. The other two studies estimate WTA for fixed durations and fixed hours and have a different choice space. However, there is an overlap in the number hours the energy company has the control of the household's electricity consumption and the three-hour attribute in our study. Clearly, the framing and the setup of the two newer surveys and our survey differ markedly and a direct one-to-one comparison in WTA is not possible. However, we will still attempt to make a comparison of the levels of WTA between the studies, having the differences in the studies in mind. Our study finds WTA estimates in the range of 4.83-99.03 €/household/year. The minimum and maximum WTA estimates represent a contract with 2 power switch-offs with 15 minutes duration switch-offs and a contract with 30 power switch-offs with 3 hours duration switch-offs. In Table 5, we compare the WTA estimate related to 30 switch-offs of three hours duration with the WTA estimates from Broberg and Persson [13] and Ruomako et al. [14]. The original study WTA estimates are compared in € 2019 values. This is done by inflating the WTPs in each study from the study year to 2019. Using the exchange rate between DKK/SEK and DKK/Euros in 2019, the WTA estimates are converted to Euros. We also adjusting for differences in purchase power parity (PPP) between Denmark, Sweden and Finland in the comparison year 2019. The inflated and PPP adjusted WTAs in euros are marked in bold in the rightmost column.

Table 5: Comparing the mean of WTA for three hours switch-offs.

	WTA	Year	Inflation (year-2019)	Exchange Rate[d]	PPP(2019)[e,f]	**WTA 2019 (€/year)**
Our study	738 DKK	2005	22.59%[a]	746.60	0.998	**121.39**
Broberg & persson (2016)	833 SEK	2014	6.67%[b]	1058.69	0.939	**88.80**

	1.409 SEK				**140.82**
Ruomako et al. 2019		2016	2.50%[c]	0.945	**58.97**
					212.02

Notes: a) Statistics Denmark[57], b) Statistics Sweden [58], c) Statistics Finland [59], d) Danmarks Nationalbank[60], e) OECD [61] and f) PPP2019/exchange rate 2019.

The converted WTAs indicate that our WTA is within the range of the estimates in Broberg and Persson [13] and Ruomako et al. [14]. However, our estimate is conditional on 30 power switch-offs per year, whereas the comparing estimates are conditional on five switch-offs per week. This is equal more than 250 switch-offs/year. In that sense, our estimates are in the high end. Beside the potentially actual differences in WTA between the samples, there are be several possible explanations for the estimated differences. Naturally, the first explanation relates to above-mentioned differences in the choice space, making the comparisons most difficult. Assuming that a comparison is possible, another explanation for the differences in WTP could be differences in information about the timing of the controlled switch-offs. In our study, the consumers do not know when the controlled switch-off will occur. This uncertainty can induce a WTA premium, which increases the level of WTA in our study. Another explanation could be that the switch-off attribute in Broberg and Persson [13] and Ruomako et al. [14] is the energy company having the control of the electricity. If the respondents do not associate control with always having reduced use of the electrical appliance in the three hours intervals in the two studies, compared to specific switch-off in our study, this could explain the lower levels of WTA in in Broberg and Persson [13] and Ruomako et al. [14]. A third explanation could be framing effects, i.e. WTA for switch-offs are conditional on the frame or scale of the good in focus. There are only three attributes in our study: The number and duration of controlled switch-offs and the compensation offered to the household. In Broberg and Persson [13] the three hours switch-off/control attribute is evaluated jointly with heating control, extreme switch-offs events, sharing of consumption data with others and the compensation attribute. In Ruomako et al. [14] the three hours switch-off attribute is evaluated with two electricity contract types, controlled heating, CO2 reductions and the compensation attribute. In this perspective, the respondents in Broberg and Persson [13] and Ruomako et al. [14] might put a different emphasis on the three hours switch-off attribute, when the switch-off attribute is embedded with other attributes. An example of such framing effects is found in Gao and Schroeder [62]. In a CE survey, they test the impact on WTP for food attributes, when increasing the number attributes in the CE from 3 to 4 attributes and from 4 to 5 attributes in an experiment. They find that when the number of attributes increase from 3 to 4, the WTP for some of the attributes decreases significantly. However, when adding the fifth attribute, the WTP increases again. In a similar test using CE, Caputo et al. [63] find that WTP decreases for the attributes in focus, when the number of attributes increases.

6.4. Critical reflection on the age of the data

One of the limitations of this study is the age of the data, which is from 2005. As we will argue in section 6.5., the policy implications are perhaps even more relevant, when compared to 15 years ago. However, the question remains if we can expect the estimated WTA relations to be persistent over time. One year and up to 30 years WTP persistency and stability have been tested and discussed in a substantial number of studies, see for example Brouwer at al. [64], Schaafsma et al. [65], Liebe et al. [66], Mørkbak and Olsen [67], Price et al. [68], Gebeye et al. [69], Lew and Wallmo [70], Matthews et al. [71], Neher et al [72] and Rolfe and Dyack [73]. The results generally point towards stability in preferences in terms of the sign of the estimated WTP for the continuous variables, such the number and duration of the controlled switch-offs in our study. This stability is even more given when we consider that analysis of WTA is about basic energy services, which have more or less the same relevance in today's households.

The absolute level of WTP might though vary between test periods. In this perspective, we would not expect people suddenly to hold positive preferences and negative WTA for making switch-offs contract with the energy company. The question remains, if the estimated non-linear relations persist? The only study that includes a non-linear coding of the continuous attributes is the study by Liebe et al. [66], having a test-retest period of 11 months. In the study, the WTP for reducing impact from wind turbines on the Red Kite population and increasing the distance of the wind farms to settlements were estimated using dummy variables to account for non-linear WTPs. The WTPs were significantly different from zero. In the case of the impacts on the Red Kite population, the WTPs were almost linear in the interval from 5 to 10 percentages reduction in the Red Kite population and 10 to15 percentages in redcution, though slightly exponentially increasing in the retest sample. The exponential increase seems insignificantly different from a linear function (though not tested in the paper). In the case of the WTP for locating the wind farms at 1,100 m or 1,500 m relative to 750 m from settlements, they are not significantly different from each other in both the test and retest samples. This suggests persistent marginally decreasing WTP for locating wind farms beyond 1,100 meters relative to 750 m over a period of 11 months. These persistent non-linear wind power preference specific results are supported by the meta-analysis by Wen et al. [74]. In the study, they find strong evidence of non-linear WTPs for locating wind farms at difference distance from shore/settlements across different studies in different years and countries.

Naturally, these studies can only be used in an indicative way to support a potential persistency in our non-linear relations between WTA and the number of controlled switch-offs. That said, independent on whether our findings of exponentially increasing WTAs for number of controlled switch-off our findings are persistent or not – the finding in itself should inspire future studies to test for similar non-linearity in WTA. Furthermore, a potential future research topic could be to re-run the choice experiment to see if there is any dynamic in the change of WTA.

6.5. Policy implications of the results

Since the survey was carried out in 2005, the policy setting in Denmark and internationally has changed markedly. Significantly landmarks were established with the Paris Agreement in 2015 [75] and the United Nations 17 world goals, particularly Goal 7, which focused on ensuring access to affordable, reliable, sustainable and modern energy for all [76]. These global initiatives have pushed forward an agenda, which directs research and policy efforts to focus on renewable energy technologies specifically and broadly in technologies that lower the costs of the green energy transition. These new policy measures do not reduce the relevance of our results, conversely. Insights into how we can minimise the costs of the green transition are in even high demand compared to when the study was carried out.

Clearly, the technology side has developed substantially from 2005 – particularly with the smart technologies enabling the consumers to respondent directly to changes in market prices. However, as the studies reviewed in the introduction part of this article demonstrate, the costs for consumers to manually change electricity demand to abrupt dynamic changes in the electricity prices are significant [11]. This, jointly with the review by Kessel et al. [12], advocates for an automated control of household electricity consumption, which is the approach in this article and in the articles by Broberg and Persson [13] and Roukamo et al [14]. Following this line of thinking, our results have several policy implications. First of all, the non-linear relation between the number of switch-offs and WTA has an impact on the choice of contract energy companies wish to make with household in order to minimise their costs. Our examples point towards that the costs of the energy companies are minimised by making many contracts with short durations, if the goal is to maximise the stock of controlled switch-offs. If the goal is to maximise the stock of controlled switch-off hours, the costs are minimised by making few contracts with many switch-offs and long duration switch-offs per household/contract. Clearly, conditional on the small samples size, the non-linearity in WTA calls for further research in order to give more precise policy recommendations. Secondly, our results also calls for a further exploration of the potential differences in WTA as a function of the households' characteristics. Our data set is small, but the significant income relations illustrated in section 6.2.3, suggest that substantial WTA heterogeneity across household can be present.

7. Conclusion

Using stated preferences from a CE in a sample of Danish household owners living in a large municipality and with an electricity consumption of 5,000-6,000 kWh per year, a WTA-space model is estimated for accepting controlled switch-offs of the household's washing machine, laundry dryer and dishwasher. The results point towards that the households are willing to endure controlled switch-offs between 2-30 times per year and with a duration of 15 minutes to 3 hours per switch-off. The models denote that the respondents on average value the compensation required for the number of switch-offs as a quadratic function. This increases the WTA for the number of controlled switch-offs exponentially. The relation between the duration per switch-off and WTA is found to be linear. Depending on the type of contract, the interval of WTA is between 4.83-99.03 € /year. Compared to other studies, these numbers are in the higher end. Depending on the aim of the energy companies and the annual fixed costs of making a contract with a household, our results illustrate two policy recommendations. If the goal of the energy companies is to have a high stock of controlled switch-offs independent of the duration of each switch-off, costs are minimised by making contracts with many households with either 12 or 30 controlled switch-offs per contract and 15 minutes duration of each switch-off. For annual fixed contract costs below approximately 13.42 € (100 DKK), contracts with 12 annual switch-offs minimise the costs, whereas 30 annual switch-offs minimise the costs if the fixed annual contract costs are approximately 13.42 € or higher. If the goal is to maximise the stock of controlled switch-off hours, the costs are minimised by making few contracts with many and long duration switch-offs per household/contract.

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Appendix A

	Household Income <400,000 DKK	Household Income ≥400,000 DKK
Mean		
No. Switch-offs/year		-1.763**
		[0.601]
No. Switch-offs/year^2	-0.0440**	
	[0.0169]	
Duration/switch-offs	-21.10***	
	[5.972]	
Duration/switch-offs^2		-4.980**
		[1.792]
ASC_AB	79.59	-9.461
	[50.43]	[25.78]
Compensation	-3.481***	-3.387***
	[0.213]	[0.242]
SD		
ASC_AB	153.84**	113.38**
	[58.18]	[34.80]
Compensation	0.000577	0.000821
	[0.514]	[0.490]
N_resp	45	40
N_choice	131	112
LL(0)	-143.92	-123.04
LL(β)	-86.72	-79.72
McFadden R2	0.397	0.352

Standard errors in brackets $^{+}$ $p < 0.10$, * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$