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$$\frac{n!}{(n-1)!} p^{m-1} (1-p)^{n-m} = p \sum_{\ell=0}^{n-1} \frac{\ell+1}{n} \frac{(n-1)!}{(n-1-\ell)! \ell!} p^{\ell} (1-p)^{n-1-\ell}$$
$$= p \frac{n-1}{n} \sum_{\ell=0}^{n-1} \left[\frac{\ell}{n-1} + \frac{1}{n-1} \right] \frac{(n-1)!}{(n-1-\ell)! \ell!} p^{\ell} (1-p)^{n-1-\ell} = p^2 \frac{n-1}{n} +$$

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Does Daylight Saving Time Save Electricity?

Evidence from Slovakia

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Abstract:

The European Union has recently decided to stop the policy of biannual clock changes in 2021. One reason is that the original rationale for the policy, energy savings, is not supported by a large portion of recent empirical studies. Whether the new permanent time will be standard time or the former daylight saving time has not been decided. Evidence on energy savings from daylight saving time is country-specific, and each country may choose its own time. We examine the effects of the policy in a country for which no studies on daylight saving exist, Slovakia. Using hourly data from the 2010-2017 period, we apply a difference-in-differences approach and estimate energy savings to equal 0.8% of annual electricity consumption. Alternatively, extrapolating the effect from the results of a previous meta-analysis (on different countries), for Slovakia we obtain an even smaller estimate, unlikely to exceed 0.5%. Moreover, our findings suggest that daylight saving time smooths the electricity demand curve.

JEL: C54, Q41, Q48

Keywords: Daylight saving time, electricity consumption, peak demand, Slovakia

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1 Introduction

Daylight saving time (DST) refers to the practice of setting clocks one hour forward in the spring and back again in the fall. Historically, the main reason for doing so has been to make better use of natural daylight at the peak hours of energy consumption. As of today, all member states of the European Union synchronize their clocks twice a year; although recently, the European Parliament endorsed a proposal to stop the seasonal clock changes starting in 2021 (EC, 2019).

The decision on the permanent time will, however, be made individually by each EU member, and some studies (such as Havranek *et al.*, 2018) indicate that the impact of DST is likely to be country-specific: some EU countries benefit from DST, whereas others consume more electricity because of the policy. Bergland & Mirza (2017) provide insight into the effects of DST in EU member states and show that the effects do indeed differ by state. Recent evidence from other continents indicates energy costs due to the policy (Kellogg & Wolff, 2008; Kotchen & Grant, 2011). In this paper, we provide the first detailed analysis of the effect of DST in Slovakia, an EU member state with one of the lowest carbon intensities in electricity production.

A common problem with studies that focus on DST in EU countries is the lack of natural experiment data. Part of our estimation strategy is based on a difference-in-differences model that exploits the fact that DST does not affect electricity demand during the midday hours (Ebersole *et al.*, 1975). We extend the model of Bergland & Mirza (2017) and analyze the overall and hourly effects, accounting for different sets of control groups, various weather conditions, temperature specifications, macroeconomic indicators, cyclicities, and seasonalities. The second part of our analysis uses the results of a meta-analysis by Havranek *et al.* (2018), who construct a synthetic best-practice study to estimate the overall DST effect. We extrapolate their Bayesian model averaging benchmark results and the preferred design of the best-practice study on the Slovak electricity market.

Our results show that the DST policy in Slovakia conserves some electricity but not much. While the difference-in-differences method shows an effect of approximately 0.8% on yearly electricity consumption, the best-practice specification extrapolated from the meta-analysis pushes the estimate downwards and suggests the overall effect is unlikely to exceed 0.5%. In Slovakia, the DST policy lowers the peak consumption during the early morning and early evening hours while slightly increasing consumption before midnight, thus redistributing the consumption

more evenly during the day.

The rest of this paper is structured as follows: Section 2 introduces the Slovak electricity market in relation to DST policy, Section 3 describes the data and methodology used to evaluate different effects, Section 4 discusses the results of the analyses, and Section 5 concludes.

2 Electricity Market and Daylight Saving in Slovakia

Slovakia, as a part of the Austro-Hungarian Empire in 1916, was among the first countries in the world to officially adopt the DST policy (Pollak, 1981). In the midst of World War I, the battling states intended to reduce coal consumption (especially for lighting purposes) and transfer the energy savings to war expenses. The allied countries (and even some neutrals) implemented the policy as an emergency wartime measure and discontinued it after World War I (EC, 2018). During World War II, in 1940, Slovakia implemented the DST policy as an autonomous country and maintained it until 1949, when it became part of the Czechoslovak Republic. Following a number of European countries reacting, especially, to the 1970s energy crisis, the policy was reintroduced in the Czechoslovak Socialist Republic in 1979, with a 6-month-long summer time.

The discordant summer-time arrangements throughout Europe forced many countries to harmonize time with their neighbors. The DST policy, however, was no longer treated as a temporary fix for energy crises and increased government spending. More sunshine in the afternoon became fairly popular, and in 1996, Slovakia prolonged the summer time to 7 months, following the existent EU directive (EC, 2018). Currently, all states of the European Union synchronize their clocks twice a year on the last Sunday of March and the last Sunday of October. Still, in 2017, just as in 1996, the European Commission stated that energy savings were a relevant reason for implementing DST (EC, 1996; Anglmayer, 2017). The popularity among Europeans, however, has decreased dramatically, and the EU regulatory bodies have called for a discontinuation of seasonal time changes (EC, 2018).

The estimates of energy savings from DST focusing on European markets are scarce and somewhat contradictory. Many come from reports of government or electricity companies rather than academic peer-reviewed articles. HMSO (1970), Hillman (1993), and Hill *et al.* (2010) report the savings for the United Kingdom; Wanko & Ingeborg (1983) and EVA (1978) report the savings for Austria; Danish Government Report (1974) and ELTRA (1984) for Denmark;

Bouillon (1983), Ebersbach & Schaefer (1980), and Fischer (2000) for Germany (these estimates are contradictory to later studies, such as TAB, 2016, showing some costs from DST in Germany); EnergieNed (1995) and SEP (1995) provide the estimates for Netherlands, Bellere (1996), ENEL (1999), and Terna (2016) for Italy; Mirza & Bergland (2011) for Norway and Sweden; ADEME (1995) and ADEME (2010) for France; and finally Castoralova (2019), who to some extent contradicts the findings of Kozuskova (2011), for the Czech Republic electricity market. Negative savings (i.e., costs) of the DST policy are not unheard of, even for the US (Kotchen & Grant, 2011) and Australian markets (Kellogg & Wolff, 2008).

Only one known estimate of the electricity savings from DST in Slovakia exists: the cross-country study of Bergland & Mirza (2017), who evaluate the savings because of DST at 1% of power consumption (and provide estimates for many countries, without focusing on Slovakia). The estimates of the effect of DST for the structurally most similar economy to Slovakia would be those of the Czech Republic, the average of which is close to 0% in terms of overall electricity consumption (Kozuskova, 2011; Castoralova, 2019; Havranek *et al.*, 2018; Bergland & Mirza, 2017; Jilek, 2000). Havranek *et al.* (2018) and Bergland & Mirza (2017) find large country heterogeneity in the literature on DST effects on energy savings. They also reveal the estimates to be strongly dependent on geographical latitude. Moreover, the patterns of national demand for electricity change over time as new technologies penetrate European markets (Bossmann & Staffell, 2015). Electronic home appliances with stand-by modes, energy-efficient light bulbs, the transition to electric heating systems, increasing occurrence of air-conditioning, smart-homes, and even electronic cars are changing the national load curves. The discussions of DST in the EU is even more problematic since, legally, the EU regulatory bodies cannot oblige a member state to select a dedicated time zone.

In recent years, following increasing economic growth and standards of living in the European Union, Slovakia recorded an increase in the demand for electricity—the net consumption was over 30 TWh in 2018 (Table 1). Overall energy consumption has also increases; thus, a tool for energy conservation and greenhouse gas emissions reduction is very relevant. The electricity mix, however, is focused on indigenous energy sources and low-carbon technologies, such as nuclear energy (54% of the electricity generated in 2017) and renewable sources (26% of the electricity generated in 2017, of which 17% is hydro power), with the remaining 20% of energy

Table 1: Electricity production deficit covered by imports

	2009	2010	2011	2012	2013	2014	2015	2016	2017
Production	26.1	27.7	28.1	28.4	28.6	27.3	27.2	27.5	28.0
Export	7.7	6.3	10.5	13.1	10.6	11.9	12.6	10.6	12.5
Import	8.3	6.7	10.9	13.4	10.7	12.9	15.0	13.2	15.6
Consumption	27.4	28.8	28.9	28.8	28.7	28.4	29.5	30.1	31.1
<i>Consumption by:</i>									
<i>Industry [%]</i>	<i>47</i>	<i>45</i>	<i>45</i>	<i>50</i>	<i>47</i>	<i>51</i>	<i>44</i>	<i>48</i>	<i>48</i>
<i>Agriculture, commerce, services [%]</i>	<i>32</i>	<i>34</i>	<i>34</i>	<i>28</i>	<i>31</i>	<i>27</i>	<i>35</i>	<i>29</i>	<i>31</i>
<i>Households [%]</i>	<i>19</i>	<i>18</i>	<i>18</i>	<i>20</i>	<i>20</i>	<i>20</i>	<i>19</i>	<i>20</i>	<i>19</i>
<i>Transportation [%]</i>	<i>2</i>	<i>2</i>	<i>2</i>	<i>2</i>	<i>2</i>	<i>2</i>	<i>2</i>	<i>2</i>	<i>2</i>

Notes: Numbers in TWh taken from SEPS (2019). Sectoral distribution of consumption in percentages (in italics) taken from SOSR (2019).

obtained from fossil fuels (SEPS, 2017). Since 2005, the Slovak electricity market has undergone full liberalization. In 2009, Slovakia joined a market coupling project with the Czech Republic; Hungary and Romania later joined in 2012 and 2014, respectively. Market coupling resulted in more efficient utilization of cross-border capacities, which currently amount to a respectable 40% of the generating capacity (IEA, 2018). Table 1 shows that the electricity production deficit in Slovakia is being covered from imported volumes. Net imports, however, do not generally cover supply limitations but rather regional business opportunities (IEA, 2018). The upcoming finalization of two units of the nuclear plant Mochovce will cover approximately 26% of the Slovak national electricity consumption (and will reduce the high carbon-intensive production from coal and imports), amounting to approximately 7 billion tons of CO₂ emissions (Janda, 2018).

Liberalization of the market made wholesale and retail open for competition. Retail prices, however, are regulated by a price cap for all households and small enterprises. Household consumption has increased over time at a similar pace as that of overall consumption: the share of households has remained steady at 20% of overall consumption. Still, it is safe to assume that the price cap discourages, to some extent, energy-efficient behavior. Moreover, market coupling is responsible for the decrease in price volatility (Janda, 2018), even though IEA (2018) reports Slovakia to have comparatively higher electricity prices than neighboring countries, especially in the industrial sector. IEA (2018) suggests a number of policy improvements to increase efficiency in energy consumption and to support competition in the market. This becomes highly relevant given the dominant trend of increasing electricity consumption in Slovakia, which according to

the prognosis of SEPS (2018), has an average year-on-year growth of 1.3%, for an estimated consumption of 33.8 TWh in 2025.

3 Research Design and Data

The literature recognizes two different approaches to estimate the savings from DST: simulation and regression. In simulation studies, authors (such as Fong *et al.*, 2007; Pout, 2006; Shimoda *et al.*, 2007) usually develop an energy consumption model of different types of buildings, such as households, industrial, and commercial buildings, and extrapolate the model to the country level. The difference-in-differences method is widely applied for assessing the impact of certain policies (see, for example Choi *et al.*, 2017; Verdejo *et al.*, 2016). The idea is a difference-in-differences comparison between the control group of data before the policy change and the treatment group of data after the policy change. Authors using regression analysis usually estimate the following model:

$$\ln \text{Consumption}_t = \alpha + DST \cdot \text{Treatment effect}_t + \text{Controls}_t + \epsilon, \quad (1)$$

where *Consumption* is energy consumption during time t , *Treatment effect* is a dummy variable for a selected treatment group that usually equals 1 for all hours that DST applies, and the coefficient *DST* is the effect of the policy. *Controls* are explanatory variables representing weather and light conditions, seasonality, holidays, heterogeneity among consumption units, and related macroeconomic conditions. ϵ represents the error term.

Both approaches face the problem of data availability. The only public source of electricity consumption data, ENTSO-E (2017), provides hourly load curves since January 2005. Given the last DST policy change in Slovakia occurred in 1996, we have no control group for the estimation. Ebersole *et al.* (1975) proposed a compelling technique to address this issue: they divide the 24 hours of the day into those affected by DST policy (treatment group) and those unaffected by DST policy (control group). Mirza & Bergland (2011) and Kotchen & Grant (2011) applied this technique: they pronounced the midday hours from 12 AM to 2 PM and the midnight hours from 12 PM to 2 AM to be unaffected by the policy, thus the control group, because these hours have the same amount of natural daylight regardless of the DST policy.

Table 2: Summary statistics of explanatory variables

Variable	Description	Mean	SD	Min	Max
Consumption	= hourly aggregate electricity consumption [in MW]	3,207.9	426.7	2,119.0	4,541.0
<i>Weather variables</i>					
Humidity	= average hourly relative air humidity [in %]	73.8	16.8	18.7	98.7
Air pressure	= average hourly air pressure [in <i>hPa</i>]	982.8	13.0	828.3	1,007.5
Sunlight	= total duration of sunshine in an hour [in <i>minutes</i>]	9.9	15.1	0.0	60.0
Precipitation	= sum of hourly rainfall [in <i>mm</i>]	0.1	0.3	0.0	13.3
Radiation	= average hourly intensity of radiation [in <i>J/cm²</i>]	36.5	51.4	0.0	328.4
<i>Temperature variables</i>					
Temperature	= average hourly air temperature [in °C]	10.2	9.2	-19.7	36.8
Cooling degrees	= hourly amount of cooling degrees [in °C]	1.0	2.6	0.0	18.8
Heating degrees	= hourly amount of heating degrees [in °C]	8.8	7.8	0.0	37.7
<i>Price variables</i>					
Electricity price	= average hourly price in a daily market [in EUR per MWh]	39.1	17.0	-150.0	200.0
Oil price	= Brent daily crude oil spot price [in USD per barrel]	83.9	29.0	26.0	128.1

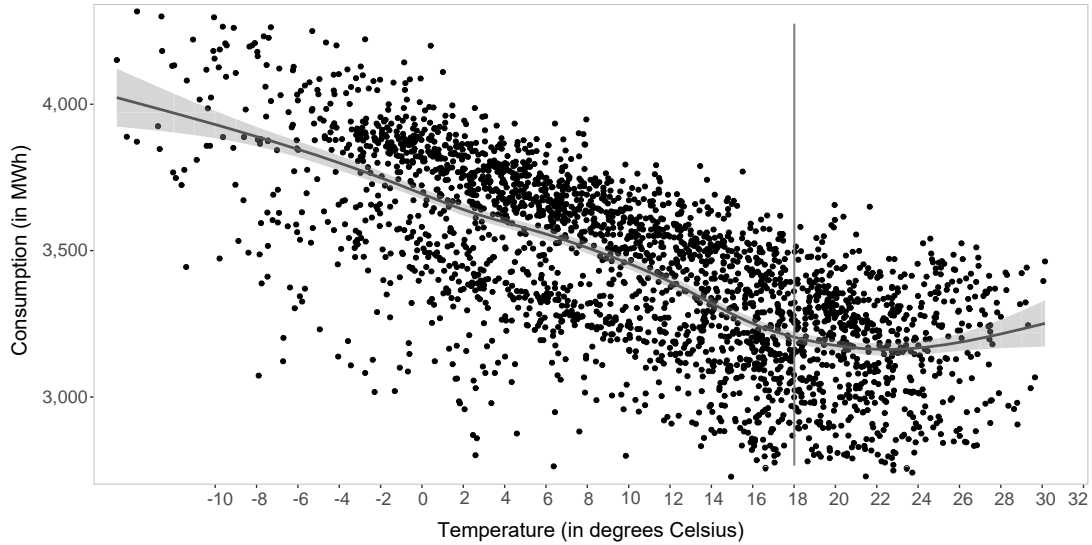
Notes: SD = standard deviation. Data set is based on the period between April 2010 and July 2017. Weather variables were constructed as consumption-weighted averages from the selected areas: Bratislava, Sliac, Kamenica nad Cirochou, and Poprad.

The remaining hours are considered to be affected by the policy and serve as the treatment group.

Table 2 provides descriptive statistics for the data used in this analysis: electricity *Consumption* with hourly granularity, the hourly amount of *Cooling degrees* and *Heating degrees*, macro variables such as *Electricity price* and *Oil Price*, and hourly data on weather conditions such as *Humidity*, *Air Pressure*, *Sunlight*, *Precipitation*, sun *Radiation*, and *Temperature*. Given the data availability for other explanatory variables, we obtain hourly aggregate electricity *Consumption* for Slovakia for the period between April 1st, 2010, and July 31th, 2017 (downloaded from ENTSO-E, 2017). Data are collected in Central European Time, which means the last Sunday in March has 23 hours and the last Sunday in October has 25 hours.

The weather data were obtained from the Slovak Hydro-Meteorological Institute for four representative meteorological stations: Bratislava airport (western Slovakia), Sliac (central Slovakia), Kamenica nad Cirochou (eastern Slovakia), and Poprad (representative of the cooler northern mountain climate). The data follow Coordinated Universal Time with the same number of hours for the last Sunday of March and October. Given our consumption data is a country aggregation, we construct a weighted average for all weather variables, where the weights are represented by time-respective regional industry consumption (annual industrial data

Figure 1: The relationship between consumption and temperature is not linear



Notes: Figure is a scatter plot of electricity consumption and average temperature at 12 AM. The vertical line represents 18 degrees Celsius, the base temperature for the calculation of heating and cooling degrees (see Table 2)—although for this hour of the day, the base temperature is actually approximately 22 degrees Celsius.

taken from SOSR, 2019).¹ Slovakia lies between temperate and continental climate zones and has relatively warm summers (reaching 35 degrees Celsius in extreme conditions according to SHMU, 2019) and cold winters (reaching -15 degrees Celsius in extreme conditions), making Slovak electricity consumption likely to be strongly related to heating and cooling.

Research, such as Choi *et al.* (2017), Hill *et al.* (2010), and Rock (1997), has shown that the relationship between temperature and electricity consumption is not necessarily linear but either U-shaped or V-shaped. Plotting the relationship of consumption and temperature in Figure 1 for the twelfth hour in the middle of the day, the data appear to follow a U-shaped relationship. Therefore, we create another variable to capture this nonlinearity, a quadratic form of temperature (*Temperature squared*). Following Choi *et al.* (2017), Kotchen & Grant (2011), and Kellogg & Wolff (2008), we also capture the relationship between electricity consumption and temperature with the variables *Cooling degrees*, defined as $\max\{Temperature - 18^{\circ}C, 0\}$, and *Heating degrees*, defined as $\max\{18^{\circ}C - Temperature, 0\}$. Here, 18°C is the base temperature. Although in Figure 1, the turning point of the curve actually at 22°C, the turning point

¹Based on geographical location, average regional weather, and demographics, we have assigned Bratislava airport weather conditions to the Slovak regions of Bratislava, Trnava, and Nitra; Sliac weather conditions to the regions of Banska Bystrica and Trencin; Poprad weather conditions to the regions of Zilina and Presov; and Kamenica nad Cirochou weather conditions to the Kosice region.

in Slovakia varies from 15°C around midnight to 22°C in the afternoon hours.

Electricity Price is not a common variable in the regression for DST effects as it introduces endogeneity into the regression (1) and is believed not to influence the estimated effect of DST savings. We believe, however, that a good representation of the electricity price could help to filter out the residual variations in demand; thus, we follow Mirza & Bergland (2011). We did not obtain a suitable instrument, but given that the incremental endogeneity should not decrease the validity of the estimated DST effect and given that the price elasticity of electricity demand in Slovakia is rather small (Bildirici & Kayikci, 2016), we use the hourly short-term market price from OKTE (2017). Moreover, given that retail prices in Slovakia are regulated, this price should not substantially affect the end-consumer behavior. In addition, to account for external macroeconomic conditions, we include the variable *Oil price*, which represents the daily (weekdays only) Brent oil spot prices collected from FRED (2017).

The last group of variables in the analysis is used to account for cyclicity, seasonality, and other time-related systematic patterns of electricity consumption. The electricity demand in our sample, irrespective of the DST policy, increases from year to year, varies from month to month (decreasing in summer regardless of DST policy), jumps on non-working days and shows hourly patterns. Therefore, we include *Cyclicity*, a trigonometric sine function, to account for cyclical patterns in consumption (Mirza & Bergland, 2011). Furthermore, *Holidays* represents a dummy variable with daily granularity for all public holidays in Slovakia, when there is a different pattern of consumption compared to working days. *Weekend* represents a dummy variable for weekends to distinguish between weekend and weekday patterns of consumption, and the *Seasonality* matrix includes dummy variables for hours, months, seasons, and years to account for several potential forms of seasonality and periodic patterns.

Given the variables above, we construct the following difference-in-differences model to estimate the DST effect:

$$\begin{aligned} \log(Consumption)_{hd} = & \beta_0 + \beta_1 DST_{hd} + \beta_2 Treatment_{hd} + \\ & + \beta_3 (DST_{hd} * Treatment_{hd}) + \\ & + \gamma' Temperature\ variables_{hd} + \delta' Weather\ variables_{hd} + \\ & + \phi' (Cyclicity, Holidays, Weekend, Seasonality)_{hd} + \end{aligned}$$

$$+ \epsilon' \text{Price variables}_{hd} + u_{hd}, \quad (2)$$

where DST_{hd} is a dummy variable equal 1 when DST policy is active at hour h of day d , $Treatment_{hd}$ is a dummy variable equal 1 if the hour h of day d belongs to the treatment group, and the interaction term $DST_{hd} * Treatment_{hd}$ captures the DST policy effect. The group of *Temperature variables* represents either the pair of variables *Temperature* and *Temperature squared* or the pair of variables *Cooling degrees* and *Heating degrees*. The group of *Weather variables* represents *Humidity*, *Air Pressure*, *Sunlight*, *Precipitation*, and *Radiation*. The group of *Price variables* represents *Electricity price* and *Oil price*.

We estimate our benchmark (2) model based on the selection of the empirically validated control hours. To provide robustness checks for the benchmark model, we estimate the models for different sets of control groups. Furthermore, we utilize the meta-analysis data set of Havranek *et al.* (2018), as well as their Bayesian model averaging results from the meta-regression analysis and their specification of the best-practice study design in the DST literature, to create a synthetic study tailored for Slovakia. Although this estimate is expected to have relatively large confidence intervals, it has significant informational value and can provide further support to the validity of our benchmark model results.

Previous research noted that the DST effect is not constant throughout the day (Mirza & Bergland, 2011; Karasu, 2010; Verdejo *et al.*, 2016). Some studies, such as Kellogg & Wolff (2008), suggest that the evening energy savings might be offset by increased morning consumption. To analyze the effect of DST on peak power demand, the following model was constructed:

$$\begin{aligned} \log(Consumption)_{hd} = & \beta_0 + \beta_1 DST_{hd} + \beta_2 Treatment_{hd} + \\ & + \gamma' Hours * (DST * Treatment, Temperature)_{hd} + \\ & + \delta' Weather\ variables_{hd} + \\ & + \phi' (Cyclicality, Holidays, Weekend, Seasonality)_{hd} + \\ & + \epsilon' Price\ variables_{hd} + u_{hd}, \end{aligned} \quad (3)$$

where $\gamma'_{DST} Hours * DST_{hd} * Treatment_{hd}$ is representation of $\gamma^1_{DST}(hour_1 * DST_{hd} * Treatment_{hd}) + \gamma^2_{DST}(hour_2 * DST_{hd} * Treatment_{hd}) + \dots + \gamma^{24}_{DST}(hour_{24} * DST_{hd} * Treatment_{hd})$ and varia-

bles $hour_1, \dots, hour_{24}$ are dummy variables for each hour of the day. The definition of variable $\gamma'_{Temp} Hours * Temperature_{hd}$ follows the same logic and represents the interactions between the temperature and the dummy variables for an hour. The rest of the variables follow (2). To avoid loosing too many degrees of freedom, and given that temperature is generally considered to be one of the most important explanatory variables in DST models, we do not include interactions of hours with explanatory variables other than *Temperature*.

4 Results

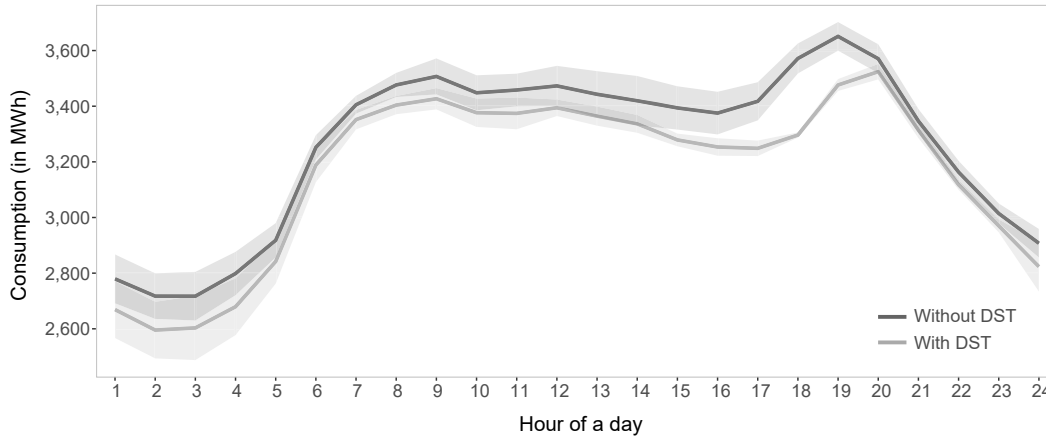
4.1 Visualization of consumption patterns

Before presenting the numerical estimates, we follow Belzer *et al.* (2008) and provide the visualization of changes in hourly patterns in consumption before and after the time shift. We compute the average consumption for each hour of a day for two different samples: consumption five days prior to the time shift and consumption five days after the time shift, both in March 2014 (since it is a data sample with no holidays around the time shift). Figure 2 presents the variation in consumption throughout the hours of the day with two peaks, one in the morning hours and one in the evening hours. The morning peak remains approximately the same for both data samples at 9 AM, while the evening peak shifts after the DST transition from 7 PM to 8 PM.

This result corresponds to an intuitive notion: because people wake up with an alarm clock at the same time and have the same morning routine, the morning peak occurs at approximately the same time, regardless of the DST policy. By contrast, the shift in the evening hours corresponds to the logic that adding additional hour of natural light shifts evening consumption by an hour. The direction of the consumption change in Figure 2 suggests a decrease in consumption after the time shift. Moreover, the difference in consumption after the time shift is smaller in the morning and in the late evening hours and the largest in the early evening hours. A similar pattern is observed for other investigated years (except those where the analyzed sample includes holidays). During the Autumn time shift, the opposite pattern is observed.

Even more revealing is Figure 3, which visualizes the pattern of electricity consumption by means of the ratio of hourly electricity consumption to the average consumption during the control hours of 12 AM to 2 PM and 12 PM to 2 AM (here, we follow Mirza & Bergland, 2011).

Figure 2: Largest difference in consumption before and after the DST change probably occurs in the evening hours



Notes: The lighter line represents the average consumption during the five days following the transition in March 2014. The darker line represents the average consumption during the five days prior to the transition in March 2014. Shaded areas represent the 95% confidence intervals.

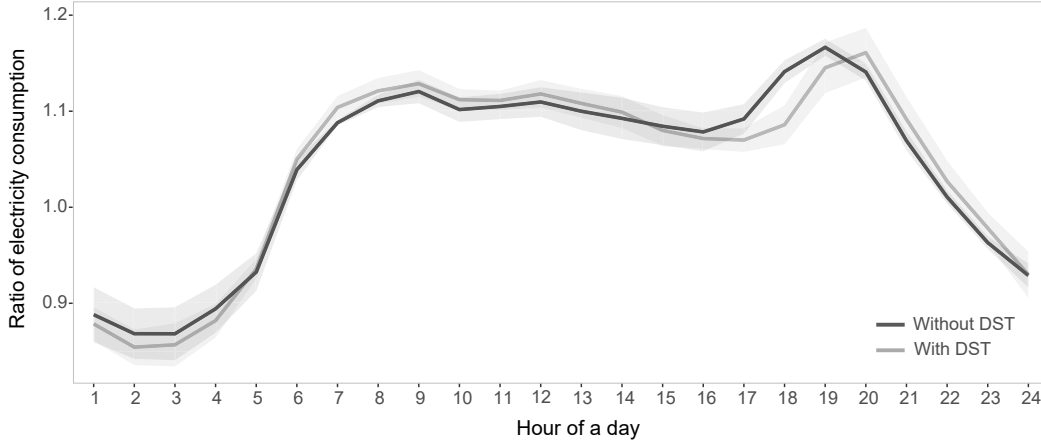
One clear pattern is increased morning consumption after the shift, possibly because throughout the darker mornings after the shift, people still need artificial light (Kotchen & Grant, 2011; Momani *et al.*, 2009). On the other hand, the decrease in consumption during the early evening hours is followed by an increase later in the evening (consistent with findings of, for example, Karasu, 2010).

Figure 3 also shows a small increase in consumption during midday hours. During the midnight hours and early morning hours, however, a decrease in consumption is observed, which indicates that using midnight hours as a control group might underestimate the DST effect, whereas using midday hours might overestimate the effect. Conclusions drawn solely from Figure 2 and Figure 3, however, might be misleading because these figures do not account for other important factors that influence consumption. In our analysis, we use three groups of control hours to account for possible biases: both midday and midnight hours, midday hours only, and midnight hours only. Still, we will have to test for the validity of these hours.

4.2 Analysis and Discussion

The first step in our analysis is to assess the validity of the chosen model and control hours. Given our model suffers from both heteroskedasticity and serial correlation, we use heteroskedasticity and serial correlation robust standard errors with a lag of 24 (Verbeek, 2008; Mirza &

Figure 3: During natural daylight hours, the DST policy might have slightly increased electricity consumption



Notes: The lighter line represents the ratio of hourly consumption to the mean consumption during the control hours averaged throughout the five days following the transition in March 2014. The darker line presents the same ratio based on the data of five days after the transition in March 2014. We consider the control group of midday hours (from 12 AM to 2 PM) and midnight hours (from 12 PM to 2 AM). Shaded areas represent 95% confidence intervals.

Bergland, 2011). Second, given that the stationarity assumption does not hold for the variable *Oil price*, we drop the variable to avoid spurious regression. To test for validity of the selected control hours, 24 regressions (one regression for every hour) are constructed adjusting (2) into the daily data form

$$\begin{aligned} \log(\text{Consumption})_d = & \beta_0 + \beta_1 \text{DST}_d + \beta_2 \text{Temperature}_d + \beta_3 \text{Temperature squared}_d + \\ & + \beta_4 \text{Electricity price}_d + \delta' \text{Weather variables}_d + \\ & + \phi'(\text{Cyclicality}, \text{Holidays}, \text{Weekend}, \text{Seasonality})_d + u_d, \end{aligned}$$

to estimate the coefficient β_1 of the DST variable. Table 7 provides an overview for hours where the coefficient of DST was statistically insignificant, including those hours that we originally considered for a control group. The results suggest that in our data sample, DST does not affect the hours of 11 AM to 1 PM, and we use these hours as the control group in our benchmark model specification of (2). Nevertheless, as a robustness check, we estimate the model for other control groups commonly appearing in the literature: 1) group of standard control hours from 12 PM to 2 AM and from 12 AM to 2 PM, 2) group of control hours from 12 PM to 2 AM, and 3) group of control hours from 12 AM to 2 PM.

Overall DST effect from the difference-in-differences analysis. The results of our benchmark model using control hours from 11 AM to 1 PM can be found in Table 3. The estimates of the DST effect (coefficient of the variable $DST*Treatment$) suggest a decrease in electricity consumption in Slovakia of between 1.3% and 1.6%, depending on how the relationship between temperature and consumption is modeled. These results are fairly consistent with the estimates from Bergland & Mirza (2017), which suggest a reduction in consumption due to DST of approximately 1%. Apart from the effect of DST policy on consumption, a few other relationships should be discussed. The coefficient of the variable $Treatment$ suggests that during our chosen control hours, consumption is lower, regardless of the DST policy (largely because the peaks in electricity consumption occur in the morning and in the evening).

Deviations from the base temperature (*Heating* and *Cooling degrees*) increase consumption, which, as Kellogg & Wolff (2008) state, is consistent with the effects of heating (when the temperature is below 18 degrees Celsius) and air-conditioning (when the temperature is above 18 degrees Celsius). Kotchen & Grant (2011) find the change in consumption greater for cooling than heating in Indiana, which is in contradiction to what we found for the Slovak data set—air-conditioning is less widespread in Slovakia and draws less electricity than heating, which is heavily used during the colder months. Moreover, the corresponding sign of the variables *Heating* and *Cooling degrees* suggests a U-shaped relationship between temperature and consumption, corroborating the evidence from the opposite signs of *Temperature* and *Temperature squared*. In addition, these results suggest that increasing the base temperature in Slovakia would also increase the savings from DST policy.

The variables capturing general weather conditions (including temperature) are mostly statistically significant, and the direction of the estimated weather effects remains in line with intuition. An increase in the length of daylight in a single hour decreases electricity consumption, which is reflected in the negative coefficient of *Sunlight*, a result compatible with many studies, including Kellogg & Wolff (2008), Hancevic & Margulis (2016) and Choi *et al.* (2017). We report a similar trend for *Air Pressure*, corroborating the results of Hancevic & Margulis (2016), who also find a significantly negative but rather small effect on electricity consumption. *Humidity* does not play a crucial role in explaining energy consumption in Slovakia or has rather negative effect, which could be due to the fact that higher air humidity in Slovakia is also

Table 3: Results of the benchmark model (2) using control hours from 11 AM to 1 PM

Variable	Benchmark using <i>Temperature squared</i>	Robust. check using <i>Cooling/Heating degrees</i>
Constant	8.227*** (0.016)	8.180*** (0.016)
<i>DST</i>	-0.017*** (0.002)	-0.012*** (0.002)
<i>Treatment</i>	-0.134*** (0.001)	-0.133*** (0.001)
DST * Treatment	-0.0127*** (0.001)	-0.0156*** (0.001)
<i>Temperature variables</i>		
Temperature	-0.005*** (0.0001)	
Temperature squared	0.0001*** (0.00000)	
Heating degrees		0.004*** (0.0001)
Cooling degrees		0.002*** (0.0001)
<i>Weather variables</i>		
Humidity	0.00003 (0.00002)	-0.0001*** (0.00002)
Air pressure	-0.0001*** (0.00001)	-0.0001*** (0.00001)
Sunlight	-0.001*** (0.00002)	-0.001*** (0.00002)
Precipitation	0.003*** (0.001)	0.003*** (0.001)
Radiation	0.0001*** (0.00001)	0.00004*** (0.00001)
<i>Price variable</i>		
Electricity Price	0.002*** (0.00001)	0.002*** (0.00001)
<i>Cyclicality</i>		
<i>Cyclicality</i>	-0.00001*** (0.00000)	-0.00001*** (0.00000)
<i>Holidays</i>		
<i>Holidays</i>	-0.068*** (0.001)	-0.068*** (0.001)
<i>Weekend</i>		
<i>Weekend</i>	-0.077*** (0.0004)	-0.077*** (0.0004)
<i>Seasonality</i>		
Summer	-0.008*** (0.001)	-0.006*** (0.001)
January	0.084*** (0.002)	0.079*** (0.002)
February	0.097*** (0.002)	0.090*** (0.002)
March	0.082*** (0.002)	0.073*** (0.002)
April	0.042*** (0.001)	0.034*** (0.001)
May	0.017*** (0.001)	0.015*** (0.001)
June	0.017*** (0.001)	0.017*** (0.001)
July	0.004*** (0.001)	0.004*** (0.001)
September	0.027*** (0.001)	0.026*** (0.001)
October	0.060*** (0.001)	0.052*** (0.001)
November	0.067*** (0.002)	0.059*** (0.002)
December	0.074*** (0.002)	0.066*** (0.002)
Year 2010	-0.067***	-0.068***

Continued on next page

Table 3 – *Continued from previous page*

Variable	Benchmark using <i>Temperature squared</i>	Robust. check using <i>Cooling/Heating degrees</i>
	(0.001)	(0.001)
Year 2011	−0.070***	−0.072***
	(0.001)	(0.001)
Year 2012	−0.056***	−0.057***
	(0.001)	(0.001)
Year 2013	−0.046***	−0.049***
	(0.001)	(0.001)
Year 2014	−0.058***	−0.060***
	(0.001)	(0.001)
Year 2015	−0.030***	−0.033***
	(0.001)	(0.001)
Year 2016	−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)
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)
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***

Notes: The table presents the results of difference-in-differences regression of the benchmark model (2). Standard errors in parentheses. *p<0.1; **p<0.05; ***p<0.01.

Table 4: Selecting the correct group of control hours matters

	Benchmark using <i>Temperature squared</i>	Robust. check using <i>Cooling/Heating degrees</i>
Benchmark group (hours 11, 12, 13)	-0.0127	-0.0156
Control group 1 (hours 12, 13, 14)	-0.0137	-0.0165
Control group 2 (hours 24, 1, 2)	-0.0080	-0.0066
Control groups 1 & 2	-0.0118	-0.0126

Notes: This table summarizes the overall DST effect estimates using different control hour groups and temperature specifications. The “Benchmark group (hours 11, 12, 13)” is identical to the coefficients of variable $DST * Treatment$ reported in Table 3. Negative coefficients represent energy consumption savings as a result of the DST policy. All reported coefficients are statistically significant at the 1% level.

associated with lower temperatures (an argument already used by Choi *et al.*, 2017). The remaining weather variables, *Precipitation* and *Radiation*, appear to have a positive effect on consumption—increasing precipitation could bring colder temperatures and therefore increase the necessity of heating. The intensity of sunshine is also at its highest in more extreme temperatures, corroborating the story of a positive effect on consumption, as well as a U-shaped relationship between temperature and consumption. Other important effects are related to *Seasonality* and non-working days.

Electricity consumption on *Holidays* and *Weekends* is lower, consistent with Kellogg & Wolff (2007) and Kandel (2007). It follows that during non-working days, people sleep longer and the morning increase in demand is mitigated by fewer morning activities. We also find that electricity consumption is reduced during summer (coefficient *Summer* is negative), and the DST policy is believed to play a role here: in the morning, the sun rises early enough for people to wake up in natural daylight, while in the evening, an extra hour of sunlight is provided. As soon as there are no early morning benefits, as happens when DST is prolonged to early spring or later autumn months, the argument loses its power (Kellogg & Wolff, 2008). Similar reasoning applies to the coefficient of *DST*, which is active mostly during the summer: the coefficient represents the percentage difference in electricity consumption between the period of active and non-active DST policy use. The coefficient *Electricity Price* suggests positive price semi-elasticity of consumption. However, it is most likely the result of endogeneity as the price is set to be highest during the peak of electricity consumption.

Previous studies using the “equivalent day normalization technique” on electricity consumption used the same set of control hours that, by common sense, should be unaffected by DST

Table 5: Based on Havranek *et al.* (2018), the DST effect in Slovakia is small and close to the European average

	Mean	95% conf. int.	
Slovakia	-0.00084	-0.00846	0.00677
European Union	-0.00083	-0.00845	0.00679

Notes: The table presents the mean estimates of the DST effect implied by Bayesian model averaging and the best practice defined by Havranek *et al.* (2018). Negative estimates represent savings because of the DST policy. The estimate for Europe is a consumption-weighted average of individual countries' savings. The confidence intervals are approximate and constructed using the standard errors estimated by OLS.

policy. As a robustness check, we show in Table 4 how the different sets of control hours and different approaches to capturing the effects of temperature could affect the estimated savings. It can be observed that using the midday hours as the control group slightly overestimates the reduction in consumption. On the other hand, if midnight hours serve as the control group, the results are underestimated. As Havranek *et al.* (2018) suggest, the estimated effect is sensitive to the study design and estimation method.

Overall DST effect using Havranek *et al.* (2018) synthetic estimate. To confront the empirical estimates of Table 4, we use the study of Havranek *et al.* (2018): we replicate their best-practice approach to estimate the DST effect based on the literature covering the last 40 years of research. The data set in Havranek *et al.* (2018) codes 162 independent estimates of the DST effect, their statistical measures of precision, and different aspects of study design, including method and publication characteristics. To show a systematic dependence between the DST effects and study design, the authors use the state-of-the-art techniques to estimate the meta-regression, taking into account the publication bias often present in the economic literature (Havranek *et al.*, 2012). We take the results of this estimation (posterior means from the Bayesian Model Averaging model of Havranek *et al.*, 2018, from Table 5 on p. 49) and the best-practice specification of Havranek *et al.* (2018) to remain consistent with their estimates.

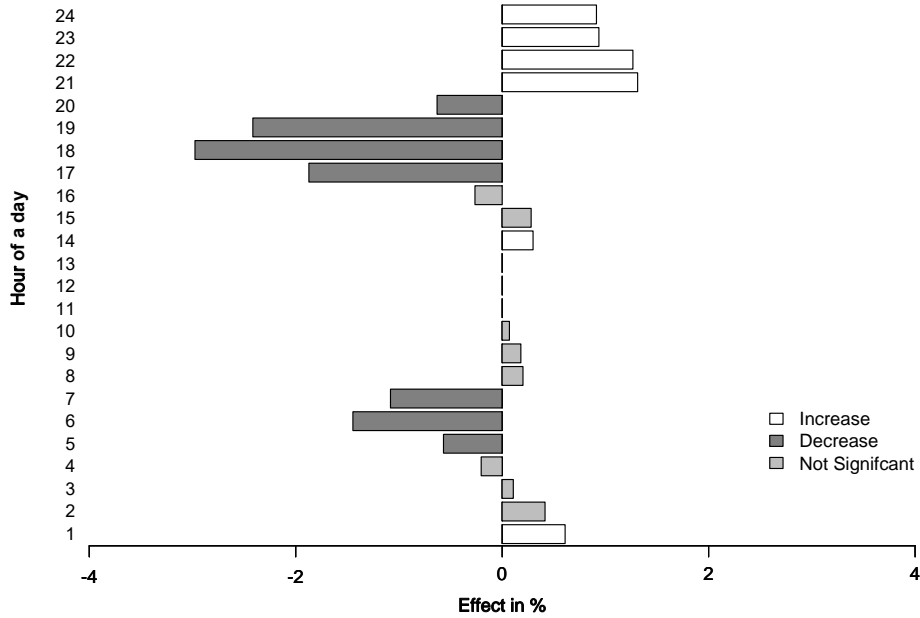
The best-practice approach, according to Havranek *et al.* (2018), is based on the difference-in-differences method of estimation covering large data sets and the latest highly cited studies published in the best journals. Furthermore, this approach considers latitudinal effects to account for geographical variation between countries of interest. To compare the results of this exercise with those of Bergland & Mirza (2017), we construct the synthetic estimates for Slovakia and the European average. The results can be found in Table 5: the Slovak estimate

of -0.084% is the percentage of total electricity consumption on days when DST is applied. In Slovakia, DST is valid for 210 days; thus, the yearly DST effect on electricity consumption amounts to $-0.084\% * 210/365$, which is hardly 0.05% of energy savings in terms of yearly electricity consumption. More importantly, the possible savings from DST are unlikely to exceed $-0.846\% * 210/365$, amounting to approximately 0.5% of yearly electricity consumption. This best-practice estimate is even smaller than what we (in Table 4) or Bergland & Mirza (2017) found. Nevertheless, some researchers (such as Hancevic & Margulis, 2016) argue that the efficiency of power supply meeting demand should be investigated on an hourly basis.

Hourly DST effects using difference-in-differences. Several studies (Kellogg & Wolff, 2008; Kotchen & Grant, 2011; Bergland & Mirza, 2017) discuss the effects of DST policy on peak demand and the commonly occurring hourly trade-offs between the positive and negative consumption changes due to DST policy throughout the day. Choi *et al.* (2017) and Kellogg & Wolff (2008) find that the evening savings are offset by the morning increase in consumption, leading to an overall non-significant effect. Kotchen & Grant (2011) show that the increase in morning consumption exceeds any savings and that the overall DST effect is an increase in consumption. The policy impact becomes especially important when no production capacity is available to meet the increased peak demand. Given that Slovakia has large generating capacity, the policy effects should not create additional installation expenses but could result in lower generation costs. Figure 3 indicates a reduction in peak electricity consumption during the morning and evening hours after the policy change but also an increase in electricity consumption during the rest of the day.

The estimation of (3) in Table 8 corresponds to such policy impacts: the largest energy savings occur during evening peak hours from 5PM to 8PM and range from 0.6% to almost 3% of hourly consumption. Another peak occurs in the morning from 5AM to 7AM and ranges between 0.5% and 1.5% savings. Similar patterns are observed in previous studies; see, for example, Mirza & Bergland (2011) and Verdejo *et al.* (2016). On the other hand, an increase in electricity demand occurs at night between 9PM and 12PM, and the cost reaches 1.3% of electricity consumption. The early morning hours bring small changes in the magnitude of the effect and are statistically insignificant. The summary of the DST impact of individual hours can be found in Figure 4.

Figure 4: DST policy results in electricity savings during both the morning and evening peak demand



Notes: The figure shows the distribution of the DST effect on electricity consumption throughout the day.

Table 6: Financial savings from reduced household consumption

Year	Reduction [GWh]	Price [EUR/MWh]	Financial Benefits [million EUR]
2010	115 - 172	15.23	1.7 - 2.6
2011	132 - 198	16.43	2.2 - 3.2
2012	132 - 198	16.66	2.2 - 3.3
2013	128 - 193	16.63	2.1 - 3.2
2014	127 - 191	13.84	1.8 - 2.6
2015	130 - 196	13.97	1.8 - 2.7
2016	137 - 206	14.21	1.9 - 2.9

Notes: The table presents a valuation for the DST estimate of our benchmark model in Table 3, 1.27%, and the synthetic best-practice estimate implied by Havranek *et al.* (2018), 0.85%. Volumes retrieved from ENTSO-E (2017), price data retrieved from Eurostat (2019).

Our benchmark model indicates that the DST effect on electricity consumption in Slovakia reaches 1.3% (Table 3), while the synthetic estimate based on the study of Havranek *et al.* (2018) indicates an effect of no more than 0.85% for the period when the DST policy is active. In Table 6, we estimate the welfare effect stemming from decreased consumption due to DST based on these two estimates. We use ENTSO-E (2017) data to estimate the portion of electricity consumption saved and the yearly residential electricity prices (retrieved from Eurostat, 2019) for the period of 2010–2016. Although the assumption that the energy savings are created only for households is strong, we want to show the maximum possible savings. This price includes the production costs of electricity, network costs, taxes and levies. The valuation of Table 6 shows savings between 100 GWh and 200 GWh, which translates between EUR 1.7M and EUR 3.3M of financial benefit. Since a common Slovak household annually consumes approximately 20 MWh (SPP, 2017), the energy savings could be compared to the total energy consumption of 5,000 to 10,000 households per year.

5 Conclusion

The daylight saving time policy in Europe was originally introduced for the purpose of energy savings. Recent academic evidence, such as Hill *et al.* (2010), Bergland & Mirza (2017), and Havranek *et al.* (2018), suggests the unified policy across the European Union has different impacts on the electricity consumption of its member states. This paper provides the first comprehensive analysis of the DST effects on electricity consumption in Slovakia. Using 2010–2017 hourly electricity load data and accounting for different weather conditions, macro variables, annual cycle and seasonality, we show that the policy does affect electricity consumption in Slovakia to some extent. The magnitude of this effect indicated by the difference-in-differences analysis using a proxy control group appears to be relatively high, around 0.8% of yearly electricity consumption. The magnitude decreases, however, to a level close to zero when we built a synthetic best-practice estimate from a meta-analysis (applying Havranek *et al.*, 2018, methodology); the best-practice also suggests that the estimate is unlikely to exceed 0.5% of yearly electricity consumption.

We also observe that the DST effect varies throughout the day. The decrease in demand for electricity due to the policy occurs mostly during the early morning hours and early evening

hours, amounting to, during some hours, almost 3% of electricity consumption when the policy is applied. The forenoon hours tend to be impacted the least, while the largest costs due to the policy are observed before midnight, reaching 1.3% of consumption when the policy is applied. The DST policy decreases peak consumption during the early morning and early evening hours and does not present any additional constraint on generating capacity. One positive effect of the policy is thus redistributing consumption more evenly during the day. The overall annual effect of 0.5%–0.8% of savings on electricity consumption corresponds to the total annual energy consumption of approximately 5,000 to 10,000 Slovak households.

There are, however, other aspects of the DST policy, besides those related to energy, that should be considered in a policy evaluation. Most of the DST literature researches the effects of changes in lighting, the effects of sleep deprivation, or both. Especially in recent years, various impacts have been thoroughly investigated: a large pool of studies has been dedicated to health issues, such as the risk of acute myocardial infarction (Manfredini *et al.*, 2019), ischemic stroke (Sipila *et al.*, 2016), psychiatric illness (Shapiro *et al.*, 1990), suicide (Berk *et al.*, 2008), and spontaneous delivery (Laszlo *et al.*, 2016), in addition to general life satisfaction (Kuehnle & Wunder, 2016), recreational evening activities (Wolff & Makino, 2012; Goodman *et al.*, 2014), and self-reported health and human capital (Jin & Ziebarth, 2016).

Researchers have also found an effect of DST on behavior and performance (of both humans and animals), such as criminal incidence (Doleac & Sanders, 2015), aggressive assaults (Umbach *et al.*, 2017), milk production (Niu *et al.*, 2014), stock market returns and volatility (Kamstra *et al.*, 2000), cyberloafing (Wagner *et al.*, 2012), cognitive performance and risk-taking behavior (Schaffner *et al.*, 2018), student performance (Herber *et al.*, 2017), laboratory mix-ups (Ehlers *et al.*, 2018) and police harassment (Wagner *et al.*, 2016). The remaining pool of studies considers road and work safety, including road lighting conditions (Bunnings & Schiele, 2018), fatal vehicle crashes (Smith, 2016), work and traffic accidents (Robb & Barnes, 2018), construction injuries (Holland & Hinze, 2000), and even animal road kill (Ellis *et al.*, 2016). The disruption of the circadian rhythm persists up to a few days (Kantermann *et al.*, 2007), so short-term effects are likely more significant than long-term effects. The magnitude and direction of these effects is, however, often inconclusive and, to the best of our knowledge, not yet evaluated for the specific case of the Slovak Republic.

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A Appendix

Table 7: Validity of control hours

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

Notes: The table presents a validation test for the correct group of control hours (insignificance indicates that the hour is not affected by the DST policy). To account for potential heteroskedasticity and serial correlation, we follow Verbeek (2008) and use heteroskedasticity and autocorrelation consistent (HAC) standard errors (SE) with 24 lags. *p<0.1; **p<0.05; ***p<0.01.

Table 8: Hourly DST effects using different groups of control hours

Variable	Benchmark control hours	Control hours	Control hours	Control hours
	11, 12, 13	24, 1, 2, 12, 13, 14	12, 13, 14	24, 1, 2
Constant	8.229*** (0.051)	8.158*** (0.053)	8.229*** (0.051)	8.107*** (0.051)
<i>DST</i>	-0.027*** (0.005)	-0.028*** (0.005)	-0.026*** (0.005)	-0.021*** (0.005)
<i>Treatment</i>	-0.123*** (0.002)	-0.018*** (0.001)	-0.123*** (0.002)	0.122*** (0.002)
DST * Treatment * Hour 1	0.0061** (0.003)		0.005* (0.003)	
DST * Treatment * Hour 2	0.0042 (0.003)		0.003 (0.003)	
DST * Treatment * Hour 3	0.0011 (0.003)	0.003 (0.002)	-0.0003 (0.003)	-0.005*** (0.002)
DST * Treatment * Hour 4	-0.002 (0.003)	-0.0002 (0.002)	-0.003 (0.003)	-0.008*** (0.002)
DST * Treatment * Hour 5	-0.0056** (0.003)	-0.004** (0.002)	-0.007*** (0.003)	-0.012*** (0.002)
DST * Treatment * Hour 6	-0.0145*** (0.003)	-0.013*** (0.002)	-0.016*** (0.003)	-0.021*** (0.002)
DST * Treatment * Hour 7	-0.0108*** (0.003)	-0.009*** (0.003)	-0.012*** (0.003)	-0.017*** (0.003)
DST * Treatment * Hour 8	0.002 (0.003)	0.003 (0.003)	0.001 (0.003)	-0.004 (0.003)
DST * Treatment * Hour 9	0.0018 (0.002)	0.002 (0.002)	0.0005 (0.002)	-0.005* (0.003)
DST * Treatment * Hour 10	0.0007 (0.001)	0.001 (0.002)	-0.001 (0.002)	-0.006** (0.002)
DST * Treatment * Hour 11		-0.0001 (0.002)	-0.002* (0.001)	-0.007*** (0.002)
DST * Treatment * Hour 12				-0.008*** (0.002)
DST * Treatment * Hour 13				-0.003 (0.002)
DST * Treatment * Hour 14	0.00299* (0.002)			-0.003 (0.003)

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Variable	Benchmark control hours 11, 12, 13	Control hours 24, 1, 2, 12, 13, 14	Control hours 12, 13, 14	Control hours 24, 1, 2
DST * Treatment * Hour 15	0.0028 (0.002)	0.005*** (0.002)	0.001 (0.002)	−0.004 (0.003)
DST * Treatment * Hour 16	−0.0026 (0.002)	−0.001 (0.002)	−0.004** (0.002)	−0.009*** (0.003)
DST * Treatment * Hour 17	−0.0187*** (0.002)	−0.017*** (0.002)	−0.020*** (0.002)	−0.025*** (0.003)
DST * Treatment * Hour 18	−0.0298*** (0.003)	−0.028*** (0.002)	−0.031*** (0.002)	−0.036*** (0.003)
DST * Treatment * Hour 19	−0.0242*** (0.003)	−0.022*** (0.002)	−0.025*** (0.002)	−0.031*** (0.003)
DST * Treatment * Hour 20	−0.0063*** (0.002)	−0.005** (0.002)	−0.008*** (0.002)	−0.013*** (0.002)
DST * Treatment * Hour 21	0.0131*** (0.002)	0.014*** (0.002)	0.012*** (0.002)	0.007*** (0.002)
DST * Treatment * Hour 22	0.0127*** (0.002)	0.014*** (0.001)	0.011*** (0.002)	0.006*** (0.001)
DST * Treatment * Hour 23	0.0094*** (0.002)	0.011*** (0.001)	0.008*** (0.002)	0.003** (0.001)
DST * Treatment * Hour 24	0.0091*** (0.002)		0.008*** (0.002)	
<i>Weather variables</i>				
Humidity	−0.0002*** (0.0001)	−0.0002*** (0.0001)	−0.0002*** (0.0001)	−0.0002*** (0.0001)
Air pressure	−0.00004 (0.00004)	−0.0001 (0.00005)	−0.00004 (0.00004)	−0.00004 (0.00004)
Sunlight	−0.0004*** (0.00004)	−0.0003*** (0.00004)	−0.0004*** (0.00004)	−0.0004*** (0.00004)
Precipitation	0.003*** (0.001)	0.004*** (0.001)	0.003*** (0.001)	0.003*** (0.001)
Radiation	−0.00002 (0.00002)	0.00000 (0.00002)	−0.00002 (0.00002)	−0.00002 (0.00002)
<i>Price variable</i>				
Electricity price	0.002*** (0.0001)	0.002*** (0.0001)	0.002*** (0.0001)	0.002*** (0.0001)
<i>Cyclicity</i>				
	−0.00001** (0.00001)	−0.00001 (0.00001)	−0.00001** (0.00001)	−0.00001** (0.00001)
<i>Weekend</i>				
	−0.076*** (0.002)	−0.074*** (0.002)	−0.076*** (0.002)	−0.076*** (0.002)
<i>Holidays</i>				
	−0.066*** (0.005)	−0.065*** (0.005)	−0.066*** (0.005)	−0.066*** (0.005)
<i>Seasonality</i>				
Summer	−0.004 (0.003)	−0.004* (0.003)	−0.004 (0.003)	−0.004 (0.003)
January	0.085*** (0.007)	0.088*** (0.007)	0.085*** (0.007)	0.085*** (0.007)
February	0.092*** (0.007)	0.095*** (0.007)	0.092*** (0.007)	0.092*** (0.007)
March	0.067*** (0.006)	0.069*** (0.006)	0.067*** (0.006)	0.067*** (0.006)
April	0.027*** (0.004)	0.028*** (0.004)	0.027*** (0.004)	0.027*** (0.004)
May	0.008** (0.004)	0.009** (0.004)	0.008** (0.004)	0.008** (0.004)
June	0.015*** (0.003)	0.015*** (0.003)	0.015*** (0.003)	0.015*** (0.003)
July	0.005 (0.003)	0.004 (0.003)	0.005 (0.003)	0.005 (0.003)
September	0.018*** (0.003)	0.019*** (0.003)	0.018*** (0.003)	0.018*** (0.003)
October	0.048*** (0.004)	0.050*** (0.004)	0.048*** (0.004)	0.048*** (0.004)
November	0.056*** (0.007)	0.059*** (0.007)	0.056*** (0.007)	0.056*** (0.007)
December	0.071***	0.075***	0.071***	0.071***

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Table 8 – Continued from previous page

Variable	Benchmark control hours 11, 12, 13	Control hours 24, 1, 2, 12, 13, 14	Control hours 12, 13, 14	Control hours 24, 1, 2
Year 2010	(0.008) –0.069*** (0.003)	(0.008) –0.069*** (0.003)	(0.008) –0.069*** (0.003)	(0.008) –0.069*** (0.003)
Year 2011	–0.074*** (0.003)	–0.074*** (0.003)	–0.074*** (0.003)	–0.074*** (0.003)
Year 2012	–0.058*** (0.003)	–0.058*** (0.003)	–0.058*** (0.003)	–0.058*** (0.003)
Year 2013	–0.049*** (0.003)	–0.048*** (0.003)	–0.049*** (0.003)	–0.049*** (0.003)
Year 2014	–0.062*** (0.003)	–0.061*** (0.003)	–0.062*** (0.003)	–0.062*** (0.003)
Year 2015	–0.033*** (0.003)	–0.031*** (0.003)	–0.033*** (0.003)	–0.033*** (0.003)
Year 2016	–0.014*** (0.003)	–0.012*** (0.003)	–0.014*** (0.003)	–0.014*** (0.003)
Hour 1	–0.029*** (0.001)	–0.077*** (0.001)	–0.029*** (0.001)	–0.029*** (0.001)
Hour 2	–0.063*** (0.001)	–0.111*** (0.001)	–0.063*** (0.001)	–0.064*** (0.001)
Hour 3	–0.081*** (0.001)	–0.112*** (0.001)	–0.081*** (0.001)	–0.203*** (0.002)
Hour 4	–0.078*** (0.001)	–0.109*** (0.001)	–0.078*** (0.001)	–0.201*** (0.002)
Hour 5	–0.061*** (0.001)	–0.092*** (0.001)	–0.061*** (0.001)	–0.183*** (0.002)
Hour 6	–0.028*** (0.001)	–0.059*** (0.001)	–0.028*** (0.001)	–0.150*** (0.002)
Hour 7	0.042*** (0.002)	0.009*** (0.002)	0.042*** (0.002)	–0.080*** (0.002)
Hour 8	0.068*** (0.002)	0.034*** (0.002)	0.068*** (0.002)	–0.055*** (0.002)
Hour 9	0.099*** (0.002)	0.064*** (0.002)	0.099*** (0.002)	–0.024*** (0.001)
Hour 10	0.125*** (0.002)	0.089*** (0.002)	0.125*** (0.002)	0.002** (0.001)
Hour 11	0.007*** (0.001)	0.093*** (0.002)	0.130*** (0.002)	0.007*** (0.001)
Hour 12	0.010*** (0.001)	0.078*** (0.001)	0.010*** (0.001)	0.010*** (0.001)
Hour 14	0.119*** (0.002)	0.065*** (0.001)	–0.003*** (0.001)	–0.003*** (0.001)
Hour 15	0.109*** (0.002)	0.073*** (0.002)	0.109*** (0.002)	–0.014*** (0.001)
Hour 16	0.105*** (0.002)	0.070*** (0.002)	0.105*** (0.002)	–0.017*** (0.001)
Hour 17	0.119*** (0.002)	0.084*** (0.002)	0.119*** (0.002)	–0.003*** (0.001)
Hour 18	0.125*** (0.002)	0.089*** (0.002)	0.125*** (0.002)	0.002 (0.001)
Hour 19	0.119*** (0.002)	0.084*** (0.002)	0.119*** (0.002)	–0.003** (0.002)
Hour 20	0.119*** (0.002)	0.084*** (0.002)	0.119*** (0.002)	–0.003** (0.001)
Hour 21	0.109*** (0.002)	0.075*** (0.001)	0.109*** (0.002)	–0.013*** (0.001)
Hour 22	0.073*** (0.001)	0.040*** (0.001)	0.073*** (0.001)	–0.049*** (0.001)
Hour 23	0.033*** (0.001)		0.033*** (0.001)	–0.090*** (0.002)
<i>Weather variables</i>				
Temperature * Hour 1	–0.004*** (0.0002)	–0.003*** (0.0002)	–0.004*** (0.0002)	–0.004*** (0.0002)
Temperature * Hour 2	–0.004*** (0.0002)	–0.003*** (0.0002)	–0.004*** (0.0002)	–0.004*** (0.0002)
Temperature * Hour 3	–0.004*** (0.0002)	–0.004*** (0.0002)	–0.004*** (0.0002)	–0.004*** (0.0002)

Continued on next page

Table 8 – *Continued from previous page*

Variable	Benchmark	Control	Control	Control
	control hours 11, 12, 13	hours 24, 1, 2, 12, 13, 14	hours 12, 13, 14	hours 24, 1, 2
Temperature * Hour 4	−0.004*** (0.0002)	−0.004*** (0.0002)	−0.004*** (0.0002)	−0.004*** (0.0002)
Temperature * Hour 5	−0.004*** (0.0002)	−0.004*** (0.0002)	−0.004*** (0.0002)	−0.004*** (0.0002)
Temperature * Hour 6	−0.005*** (0.0002)	−0.005*** (0.0002)	−0.005*** (0.0002)	−0.005*** (0.0002)
Temperature * Hour 7	−0.004*** (0.0003)	−0.004*** (0.0003)	−0.004*** (0.0003)	−0.004*** (0.0003)
Temperature * Hour 8	−0.003*** (0.0003)	−0.003*** (0.0003)	−0.003*** (0.0003)	−0.003*** (0.0003)
Temperature * Hour 9	−0.002*** (0.0002)	−0.002*** (0.0002)	−0.002*** (0.0002)	−0.002*** (0.0002)
Temperature * Hour 10	−0.002*** (0.0002)	−0.002*** (0.0002)	−0.002*** (0.0002)	−0.002*** (0.0002)
Temperature * Hour 11	−0.002*** (0.0002)	−0.002*** (0.0002)	−0.002*** (0.0002)	−0.002*** (0.0002)
Temperature * Hour 12	−0.002*** (0.0002)	−0.002*** (0.0002)	−0.002*** (0.0002)	−0.002*** (0.0002)
Temperature * Hour 13	−0.001*** (0.0002)	−0.001*** (0.0002)	−0.001*** (0.0002)	−0.001*** (0.0002)
Temperature * Hour 14	−0.001*** (0.0002)	−0.001*** (0.0002)	−0.001*** (0.0002)	−0.001*** (0.0002)
Temperature * Hour 15	−0.001*** (0.0002)	−0.001*** (0.0002)	−0.001*** (0.0002)	−0.001*** (0.0002)
Temperature * Hour 16	−0.002*** (0.0002)	−0.002*** (0.0002)	−0.002*** (0.0002)	−0.002*** (0.0002)
Temperature * Hour 17	−0.002*** (0.0002)	−0.002*** (0.0002)	−0.002*** (0.0002)	−0.002*** (0.0002)
Temperature * Hour 18	−0.002*** (0.0002)	−0.002*** (0.0002)	−0.002*** (0.0002)	−0.002*** (0.0002)
Temperature * Hour 19	−0.003*** (0.0002)	−0.003*** (0.0002)	−0.003*** (0.0002)	−0.003*** (0.0002)
Temperature * Hour 20	−0.003*** (0.0002)	−0.003*** (0.0002)	−0.003*** (0.0002)	−0.003*** (0.0002)
Temperature * Hour 21	−0.003*** (0.0002)	−0.003*** (0.0002)	−0.003*** (0.0002)	−0.003*** (0.0002)
Temperature * Hour 22	−0.003*** (0.0002)	−0.003*** (0.0002)	−0.003*** (0.0002)	−0.003*** (0.0002)
Temperature * Hour 23	−0.003*** (0.0002)	−0.003*** (0.0002)	−0.003*** (0.0002)	−0.003*** (0.0002)
Temperature * Hour 24	−0.003*** (0.0002)	−0.006*** (0.0002)	−0.003*** (0.0002)	−0.003*** (0.0002)
Observations	63,427	63,427	63,427	63,427

Notes: The table presents the results of difference-in-differences regression of the hourly demand model in (3). Standard errors in parentheses. *p<0.1; **p<0.05; ***p<0.01.

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