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Does Daylight Saving Time Save Energy? Evidence from Slovakia

Bachelor thesis

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Declaration of Authorship

The author hereby declares that he compiled this thesis independently, using only the listed resources and literature, and the thesis has not been used to obtain a different or the same degree.

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Prague, April 26, 2018

Signature

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Bibliographic note

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Abstract

This thesis studies the impact of the daylight saving time (DST) on electricity consumption in Slovakia in the period between April 2010 and July 2017. Recently the relevance of the DST policy has been questioned by the European Parliament which calls on the revaluation of the policy. Research conducted in other countries has suggested that in some countries the DST might be an outdated or not suitable policy. To determine the magnitude and the direction of the effect in Slovakia difference-in-difference estimation is used. Relevant factors are controlled for (e.g. price, weather, seasonality). The lack of the control group is solved by using "equivalent day normalization" technique. The results suggest yearly overall savings in electricity consumption due to the DST policy to range between 1.27% and 1.56% which, given the price levels in 2016, amounts from 6.3 to 7.8 million Euros. DST is estimated to cause the highest energy savings during the peak of electricity consumption which occurs in the early evening hours. On the other hand, during the late evening hours the DST seems to increase the electricity consumption which partially mitigates the overall savings.

JEL Classification	C51, H77, Q48
Keywords	daylight saving time, difference in difference, energy, Slovakia

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Abstrakt

Táto práca skúma vplyv letného času na spotrebu elektrickej energie na Slovensku v čase od apríla roku 2010 do júla roku 2017. V súčastnosti bola relevantnosť' letného času spochybňovaná Európskym parlamentom, ktorý požiadal o prehodnotenie tejto politky. Výskumy v iných krajinách naznačili, že pre niektoré je letný čas zastaralou či nevhodnou politikou. Na určenie veľkosti a smeru vplyvu letného času na Slovensku je použitá metóda difference-in-difference. Zahrnuté sú relevantné kontrolné premenné (e.g. cena, počasie, sezónnosť). Absencia kontrolnej skupiny je vyriešená technikou "ekvivalentnej dennej normalizácie". Výsledky naznačujú, že ročné úspory celkovej spotreby elektrickej energie v dôsledku letného času sa pohybujú v rozmedzí 1.27 % a 1.56 %, čo berúc do úvahy cenovú hladinu v roku 2016 činí 6.3 až 7.8 milióna eur. Odhaduje sa, že letný čas spôsobí najvyššie úspory v špičke spotreby elektrickej energie, ktorá nastáva počas skorých večerných hodín. Na druhej strane v neskorých večerných hodinách letný čas zvyšuje spotrebu elektrickej energie, čo čiastočne znižuje celkové úspory.

Klasifikace JEL	C51, H77, Q48
Klíčová slova	letný čas, difference in difference, energia, Slovensko

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Contents

List of Tables

List of Figures

Acronyms

DID Difference in Difference

DDST Double Daylight Saving Time

DST Daylight Saving Time

EU European Union

UTC Coordinated Universal Time

Bachelor Thesis Proposal

Author	Peter Kúdel'a
Supervisor	PhDr. Zuzana Havránková Ph.D.
Proposed topic	Does Daylight Saving Time Save Energy? Evidence from Slovakia

Research question and motivation Daylight saving time (DST) policy in Europe has been originally introduced for the purposes of energy savings. As of today, all states of the European Union synchronize their clocks twice a year following the same directive (2000/84/EC). Recently, a number of EU members raised the question whether the harmonization of summertime still provides the presumed benefits, calling for an abolishment of the policy. The existent academic literature on this topic is relatively scarce (see, for example, Havranek et al. 2016) and yields not only discordant evidence on the size of the effect but also on the direction of the effect (Kotchen & Grant 2011, for example, find that DST increases electricity demand). Few empirical studies provide an analysis for EU states, such as Hill et al. (2010) for the United Kingdom, Fisher (2000) for Germany, Wanko & Ingeborg (1983) for Austria, or Mirza & Bergland (2011) for Norway and Sweden; but many European electricity markets have not been analyzed, yet. The aim of my thesis is to bridge the gap for one of the missing national markets, Slovakia, and to determine whether DST has a positive or negative effect on the electricity consumption in Slovakia. Therefore, using the evidence from Slovak market, I will tackle the research question of whether the daylight saving time policy indeed saves the energy in Slovakia.

Contribution To the best of my knowledge, there has been no study on DST effect in Slovakia conducted, so far. The main contribution of my thesis will thus be an original and comprehensive analysis on whether the DST policy in Slovakia saves the electricity or not. My results can be potentially further used as a supporting academic evidence in the ongoing European Parliament discussions on the implications of DST policy among the member states.

Methodology There are several methodological approaches on how to estimate the DST effect: most of the studies use either regression analysis or simulation techniques. The simulations are based on modelling the electricity flows within a building and extrapolating the model to a more aggregate level. Given the data availability for Slovak electricity market I am left with the econometric approaches. In general, the authors regress the electricity consumption on a set of control variables including the treatment effect which represents a group of data where DST applies. First, my thesis will utilize the data on hourly loads for the period of 2006-2015 from the ENTSO-E database published online by the European Network of Transmission System Operators, aggregated at the country level. The potential for improvement here is to gain the access to a more disaggregate datasets, possibly at the industrial, commercial, or household level (currently unavailable). Secondly, for a set of explanatory variables I will use historical hourly weather data provided by the Slovak Hydrometeorological Institute which include, apart from temperature, other consumption-relevant factors such as humidity, air pressure, precipitation, or the intensity of sunlight. Based on the final aggregation of the consumption data, other than weather explanatory variables might be considered for inclusion. At this stage of research, I intend to follow Mirza & Bergland (2011) and use the difference-in-difference approach to estimate the DST effect. The difference-in-difference approach is based on the analysis of two different groups of historical data: the consumption affected and the consumption unaffected by the introduced policy. The obvious difficulty rises from the fact that we do not have data before the policy introduction at disposal (DST policy was introduced in Slovakia in 1979 with 6-months long summer time, since 1996 the prolongation to 7-months was introduced based on the common EU directive). For this reason, following Kotchen & Grant (2011) and Mirza & Bergland (2011), I intend to use the "equivalent day normalization" technique which considers the morning and evening hours as DST-affected, and midday and midnight hours as DST-unaffected. This distinction allows me to estimate the differences in the difference between the influenced and un-influenced periods. As a possible robustness check to the main estimation outlined above, I would apply the approach of Kandel & Metz (2001) who use a simplified simulation technique based on the regression analysis to conduct their estimation: they model a system of 24 linear equations, one for every hour of the day and estimate the system using iterated seemingly unrelated regressions approach (Zellner 1962). This method allows the relationship between the dependent variable (electricity consumption) and independent variable (for example temperature) to vary throughout the day, while considering the correlation between energy use over the hours of the day.

Outline

1. Introduction of the DST and motivation
2. Literature review
3. Data and estimation techniques
4. Empirical results and discussion
5. Conclusion
6. References

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Author Supervisor

Chapter 1

Introduction

Daylight Saving Time (DST) is the practice of setting the clocks 1 hour forward from the standard time during the summer months and back again in the fall, in order to make better use of the natural daylight. The main purpose of this policy in Europe was originally saving of energy. As of today, all states of the European Union synchronize their clocks twice a year following the directive 2000/84/EC.

Recently, the European Parliament raised the question whether the harmonization of summertime still provides presumed benefits (EP, 2018). Concerns about the DST raised due to several reasons. Firstly, there are studies suggesting that DST effect on energy consumption heavily depends on the geographical location (Bergland *et al.*, 2017; Havranek *et al.*, 2018). The countries in the moderate zones are more affected by the DST policy. For example, in spring the shift causes people to wake up before sunrise and hence it may increase consumption in the morning. However, this might not hold for countries further north with very short days or closer to the equator with relatively longer days. Secondly, due to the technological progress, people tend to follow their clock rather than daylight. Therefore, the consumption pattern nowadays may have changed compared to the past when this policy was introduced. Lastly, a number of studies indicate undesirable influence of the DST policy on people's biorhythm, injuries and car accidents during the spring transition period (Coren, 1996; Barnes & Wagner, 2009; Harrison, 2013; Robb & Barnes, 2018).

The existing academic literature on the policy of adopting DST and the potential effect of such policy on energy consumption is relatively limited and yields not only discordant results in the magnitude of the effect but also in its direction. Some studies suggested that DST decreases energy consumption

(Mirza & Bergland, 2011; Verdejo *et al.*, 2016; Momani *et al.*, 2009). Others indicated no significant effect of the DST on the electricity demand (Choi *et al.*, 2017; Kellogg & Wolff, 2008). There are even studies that estimated increase in the consumption due to the DST (Kotchen & Grant, 2011).

Considering the discordant results of previous literature and the conclusions about geographical location (Bergland *et al.*, 2017; Havranek *et al.*, 2018), the effect of the daylight saving time on electricity consumption is likely to be country specific. To the best of my knowledge, there is only one unpublished available estimate of the DST effect for Slovakia in the pan-european analysis of Bergland *et al.* (2017). However, there has been no study so far that would provide a comprehensive analysis of the DST impact on the Slovak electricity market.

To provide such an analysis I use difference-in-difference estimation on the hourly aggregate consumption data from April 2010 until July 2017. Various control variables are included to account for the effect of price, weather conditions and seasonality. The results of the analysis suggest positive savings in electricity consumption between 1.27% and 1.56%.

The structure of the thesis is the following: firstly the history of DST and description of Slovak electricity market are briefly addressed. Secondly, the already existing research is outlined. Then, in Chapter 4 the methodology is introduced and the used data are described . In Chapter 5 the results are presented. In the last chapter the whole thesis including the main findings is summarized.

Chapter 2

History of DST and Background

The first two sections of this chapter provide overview of the history of the daylight saving time in the world and in Slovakia. Last section briefly describes Slovak electricity market.

2.1 World

A letter written by Benjamin Franklin in 1784 in Paris to the Journal of Paris is attributed to be one of the first mentions indicating a possible improvement in the use of the sunlight during the day (Franklin, 1784). In his letter Benjamin Franklin suggested that people should start their daily routine in summer one hour earlier and finish an hour sooner in order to have better use of natural daylight. On the turn of 19^{th} and 20^{th} century one of the first unsuccessful proposals of the modern DST emerged in England (Willett, 1907).

The first two countries in Europe adopting the DST were the German Empire and Austria during the World War I in April 1916 (Pollak, 1981). The intention behind adopting the daylight saving time was to preserve the coal consumption and transfer the savings to war expenses. Soon Britain and other European countries followed the German Empire and Austria in adopting this policy. The trend of adopting the DST continued in the world (Russia in 1917, U.S. in 1918). Eventually, most of the countries abolished the policy after the World War I (Pollak, 1981).

Since then, the DST was widely adopted mostly in times when energy savings were needed, for example during World War II and also during the energy crisis in 1970s. After this period the DST policy had differed among the countries in the duration of the DST within a year and also in the number of years during which this policy was active (Reincke & Van den Broek, 1999).

In 2018, 75 countries in the world use the DST (Time and Date AS, 2018). As there were 87 countries using this policy in 2009, this may imply a declining trend in the usage of DST (Time and Date AS, 2018). While some countries decide to implement this policy, almost every year there is a country abolishing it (Time and Date AS, 2018). Possible reason for abolishing might be that the negative effects during the transition (e.g. change in biorhythm, accidents, overall dissatisfaction of the country's population with the policy) exceed the positive effects (e.g. energy savings).

2.2 Slovakia

The history of using the DST during the summer months in Slovakia dates back to the first decades of the 20$^{\text{th}}$ century (Pollak, 1981). Under the reign of Austria-Hungary on the territory of present Slovakia the DST was introduced during World War I, from 1916 until 1918. During the World War II Slovakia implemented the DST as an autonomous country in 1940 and maintained it until 1949 when Slovakia was part of the Czechoslovak Republic.

The daylight saving time policy was introduced again in Slovakia (more specifically in the Czechoslovak Socialist Republic) in 1979 with 6-months long summer time. Since 1996 the period for which the DST is used was prolonged to 7-months. This extension was later coherent with the common EU directive. As of today, all states of the European Union synchronize their clocks twice a year following the same directive (2000/84/EC). All members of the European Union start the DST on the last Sunday of March at 01:00 UTC and end it on the last Sunday of October at 01:00 UTC.

2.3 Electricity Market in Slovakia

The Slovak electricity market is part of the CENTREL area. This area integrates the electricity markets of Slovakia, the Czech Republic, Poland and Hungary (SEAS, 2018). In the investigated period, there has been no price regulation as Slovak electricity market was fully liberalized in January 2005 (SEAS, 2018). Import and export prices are determined through Market Coupling between SK-CZ-HU-RO.

Almost 70% of the Slovakia generation market is provided by Slovenské elektrárne with the main source of the energy production being the nuclear power with approximately 79% of the generated energy in 2017 (SEAS, 2018). It is important to mention also the structure of the final consumption in Slovakia, as the DST policy is expected to influence mainly household consumption. The distribution of the final consumption in 2014 was 17.15% for households and rest for the non-households (URSO, 2018).

Chapter 3

Literature Review

This chapter provides a literature review of the previous studies conducted on the topic of the daylight saving time until 2017. First part focuses on the studies that investigate the causal effect of this policy on energy consumption, specifically electricity consumption. Second part briefly summarizes selected papers regarding other possible effects of the DST on society (for example the number of accidents on the days following the time shift).

3.1 DST and Energy Consumption

Analysis of this thesis is based on the research conducted by Mirza & Bergland (2011). Mirza & Bergland (2011) studied the effect of the DST on the electricity consumption in southern Norway and Sweden. The results presented by them indicate that the reduction in overall demand for electricity is at least 1% in both countries. Even though the savings seem to be negligible it corresponds with annual financial savings of 16.1 million Euros for the southern Norway and 30.1 million Euros for the southern Sweden, which is a considerable amount. Generally, a major drawback of the research (including the one conducted by Mirza & Bergland (2011)) is the lack of precisely defined control group as there is usually no suitable period for which the DST was not adopted, that could serve as the control group. Mirza & Bergland (2011) and Kotchen & Grant (2011) solved the absence of the control group by using "equivalent day normalization" technique which divides hours into DST-affected hours (morning and evening hours) and DST-unaffected hours (hours around midday and midnight). This identification of the control group allows the usage of DID (difference-in-difference) estimation method. Further details of this method are described in the methodological part of the thesis.

On the other hand, Rock (1997) used a different approach, specifically an engineering model, and provided evidence that DST might actually increase the consumption on average by 0.244%. Also Hill *et al.* (2010) conducted the research by using the engineering model and non-linear approach. Hill *et al.* (2010) predicted the electricity consumption in winter in the Uninted Kingdom. They further investigated the potential impact of advancing the clock by an hour in winter on electricity comsumption. They presented an evidence that this shift would decrease the consumption by 0.3%. According to Hill *et al.* (2010) 0.3% saving in energy consumption corresponds with the cut of at least $450,000$ tons of CO_2 a year. Non-linearity of the problem lies in the relationship between energy consumption and temperature, as one of the most important variables. The arguments in favour of the non-linear relationship are that heating and cooling temperatures affect the consumption in an non-linear way and also losses in transmission cables differ as the temperature changes. The results of the study show attempts to quantify this relationship as linear typically perform poorly (Hill *et al.*, 2010).

Kandel & Metz (2001) use a simplified simulation technique based on the regression analysis to conduct their estimation. They model a system of 24 linear equations, one for every hour of the day and estimate the system using iterated seemingly unrelated regressions approach (Zellner, 1962). This method allows the relationship between the dependent variable (electricity consumption) and independent variable (for example temperature) to vary throughout the day, while taking into account the correlation between energy use over the hours of the day. Their research attempts to predict the effect of prolonging the existing DST to more months (Winter DST) and to investigate potential influence of implementing double daylight saving time (DDST)[1] on the months under the DST in California. Their findings suggest overall 0.5% (about 3400MWh) drop if the Winter DST would be have been adopted. Regarding DDST the results suggest a reduction of electricity consumption in afternoon hours and increase in the morning hours with overall effect corresponding daily to 0.2% (1500MWh) saving. In financial terms Winter DST is estimated to save \$60-\$350 million and DDST is estimated to save \$300-\$900 million.

As already mentioned, most of the research has to deal with the not clearly identified control group. Intuitively the most ideal situation for the researchers

[1]Double Daylight Saving Time is simply shifting the clock by two hours instead of one.

is to examine the impact of DST using natural experiment, where there is clear distinction between the control group and the treatment group. Kellogg & Wolff (2008) used this advantage by examining quasi-experiment in Australia during the Sydney Olympics in 2000. Three out of six states in Australia use daylight saving time. In order to facilitate the Olympics, two of three Australian states that used DST introduced the time shift two months earlier than usual. One of these states using DST in Australia was Victoria which did not host the Olympics and therefore by not altering the period for which DST was used served as a perfect control group. Using the difference-in-difference estimation method their results support the theory that the DST decreases the demand for electricity in the evening hours. However, this decrease appears to be offset by an increase in the consumption during the morning hours. This leads to the conclusion that the DST seems not to have any significant impact on the overall electricity consumption. This study raised concerns about actual validity of this policy in terms of energy management.

Another natural experiment occurred in 2006 in Indiana. A change in the state law required all countries in Indiana to start practice the DST. Prior to this change only some countries had already practised this policy, which provided ideal conditions for the analysis of the possible effect of implementing the DST. Kotchen & Grant (2011) conducted a research in Indiana, providing the results on the DST effect on the residential electricity consumption. Difference-in-difference method showed overall increase in the residential electricity demand by approximately 1%, exactly the opposite to what was anticipated. Moreover, this increase is not constant throughout the year due to the fact that in spring there is only slight increase but in the autumn the results indicate increase from 2% to 4%. Therefore, estimated costs to Indiana households were \$9 million per year and environmental costs varied from \$1.7 million to \$5.5 million a year.

Recently Choi *et al.* (2017) took advantage of the natural experiment in Western Australia. In this area the DST was introduced from December 2006 until 2009 and abolished after. Therefore, using the data from 2006 until 2013 and the DID methodology Choi *et al.* (2017) conclude that DST increases the electricity consumption in the majority of the morning hours and in the late night hours with the largest increase being 2.99% at 10 pm. Further, it decreases electricity demand in the early evening hours with the largest decrease being 6.61% at 7 pm and has no effect on electricity demand during the midday (11 am until 4 : 30 pm). Since the saving in the evening is offset by the increase in the morning, the overall effect of DST is found to be economically and statistifically insignificant. Choi *et al.* (2017) suggest that DTS does not save energy, only shifts the patterns in consumption from evening to the morning. Moreover, the authors indicate thet the DST might be out of date policy in terms of the original intention to save energy.

In Chile, Verdejo *et al.* (2016) have taken not only econometric approach (DID) but also heuristic approach. Due to the rather specific geographical shape of Chile four main representative regions were analysed: Arica, Concepcion, Santiago, and Punta Arenas. Results in favour of reduction in residential consumption indicated overall decrease of 3.18%. However, the results vary in different regions which might be a consequence of geographical heterogenities of Chile. In Santiago the savings are the highest (0.55%) followed by Punta Arenas (0.48%) and Arica (0.04%). The results in Concepcion indicated exactly the contrary to the policy intentions, an increase by 0.32%.

A summary of existing researches until 2008 is provided by Aries & Newsham (2008). They conclude that knowledge about the effect of DST is liminted and yield contradictory results due to the economical, geographical and climatological factors specific for every country. Moreover, Aries & Newsham (2008) highlighted the significant influence of the society behaviour on electricity consumption that has changed substantially since the first introduction of DST.

One of the most recent papers presented by Havranek *et al.* (2018) contributes to the existing literature by meta-analysis of the previous 44 studies on this topic. Havranek *et al.* (2018) focuse on identifying main factors that led to a discordant result in size and the direction of estimated DST effect on electricity consumption. The findings shows that heterogeneity in the results of the papers is cause by not only the different methods and data frequency used fo the analysis, but also due to the latitude. Thus, countries closer to the equator tend to consume more electricity due to the DST. On the contrary, countries further from the equator tend to have higher savings. Havranek *et al.* (2018) conclude that the electricity demand decreases on average by 0.34% due to DST.

Lastly regarding the DST effect on the electricity consumption, the most recent work conducted by Bergland *et al.* (2017) was made publicaly available as a working paper while this thesis was being written (March 2018) under the title:"Latitudinal Effect on Energy Savings from Daylight Savings Time". Bergland *et al.* (2017) investigate the latitude effect of DST on energy savings. This research provides one of the first multi-country analysis as it investigates the effect of the DST in 35 countries in Europe, including Slovakia. The magnitude of the proposed savings vary from 0.5% to more than 2.5%. Specifically, according to Bergland *et al.* (2017) the savings in the electricity consumption due to the DST policy are estimated to be approximately 1% in Slovakia.

3.2 DST effect in other aspects

There are several other publications focusing on the DST that examine other possible consequences of adapting the DST other than its effect on electricity consumption. They mostly concentrate on the days following right after the time shift and the externalities of this policy.

Coren (1996) indicated that on average the number of traffic accidents increases by approximately 8% due to the spring shift to DST in Canada. By approximately the same percentage the traffic accidents are estimated to decrease rigth after the autumn shift from the DST. Barnes & Wagner (2009) found out that on the Monday after the change to DST, when clocks are shifted one hour ahead (i.e. one hour of sleep is lost), injuries during working hours are more common.

However, some other publications on similar topic of the effect of DST on the number of car and work accidents reported conflicting results. Holland & Hinze (2000) suggested no significant influence of the DST on the occurance of injuries in the workplace. They indicated that people themselves anticipate higher risk during the transition period, and thus put more effort is in safety during the this period. Huang & Levinson (2010) found no statistical significance of the DST effect on car accidents in the morning hours during the transition. Furthermore, evening hours are associated with decrease in the car accidents as one hour of the daylight is gained.

Robb & Barnes (2018) studied not only the frequency of traffic and work accidents during the DST transition, but also the frequency of accidents occurring in households. The results showed that the frequency of car accidents increases during the first day of transition to DST by approximately 16%, the effect of DST on number of work accidents is limited and the number of household accidents declines prior to the DST shift, which might be again caused by the increase in the people' s awareness of the riskier period.

Not only the potential effect of the DST on the occurence of accidents was examined but also the effect on the biorythms of human body has been subject to research. Harrison (2013) investigated the the impact of the DST on the sleep patterns. This study pointed out that the sleep fragmentation and cumulative sleep loss occurs not only in first week in the spring transition but also in the autumn. Even though autumn shift provides one more hour of sleep during the first day, overall effect of the week after transition indicated loss of sleep. Moreover Janszky *et al.* (2012) found out that the disturbance in the sleeping pattern during the spring transition might be associated with higher occurrence of the acute myocardial infarction.

Lastly, Herber *et al.* (2017) investigated the impact of the DST on the students' performance. The estimated impact on students was not large nor statistically significant.

This papers are presented here only to show that the potential reduction in electricity consumption might be only one side of the story regarding the effects of using the DST. However, this thesis focuses only on the potential impacts on the electricity consumption as this the mostly discussed topic regarding the DST nowadays.

Chapter 4

Methodology

4.1 Background and Identification

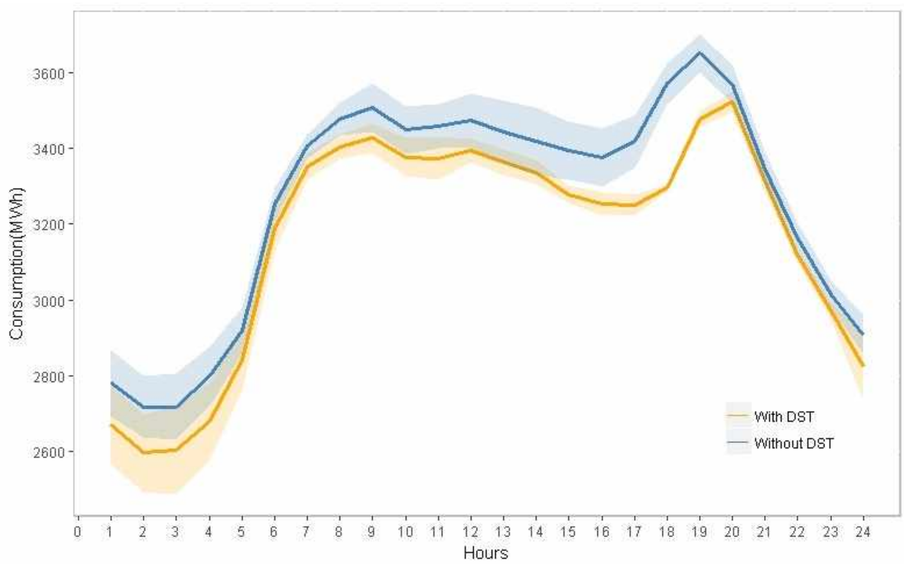
The research conducted in this thesis intends to follow Mirza & Bergland (2011) and use the difference-in-difference method to estimate the DST effect (Wooldridge, 2010). The difference-in-difference approach is based on the analysis of two different groups of historical data - the ones affected by a certain policy or an event and the ones unaffected by such an event. In our case, the event affecting the treatment group is the usage of DST.

DST policy was introduced in Slovakia in 1979 with 6-months long summer time, since 1996 the prolongation to 7-months was introduced based on the common EU directive. Since then, there is no period for which the DST was not used in Slovakia nor there are any apparent suitable subjects that could serve as a control group. Therefore, the obvious obstacle arising for the usage of the DID method is that the control and treatment group are not clearly defined for the available data. For this reason, the lack of a clearly defined control group is tackled by using the identification procedure used by Mirza & Bergland (2011); Kotchen & Grant (2011). This so-called "equivalent day normalization technique" consists of dividing 24 hours of the day into two groups: DST-unaffected and DST-affected. Midday (12,13,14) and midnight(24,1,2) hours, when the number of hours of daylight is the same regardless of the DST and therefore they are presumably not effected by the policy, are considered as the DST-unaffected (i.e. serve as control group). Remaining hours are considered to be DST-affected (eg. serve as a treatment group).

This distinction allows to estimate the differences in difference between the influenced and uninfluenced periods as both of these groups are assumed to follow the same pattern before the introduction of the DST. In terms of common sense it appears to be intuitive that hours during the night where the shift does not increase the length of natural daylight are uninfluenced. Same reasoning could be applied to midday hours where there is no gain or loss of natural daylight attributed to DST either.

Figure 4.1 presents the average electricity consumption before and after the transition in March 2014 in order to visualize the impact of the DST. Year 2014 was chosen as it is one of the years in our observed period in which the transition to the DST occurred before the Easter. During the Easter and generally during any holiday the pattern of consumption differs. The years where the time was changed around Easter may provide misleading picture. Blue line in the figure represents average consumption during the five working days preceding the transition to DST on the last Sunday of March. Orange line represents the average consumption during the five days following the transition.

Figure 4.1: Average hourly consumption 5 days before and 5 days after the transition to DST in March 2014.



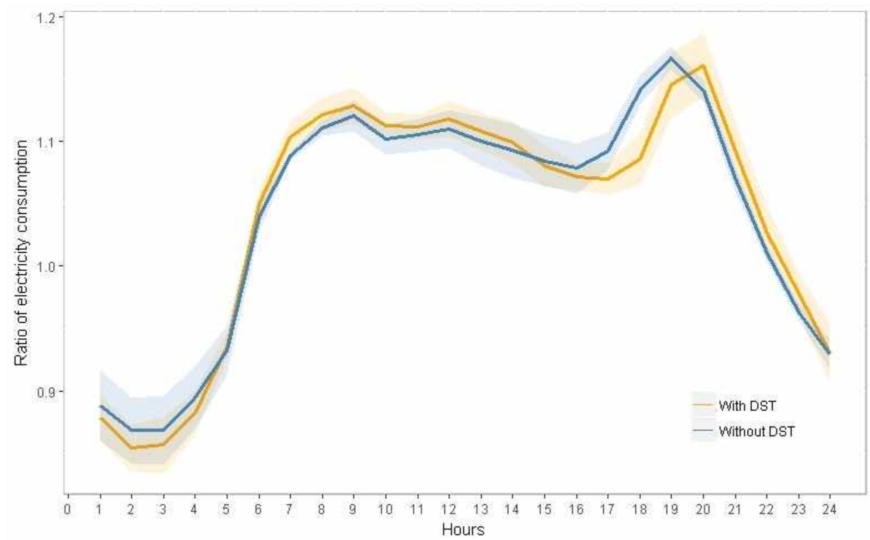
Note: Shaded areas represent 95% confidence intervals.

There are two visible peaks in consumption throughout the day - one in the morning and one in the evening. In the period without the DST, the morning peak is a approximately at 9 am and the evening peak is at 7 pm. In the period after the transition to DST, the morning peak remained at 9 am and the evening peak is shifted from 7 pm to 8 pm. This corresponds with the intuition behind the daylight saving time. On one hand, people wake up at the same time so the morning consumption routine is the same and peak occurs approximately at the same time. On the other hand, the shift in the evening hours corresponds with the logic that adding additional hour of natural light shifts the evening consumption by an hour. Overall, the difference between the lines suggests that there is a decrease in the consumption in every hour of the day after introduction of the DST. Moreover, it can be observed that the difference is smallest in the morning and in the late evening hours and the biggest in the early evening hours. However, conclusion drawn solely based on this graph are likely to be misleading because of the fact that the Figure 4.1 does not account for other factors that influence consumption (such as weather conditions) and depicts a rather specific and limited period of time.

Similar pattern in consumption is observed in all investigated years. Some differences can be observed in years in which the DST transition occurred during the Easter. In the autumn the pattern is intuitively the opposite.

Following Mirza & Bergland (2011), Figure 4.2 was constructed. This figure also visualizes the pattern of the electricity consumption, but using ratio of hourly electricity consumption to the average of consumption during control hours (12, 13, 14, 24, 1, 2). Data from the same time horizon in 2014 as in the previous figure are used (i.e. 5 working days before and 5 working days after the transition to DST in March).

Figure 4.2: Ratio of the average hourly consumption to the mean of the control hours 5 days before and 5 days after change to DST in March 2014.



Note: Mean of the control hours (12,13,14,24,1,2). Shaded areas represent 95% confidence intervals

According to (Mirza & Bergland, 2011), this visualisation based on the control hours should suggest the direction and the magnitude of the effect of the DST on individual hours more precisely. There is a visible pattern during the morning hours, where the morning consumption after the transition increased. This might be due to the fact that there is still dark when people wake up after the time change and therefore they need artificial light. This trend is also observed in other studies (Kotchen & Grant, 2011; Momani *et al.*, 2009). Decrease in the consumption during the early evening hours is followed by increase later in the evening, which also has been observed by Karasu (2010). Lastly, it indicates a minor increase of consumption during the midday. The same is not observed during the midnight hours, as there seems to be a slight decrease in the consumption around midnight and yearly morning hours. Therefore, the main conclusion arising from this is that using midnight hours as control might underestimate the results of the effect and using the midday hours may overestimate the results.

In order to at least partially capture the possible under- or over-estimation, the estimation is conducted using three groups of control hours: the first being both midday and midnight hours, the second being only the midday hours, and the third being the midnight hours only.

4.2 Data

This study employs hourly data from Slovakia for the period between the 1st April 2010 and the 31st July 2017. The data on hourly aggregate electricity consumption for Slovakia were obtained from the European Network of Transmission System Operators for Electricity[1]. The hourly data are collected in the Central European Time (CET). Therefore, it has to be taken into account for the fact that on last Sunday in March there are only 23 hours in a day (as the time is shifted ahead by one hour due to the adoption of the DST). On the contrary, there are 25 hourly observations for the last Sunday in October, when the DST in Slovakia ends.

To control for weather conditions in Slovakia data from four different parts of Slovakia are used, namely Bratislava-airport, Sliač, Kamenica nad Cirochou and Poprad. Bratislava-airpot was chosen as Bratislava is the capital city of Slovakia with one of the largest electricity consumption in industry. Due to the

[1] https://www.entsoe.eu

geographical location data obtained from Bratislava-airport are also selected to represent the western region of Slovakia. Weather conditions from Sliač-airport represent the central part of Slovakia. As Poprad is located in the North of Slovakia where there is a cooler climate due to the mountains, it serves as the representative for the mountainous region of Slovakia. Lastly, data obtained from Kamenica nad Cirochou represent weather conditions for the eastern region. The data on weather conditions has been provided by the Slovak Hydrometeorological Institute. This data are collected following the UTC time and not the CET as data on consumption. Therefore, there are no deviations on the last Sunday in March and October in the number of hourly observations per day. Apart from temperature they include other consumption-relevant weather characteristics, such as humidity, air pressure, precipitation and the intensity of sunlight.

Having only data on the aggregate electricity consumption for the whole country but weather conditions for specific regions, leads to a problem of assigning the weights to the weather conditions in the regions when investigating overall effect of DST on aggregate electricity consumption in Slovakia. For the purpose of having weighted average of weather conditions for Slovakia , the data for annual industry consumption in every region have been used (for further details see 4.3.1). This data set was obtained from Statistical Office of Slovak Republic.[2]

The price of electricity is also one of the main factors that affect consumption and should be therefore controlled for. The hourly data for the prices of daily market in Slovakia are used. This data are obtained from OKTE, a.s, short-term electricity market operator[3] Lastly, to account for overall market performance and economic conditions in a given period, the daily (weekdays only) Brent oil spot prices are collected from the Federal Reserve Bank of St.Louis, as Brent is the leading global price benchmark for Atlantic basin crude oils.[4] The descriptive statistics of all the data and variables can be found in the Table 4.1.

[2]https://slovak.statistics.sk
[3]www.okte.sk/en/
[4]https://fred.stlouisfed.org

Table 4.1: Summary statistics of regression variables and the data from the period between April 2010 and July 2017

Variable	Units	Mean	Sd	Min	Max
cons	MW	3207.873	426.7323	2119	4541
price	€	39.1	17.01	-150	200
brent	€	83.93	28.98	26.01	128.14
c_deg	°C	1.01	2.58	0	18.83
h_deg	°C	8.84	7.79	0	37.67
temp_avg	°C	10.17	9.23	-19.66	36.8
hum_avg	%	73.75	16.77	18.65	98.69
press_avg	hPa	982.77	12.99	828.3	1007.494
sun_avg	$minutes$	9.81	15.08	0	60
rain_avg	mm	0.073	0.33	0	13.30
intensity_avg	J/cm^2	36.52	51.36	0	328.35
temp BA	°C	11.56	9.13	-15.5	38.9
hum BA	%	70.62	18.13	11	100
press BA	hPa	1001.06	7.65	960.9	1025.5
sun BA	$minutes$	13.26	22.79	0	60
rain BA	mm	0.068	0.563	0	32.3
intensity BA	J/cm^2	53.11	90.90	0	427
temp PO	°C	7.37	9.20	-28.1	33.2
hum PO	%	76.58	16.80	14	100
press PO	hPa	935.41	6.99	893.8	957.5
sun PO	$minutes$	10.77	20.42	0	60
rain PO	mm	0.0673	0.490	0	27
intensity PO	J/cm^2	29.80	69.43	0	529
temp SL	°C	9.83	9.78	-24.4	37.4
hum SL	%	75.61	20.00	14	100
press SL	hPa	979.48	7.36	937.7	1004.2
sun SL	$minutes$	2.30	10.57	0	60
rain SL	mm	0.083	0.578	0	30.5
intensity SL	J/cm^2	9.02	39.52	0	357
temp KA	°C	9.97	9.55	-25.3	37.6
hum KA	%	75.83	18.70	15	100
press KA	hPa	990.10	75.93	905.4	1020.40
sun KA	$minutes$	14.16	23.15	0	60
rain KA	mm	0.076	0.59	0	41
intensity KA	J/cm^2	52.55	83.48	0	385

Note: cons = hourly aggregate electricity consumption; price = average hourly price in a daily market in Slovakia; brent = daily oil spot price, h_deg = hourly amount of heating degrees, c_deg = hourly amount of cooling degrees temp = average hourly air temperature; hum = average hourly relative air humidity; press = average hourly air pressure, sun = total duration of sunshine in an hour; rain = sum of hourly precipitation; intensity = average hourly intensity of radiation; acronyms BA, PO, SL, KA represent areas Bratislava-airport, Poprad, Sliač, Kamenica nad Cirochou, respectively; suffix "_avg" stands for the weighted average of these areas (see 4.3.1)

4.3 Model

Following the identification above, the existing literature and the data provided the following model is constructed:

$$\begin{aligned} log(cons)_{hd} = {} & \beta_0 + \beta_1 DST_{hd} + \beta_2 treat\_group_{hd} + \beta_3(treat\_group_{hd} * DST_{hd}) \\ & + \delta' temp\_vars_{dh} + \beta_4 hum\_avg_{hd} + \beta_5 press\_avg_{hd} + \beta_6 sun\_avg_{hd} \\ & + \beta_7 rain\_avg_{hd} + \beta_8 intensity\_avg_{hd} + \beta_9 brent_d + \beta_{10} price_{hd} \\ & + \beta_{11} sine_{hd} + \beta_{12} holidays_d + \beta_{13} weekend_d + D_{H,M,Y} + u_{hd} \end{aligned}$$

where:

- DST_{hd} is the dummy variable representing whether DST is present (i.e. during periods when DST is active is equal to 1, 0 otherwise)
- $treat\_group_{hd}$ accounts for possible difference between control and treatment group prior to the policy (DST) change (i.e. is equal to 1 if the corresponding hour belongs to treatment group and 0 otherwise)
- $treat\_group_{hd} * DST_{hd}$ is our DID variable of interest which captures the DST policy effect
- $\delta' temp\_vars_{dh}$ represents a vector of variables regarding the temperature (see, section 4.3.1)
- hum_avg_{hd}, $press\_avg_{hd}$, sun_avg_{hd}, $rain\_avg_{hd}$ and $intensity\_avg_{hd}$ account for different weather conditions, where avg stand for the weighted average of weather conditions (see, section 4.3.1)
- $brent_d$ stands for the crude oil price index for specific day
- $price_{hd}$ represents price in the short-term electricity market in the Slovak Republic. One should be aware that the price is endogenous in the demand function, hence also in the electricity consumption. A suitable instrument would be a solution for this problem, for example nuclear electricity production can serve as one (Mirza & Bergland, 2011). However, a suitable instrument was not obtained. Despite this fact, price is included in the model as it is an important control variable for consumption. Moreover, its coefficient is not the interest of the analysis, therefore the endogeneity of price and consumption should not decrease the validity of the estimated effect of DST on electricity consumption.

- *sine* is trigonometric function sine, which accounts for annual cyclicity in consumption (Mirza & Bergland, 2011)
- $holidays_d$ represents a dummy variables for all holiday in Slovakia (Christmas,Easter, etc.), when there is a different pattern in consumption compared to working days
- $weekend_d$ stands for the dummy variable for weekend to distinguish between weekend and week patterns in consumption
- $D_{H,M,Y}$ includes dummy variables for hours, months and years to account for several potential forms of seasonality. As DST is active during summer months when electricity consumption is lower regardless of DST, this decrease in consumption not caused by the DST has to be controlled for. The dummy variables are chosen in a way which accounts for possible forms of year and day seasonality as well as for possible year specific factors that may influence electricity consumption (such as extensive production leading to extensive electricity consumption or technological progress). They also control for potential trend in electricity consumption. Due to the high number of the dummy variables, they had to be chosen carefully in order to avoid the dummy variable trap. As these variables are not important for the analysis (except for their correct specification of the model), they are not specified further. The full set can be found in summary tables of the models in the Appendix (Table A.2).

The model was estimated using software R version 3.4.3.. Following Mirza & Bergland (2011), in order to account for potential heteroskedasticity and serial correlationd HAC (heteroskedasticity and autocorrelation consistent) standard errors with lag being equal to 24 (Verbeek, 2008) were used.

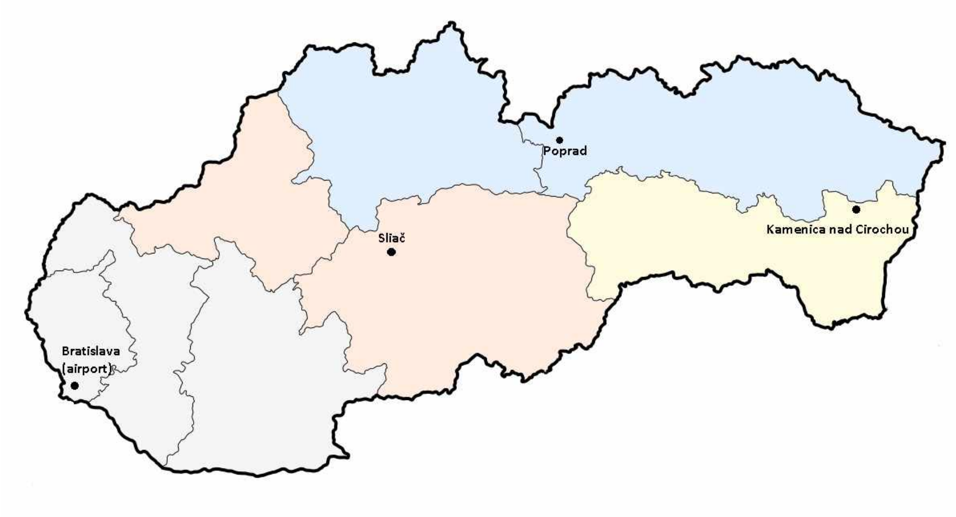
4.3.1 Variables

There is a consensus in literature that weather conditions are the most important variables affecting the electricity consumption. This subsection is devoted to the reasoning behind including particular variables in our model and their form. Firstly, it is explained how the variables $temp\_avg_{hd}$, hum_avg_{hd}, $press\_avg_{hd}$, $rain\_avg_{hd}$, $intensity\_avg_{hd}$, sun_avg_{hd} were constructed. Secondly, the two approaches used in the estimation to account for the nonlinear relationship between temperature and electricity consumption are presented. The first one is to include both $temp\_avg_{hd}$ and its quadratic form

$temp\_avg\_sq_{hd}$. The second is the concept of heating degrees (h_deg_{dh}) and cooling degrees (c_deg_{dh}).

As already mentioned in section 4.3 the _avg stands for the weighted average. As Slovakia consists of 8 regions: Banská Bystrica, Bratislava, Košice, Nitra, Prešov, Trenčín, Trnava, Žilina, every of this regions was assigned to one of the area from which the data on the weather conditions are available (specifically to the regions Bratislava-Airport, Sliač, Poprad and Kamenica nad Cirochou). They were assigned to the corresponding based on their geographical location and characteristics. Therefore, Bratislava-airport weather conditions represents regions: Bratislava, Trnava, Nitra. Sliač represents regions: Banská Bystrica, Trenčín. Poprad represents regions: Žilina, Prešov. Lastly, Kamenica nad Cirochou represents region: Košice. This division is visualized in Figure 4.3. Altough Sliač seems to be closer to the Žilina region, Žilina region is assigned to the Poprad weather conditions. This is due to the fact that the whole northern part of Slovakia including Žilina is mostly in the mountains and so is Poprad. Therefore, Poprad's climate is more likely to reflect the weather conditions in Žilina region more precisely than Sliač would.

Figure 4.3: Division of 8 regions into 4 areas.



Note: Bratislava-airport area regions: (left-to-right) Bratislava, Trnava, Nitra. Sliač area regions: (left-to-right) Trenčín, Banská Bystrica. Poprad area regions: (left-to-right) Žilina, Prešov. Kamenica nad Cirochou area: Košice region.

By looking at the demographical data from Statistical Office of Slovak Republic, the population in every region appears to be approximately the same. Therefore, industrial electricity consumption appears to be reasonable measure according to which the distribution of the weights to the region can be assigned. From the data about annual industry consumption in each region obtained from Statistical Office of Slovak Republic, the annual relative consumption of each region to aggregate consumption in Slovakia was calculated. This fractions then serve as the relative weights for weather conditions. The precise weights 0.41, 0.29, 0.16, 0.14 were assigned to the areas Bratislava-airport, Sliač, Poprad, Kamenica nad Cirochou, respectively. Thus, the variable $temp\_avg_{hd}$, is created by using the following formula:

$$\begin{aligned} temp\_avg_{hd} = {} & temp\_BA_{hd} * 0.41 + temp\_SL_{hd} * 0.29 + temp\_PO_{hd} * 0.0.16 \\ & + temp\_KA_{hd} * 0.14, \end{aligned}$$

where, $temp\_BA_{hd}$ is average temperature in Bratislava-Airport in hour h on day d, $temp\_SL_{hd}$ is average temperature in Sliač in hour h on day d, $temp\_PO_{hd}$ is average temperature in Poprad in hour h on day d, $temp\_KA_{hd}$ is average temperature in Kamenica nad Cirochou in hour h on day d. Analogously, the variables hum_avg_{hd}, $press\_avg_{hd}$, $intensity\_avg_{hd}$, $rain\_avg_{hd}$ and sun_avg_{hd} were constructed using the same weights.

As previous researches indicated, the relationship between temperature and the electricity consumption is not linear (Choi *et al.*, 2017; Hill *et al.*, 2010; Rock, 1997). In fact, this relationship appear to be either U-shaped or V-shaped. According to the Figure 4.4 our data appear to follow the U-shaped relationship. Therefore, it is important to include also quadratic form of temperature ($temp\_avg\_sq_{hd}$), in order to model the shape of the relationship more precisely.

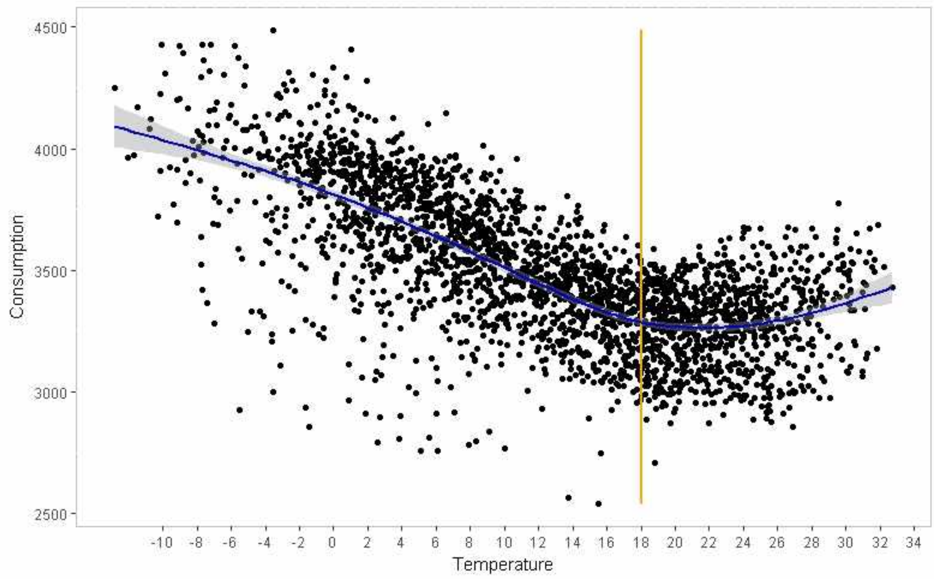
Another approach how to capure the relationship between electricity consumption and temperature is to use the cooling degrees (c_deg_{dh}) and heating degrees (h_deg_{dh}) framework used by Choi *et al.* (2017); Kotchen & Grant (2011); Kellogg & Wolff (2008). The two corresponding variables were obtained using the following equations:

$$\begin{aligned} c\_deg_{dh} &= max\{temp\_avg_{dh} - base\ temperature, 0\} \\ h\_deg_{dh} &= max\{base\ temperature - temp\_avg_{dh}, 0\}, \end{aligned}$$

where, the base temperature is assumed to be 18°C in order to be consistent with the existing literature. However, as we can see in Figure 4.4 the turning point appears not to be at 18°C, but rather at 22°C. In fact, the turning point in Slovakia varies from 15°C around midnight, up to a 22°C in the afternoon hours. Moreover, every country has different climate and other specifications and consequently there is no unified base temperature. Nevertheless, 18°C were chosen as the base temperature. However, it might be useful to check how the coefficient (β_3) in front of the investigated variable ($treat\_group_{hd} * DST_{hd}$) responds to change in the base temperature.

Hence the variable $\delta' temp\_vars_{dh}$ represents either $\delta_1 h\_deg_{dh}$, $\delta_1 c\_deg_{dh}$, or $\delta_1 temp\_avg_{dh}$, $\delta_2 temp\_avg\_sq_{dh}$.

Figure 4.4: The scatter plot of electricity consumption and average temperature at midday (12p.m.).



Note: Vertical (orange) line represents the base temperature for the calculation of heating and cooling degrees.

4.3.2 Hourly effect model

The overall effect is only one side of the DST influence. As the electricity consumption during the day is divided into peak and off-peak periods, it could be useful to investigate not only the overall effect of the DST but also the effect in different part of the day. This can help the policy makers with energy management decisions. Previous research pointed out that the effect of the daylight saving time is indeed not constant throughout the day (Mirza & Bergland, 2011; Karasu, 2010; Verdejo *et al.*, 2016). It varies depending on individual hour. Some studies suggest the evening saving might be offset by morning increase in consumption (Kellogg & Wolff, 2008).

Another reason to investigate the hourly effect lies in the research conducted by Hancevic & Margulis (2017), where they discussed the trade-off between overall effect and peak demand effect. On one hand, their results indicated overall increase in the electricity consumption due to DST. On the other hand, there was a reduction in the peak demand. Therefore, Hancevic & Margulis (2017) indicate three consequences that policy makers face. First, additional expenses due to higher overall increase. Second, lower generation costs at peak period. Third, long term decision of cutting the installed capacities, as the peak determines what are the installed capacities of the electricity production.

In order to show detailed picture of the effect of the daylight saving time in every individual hour the following model was constructed:

$$\begin{aligned} log(cons)_{hd} = {} & \beta_0 + \beta_1 DST_{hd} + \beta_2 treat\_group_{hd} + \gamma' treat\_hours \\ & + \delta' temp\_interaction\_vars_{dh} + \beta_3 hum\_avg_{hd} + \beta_4 press\_avg_{hd} \\ & + \beta_5 sun\_avg_{hd} + \beta_6 rain\_avg_{hd} + \beta_7 intensity\_avg_{hd} + \beta_8 brent_d \\ & + \beta_9 price_{hd} + \beta_{10} sine_{hd} + \beta_{11} holidays_d + \beta_{12} weekend_d + D_{H,M,Y} \\ & + \epsilon_{hd} \end{aligned}$$

where:

- $\gamma' treat\_hours$ is a vector of variables $\gamma_1(hour_1 * DST_{dh}) + \gamma_2(hour_2 * DST_{dh}) + \cdots + \gamma_{24}(hour_{24} * DST_{dh})$, where variables $hour_1, \ldots, hour_{24}$ are dummy variables for each hour of the day
- $\delta' temp\_interaction\_vars_{dh}$ is also a vector of variables. This variables consist of the interaction terms between the temperature and dummy variables for hour and the interaction terms between temperature squared and the dummy variables for individual hours

All other variables are the same as in the overall effect model (section 4.3). Since the temperature is probably the most important variable of the weather conditions variables only the interaction terms between temperature and individual hours are included.

4.4 Stationarity

Taking into account the fact that the used data are time series data, one should test whether the variables satisfy stationarity assumption. If our variables follow unit root process our estimates of the effect of DST could be inaccurate. Following Mirza & Bergland (2011) we have conducted Philips-Perron test which is robust to the unspecified autocorrelation and heteroskedacticity in the error term.

Chapter 5

Results

In the first section several assumptions needed for the estimation are tested. First the stationarity , heteroskedasticity and serial correlation are tested. Then the validity of the selected control hours is assessed. Second section provides the results of the estimated effect of the DST. Third section focuses on the benefits of the DST policy in the monetary terms.

5.1 Standard tests

Stationarity

According to the results in Table A.1 we conclude that almost all of our variables does not follow unit root process. Since the p-value is 0.01 for almost all variables, the null hypothesis (unit root process) is rejected even at 1% significance level. Brent (oil price) is the only variable which may follow the unit root process since the p-value is rather high (around 0.5). Therefore, inclusion of this variable may lead to a spurious regression. Also including or excluding this variable influence the magnitude of our coefficient of interest greatly. Hence, this variable is omitted from the model due to its non-stationarity.

Heteroskedasticity

The possible presence of heteroskedasticity was tested using Breusch-Pagan test: H_0: Constant Variance against H_a: Heteroskedasticity. The null hypothesis was clearly rejected.

Serial correlation

The serial correlation in the error term was tested using the following regression based test:

$$\begin{aligned} u_{hd} = &\beta_0 + \gamma u_{(h-1)d} + \beta_1 DST_{hd} + \beta_2 treat\_group_{hd} + \beta_3(treat\_group_{hd} * DST_{hd}) \\ &+ \delta' temp\_vars_{dh} + \beta_4 hum\_avg_{hd} + \beta_5 press\_avg_{hd} + \beta_6 sun\_avg_{hd} \\ &+ \beta_7 rain\_avg_{hd} + \beta_8 intensity\_avg_{hd} + \beta_9 brent_d + \beta_{10} price_{hd} \\ &+ \beta_{11} sine_{hd} + \beta_{12} holidays_d + \beta_{13} weekend_d + D_{H,M,Y} + \epsilon_{dh} \end{aligned}$$

The following null hypothesis is tested: $H_0 : \gamma = 0$. The results are presented in Table A.5. The coefficient γ is different from zero and statistically significant, therefore the serial correlation is present.

The model suffers from both heteroskedasticity and serial correlation problem. This is solved using heteroskedasticity and serial correlation robust standard errors (HAC) with the lag of 24 (Mirza & Bergland, 2011).

Control Hours' Validity

To obtain consistent estimates, it is important to use valid control hours, meaning hours that are unaffected by DST. To test for validity of the selected control hours 24 regressions (one regression for every hour) are constructed in the following form:

$$\begin{aligned} log(cons)_d = &\beta_0 + \beta_1 DST_d + \beta_2 temp\_avg_d + \beta_3 temp\_avg\_sq_d + \\ &\beta_4 hum\_avg_d + \beta_5 press\_avg_d + \beta_6 sun\_avg_d + \beta_7 rain\_avg_d + \\ &\beta_8 intensity\_avg_d + \beta_{10} price_d + \beta_{11} sine_d + \beta_{12} holidays_d + \\ &\beta_{13} weekend_d + D_{M,Y} + \epsilon_d. \end{aligned}$$

In this case the variable of interest is the dummy variable for DST. Significance of the coefficient β_1 in every equation suggests whether the DST affects the consumption in the specific hour. The overview of the coefficient with their respecitive standard erros can be seen in Table 5.1. The midnight hours are affected by the DST, since the effect of DST is strongly statistically significant with p-value close to 0. DST has statistically insignificant effect for hours 12 and 13 with p-values 0.20 and 0.21, respectively. The hour 14 is also statistically significant. However we can see that hour 11, which can be considered as the midday hour is not affected by the DST based on the test. All other regression (hours) indicate strong significance of the DST variable. This corresponds with the intuition of midday not be affected by the DST. However,in the case of the data from Slovakia it seems that midday hours are 11,12,13, which slighty differ from other studies (e.g. Mirza & Bergland (2011) used 12, 13 and 14 as midday hours). Thus, I have decided to swap the control hour 14 with the hour 11. Moreover, as midnight hours are all affected by the DST I have decided to drop them from the control group in my final results.

In the next chapter I will focus mainly on the findings, resulting from the regression with control group being hours 11,12,13. Nevertheless, I include results with other control groups (12,13,14,24,1,2) , (24,1,2) , (12,13,14) in the Appendix in Table A.4 for comparison.

Table 5.1: Validity of control hours

DST Dummy	Coefficient	HAC Standard Error
Hour 24	-0.049	0.015
Hour 1	-0.046	0.014
Hour 2	-0.054	0.011
Hour 12	-0.019	0.015
Hour 13	-0.017	0.014
Hour 14	-0.027	0.012
Hour 11	-0.019	0.014

5.2 Effect of the DST

5.2.1 Overall impact

The presented results consider control group to be the altered midday hours (11,12,13). The estimates of the overall effect model regression suggest decrease in the electricity consumption in Slovakia between 1.27% and 1.56% depending on how the relationship between temperature and consumption is modelled.

Using variables $temp\_avg_{hd}$ and $temp\_avg\_sq_{hd}$ the estimated effect is -0.0127 and statistically significant. This implies a decrease of 1.27% in the electricity consumption. Using the cooling and heating degrees framework with 18°C as the base temperature, the finding suggest a decrease of 1.56%. Regarding the base temperature for this temperature specification framework, the results indicate that increasing the base temperature also increases the estimated savings of the DST.

The findings of this study are coherent with other studies supporting the reduction of consumption due to the DST (e.g. Mirza & Bergland (2011); Hill *et al.* (2010)). Moreover,Bergland *et al.* (2017) working paper estimated the reduction for Slovakia to be between 0.92 and 1.08 percent. Altought, the findings presented in this thesis correspond with Bergland *et al.* (2017) results in sign, the results diverge slightly in magnitude due to different model specification.

Looking at the control variables, the estimated results are consistent with initial expectations. For example, the coefficient in front of the variable *treat_g* suggest decrease in the consumption. This is consistent with the fact that during control hours (11,12,13) the consumption is lower regardless of the DST policy because the peak in the electricity consumption occurs in the morning and in the evening. As the DST policy is active mostly during the summer when the energy consumption is lower, the coefficient of DST variable intuitively indicates decrease in consumption. Similar reasoning holds for the dummy variables for weekends and holidays, where the consumption is expected to be lower compared to the consumption during working days. Regarding weather variables, the corresponding coefficients for *temp_avg* and *temp_avg_sq* confirm that the relationship between temperature and electricity consumption is indeed U-shaped. Moreover, increase in the consumption for both heating and cooling degrees also supports this. Lastly, one should not misinterpret estimated coefficient for the price. The coefficient suggest that the increase in price is associated with the increase in consumption. However, it is more likely result of endogeneity as the price is set to be highest during the peak of electricity consumption. Detailed results can be found in Table A.2

As was already mentioned, hours 1,2,14,24 did not passed the validity test of being unaffected by DST. Nevertheless, the results for the regression using different variation of the control hours are included in Table A.3 as a possible check of the consistency. It can be observed that using hours 12,13,14 as a control group slightly overestimates the reduction. On the other hand, if midnight hours serve as a control group, the results are highly underestimated compared to the benchmark control group (11,12,13). Intuitively, having both midday and midnight hours as control group yields underestimated results. The underestimation is however likely to be lower compared to including only the midday hours as including midnight hours reduces the estimated effect.

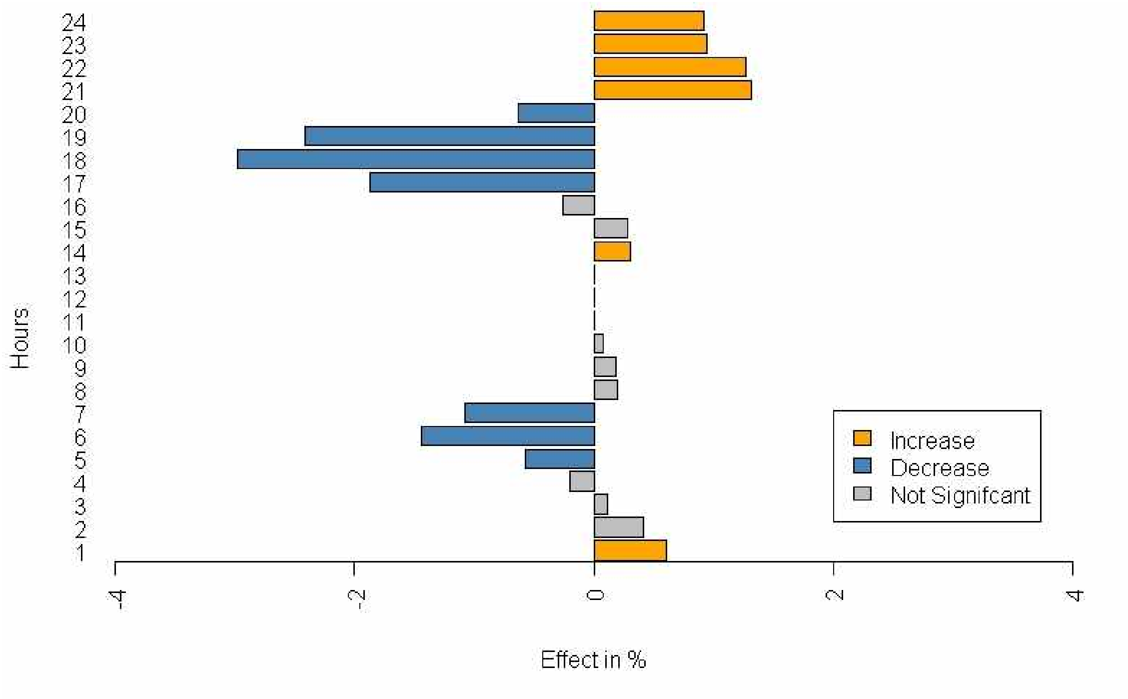
5.2.2 Hourly impact

The estimated effects of the DST in every individual hour, using the hours 11, 12, 13 as control hours, are coherent with the effects that could have been drawn from Figure 4.2. Firstly, DST reduces the consumption in two periods of the day in Slovakia. The evening hours pattern yields the highest savings with reduction of 1.87%, 2.98%, 2.42%, 0.63% in hours 17, 18, 19, 20, respectively. This is intuitive, since the main purpose of the DST is to provide more natural daylight during evening hours. Another period of the reduction is in the morning, with highest saving (1.45%) occurring at 6. This patterns can be also found in the literature (Mirza & Bergland, 2011; Verdejo *et al.*, 2016).

Secondly, a rise in the electricity demand occurs in the late evening and around the midnight. The highest increase the electricity demand is at 21 and 22 with the increase of 1.31% and 1.27%, respectively. Thirdly, the early morning hours (2,3,4,10) are statistically insignificant. Although hours 8 and 9 are statistically insignificant, by looking at the weekly data only (excluding weekend) they become statistically significant and change slightly in magnitude. The summary of the impact of DST on each individual hours can be seen in Figure 5.1. All regressions' results are included in the Apendix in Table A.4.

Regarding other studies, some proposed that the evening savings are offset by the morning increase in consumption leading to the overall insignificant effect (Choi *et al.*, 2017; Kellogg & Wolff, 2008). Others indicated that the morning contribution prevails and that DST increases the consumption(Kotchen & Grant, 2011). Even though, the presented results indicate that the savings are indeed partially offset due to the increase in consumption during late evening hours, this increase in consumption is not large enough to diminish the early evening savings entirely. Therefore, the findings indicate similar results as Mirza & Bergland (2011); Bergland *et al.* (2017); Karasu (2010) that the DST saves energy by at least 1%.

Figure 5.1: The distribution of the DST effect on electricity consumption throughout the day.



5.3 Financial Benefits

As already mentioned, the DST effect on the electricity consumption in Slovakia is estimated to be a reduction between 1.27% and 1.56% during the period when the DST is active. To calculate financial benefits in specific year, the consumption without DST is simulated by increasing actual consumption by 1.27% or 1.56% during the period of the DST. The difference between predicted consumption and actual consumption are the estimated savings. To estimate the price, the average of the price during the same period in the particular year is calculated.

For example, the highest estimated financial benefits occurred in year 2011 (10.2-12.5 million €) with the reduction of consumption being 198-243 GWh. The same reduction occurred in year 2012 but the average price of electricity declined, therefore the financial benefits were lower. The lowest estimated financial benefits (6.3-7.7 million €) occured in 2014 with savings in consumption being 191-234 GWh.

Table 5.2 provide the summary of the annual financial benefits in our examined period. However, financial estimation for the year 2017 is not included due to the fact that the investigated period starts on the 1st April 2010 and ends on 31st of July 2017. Therefore, this year is missing almost half of the DST affected period and the effect can not be computed. Year 2010 is included but can be biased because the DST affected period is missing four days.

Table 5.2: Summary of financial benefits in the examined period.

Year	Reduction (in GWh)	Price per MWh (€)	Financial Benefits (in million €)
2010	172-211	44.0	7.6-9.3
2011	198-243	51.7	10.2-12.5
2012	198-243	42.1	8.3-10.2
2013	193-237	36.1	7.0-8.5
2014	191-234	32.8	6.3-7.7
2015	196-240	33.5	6.6-8.1
2016	206-253	30.7	6.3-7.8

Chapter 6

Conclusion

The previous literature suggests that even though the European Union has unified DST policy (directive 2000/84/EC) the benefits in terms of energy consumption vary across the member states (Hill *et al.*, 2010; Mirza & Bergland, 2011; Bergland *et al.*, 2017).

This thesis represents a first attempt of a comprehensive analysis of the DST effects on electricity consumption in Slovakia. Using the difference-in-difference estimation technique (Wooldridge, 2010) and the data for the period of 2010-2017 Slovak (fully liberalized) electricity market was analysed. The model accounts for different weather conditions, price of the electricity, annual cycle and seasonality using various variables. The lack of the control group is solved using the "day normalization technique" (Mirza & Bergland, 2011; Kotchen & Grant, 2011), where the 24 hours of a day were divided into DST-affected and DST-unaffected (i.e. treatment and control group). However, this procedure can lead to biased results. Therefore, the most ideal opportunity for further researches in future would be a period in which Slovakia cancels, prolongs or shortens the period during which the DST is active. This would provide with a clearly defined control and treatment group.

Regarding the estimated effect, DST is found to decrease the demand for electricity mostly in the early evening hours with the highest savings (2.98%) occurring at 6 pm. Early morning hours also suggest decrease in consumption. On the other hand, as the increase in consumption during the late morning hours was found to be statistically insignificant, the main source that diminishes the overall savings lies in the late evening hours. The highest increase in consumption (1.31%) occurs at 9 pm. The overall impact of the DST on the electrical consumption in Slovakia is estimated to be at least 1 percent decrease in the consumption (specifically 1.27% - 1.56%). This corresponds with the annual electricity consumption savings in 2016 ranging between 206GWh and 253GWh. In financial terms this can be related to savings between 6.3 and 7.8 million Euros. Relative to the GDP of Slovakia in 2016 (81 bn €) these financial savings seem negligible (roughly 0.01%). However, as an average household annually consumes approximately 20MWh (SPP,2017), the energy savings could be compared to the annual energy consumption of at least 10 300 households.

Thus, the results support that the intention of the policy to save the energy is likely to be valid for Slovakia even in the modern society, at least in the field of electricity. However, one has to account for other aspects of the DST policy and its externalities. On one hand, psychological effects and changes in biorhythm during the transition may be seen as disadvantages of using DST. On the other hand, adding one additional hour of daylight in the evening hours when most of the people are active can be seen as a benefit to society. As these aspects has not been analysed for Slovakia, further research might focus on more complex cost-benefit analysis of the impact of DST in Slovakia.

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Appendix A

Supplementary tables

Table A.1: Unit root test results

Variable	Phillips Perron	p-value
cons	-27.37	0.01
temp	-12.37	0.01
hum	-34.17	0.01
press	-21.33	0.01
sun	-69.09	0.01
rain	-228.12	0.01
price	-44.89	0.01
brent	-2.19	0.50
production	-44.89	0.01

Table A.2: Results of benchmark model (using control hours 11,12,13)

Variable:	(1) Model with *temp_avg_sq*	(2) Model with C/H degrees
DST	-0.017^{***}	-0.012^{***}
	(0.002)	(0.002)
Price	0.002^{***}	0.002^{***}
	(0.00001)	(0.00001)
sin	-0.00001^{***}	-0.00001^{***}
	(0.00000)	(0.00000)
treat_g	-0.134^{***}	-0.133^{***}
	(0.001)	(0.001)
holidays	-0.068^{***}	-0.068^{***}
	(0.001)	(0.001)

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Table A.2 – *Continued from previous page*

Variable:	(1) Model with *temp_avg_sq*	(2) Model with C/H degrees
weekend	-0.077^{***}	-0.077^{***}
	(0.0004)	(0.0004)
DST*treat_g	-0.0127^{***}	-0.0156^{***}
	(0.001)	(0.001)
temp_avg	-0.005^{***}	
	(0.0001)	
temp_avg_sq	0.0001^{***}	
	(0.00000)	
h_deg		0.004^{***}
		(0.0001)
c_deg		0.002^{***}
		(0.0001)
hum_avg	0.00003	-0.0001^{***}
	(0.00002)	(0.00002)
press_avg	-0.0001^{***}	-0.0001^{***}
	(0.00001)	(0.00001)
sun_avg	-0.001^{***}	-0.001^{***}
	(0.00002)	(0.00002)
rain_avg	0.003^{***}	0.003^{***}
	(0.001)	(0.001)
intensity_avg	0.0001^{***}	0.00004^{***}
	(0.00001)	(0.00001)
summer	-0.008^{***}	-0.006^{***}
	(0.001)	(0.001)
jan	0.084^{***}	0.079^{***}
	(0.002)	(0.002)
feb	0.097^{***}	0.090^{***}
	(0.002)	(0.002)
mar	0.082^{***}	0.073^{***}
	(0.002)	(0.002)
apr	0.042^{***}	0.034^{***}
	(0.001)	(0.001)
may	0.017^{***}	0.015^{***}
	(0.001)	(0.001)
jun	0.017^{***}	0.017^{***}
	(0.001)	(0.001)
jul	0.004^{***}	0.004^{***}
	(0.001)	(0.001)
sep	0.027^{***}	0.026^{***}
	(0.001)	(0.001)
oct	0.060^{***}	0.052^{***}
	(0.001)	(0.001)

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Table A.2 – *Continued from previous page*

Variable:	(1) Model with *temp_avg_sq*	(2) Model with C/H degrees
nov	0.067***	0.059***
	(0.002)	(0.002)
dec	0.074***	0.066***
	(0.002)	(0.002)
y2010	−0.067***	−0.068***
	(0.001)	(0.001)
y2011	−0.070***	−0.072***
	(0.001)	(0.001)
y2012	−0.056***	−0.057***
	(0.001)	(0.001)
y2013	−0.046***	−0.049***
	(0.001)	(0.001)
y2014	−0.058***	−0.060***
	(0.001)	(0.001)
y2015	−0.030***	−0.033***
	(0.001)	(0.001)
y2016	−0.013***	−0.015***
	(0.001)	(0.001)
hour_1	−0.033***	−0.034***
	(0.001)	(0.001)
hour_2	−0.071***	−0.072***
	(0.001)	(0.001)
hour_3	−0.092***	−0.092***
	(0.001)	(0.001)
hour_4	−0.091***	−0.092***
	(0.001)	(0.001)
hour_5	−0.079***	−0.080***
	(0.001)	(0.001)
hour_6	−0.054***	−0.056***
	(0.001)	(0.001)
hour_7	0.023***	0.022***
	(0.001)	(0.001)
hour_8	0.066***	0.066***
	(0.001)	(0.001)
hour_9	0.104***	0.104***
	(0.001)	(0.001)
hour_10	0.131***	0.132***
	(0.001)	(0.001)
hour_11	−0.003***	−0.003***
	(0.001)	(0.001)
hour_12	0.003**	0.003**
	(0.001)	(0.001)

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Table A.2 – *Continued from previous page*

Variable:	(1) Model with *temp_avg_sq*	(2) Model with C/H degrees
hour_14	0.136***	0.137***
	(0.001)	(0.001)
hour_15	0.125***	0.125***
	(0.001)	(0.001)
hour_16	0.115***	0.115***
	(0.001)	(0.001)
hour_17	0.115***	0.115***
	(0.001)	(0.001)
hour_18	0.108***	0.108***
	(0.001)	(0.001)
hour_19	0.102***	0.102***
	(0.001)	(0.001)
hour_20	0.108***	0.108***
	(0.001)	(0.001)
hour_21	0.110***	0.110***
	(0.001)	(0.001)
hour_22	0.080***	0.080***
	(0.001)	(0.001)
hour_23	0.037***	0.037***
	(0.001)	(0.001)
Constant	8.227***	8.180***
	(0.016)	(0.016)
Observations	63,427	63,427
R^2	0.902	0.902
Adjusted R^2	0.902	0.902
Residual Std. Error (df = 63371)	0.042	0.042
F Statistic (df = 55; 63371)	10,582.770***	10,607.410***
Note:		*p<0.1; **p<0.05; ***p<0.01

Table A.3: Summary of final DST effect using different control groups and temperature specifications

Control Group	Temperature specification	DST effect
11,12,13	temp+temp_sq	-1.27 %
11,12,13	H/C degrees	-1.56 %
24,1,2,12,13,14	temp+temp_sq	-1.18 %
24,1,2,12,13,14	H/C degrees	-1.26 %
12,13,14	temp+temp_sq	-1.37 %
12,13,14	H/C degrees	-1.65 %
24,1,2	temp+temp_sq	-0.80 %
24,1,2	H/C degrees	-0.66 %

Note: H/C deg represents model where heating and cooling degrees framework was used; temp+temp_sq represents model with variables $temp\_avg_{dh}$, $temp\_avg\_sq_{dh}$ as temperature specification; DST effect represents the estimated effect of daylight saving time on electricity consumption

Table A.4: Results of robustness checks to benchmark model (using different control hours)

Variable:	Control hours 11,12,13	Control hours 24,1,2,12,13,14	Control hours 12,13,14	Control hours 24,1,2
Price	0.002***	0.002***	0.002***	0.002***
	(0.0001)	(0.0001)	(0.0001)	(0.0001)
weekend	−0.076***	−0.074***	−0.076***	−0.076***
	(0.002)	(0.002)	(0.002)	(0.002)
holidays	−0.066***	−0.065***	−0.066***	−0.066***
	(0.005)	(0.005)	(0.005)	(0.005)
DST	−0.027***	−0.028***	−0.026***	−0.021***
	(0.005)	(0.005)	(0.005)	(0.005)
sin	−0.00001**	−0.00001	−0.00001**	−0.00001**
	(0.00001)	(0.00001)	(0.00001)	(0.00001)
treat_g	−0.123***	−0.018***	−0.123***	0.122***
	(0.002)	(0.001)	(0.002)	(0.002)
treat1	0.0061**		0.005*	
	(0.003)		(0.003)	
treat2	0.0042		0.003	
	(0.003)		(0.003)	
treat3	0.0011	0.003	−0.0003	−0.005***
	(0.003)	(0.002)	(0.003)	(0.002)

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Table A.4 – *Continued from previous page*

Variable:	11,12,13	24,1,2,12,13,14	12,13,14	24,1,2
treat4	−0.002	−0.0002	−0.003	−0.008***
	(0.003)	(0.002)	(0.003)	(0.002)
treat5	−0.0056**	−0.004**	−0.007***	−0.012***
	(0.003)	(0.002)	(0.003)	(0.002)
treat6	−0.0145***	−0.013***	−0.016***	−0.021***
	(0.003)	(0.002)	(0.003)	(0.002)
treat7	−0.0108***	−0.009***	−0.012***	−0.017***
	(0.003)	(0.003)	(0.003)	(0.003)
treat8	0.002	0.003	0.001	−0.004
	(0.003)	(0.003)	(0.003)	(0.003)
treat9	0.0018	0.002	0.0005	−0.005*
	(0.002)	(0.002)	(0.002)	(0.003)
treat10	0.0007	0.001	−0.001	−0.006**
	(0.001)	(0.002)	(0.002)	(0.002)
treat14	0.00299*			−0.003
	(0.002)			(0.003)
treat11		−0.0001	−0.002*	−0.007***
		(0.002)	(0.001)	(0.002)
treat12				−0.008***
				(0.002)
treat13				−0.003
				(0.002)
treat15	0.0028	0.005***	0.001	−0.004
	(0.002)	(0.002)	(0.002)	(0.003)
treat16	−0.0026	−0.001	−0.004**	−0.009***
	(0.002)	(0.002)	(0.002)	(0.003)
treat17	−0.0187***	−0.017***	−0.020***	−0.025***
	(0.002)	(0.002)	(0.002)	(0.003)
treat18	−0.0298***	−0.028***	−0.031***	−0.036***
	(0.003)	(0.002)	(0.002)	(0.003)
treat19	−0.0242***	−0.022***	−0.025***	−0.031***
	(0.003)	(0.002)	(0.002)	(0.003)
treat20	−0.0063***	−0.005**	−0.008***	−0.013***
	(0.002)	(0.002)	(0.002)	(0.002)
treat21	0.0131***	0.014***	0.012***	0.007***
	(0.002)	(0.002)	(0.002)	(0.002)
treat22	0.0127***	0.014***	0.011***	0.006***
	(0.002)	(0.001)	(0.002)	(0.001)
treat23	0.0094***	0.011***	0.008***	0.003**
	(0.002)	(0.001)	(0.002)	(0.001)
treat24	0.0091***		0.008***	
	(0.002)		(0.002)	

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Table A.4 – *Continued from previous page*

Variable:	11,12,13	24,1,2,12,13,14	12,13,14	24,1,2
hum_avg	−0.0002***	−0.0002***	−0.0002***	−0.0002***
	(0.0001)	(0.0001)	(0.0001)	(0.0001)
press_avg	−0.00004	−0.0001	−0.00004	−0.00004
	(0.00004)	(0.00005)	(0.00004)	(0.00004)
sun_avg	−0.0004***	−0.0003***	−0.0004***	−0.0004***
	(0.00004)	(0.00004)	(0.00004)	(0.00004)
rain_avg	0.003***	0.004***	0.003***	0.003***
	(0.001)	(0.001)	(0.001)	(0.001)
intensity_avg	−0.00002	0.00000	−0.00002	−0.00002
	(0.00002)	(0.00002)	(0.00002)	(0.00002)
summer	−0.004	−0.004*	−0.004	−0.004
	(0.003)	(0.003)	(0.003)	(0.003)
temph1	−0.004***	−0.003***	−0.004***	−0.004***
	(0.0002)	(0.0002)	(0.0002)	(0.0002)
temph2	−0.004***	−0.003***	−0.004***	−0.004***
	(0.0002)	(0.0002)	(0.0002)	(0.0002)
temph3	−0.004***	−0.004***	−0.004***	−0.004***
	(0.0002)	(0.0002)	(0.0002)	(0.0002)
temph4	−0.004***	−0.004***	−0.004***	−0.004***
	(0.0002)	(0.0002)	(0.0002)	(0.0002)
temph5	−0.004***	−0.004***	−0.004***	−0.004***
	(0.0002)	(0.0002)	(0.0002)	(0.0002)
temph6	−0.005***	−0.005***	−0.005***	−0.005***
	(0.0002)	(0.0002)	(0.0002)	(0.0002)
temph7	−0.004***	−0.004***	−0.004***	−0.004***
	(0.0003)	(0.0003)	(0.0003)	(0.0003)
temph8	−0.003***	−0.003***	−0.003***	−0.003***
	(0.0003)	(0.0003)	(0.0003)	(0.0003)
temph9	−0.002***	−0.002***	−0.002***	−0.002***
	(0.0002)	(0.0002)	(0.0002)	(0.0002)
temph10	−0.002***	−0.002***	−0.002***	−0.002***
	(0.0002)	(0.0002)	(0.0002)	(0.0002)
temph11	−0.002***	−0.002***	−0.002***	−0.002***
	(0.0002)	(0.0002)	(0.0002)	(0.0002)
temph12	−0.002***	−0.002***	−0.002***	−0.002***
	(0.0002)	(0.0002)	(0.0002)	(0.0002)
temph13	−0.001***	0.002***	−0.001***	−0.001***
	(0.0002)	(0.0002)	(0.0002)	(0.0002)
temph14	−0.001***	−0.001***	−0.001***	−0.001***
	(0.0002)	(0.0002)	(0.0002)	(0.0002)
temph15	−0.001***	−0.001***	−0.001***	−0.001***
	(0.0002)	(0.0002)	(0.0002)	(0.0002)

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Table A.4 – *Continued from previous page*

Variable:	11,12,13	24,1,2,12,13,14	12,13,14	24,1,2
temph16	−0.002***	−0.002***	−0.002***	−0.002***
	(0.0002)	(0.0002)	(0.0002)	(0.0002)
temph17	−0.002***	−0.002***	−0.002***	−0.002***
	(0.0002)	(0.0002)	(0.0002)	(0.0002)
temph18	−0.002***	−0.002***	−0.002***	−0.002***
	(0.0002)	(0.0002)	(0.0002)	(0.0002)
temph19	−0.003***	−0.003***	−0.003***	−0.003***
	(0.0002)	(0.0002)	(0.0002)	(0.0002)
temph20	−0.003***	−0.003***	−0.003***	−0.003***
	(0.0002)	(0.0002)	(0.0002)	(0.0002)
temph21	−0.003***	−0.003***	−0.003***	−0.003***
	(0.0002)	(0.0002)	(0.0002)	(0.0002)
temph22	−0.003***	−0.003***	−0.003***	−0.003***
	(0.0002)	(0.0002)	(0.0002)	(0.0002)
temph23	−0.003***	−0.003***	−0.003***	−0.003***
	(0.0002)	(0.0002)	(0.0002)	(0.0002)
temph24	−0.003***	−0.006***	−0.003***	−0.003***
	(0.0002)	(0.0002)	(0.0002)	(0.0002)
jan	0.085***	0.088***	0.085***	0.085***
	(0.007)	(0.007)	(0.007)	(0.007)
feb	0.092***	0.095***	0.092***	0.092***
	(0.007)	(0.007)	(0.007)	(0.007)
mar	0.067***	0.069***	0.067***	0.067***
	(0.006)	(0.006)	(0.006)	(0.006)
apr	0.027***	0.028***	0.027***	0.027***
	(0.004)	(0.004)	(0.004)	(0.004)
may	0.008**	0.009**	0.008**	0.008**
	(0.004)	(0.004)	(0.004)	(0.004)
jun	0.015***	0.015***	0.015***	0.015***
	(0.003)	(0.003)	(0.003)	(0.003)
jul	0.005	0.004	0.005	0.005
	(0.003)	(0.003)	(0.003)	(0.003)
sep	0.018***	0.019***	0.018***	0.018***
	(0.003)	(0.003)	(0.003)	(0.003)
oct	0.048***	0.050***	0.048***	0.048***
	(0.004)	(0.004)	(0.004)	(0.004)
nov	0.056***	0.059***	0.056***	0.056***
	(0.007)	(0.007)	(0.007)	(0.007)
dec	0.071***	0.075***	0.071***	0.071***
	(0.008)	(0.008)	(0.008)	(0.008)
y2010	−0.069***	−0.069***	−0.069***	−0.069***
	(0.003)	(0.003)	(0.003)	(0.003)

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Table A.4 – *Continued from previous page*

Variable:	11,12,13	24,1,2,12,13,14	12,13,14	24,1,2
y2011	−0.074***	−0.074***	−0.074***	−0.074***
	(0.003)	(0.003)	(0.003)	(0.003)
y2012	−0.058***	−0.058***	−0.058***	−0.058***
	(0.003)	(0.003)	(0.003)	(0.003)
y2013	−0.049***	−0.048***	−0.049***	−0.049***
	(0.003)	(0.003)	(0.003)	(0.003)
y2014	−0.062***	−0.061***	−0.062***	−0.062***
	(0.003)	(0.003)	(0.003)	(0.003)
y2015	−0.033***	−0.031***	−0.033***	−0.033***
	(0.003)	(0.003)	(0.003)	(0.003)
y2016	−0.014***	−0.012***	−0.014***	−0.014***
	(0.003)	(0.003)	(0.003)	(0.003)
hour_1	−0.029***	−0.077***	−0.029***	−0.029***
	(0.001)	(0.001)	(0.001)	(0.001)
hour_2	−0.063***	−0.111***	−0.063***	−0.064***
	(0.001)	(0.001)	(0.001)	(0.001)
hour_3	−0.081***	−0.112***	−0.081***	−0.203***
	(0.001)	(0.001)	(0.001)	(0.002)
hour_4	−0.078***	−0.109***	−0.078***	−0.201***
	(0.001)	(0.001)	(0.001)	(0.002)
hour_5	−0.061***	−0.092***	−0.061***	−0.183***
	(0.001)	(0.001)	(0.001)	(0.002)
hour_6	−0.028***	−0.059***	−0.028***	−0.150***
	(0.001)	(0.001)	(0.001)	(0.002)
hour_7	0.042***	0.009***	0.042***	−0.080***
	(0.002)	(0.002)	(0.002)	(0.002)
hour_8	0.068***	0.034***	0.068***	−0.055***
	(0.002)	(0.002)	(0.002)	(0.002)
hour_9	0.099***	0.064***	0.099***	−0.024***
	(0.002)	(0.002)	(0.002)	(0.001)
hour_10	0.125***	0.089***	0.125***	0.002**
	(0.002)	(0.002)	(0.002)	(0.001)
hour_11	0.007***	0.093***	0.130***	0.007***
	(0.001)	(0.002)	(0.002)	(0.001)
hour_12	0.010***	0.078***	0.010***	0.010***
	(0.001)	(0.001)	(0.001)	(0.001)
hour_14	0.119***	0.065***	−0.003***	−0.003***
	(0.002)	(0.001)	(0.001)	(0.001)
hour_15	0.109***	0.073***	0.109***	−0.014***
	(0.002)	(0.002)	(0.002)	(0.001)
hour_16	0.105***	0.070***	0.105***	−0.017***
	(0.002)	(0.002)	(0.002)	(0.001)

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Table A.4 – *Continued from previous page*

Variable:	11,12,13	24,1,2,12,13,14	12,13,14	24,1,2
hour_17	0.119***	0.084***	0.119***	−0.003***
	(0.002)	(0.002)	(0.002)	(0.001)
hour_18	0.125***	0.089***	0.125***	0.002
	(0.002)	(0.002)	(0.002)	(0.001)
hour_19	0.119***	0.084***	0.119***	−0.003**
	(0.002)	(0.002)	(0.002)	(0.002)
hour_20	0.119***	0.084***	0.119***	−0.003**
	(0.002)	(0.002)	(0.002)	(0.001)
hour_21	0.109***	0.075***	0.109***	−0.013***
	(0.002)	(0.001)	(0.002)	(0.001)
hour_22	0.073***	0.040***	0.073***	−0.049***
	(0.001)	(0.001)	(0.001)	(0.001)
hour_23	0.033***		0.033***	−0.090***
	(0.001)		(0.001)	(0.002)
Constant	8.229***	8.158***	8.229***	8.107***
	(0.051)	(0.053)	(0.051)	(0.051)
Note:	*p<0.1; **p<0.05; ***p<0.01			

Table A.5: Test for serial correlation

Variable:	Coefficient(standard error)
u_1	0.888***
	(0.002)
DST	−0.0004
	(0.001)
Price	−0.0001***
	(0.00001)
sin	−0.00000**
	(0.00000)
treat_g	0.00004
	(0.001)
holidays	0.0003
	(0.0004)
weekend	0.0002
	(0.0002)
Effect_final	0.002***
	(0.0005)

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Table A.5 – *Continued from previous page*

Variable:	Coefficient(standard error)
temp_avg	−0.00004
	(0.00003)
temp_avg_sq	−0.00000**
	(0.00000)
hum_avg	0.0001***
	(0.00001)
press_avg	−0.00000
	(0.00001)
sun_avg	0.0001***
	(0.00001)
rain_avg	−0.002***
	(0.0002)
intensity_avg	−0.00003***
	(0.00000)
summer	0.0004
	(0.0004)
jan	−0.0004
	(0.001)
feb	−0.0003
	(0.001)
mar	−0.0001
	(0.001)
apr	−0.0005
	(0.001)
may	−0.0004
	(0.001)
jun	0.00001
	(0.0005)
jul	0.00000
	(0.0004)
sep	−0.0004
	(0.0004)
oct	−0.001
	(0.001)
nov	−0.0002
	(0.001)
dec	−0.001
	(0.001)
y2010	0.00003
	(0.0004)
y2011	0.0004
	(0.0004)

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Table A.5 – *Continued from previous page*

Variable:	Coefficient(standard error)
y2012	−0.0003
	(0.0004)
y2013	−0.001***
	(0.0004)
y2014	−0.001***
	(0.0004)
y2015	−0.001*
	(0.0004)
y2016	−0.001**
	(0.0004)
hour_1	−0.002***
	(0.001)
hour_2	−0.003***
	(0.001)
hour_3	−0.003***
	(0.001)
hour_4	−0.003***
	(0.001)
hour_5	−0.003***
	(0.001)
hour_6	−0.003***
	(0.001)
hour_7	−0.003***
	(0.001)
hour_8	−0.003***
	(0.001)
hour_9	−0.002***
	(0.001)
hour_10	−0.001***
	(0.001)
hour_12	0.001
	(0.001)
hour_13	0.001*
	(0.001)
hour_15	−0.0001
	(0.001)
hour_16	−0.0004
	(0.001)
hour_17	−0.0004
	(0.001)
hour_18	−0.0004
	(0.001)

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Table A.5 – *Continued from previous page*

Variable:	Coefficient(standard error)
hour_19	-0.0003
	(0.001)
hour_20	-0.0002
	(0.001)
hour_21	-0.0002
	(0.001)
hour_22	-0.001^{*}
	(0.001)
hour_23	-0.001^{**}
	(0.001)
hour_24	-0.002^{***}
	(0.001)
Constant	0.008
	(0.007)
Observations	63,426
R^2	0.787
Adjusted R^2	0.786
Residual Std. Error	0.019 (df = 63369)
F Statistic	$4,170.728^{***}$ (df = 56; 63369)
Note:	*p<0.1; **p<0.05; ***p<0.01