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Negative Electricity Prices in North America

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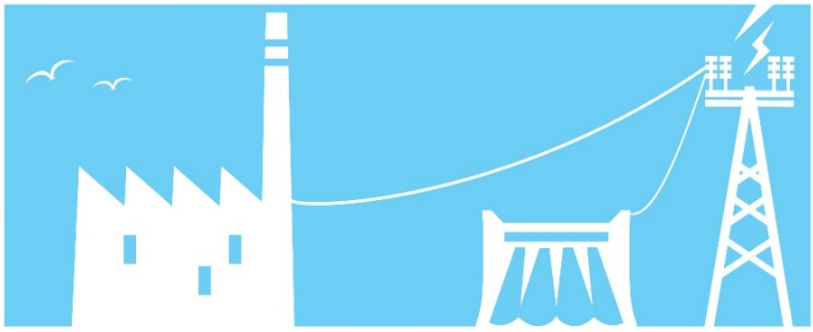

Negative Electricity Prices in North America

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1. Introduction

Unlike many other commodities, electricity prices may be negative (Zhou et al, 2016). Negative prices have been observed and studied in electricity markets in the United States (Huntowski et al. 2012), in Canada (Schneider, 2010) as well as in markets in other countries, such as the Nordic Power Exchange (Sewalt and de Jong 2003), the European Energy Exchange (Genoese et al. 2010, Nicolosi 2010, Brandstätt et al. 2011), and the Australian Energy Market Operator (Australian Energy Market Operator 2009).

Due to the inability of electricity to be stored on a large scale, system operators must carefully balance generation and demand on a moment-by-moment basis, around the clock, to ensure grid reliability. In competitive markets, wholesale electricity prices are determined by the price at which electricity is supplied to the market and how much electric demand there is in at the same time. These prices contribute to the necessary balance (Huntowski et al, 2012). However, because supply cannot always be adjusted to meet demand a few hours early, especially considering the difficulty of storing electricity on a large scale, negative prices ensue (Atănăsoae et al., 2020).

2. Causes of Negative Prices

The literature on negative electricity prices has not matured yet. Nonetheless, four major phenomena can be identified in the literature causing electricity prices to be negative. Each of the following reasons can be considered as a potential avenue for future research contributions:

- **Inflexible supply:** Technological constraints on adjusting the generation levels of coal or nuclear power plants, or the high cost of doing so, can force the supplier of such plants to pay others to purchase their excess power during periods of low electricity demand, such as at night (Sewalt and de Jong 2003, Knittel and Roberts 2005, Genoese et al. 2010, Nicolosi 2010, Brandstätt et al. 2011, Brown 2012).
- **Transmission constraints:** Insufficient transmission capacity can result in an excess of local electricity supply, as is the case in the ERCOT, where wind energy generated in the western zone cannot be transmitted outside the region (Brown 2012).
- **Financial incentives:** The Production Tax Credit earned by wind-based energy generators in the United States, valued at approximately $23 per megawatt-hour (MWh) (Database of State Incentives for Renewable Energy 2015), can motivate wind generators to bid at a negative price and yet earn a profit from the sale. (Fink et al. 2009, Brown 2012, Huntowski et al. 2012).
- **Priority dispatch:** Short-term supply gluts can occur as a result of policies that prioritize renewable (wind and solar) electricity generation, such as those in Germany, and which prohibit curtailment except for reliability reasons (Genoese et al. 2010, Nicolosi 2010, Brandstätt et al. 2011, Gürtler and Paulsen 2018, de Lagarde et al. 2018, Do et al. 2019). Negative pricing are commonly predicted to grow more frequent and higher in size in the future as wind energy usage increases (Genoese et al. 2010,

Nicolosi 2010, Brandstätt et al. 2011). Genoese et al. (2010) examined negative electricity prices in the German day-ahead spot market and found that wind had the highest correlation with negative electricity prices of all the global variables that characterize the market.

On the other hand, the literature on the consequences of negative electricity prices is quite limited, providing an opportunity for future research contributions. Barbour et al. (2014) is one of the few studies that examines these consequences. They explore whether negative electricity prices can change the rationale that efficient energy storage devices are more economical for arbitrage in electricity markets. One possibility is to examine the inverse causality between the aforementioned reasons and negative prices. For instance, while the effects of renewable energy on electricity prices have been studied, it might be worthwhile to investigate whether negative electricity prices influence renewable energy generation.

3. Data

3.1. Data Sources

In Table 1, we summarize data sources and their availability in terms of time frequency. All the data is available from the beginning of 2015 to the end of 2020, except for the day-ahead price data for CAISO which is available from the beginning of 2016. Furthermore, as there is no day-ahead market in Ontario, only real-time data is available for the IESO (Ontario).

Table 1: Data Sources and Their Availability

Region	Type of Data	Source	Frequency
NYISO (New York)	Real Time Price	Link	5 Minutes
	Day Ahead Price	Link	1 Hour
	Load	Link	5 Minutes
MISO (US Midwest)	Real Time Price	Link	1 Hour
	Day Ahead Price	Link	1 Hour
	Load	Link	1 Hour
ERCOT (Texas)	Real Time Price	Link	15 Minutes
	Day Ahead Price	Link	1 Hour
	Load	Link	1 Hour
CAISO (California)	Real Time Price	Link	5 Minutes
	Day Ahead Price	Link	1 Hour
	Load	Link1, Link2	1 Hour
PJM[1]	Real Time Price	Link	5 Minutes, 1 Hour
	Day Ahead Price	Link	1 Hour
	Load	Link	1 Hour
ISONE (New England)	Real Time Price	Link	1 Hour
	Day Ahead Price	Link	1 Hour
	Load	Link	1 Hour
IESO (Ontario)	Real Time Price	Link	1 Hour
	Day Ahead Price	-	-

[1] The PJM interconnection includes parts of Delaware, Illinois, Indiana, Kentucky, Maryland, Michigan, New Jersey, North Carolina, Ohio, Pennsylvania, Tennessee, Virginia, West Virginia, and the District of Columbia.

	Load	Link	1 Hour
AESO (Alberta)	Real Time Price	Link	1 Hour
	Day Ahead Price	Link	1 Hour
	Load	Link	1 Hour

3.2. Electricity Markets and Negative Prices

In a regulated electricity market, vertically integrated utilities cover the entire value chain (generation, transmission, distribution, and retail supply) under the oversight of a public regulator. The utility ensures that energy is generated, transmitted to the grid, and delivered to users. Customers in regulated markets have no choice and are therefore dependent on the local utility. Prices are regulated by authorities, which have traditionally adopted an average cost pricing approach.

In deregulated electricity markets, also referred to as "competitive", market parties other than utilities own power plants and transmission networks. In these circumstances, power producers sell electricity in an organized wholesale market, where large consumers and retail energy suppliers can purchase it. Owners and operators of the transmission and distribution grids are network corporations or utility businesses. Under deregulation, energy prices (as opposed to transmission and distribution prices) are determined by the intersection of supply and demand. Thus, as previously discussed, negative prices are a by-product of supply and demand for electricity output and can arise only in a competitive electricity market.

The competitive short-term spot electricity market is divided into two segments with varying lead times: day-ahead (DA) and real-time (RT). On the DA market, market players trade electricity for the following day. Bids and offers indicating the quantity and delivery date must be submitted by midday. The exchange (market operator) then determines the wholesale price for the next day's hours and approves the winning bids and offers. The DA wholesale price determined in this manner serves as a critical reference point for the electrical market, similar to the closing price of a stock on the stock exchange.

To balance supply and demand on a shorter-term basis, a RT market also exists. In this continuous intraday market, electricity can be traded until 30 minutes before supply. Trading within a control area[2] takes only five minutes.

The DA electricity market enables participants to adjust their positions in response to system expectations, to help avoid price volatility. Additionally, due to the cyclical nature of power demand, the majority of electricity trade can occur up to one day prior to delivery, in the DA market. Given the higher volatility and shorter reaction time in the RT market, it is reasonable to expect that the majority of negative prices will occur in this market, which represents for a small portion of the whole market and offers little opportunity for planning.

3.3. Descriptive Statistics

In Tables 2 and 3, we summarize the descriptive statistics for the data on the RT prices, DA prices and load for all the regions. The descriptive statistics show that RT prices are on average lower

[2] A control area is a spatially defined network area under the responsibility of a transmission system operator.

than DA prices and, except in Alberta, are more volatile (have higher standard deviation) than DA prices.

The percentages of RT and DA negative prices are reported in Tables 4 and 5. As can be seen, negative prices are more common in RT markets, whereas negative prices are rare in DA markets.

Table 2: Descriptive Statistics for Real-Time and Day-Ahead Prices ($/MWh, Hourly, 2015-2020)

	Real-Time Prices					Day-Ahead Prices				
Region	**Count**	**Min**	**Mean**	**Max**	**Sd**	**Count**	**Min**	**Mean**	**Max**	**Sd**
Ontario	52,608	-67.08	17.08	1,823.00	29.38					
Alberta	52,601	0.00	37.62	1000.00	75.06	52,601	0.00	40.42	1000.00	89.70
New England	52,608	-156.00	33.57	2455.00	34.88	52,608	-5.00	33.94	320.00	24.84
New York	52,603	-415.40	27.05	1173.00	26.52	52,603	1.59	27.33	299.90	17.91
PJM	52,602	-228.40	28.04	594.80	21.30	52,602	1.52	28.28	399.50	16.16
California	52,346	-186.30	31.49	985.80	42.45	43,669	-21.25	35.45	1231.00	33.89
MISO	52,584	-26.42	24.82	552.90	14.06	52,584	3.63	25.26	210.70	8.87
Texas	52,596	-24.26	27.18	9000.00	101.30	52,596	1.15	28.19	5009.00	77.68

Table 3: Descriptive Statistics for the Load Data (GWh, Hourly, 2015-2020)

Region	**Count**	**Min**	**Mean**	**Max**	**Sd**	**Median**
Ontario	52,608	9.83	15.41	24.45	2.35	15.30
Alberta	52,601	6.60	9.43	18.50	0.84	9.44
New England	52,608	8.39	13.92	26.02	2.77	13.74
New York	52,603	1.33	18.21	45.84	3.67	17.79
PJM	52,602	55.53	90.24	446.40	16.88	87.66
California	52,346	15.59	25.85	49.90	4.94	25.05
MISO	52,584	0.00	75.57	121.20	12.56	74.19
Texas	52,596	0.00	41.79	74.67	9.58	39.54

Table 4: The Share of Real-Time Negative Prices (%)

Region	**2015**	**2016**	**2017**	**2018**	**2019**	**2020**	**2015-2020**
Ontario	9.37	12.25	18.61	4.20	10.06	3.76	9.71
Alberta	0.00	0.00	0.00	0.00	0.00	0.00	0.00
New England	1.15	2.03	1.15	1.08	0.57	0.33	1.05
New York	0.34	0.81	0.61	0.57	0.40	0.16	0.48
PJM	0.54	0.23	0.24	0.11	0.08	0.05	0.21
California	3.05	5.40	6.37	2.90	3.21	2.58	3.92
MISO	0.14	0.14	0.00	0.00	0.00	0.18	0.08
Texas	0.63	1.46	0.48	0.33	0.51	0.98	0.73

Table 5: The Share of Day-Ahead Negative Prices (%)

Region	**2015**	**2016**	**2017**	**2018**	**2019**	**2020**	**2015-2020**
Ontario							
Alberta	0.00	0.00	0.00	0.00	0.00	0.00	0.00
New England	0.06	0.00	0.00	0.00	0.00	0.00	0.01
New York	0.00	0.00	0.00	0.00	0.00	0.00	0.00

PJM	0.00	0.00	0.00	0.00	0.00	0.00	0.00
California		0.09	1.27	0.80	1.04	2.29	1.10
MISO	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Texas	0.00	0.00	0.00	0.00	0.00	0.00	0.00

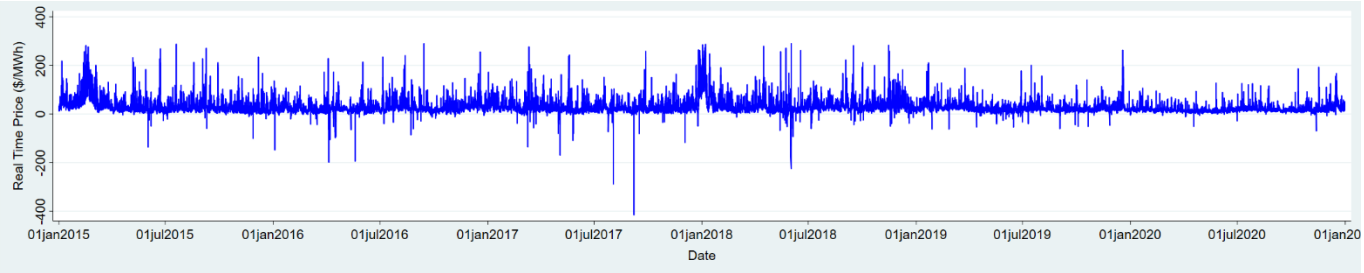
3.4. Data Visualization

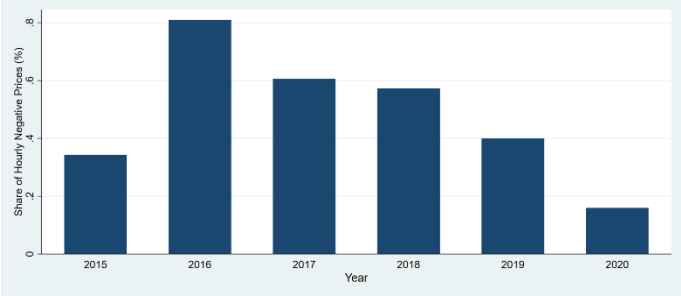
To properly depict the data, we exclude the 0.1 percent upper quantile of RT price data (about 50 out of 50,000 observations for each region) in order to eliminate high values in the data and make the plots more meaningful.[3]

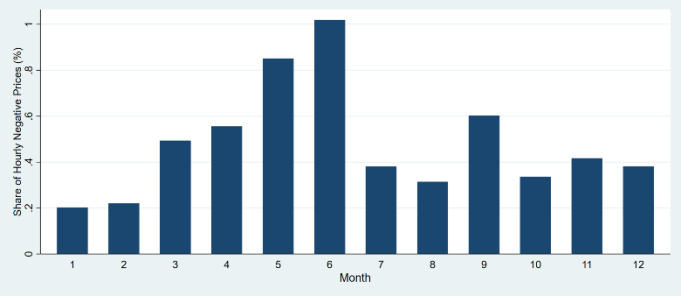
We plot a variety of numbers for each region: initially, we plot a time series of electricity prices to observe the variations over time. In the second and third rows, we present four figures illustrating the bar plot for the ratio of negative prices to the total across various time scales to illustrate how prices behave seasonally. Additionally, we draw two scatter plots in the fourth row for negative prices versus month and hour. Finally, we exhibit two scatter plots for negative prices versus DA prices and load, with negative price observations shown in red.

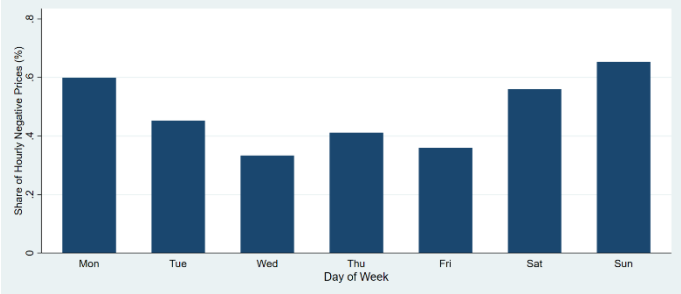
[3] In the appendix, we report the descriptive statistics for the RT prices, DA prices, and load data after dropping the outliers.

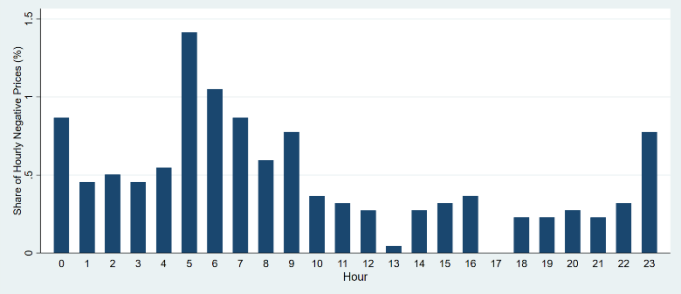
Figure 1: New York

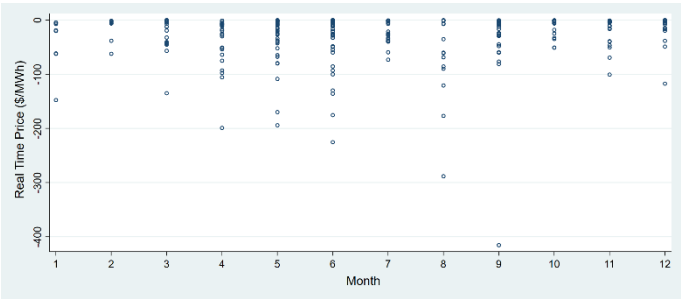


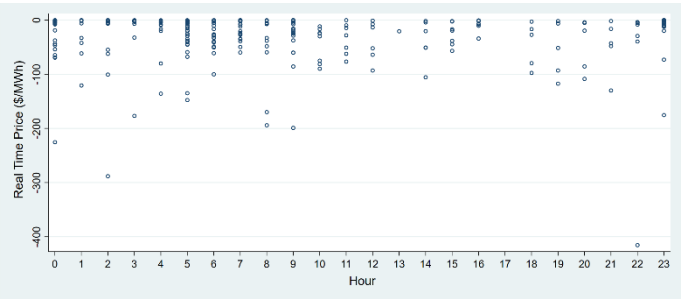


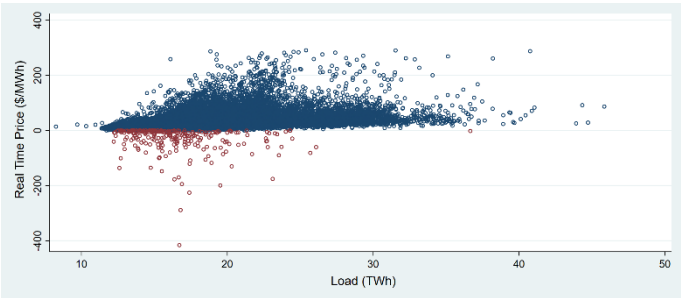












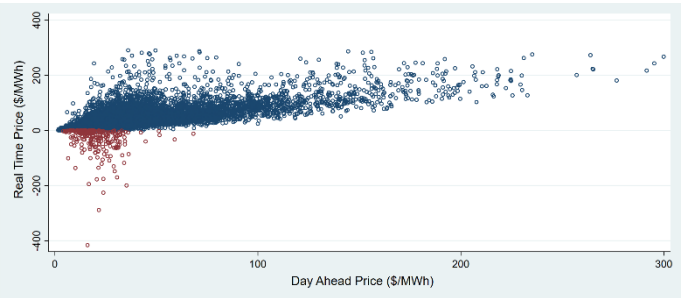
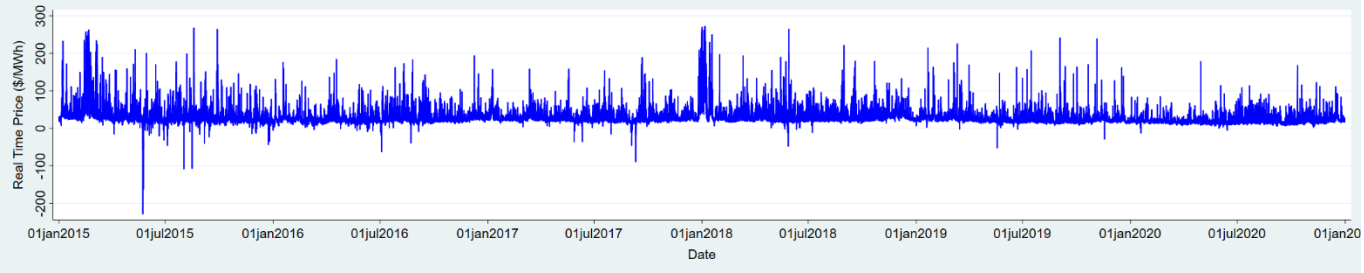
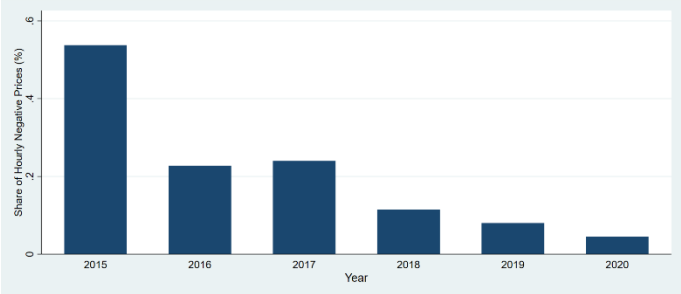
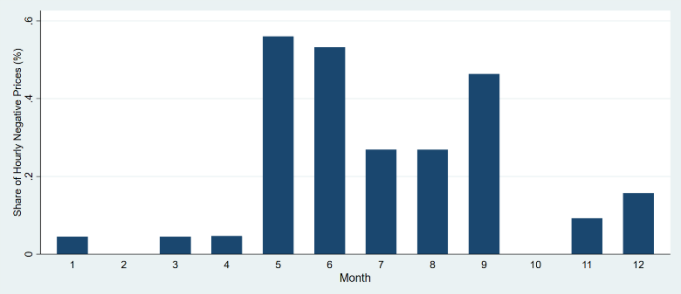
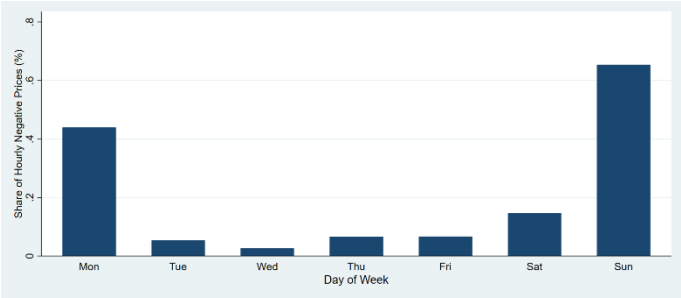


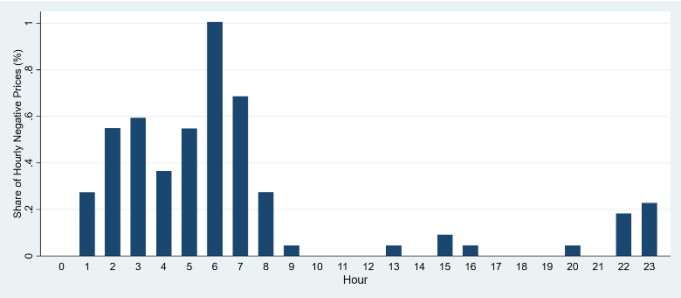
Figure 2: PJM

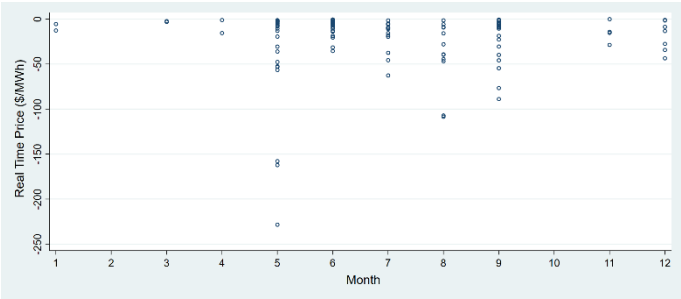

Real Time Price ($/MWh)
300
200
100
0
-100
-200
01jan2015
01jul2015
01jan2016
01jul2016
01jan2017
01jul2017
01jan2018
01jul2018
01jan2019
01jul2019
01jan2020
01jul2020
01jan20
Date

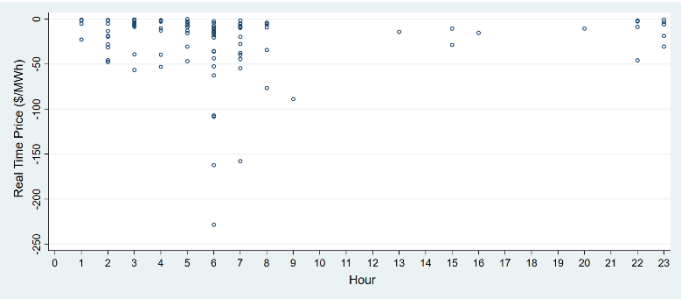

Share of Hourly Negative Prices (%)
.6
.4
.2
0
2015
2016
2017
2018
2019
2020
Year

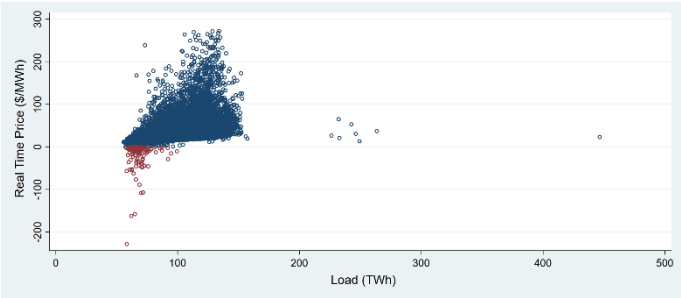

Share of Hourly Negative Prices (%)
.6
.4
.2
0
1
2
3
4
5
6
7
8
9
10
11
12
Month


Share of Hourly Negative Prices (%)
.8
.6
.4
.2
0
Mon
Tue
Wed
Thu
Fri
Sat
Sun
Day of Week


Share of Hourly Negative Prices (%)
1
.8
.6
.4
.2
0
0
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
17
18
19
20
21
22
23
Hour


Real Time Price ($/MWh)
0
-50
-100
-150
-200
-250
1
2
3
4
5
6
7
8
9
10
11
12
Month


Real Time Price ($/MWh)
0
-50
-100
-150
-200
-250
0
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
17
18
19
20
21
22
23
Hour


Real Time Price ($/MWh)
300
200
100
0
-100
-200
0
100
200
300
400
500
Load (TWh)

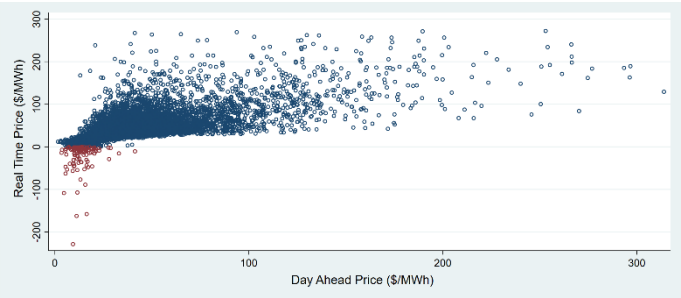
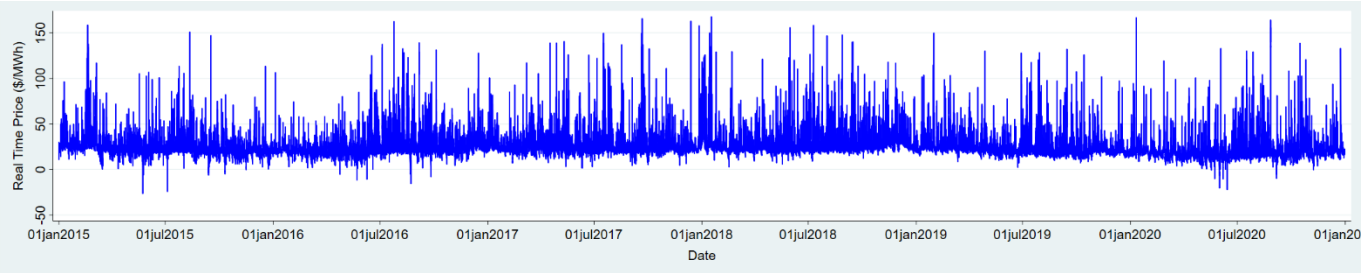
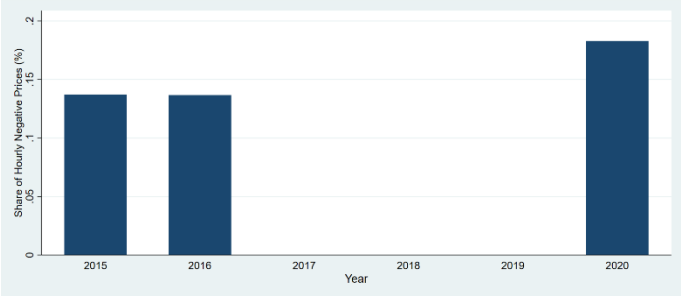
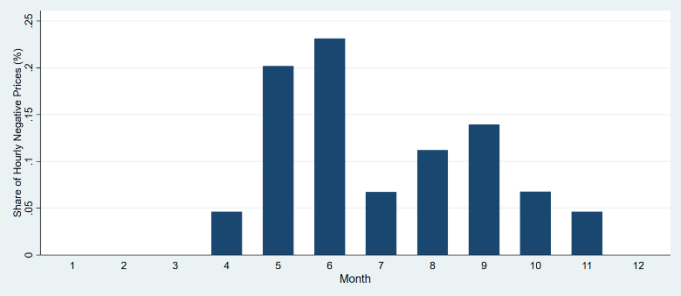
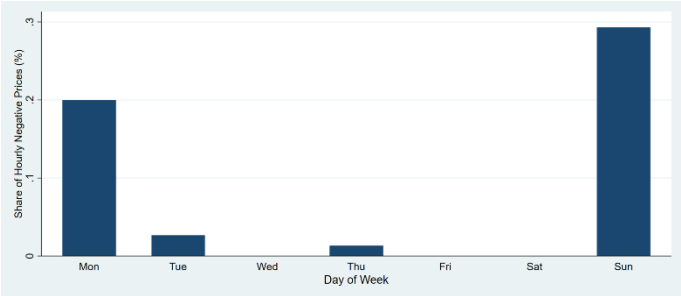

Real Time Price ($/MWh)
300
200
100
0
-100
-200
0
100
200
300
Day Ahead Price ($/MWh)

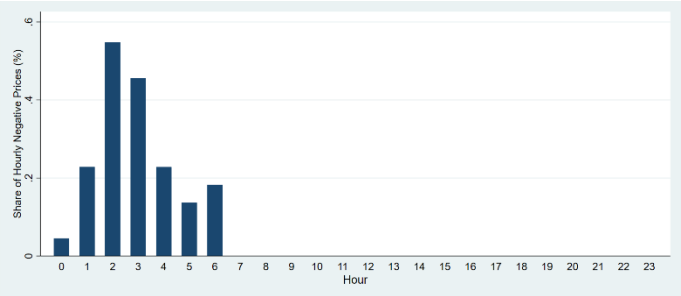
Figure 3: MISO

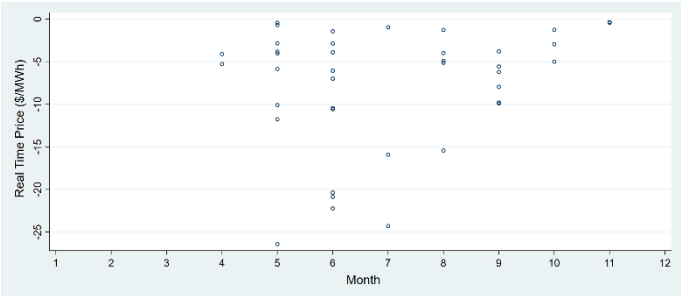


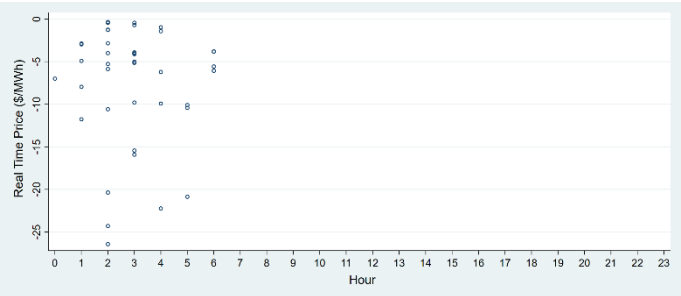


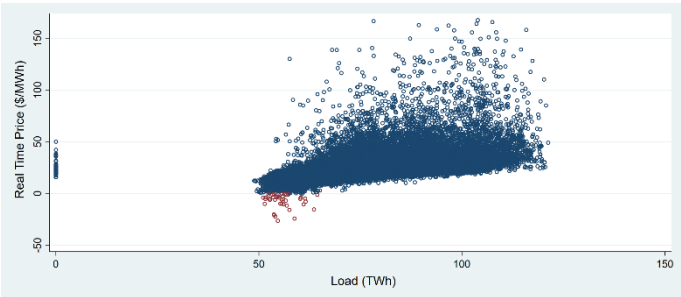


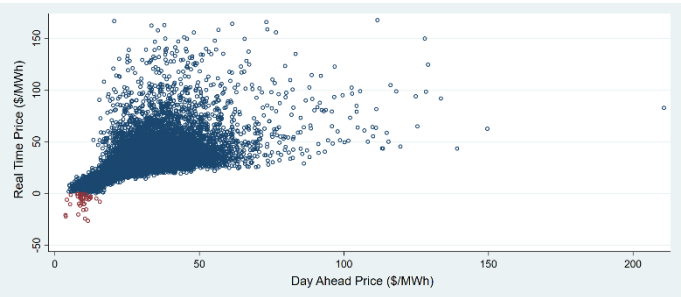












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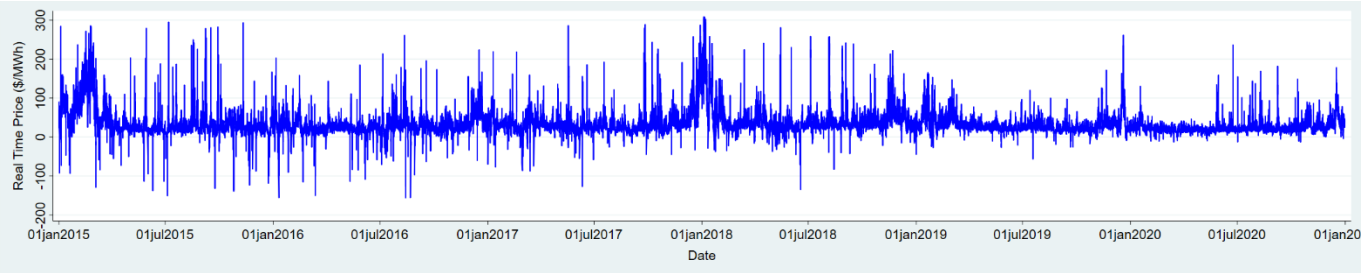
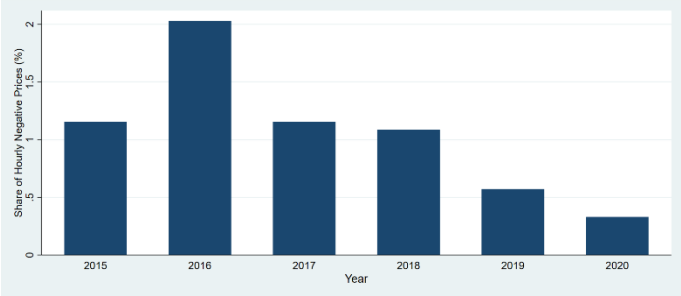
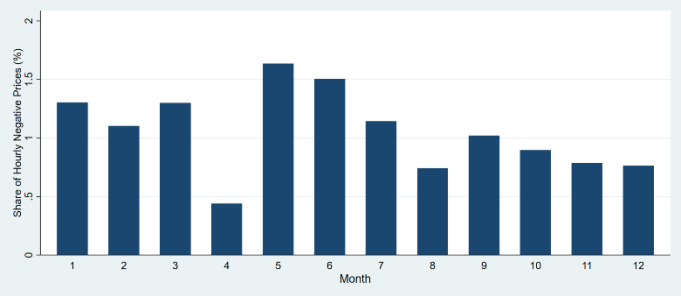
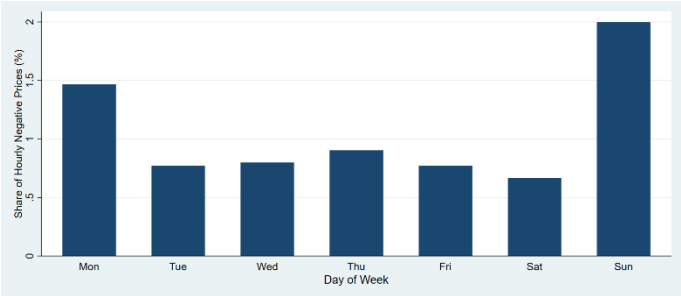
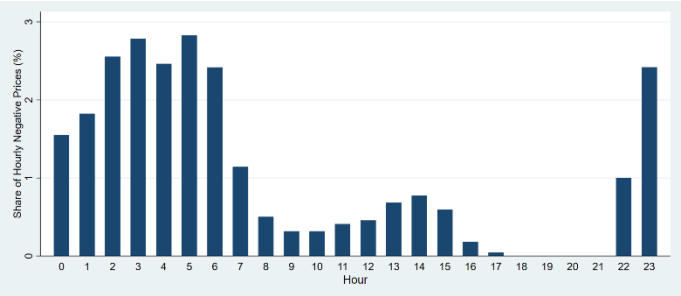
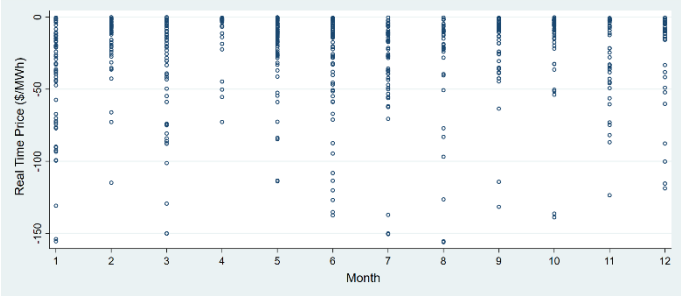


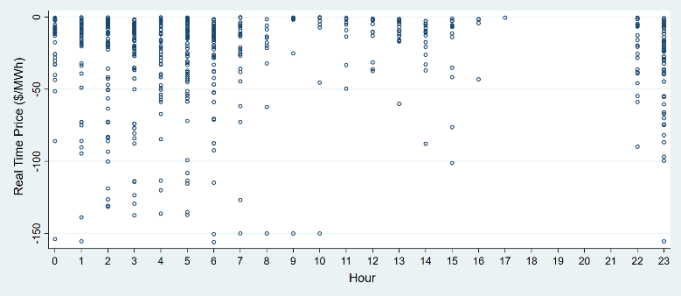


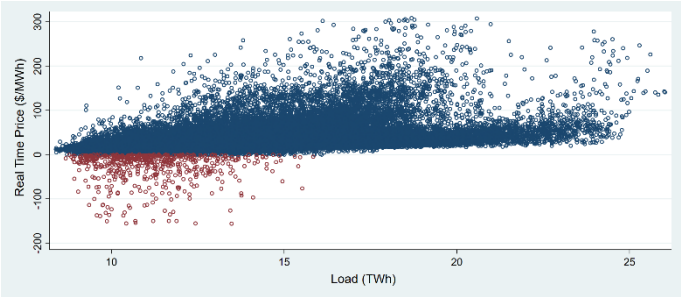












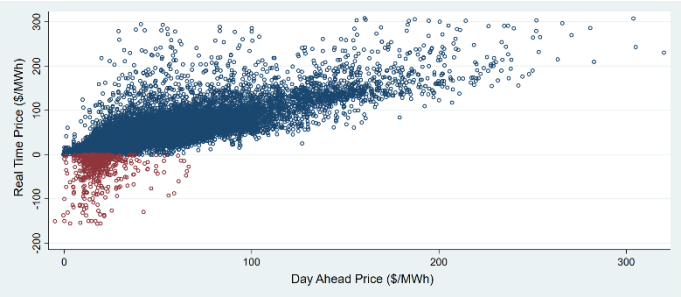
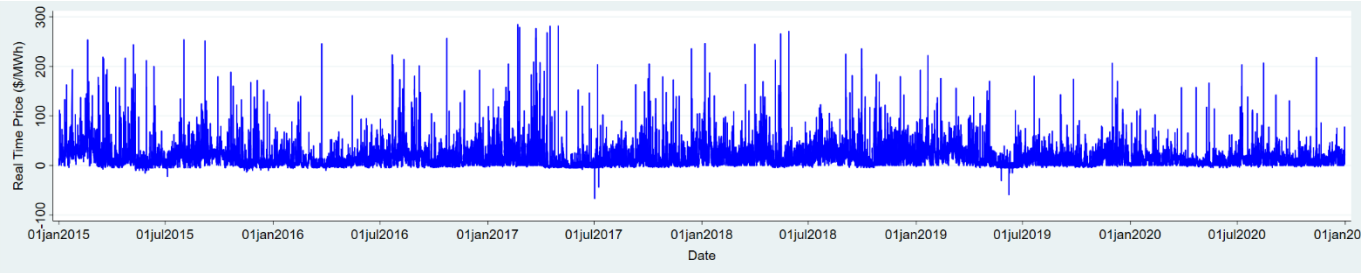
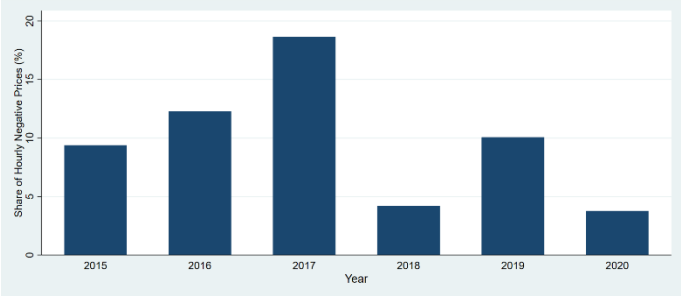
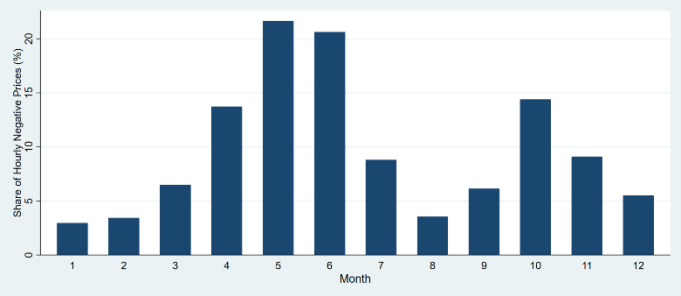
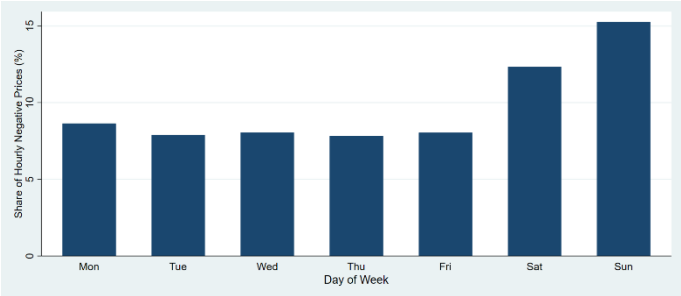


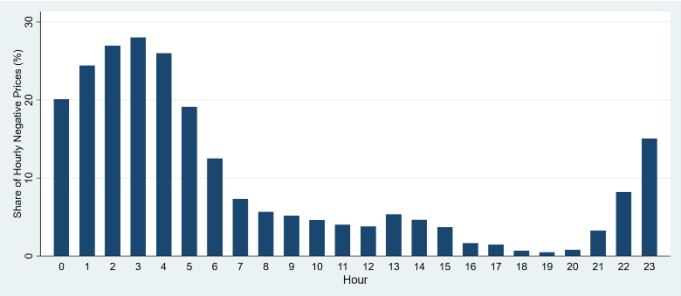
Figure 5: Ontario

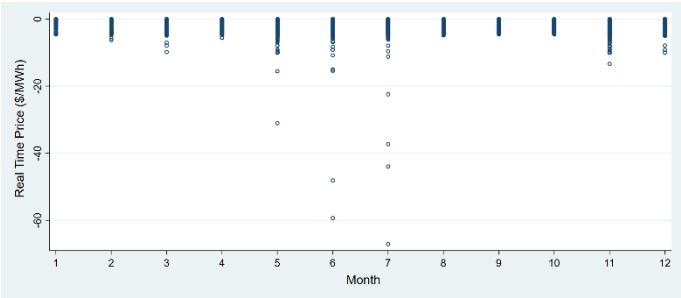


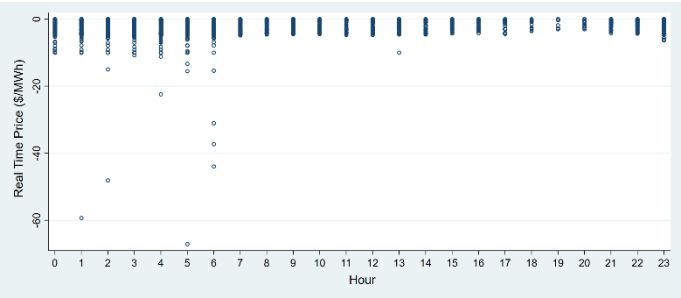












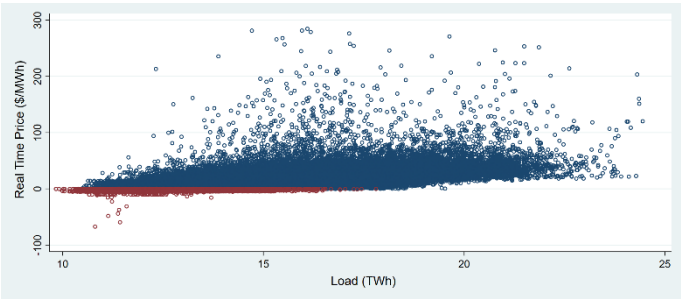
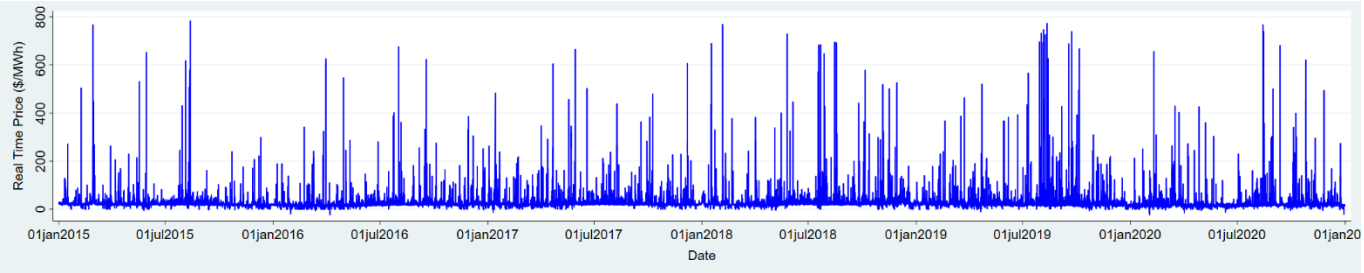
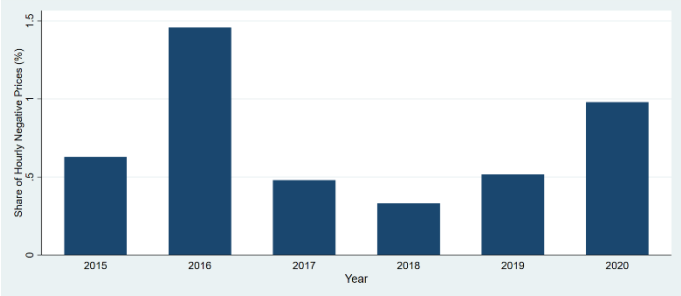
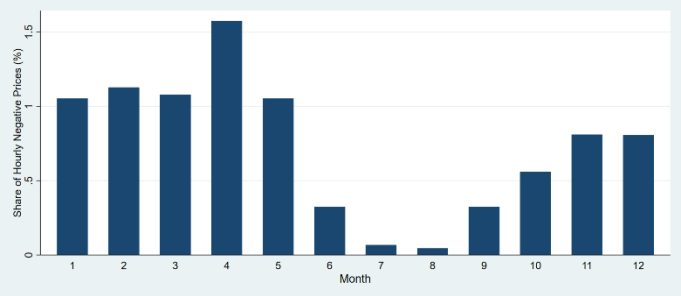
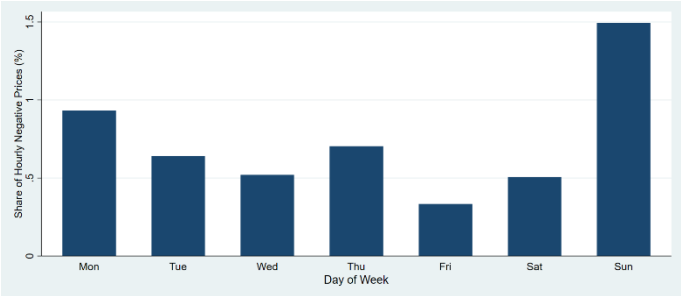


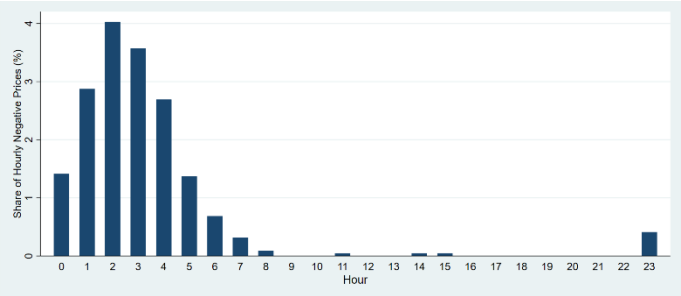
Figure 6: Texas

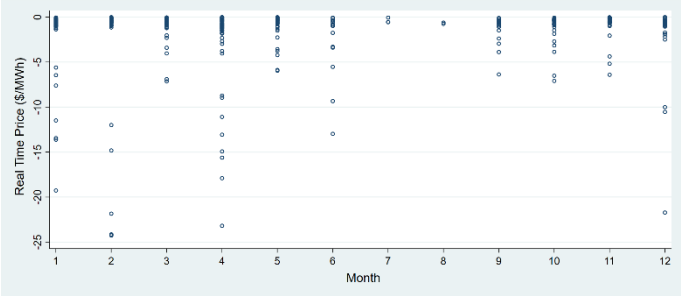


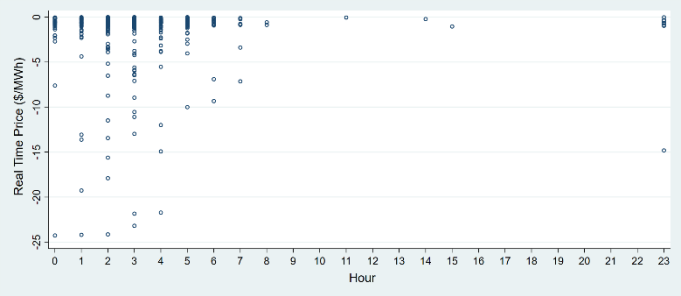


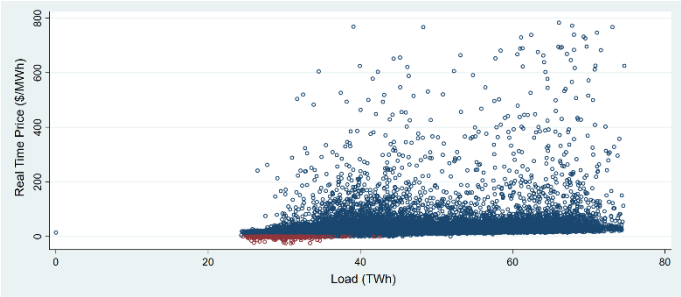












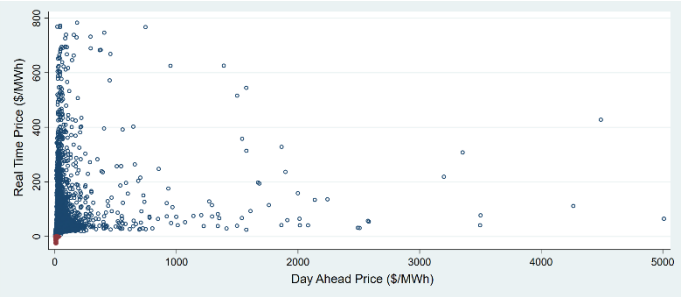
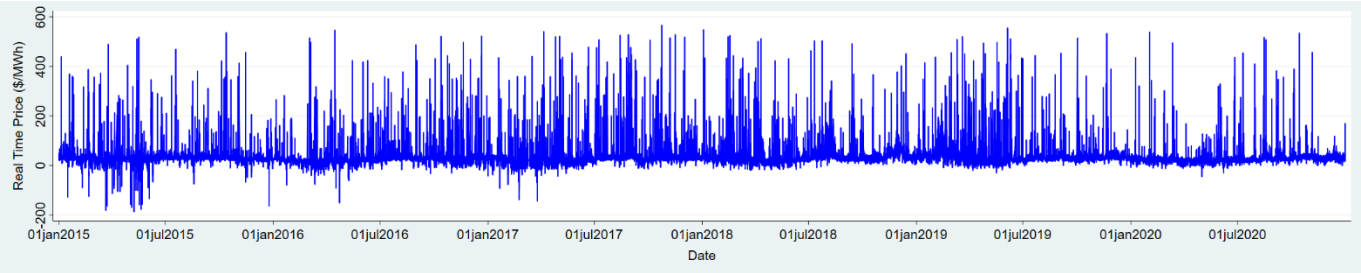
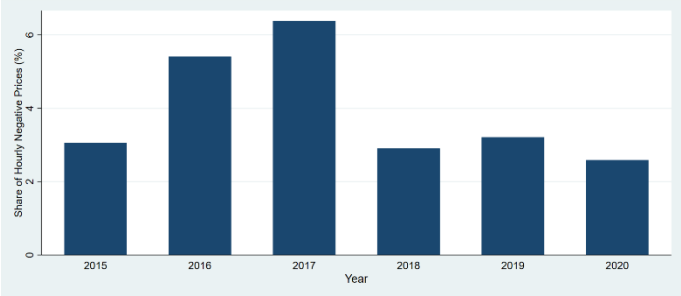
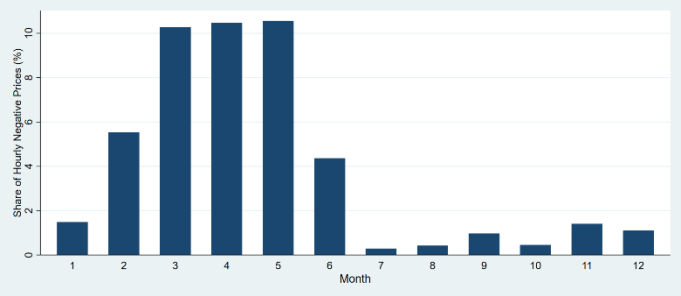
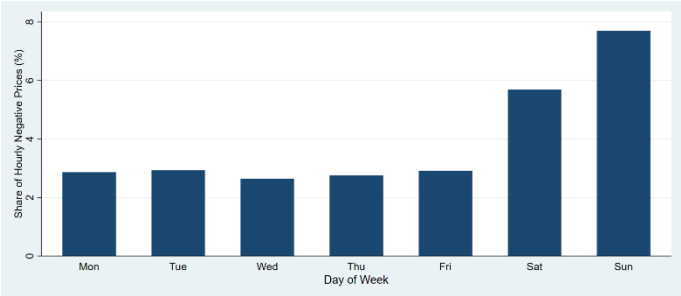


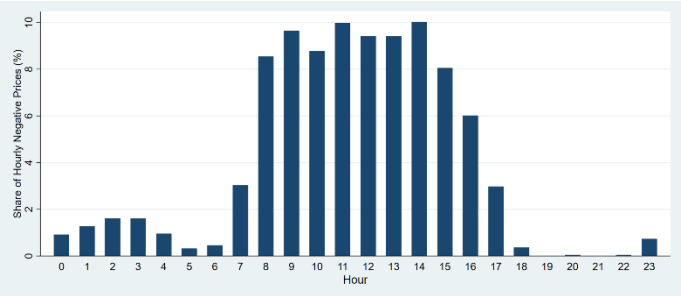
Figure 7: California

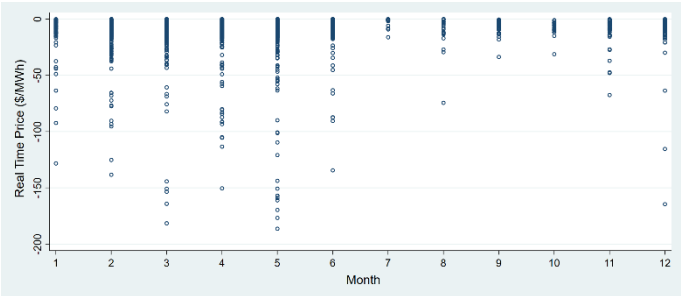


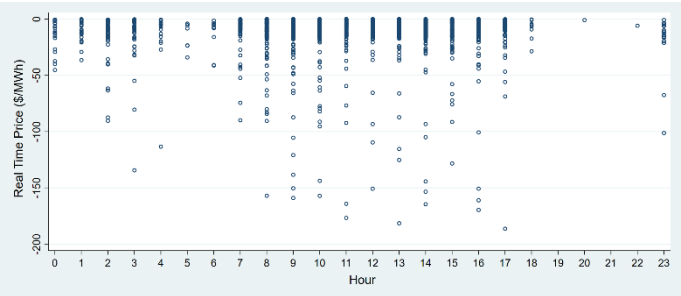


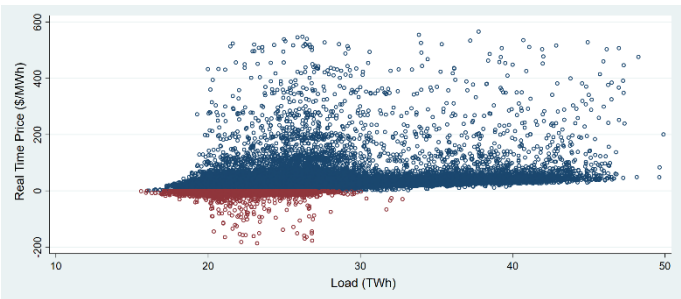


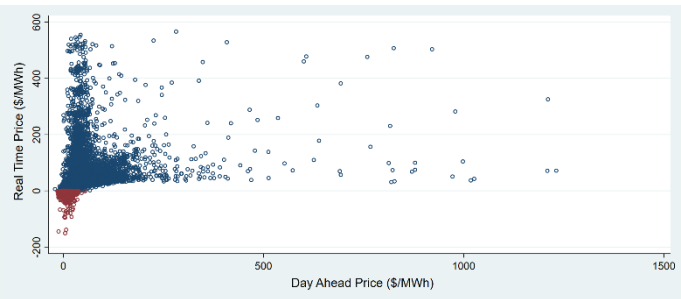












3.5 Discussion

Some observations are worth noting. The frequency of negative prices tends to:

- **Decrease over the year**. Except in Texas and MISO, the frequency of negative prices tends to decline year after year.
- **Be higher in the spring**. It appears that April, May, and June have a higher probability of negative prices than other months.
- **Be higher on Sundays.** In all markets, Sundays have the higher frequency of negative prices, Saturdays and Mondays come next.
- **Be higher in early morning hours**. This is true in all markets, except in California where sunshine hours are those with the most negative prices.

Overall, negative RT prices happen during of hours of low loads. Related to this, negative RT prices happen in hours of low DA prices.

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Appendix

We summarize the descriptive statistics for RT prices, DA prices, and load data in Tables 6 and 7, after removing outliers (the 0.1 percent upper quantile of RT prices data).

Table 6: Descriptive Statistics for the Data of Real Time and Day-Ahead Prices After Dropping the Outliers ($/MWh, Hourly, 2015-2020)

	Real Time Prices					Day-Ahead Prices				
Region	**Count**	**Min**	**Mean**	**Max**	**Sd**	**Count**	**Min**	**Mean**	**Max**	**Sd**
Ontario	52,556	-67.08	16.50	284.60	19.07					
Alberta	52,549	0.00	36.68	969.10	68.82	52,549	0.00	39.48	1000.00	84.66
New England	52,556	-156.00	33.10	308.40	29.19	52,556	-5.00	33.86	320.00	24.59
New York	52,551	-415.40	26.63	290.70	22.13	52,551	1.59	27.25	299.90	17.63
PJM	52,550	-228.40	27.70	272.30	18.29	52,550	1.52	28.16	313.90	15.47
California	52,294	-186.30	30.81	566.30	36.46	43,625	-21.25	35.29	1231.00	32.21
MISO	52,532	-26.42	24.58	167.60	11.37	52,532	3.63	25.24	210.70	8.82
Texas	52,544	-24.26	25.09	783.40	33.04	52,544	1.15	27.60	5009.00	70.35

Table 7: Descriptive Statistics for the Load Data After Dropping the Outliers (GWh, Hourly, 2015-2020)

Region	**Count**	**Min**	**Mean**	**Max**	**Sd**	**Median**
Ontario	52,556	9.83	15.41	24.45	2.35	15.29
Alberta	52,549	6.60	9.42	18.50	0.84	9.44
New England	52,556	8.39	13.91	26.02	2.76	13.74
New York	52,551	1.33	18.21	45.84	3.65	17.78
PJM	52,550	55.53	90.21	446.40	16.85	87.64
California	52,294	15.59	25.84	49.90	4.93	25.05
MISO	52,532	0.00	75.56	121.20	12.54	74.18
Texas	52,544	0.00	41.76	74.67	9.56	39.53