Interim Report:

The Energy Impact of Daylight Saving Time Implementation in Indiana

Indiana Fiscal Policy Institute

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Analysis Performed by Indiana Fiscal Policy Institute

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Introduction

Our investigation of Daylight Saving Time study was an effort to duplicate a California Energy Commission report entitled the Effects of Daylight Saving Time on California Electricity Use (http://www.house.gov/science/energy/may24/comm.htm). The model, used to estimate megawatt usage in California, was duplicated using similar Indiana data. In replicating the California model, we hoped to determine if their approach was useful in obtaining information on DST for Indiana.

The California Approach:

The California model relates the level of electricity usage with the time of day. The model estimates hourly electricity use for California by combining basic workday, employment, and weather data with complex temperature and lighting variables. The model contains 24 linear equations, one for each of the hours of the day and uses the Seeming Unrelated Regression (SUR) model. The SUR allows "the estimated relationship between the independent variables and energy use to change throughout the day while taking into account the correlation between energy use over the hours of the day."[1] The model assumes people respond to certain weather and lighting conditions due to the time of day. For instance, at 5pm people are beginning to leave work. Therefore, the model predicts that by changing clock time, one can change peak energy use and possibly lower overall energy consumption.

The energy savings in the model comes from two sources. The first is that more daylight in the evening keeps people outside and away from indoor activities that consume electricity. The model predicts this will be greater than the increase in electricity use in the morning as people spend less time at home before leaving for work. The second is that peak demand or when electricity is most expensive will be pushed back an hour where electricity is less in demand.

The California model was used to predict energy use for three scenarios, No Daylight Saving Time, Double Daylight Saving Time, and Winter Daylight Saving Time. In each, the California model predicted either peak or overall energy savings with DST with varying degrees of confidence.

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[1] "Effects of Daylight Saving Time on California Energy Use," California Energy Commission Draft Staff Report, May 2001.

California Model, Description of Data and Variables:

In the model, numerous variables are included in the equation. The collected data includes hourly electricity use in Megawatts, employment in non-agricultural jobs that month, humidity, precipitation, barometer pressure, wind speed, visibility, cloud cover, temperature variables, and lighting variables.

The temperature variable is broken down into several more complex variables to take into account the previous hours' and days' temperature. The previous hour's temperature variable is the weighted average of .45 times the temperature in the hour that includes the last half-hour of an electricity use hour, .45 times the temperature in the hour that includes the first half-hour, and .10 times the previous hour. The variable enters the equation in three forms: simple, quadratic, and cubic. The previous day's temperature variable takes into account the previous 3 days with 60 percent on one day lagged, 30 percent on two days lagged, and 10 percent on 3 days lagged. This variable is further separated into "hot," "cold," and "warm."[2]

As with the temperature variable, the lighting variable is broken down into separate variables. Percent twilight and percent light were included for certain cities (San Diego, San Francisco, and Crescent City) in California and are only included for morning (6-9am) and evening hours (5-10pm). In addition, 8 am data is replaced with averaged 7 to 9 am data, and 9 am data with 8 to 10 am data.

The structure and specification of the model and complexity of the variable definitions indicates the effort required by the California example. Given the inherent differences between Indiana and California in geography, climate, and other factors, we expected that exact duplication would likely not be productive. However, to maintain as much consistency as possible, we used, as a starting point for our analysis, the final California specification and variables. To that end, we began our research by obtaining, as much as possible, data in Indiana that was consistent with that used in California. At the same time, we recognized that, as we progressed in our analysis, refinement or modification of the variables might be necessary to produce useful output.

Indiana Model, Description of Data and Variables:

A. Data Obtained –
   - All data obtained covers three years 1998, 1999, and 2000.
   - We obtained hourly energy data, in Megawatts, from Cinergy served counties in Central Indiana. The sixty-nine counties are listed in Appendix A.
   - We gathered hourly weather variables from Huntingburg, Lafayette, and Indianapolis consisting of Temperature, Humidity, Barometer, Wind Speed, Cloud Cover, Visibility; and Precipitation every 6th hour.
   - Sunset/Sunrise and Twilight Begin/End times for Huntingburg, Lafayette, and Indianapolis were obtained for each day.

[2] Ibid.

- We obtained non-farm Indiana monthly employment, for the counties in question.

B. Format of the Data –

- As in the California approach, temperature, humidity, and barometer data were averaged for the three years of data for each hour.
- The temperature variable was further broken down into a basic variable and a separate variable that was based on the temperature of the three immediately preceding days. The basic temperature entered as three different variables (simple, quadratic, and cubic) taking into account the previous hour's temperatures while the separate temperature variable entered the model as one variable taking into account the previous day's temperature.

  Simple Temperature Variable:
  SmpTmp = (.90 * the current hour's temp + .10 * the previous hour's temperature)

  Quadratic Simple Temperature Variable:
  QTmp= (.90 * the current hour's temp + .10 * the previous hour's temperature)^2

  Cubic Simple Temperature:
  CubTmp = (.90 * the current hour's temp + .10 * the previous hour's temperature)^3

  Separate Temperature Variable:
  SepTmp = (.60 * the averaged temp 1 day lagged + .30 * averaged temperature 2 days lagged + .10 * averaged temp 3 days lagged)

- Lighting variables were broken down as percent of hour in light and percent of hour in twilight. The only hours included in the model were those observations in which a percentage of light or twilight existed. The morning hours included 6 to 9 am and the evening hours included 5 to 9 pm. As the California approach suggested, 8 a.m. data was replaced with averaged 7 to 9 a.m. data and 9 a.m. data with 8 to 10 a.m. data. In addition, the percent light and twilight variables were defined separately to account for the morning and evening hours.

  Percent Light:
  Morning = 1 – Percent Twilight
  Evening = ((Sunset Time – Current Hour) / 60) * 100

  Percent Twilight:
  Morning = ((Twilight Begin – Current Hour) / 60) * 100
  Evening = ((Twilight End – Current Hour) / 60) * 100

On certain days there was both light and twilight observed in the same hour of the morning or evening. In the morning this introduced no additional calculation as the formula states that anything past morning twilight is daylight. However, in the evening the percent twilight is observed from sunset until twilight end. Therefore, in order to capture percent twilight in those evening hours it was necessary to modify the formula.

Percent Twilight:

Evening = ((Twilight End – Sunset)/ 60) * 1000

- A Workday variable was used in order to differentiate between a workday and a weekend/holiday.

Estimating the Model of Electricity Consumption in Indiana:

Our model took the same form, Seemingly Unrelated Regressions (SUR), employed by California. As in California, the Indiana model is a system of 24 linear equations, one for each hour of the day.

California's model was of the general form[3]

Megawatt use = a constant (c) + *b**Employment + *b**(Workday) + *b**(Weather Variables) + *b**(Lighting Variables) + an error term (e)

For Indiana, we began by attempting to specify the model as closely to the California specification as possible. Our initial attempts included all of the variables for which we were able to obtain data. In addition, for the cases where we had data for the cities of Indianapolis, Lafayette, and Huntingburg, we included that data as well. In the first trials, our equation took the form of

Megawatts = c + *b**(Workday) + *b**(Employment) + *b* *(Temperature) + *b* *(Humidity) + *b* *(Barometric Pressure) + *b* *(Wind) + *b* *(Precipitation) + *b* *(Visibility) + *b* *(Cloud Cover) + *b* *(Sunrise) + *b* *(Sunset) + *b* *(Morning Twilight) + *b* *(Evening Twilight) + *e*

The weather variables – Temperature, Humidity, Barometric Pressure, Wind, Precipitation, Visibility, and Cloud Cover were included with specific values for each city. Our data included Sunrise, Sunset, and Twilight information for each city, as well, but because there was very little difference between the three cities, we averaged the light variables and used one value.

The initial results were not statistically encouraging. The explanatory value of the equation, measured by "r-squared" and "adjusted r-squared" was poor. In addition, many

[3] ibid.

of the variables were not statistically significant (low "T" statistics) and several appeared to affect megawatt consumption in contrast to what would be expected (wrong sign on the coefficient).

It was clear that a direct replication of the California approach would not produce similar or credible results. We used a systematic approach to identify variables that appeared to have little or no value in the equations. Some, like precipitation, included data that was suspect and the statistical results appeared to confirm our suspicions. Others, such as the city-specific weather variables, were not significant or inconsistent across the cities. We made adjustments to variable definition or variable inclusion by an iterative process to attempt to isolate those variables that should be excluded or redefined. Subsequent estimations (adjusted iterations) improved both the adjusted r-squared values and the T-statistics. In addition, there were fewer wrong signs.

The resulting model took the form

$$\text{Megawatts} = c + b*(\text{Workday}) + b*(\text{Employment}) + b*(\text{Temperature}) + b*(\text{Humidity}) + b*(\text{Barometric Pressure}) + b*(\text{Wind}) + b*(\text{Visibility}) + b*(\text{Sunrise}) + b*(\text{Sunset}) + b*(\text{Morning Twilight}) + b*(\text{Evening Twilight}) + e$$

The remaining weather variables are averaged across the three cities and do not include precipitation (questionable data) or cloud cover, which was insignificant and appeared to be strongly correlated with barometric pressure. That correlation is not surprising, intuitively, as high pressure normally brings clear skies and low pressure often brings storms and clouds. While Indiana is known for fast-changing weather, which means that temperatures and other weather conditions sometimes vary dramatically across the state, this did not appear to affect our averaging of the weather variables across the cities. Statistics improved for those variables after averaging.

It should be noted that California incorporated significant complexity into several of the variables, notably temperature and, to a lesser extent, lighting. Our analysis indicated that the geographic and climatic differences across the 850 mile long state of California were quite significant but Indiana is a much more homogeneous state, at least in terms of how geography and climate affect electricity use. Our approach was to replicate, where appropriate, the California model and variable definition, but recognizing and making adjustments for Indiana when the specification and statistics were improved.

The basic theoretical structure and analytical framework of our model is the same as California. Our assumptions (the same as California):

- That consumption behavior will not change – that is, that the relationship between consumption and the explanatory variables will be the same in the future.
- That workday schedules will not change due to DST, that is, if the workday ends at 5:00 PM currently, it will still end at 5:00 PM under DST.

- That the weather in the simulated year will be the average of the weather during 1998, 1999, and 2000.

Interpretation of the Estimation and the Simulation:

The detailed statistics of the SUR model are included in appendix B. Generally, adjusted r-squared values ranged from .70 to .82. The Workday, most of the Temperature, Barometric Pressure, and some of the Light Variables were generally significant. Wind and Visibility were insignificant in most equations. There were occasional inconsistent signs, particularly in the temperature and light variables. Interpretation of these results is difficult and analysis by other statistical experts would be appropriate and helpful. Nevertheless, our analysis indicated that the specification was adequate to perform a simulation of Daylight Saving Time.

Since California uses DST, their simulations are not directly applicable to Indiana. Likewise, a simulation of DST in Indiana would not necessarily be applicable to California. However, the basic assumptions about electricity use behavior patterns should hold in Indiana and we expected that an Indiana simulation, given California's results, would indicate the potential for reduced energy use.

Because of the limitations of our model, based on the statistical results discussed above, we did not expect statistically significant and definitive results. Rather, we expected that we would see a definite indication of a change in consumption patterns, specifically at the hour of sunset and twilight in the evening.

To simulate the effect of Daylight Saving Time in Indiana, we applied the hourly variable coefficient estimates for the weather and lighting variables for each hour to the variable values of one hour earlier. For the remainder of the variables, the coefficients and variable values for the applicable hour were used. In other words, since daylight saving time moves the clock one hour ahead, electricity consumption behavior will be, when it is 8:00 PM under DST, as if it were 7:00 PM under non-DST.

Our results are similar, although certainly not identical to or consistent with, California's. As Appendix C demonstrates, in Indiana, there appears to be a change in consumption over the day and, most noticeably, at the additional hour of daylight in the evening. However, our results are in contrast with California in that electricity consumption appears to be lower (in contrast with higher) during the morning hours and increases (in contrast with decreases) during that additional hour of daylight in the evening.

We have not performed hypothesis tests on the results. In addition, as discussed above, further examination of the SUR model specification is needed before additional analysis can be done. Therefore, these results are not definitive or conclusive. We cannot infer, from our work so far, that DST in Indiana would either increase or decrease electricity consumption.

Based upon our research and analysis to this point, we recommend further analysis of the effect of Daylight Saving Time be performed, incorporating expertise in the specific statistical analysis tool of Seemingly Unrelated Regression.

Appendix A

Cinergy Served Counties in Indiana

Bartholomew
Benton
Boone
Brown
Carroll
Cass
Clark
Clay
Clinton
Crawford
Daviess
Dearborn
Decatur
Delaware
Dubois
Fayette
Floyd
Fountain
Franklin
Fulton
Gibson
Grant
Greene
Hamilton
Hancock
Harrison
Hendricks
Henry
Howard
Huntington
Jackson
Jefferson
Jennings
Johnson
Knox
Kosciusko
Lawrence
Madison
Marion
Martin
Miami
Monroe
Montgomery
Morgan
Orange
Owen
Parke
Pike
Posey
Putnam
Randolph
Ripley
Rush
Scott
Shelby
Sullivan
Switzerland
Tippecanoe
Tipton
Union
Vermillion
Vigo
Wabash
Warren
Warrick
Washington
Wayne
Wells
Whitley