Do Large Consumers Respond to Wholesale Price Spikes?

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Frontier Associates LLC
1515 S. Capital of Texas Hwy, Suite 110
Austin, Texas 78746
www.FrontierAssoc.com

To understand if large industrial consumers respond to wholesale price spikes in Texas, Frontier Associates looked at 15-minute interval aggregated load data for two groups of energy consumers thought most likely to respond to increases in wholesale prices– consumers served at transmission voltage and consumers served at primary voltage. These data were obtained from ERCOT. These consumers consisted of 1) consumers served at transmission voltage with a non-coincident peak demand (billing demand) that exceeded 1 MW at least 10 times since January 2002 and 2) consumers served at primary voltage with a peak demand meeting these same criteria. The former group includes many very large refineries and chemical production facilities along the Gulf Coast. Data for the period from January 2007 through mid-2012 were used in this analysis.

The methods used in this analysis were the following:

1. Simple regression models were run to estimate the relationship between price changes and changes in energy consumption by energy consumers served at transmission and primary voltage, while controlling for the effects of weather, responses to coincident peak (4CP) events, day of the week, month of the year, and time of day.

2. Actual energy use during a price spike was compared to an historical baseline energy usage, calculated as the same interval during the previous five weekdays (if the price spike occurred on a weekday) or the same interval on the previous Saturday or Sunday (if the price spike occurred on a Saturday or Sunday). In constructing the historical baselines, any intervals with a price spike, a 4CP event, or a deployment of responsive reserves were removed from the calculation.

3. Actual energy use during a price spike was compared to usage during the interval immediately preceding the price spike.

These work papers explain the calculations and report findings.

Regression Analysis on All Data

Four regression models were used to explore the extent to which the two groups of energy consumers respond to prices. Using 136,845 15-minute intervals for a period of time the zonal market was in operation (from January 1, 2007 to November 30, 2010), the following relationships were estimated:

$$\mathit{ln}(\mathit{TransmissionVoltageCustomers}) = a + b1*\mathit{ln}(\mathit{Average\ of\ Houston\ and\ North\ MCPE}) + b2*\mathit{CP} + b3*\mathit{Morning} + b4*\mathit{Afternoon} + b5*\mathit{CDD} + \sum_{m=1}^{11} Month_m + \sum_{d=1}^{6} Day_d + \varepsilon$$

$$\mathit{ln}(\mathit{PrimaryVoltageCustomers}) = a + b1*\mathit{ln}(\mathit{Average\ of\ Houston\ and\ North\ MCPE}) + b2*\mathit{CP} + b3*\mathit{Morning} + b4*\mathit{Afternoon} + b5*\mathit{CDD} + \sum_{m=1}^{11} Month_m + \sum_{d=1}^{6} Day_d + \varepsilon$$

Here, the dependent variables represent the total energy in kWh consumed by transmission voltage or primary voltage energy consumers within the interval. A simple average of the market clearing price of balancing energy in the Houston and North zones was used to represent wholesale market prices, since most of the consumers in these groups reside within these two zones. The natural logarithm (as designated by *ln*) of the price and quantity variables was used in the estimation, so that the coefficient b1 would represent the price elasticity of demand. A control variable reflecting the presence of one of the four coincident peaks was used to assist in distinguishing the response to a transmission price from response to a wholesale generation price. CDD represents the number of degrees that the temperature in Austin (a central location within EROT) exceeds 65° F. The coefficients a, b1-b4, m1-m11, and d1-d6 were estimated using ordinary least-squares. The error term is represented by ε. The time index on all variables has been suppressed to simplify the notation.

A separate pair of regression models was estimated for the period since the introduction of the nodal market on December 1, 2010. It was thought appropriate to estimate relationships in the nodal market separately, since the nodal prices include the costs of managing local transmission congestions, whereas the zonal prices do not. The introduction of the nodal market was also accompanied by large changes in the revenues received (and returned to the market) from transmission rights. Finally, an increase in the offer cap accompanied the change in market structure. Since prices were effectively "redefined" by the change in market structure, different relationships between the quantity of electricity purchased from the grid and the generation price should be expected. Thus, for the nodal market, a different price term – the simple average of the zonal locational marginal prices or LMPs quoted by ERCOT for the Houston and North zones -- is used.

$$\mathit{ln}(\mathit{TransmissionVoltageCustomers}) = a + b1 * \mathit{ln}(\mathit{Average\ of\ Houston\ and\ North\ Zonal\ Average\ LMPs}) + b2 * \mathit{CP} + b3 * \mathit{Morning} + b4 * \mathit{Afternoon} + b5 * \mathit{CDD} + \sum_{m=1}^{11} Month_m + \sum_{d=1}^{6} Day_d + \varepsilon$$

$$\mathit{ln}(\mathit{PrimaryVoltageCustomers}) = a + b1 * \mathit{ln}(\mathit{Average\ of\ Houston\ and\ North\ Zonal\ Average\ LMPs}) + b2 * \mathit{CP} + b3 * \mathit{Morning} + b4 * \mathit{Afternoon} + b5 * \mathit{CDD} + \sum_{m=1}^{11} Month_m + \sum_{d=1}^{6} Day_d + \varepsilon$$

While simple log-linear relationships between prices and quantities demanded are assumed here, we are presently seeking to model this relationship with a production function approach, as we have done in some previous studies.[1] However, computer programs adopting Symmetric Generalized McFadden and Generalized Leontief functional forms require some further debugging.

During the zonal period, an increase in price was accompanied, on average, by an increase in the quantity demanded for both groups, after controlling for the effects of the exogenous variables, as can be seen in Figure 1 and Figure 2. The results for the estimation during the nodal market structure suggest small price elasticity of demands of about -.0.01 (and thus the proper direction) for the two groups. Given the large sample sizes, little credence should be placed in the t-statistics and p-values.

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[1] See J. Zarnikau, G. Landreth, I. Hallett, and S.C. Kumbhakar, Industrial customer response to wholesale prices in the restructured Texas electricity market, Energy, Volume 32, Issue 9, Pages 1543-1790 (September 2007); and J. Zarnikau and I. Hallett, Aggregate industrial energy consumer response to wholesale prices in the restructured Texas electricity market, Energy Economics, Volume 30, Issue 4, July 2008, Pages 1798–1808.

Figure 1
Price elasticity of demand in ERCOT for transmission energy consumers, log-log form, Zonal period only

The REG Procedure
Model: MODEL1
Dependent Variable: lnTrans

Number of Observations Read	137280
Number of Observations Used	136845
Number of Observations with Missing Values	435

Root MSE	0.05908	**R-Square**	0.4622
Dependent Mean	13.59008	**Adj R-Sq**	0.4621
Coeff Var	0.43471		

Parameter Estimates

Variable	DF	Parameter Estimate	Standard Error	t Value	Pr > |t|
Intercept	**1**	13.31194	0.00139	9587.66	<.0001
lnAvgPrice	**1**	0.04560	0.00028667	159.06	<.0001
CP	**1**	-0.07590	0.01478	-5.14	<.0001
Morning	**1**	0.00518	0.00076060	6.81	<.0001
Afternoon	**1**	-0.01098	0.00064133	-17.12	<.0001
CDD1	**1**	-0.00008848	0.00002736	-3.23	0.0012
M1	**1**	0.02686	0.00082860	32.42	<.0001
M2	**1**	0.04798	0.00084553	56.74	<.0001
M3	**1**	0.04410	0.00083157	53.03	<.0001
M4	**1**	0.06329	0.00084331	75.05	<.0001
M5	**1**	0.09703	0.00088119	110.11	<.0001
M6	**1**	0.12352	0.00094534	130.66	<.0001
M7	**1**	0.13120	0.00095301	137.67	<.0001
M8	**1**	0.13679	0.00098102	139.44	<.0001
M9	**1**	0.08813	0.00091159	96.68	<.0001
M10	**1**	0.08779	0.00085441	102.75	<.0001
M11	**1**	0.06474	0.00084024	77.05	<.0001
D1	**1**	-0.01355	0.00059957	-22.61	<.0001
D2	**1**	0.02100	0.00059779	35.13	<.0001
D3	**1**	0.04020	0.00059723	67.31	<.0001
D4	**1**	0.03648	0.00059818	60.98	<.0001
D5	**1**	0.03868	0.00059798	64.69	<.0001
D6	**1**	0.03440	0.00059778	57.54	<.0001

Figure 2
Price elasticity of demand in ERCOT for primary voltage energy consumers, log-log form, Zonal period only

The REG Procedure
Model: MODEL1
Dependent Variable: lnPrimary

Number of Observations Read	137280
Number of Observations Used	136845
Number of Observations with Missing Values	435

Root MSE	0.05924	**R-Square**	0.7557
Dependent Mean	13.07138	**Adj R-Sq**	0.7557
Coeff Var	0.45317		

Parameter Estimates

Variable	DF	Parameter Estimate	Standard Error	t Value	Pr > |t|
Intercept	1	12.69668	0.00139	9120.16	<.0001
lnAvgPrice	1	0.03569	0.00028744	124.17	<.0001
CP	1	-0.01595	0.01482	-1.08	0.2817
Morning	1	-0.00164	0.00076264	-2.15	0.0315
Afternoon	1	0.06056	0.00064305	94.18	<.0001
CDD1	1	0.00326	0.00002744	118.71	<.0001
M1	1	0.03025	0.00083082	36.41	<.0001
M2	1	0.04933	0.00084779	58.19	<.0001
M3	1	0.05498	0.00083379	65.94	<.0001
M4	1	0.06840	0.00084556	80.90	<.0001
M5	1	0.09628	0.00088355	108.97	<.0001
M6	1	0.13628	0.00094786	143.78	<.0001
M7	1	0.13315	0.00095556	139.34	<.0001
M8	1	0.15545	0.00098364	158.04	<.0001
M9	1	0.12595	0.00091403	137.80	<.0001
M10	1	0.10202	0.00085669	119.08	<.0001
M11	1	0.05203	0.00084248	61.75	<.0001
D1	1	-0.04154	0.00060117	-69.10	<.0001
D2	1	0.08490	0.00059939	141.64	<.0001
D3	1	0.11417	0.00059883	190.66	<.0001
D4	1	0.11613	0.00059978	193.63	<.0001
D5	1	0.11260	0.00059958	187.80	<.0001
D6	1	0.09096	0.00059938	151.76	<.0001

Figure 3

Price elasticity of demand in ERCOT for transmission energy consumers, log-log form, Nodal period only

The REG Procedure
Model: MODEL1
Dependent Variable: lnTrans

Number of Observations Read	97056
Number of Observations Used	90997
Number of Observations with Missing Values	6059

Root MSE	0.14767	**R-Square**	0.1227
Dependent Mean	13.59487	**Adj R-Sq**	0.1225
Coeff Var	1.08624		

Parameter Estimates

Variable	DF	Parameter Estimate	Standard Error	t Value	Pr > |t|
Intercept	**1**	13.57801	0.00477	2846.74	<.0001
lnAvgPrice	**1**	-0.01018	0.00116	-8.78	<.0001
CP	**1**	-0.07390	0.04674	-1.58	0.1139
Morning	**1**	-0.00332	0.00233	-1.43	0.1540
Afternoon	**1**	0.00102	0.00197	0.52	0.6043
CDD1	**1**	0.00277	0.00008427	32.84	<.0001
M1	**1**	0.00400	0.00248	1.61	0.1065
M2	**1**	-0.00428	0.00252	-1.70	0.0892
M3	**1**	0.00242	0.00249	0.97	0.3320
M4	**1**	0.01649	0.00257	6.41	<.0001
M5	**1**	0.02754	0.00267	10.30	<.0001
M6	**1**	0.04572	0.00292	15.67	<.0001
M7	**1**	0.04796	0.00292	16.43	<.0001
M8	**1**	-0.13928	0.00321	-43.37	<.0001
M9	**1**	0.02844	0.00301	9.44	<.0001
M10	**1**	-0.00520	0.00278	-1.87	0.0619
M11	**1**	0.01370	0.00275	4.98	<.0001
D1	**1**	-0.01858	0.00183	-10.14	<.0001
D2	**1**	0.01480	0.00183	8.08	<.0001
D3	**1**	0.04449	0.00183	24.29	<.0001
D4	**1**	0.04454	0.00184	24.27	<.0001
D5	**1**	0.04322	0.00183	23.56	<.0001
D6	**1**	0.03721	0.00183	20.33	<.0001

Figure 4
Price elasticity of demand in ERCOT for primary voltage energy consumers, log-log form, Nodal period only

The REG Procedure
Model: MODEL1
Dependent Variable: lnPrimary

Number of Observations Read	97056
Number of Observations Used	90997
Number of Observations with Missing Values	6059

Root MSE	0.07678	**R-Square**	0.6100
Dependent Mean	13.10153	**Adj R-Sq**	0.6099
Coeff Var	0.58602		

Parameter Estimates

Variable	DF	Parameter Estimate	Standard Error	t Value	Pr > |t|
Intercept	**1**	12.92066	0.00248	5210.28	<.0001
lnAvgPrice	**1**	-0.00751	0.00060233	-12.47	<.0001
CP	**1**	-0.01127	0.02430	-0.46	0.6428
Morning	**1**	-0.00676	0.00121	-5.59	<.0001
Afternoon	**1**	0.06929	0.00102	67.79	<.0001
CDD1	**1**	0.00428	0.00004381	97.63	<.0001
M1	**1**	0.00962	0.00129	7.47	<.0001
M2	**1**	0.01872	0.00131	14.28	<.0001
M3	**1**	0.03565	0.00130	27.52	<.0001
M4	**1**	0.05114	0.00134	38.22	<.0001
M5	**1**	0.07030	0.00139	50.57	<.0001
M6	**1**	0.10585	0.00152	69.79	<.0001
M7	**1**	0.10576	0.00152	69.66	<.0001
M8	**1**	0.05007	0.00167	29.99	<.0001
M9	**1**	0.08775	0.00157	56.02	<.0001
M10	**1**	0.05960	0.00145	41.18	<.0001
M11	**1**	0.02320	0.00143	16.23	<.0001
D1	**1**	-0.04439	0.00095287	-46.58	<.0001
D2	**1**	0.07614	0.00095213	79.97	<.0001
D3	**1**	0.10789	0.00095219	113.30	<.0001
D4	**1**	0.11121	0.00095417	116.55	<.0001
D5	**1**	0.10836	0.00095376	113.61	<.0001
D6	**1**	0.08369	0.00095144	87.96	<.0001

Thus, our estimated response to wholesale generation prices for the period from January 1, 2007 to December 1, 2010 does not appear to be credible. We find a small response since the implementation of the nodal market (and the accompanying increase in the wholesale offer cap) on December 1, 2010.

Estimating the Impacts with an Historical Baseline Approach

Graphical analysis illustrates how difficult it is to identify and quantify a response to a wholesale price spike in this market. Figure 1 through 7 compare actual interval-level energy consumption by transmission voltage consumers against a baseline usage pattern. To analyze the industrial consumers' change in consumption, Frontier calculated the change in consumption relative to:

- The average consumption during the same interval of the 5 previous weekdays (in the case of a price spike on a weekday), or the same interval of the previous Saturday or Sunday (if the price spike was on a Saturday or Sunday).
- The consumption level just before the beginning of the price spike. (Previous intervals within the price spike were not included).

CP days, as well as system emergencies and responsive reserves were also excluded from the baselines, as these days tend to skew the data.

Figure 5 illustrates the demand reduction during price spikes in the dataset. The horizontal axis measures the increase or decrease in consumption by this group of consumers, relative to their average consumption during the same intervals of the five previous weekdays (if the price spike fell on a weekday) or the one interval of the previous weekend (if the price spike fell on a weekend). The vertical axis shows the frequency of the increase or decrease in demand over the time period 2007-mid 2012.

Figure 5
Average Change in MWh for Energy Consumers served at Transmission Voltage During Price Spike Based on Previous 5 Day Baseline (for Weekday prices spikes) or Same Interval on Prior Weekend (for Weekend price spikes) for all Price Spikes Since January 2007. Note: x-axis labels represent end-points of each range.

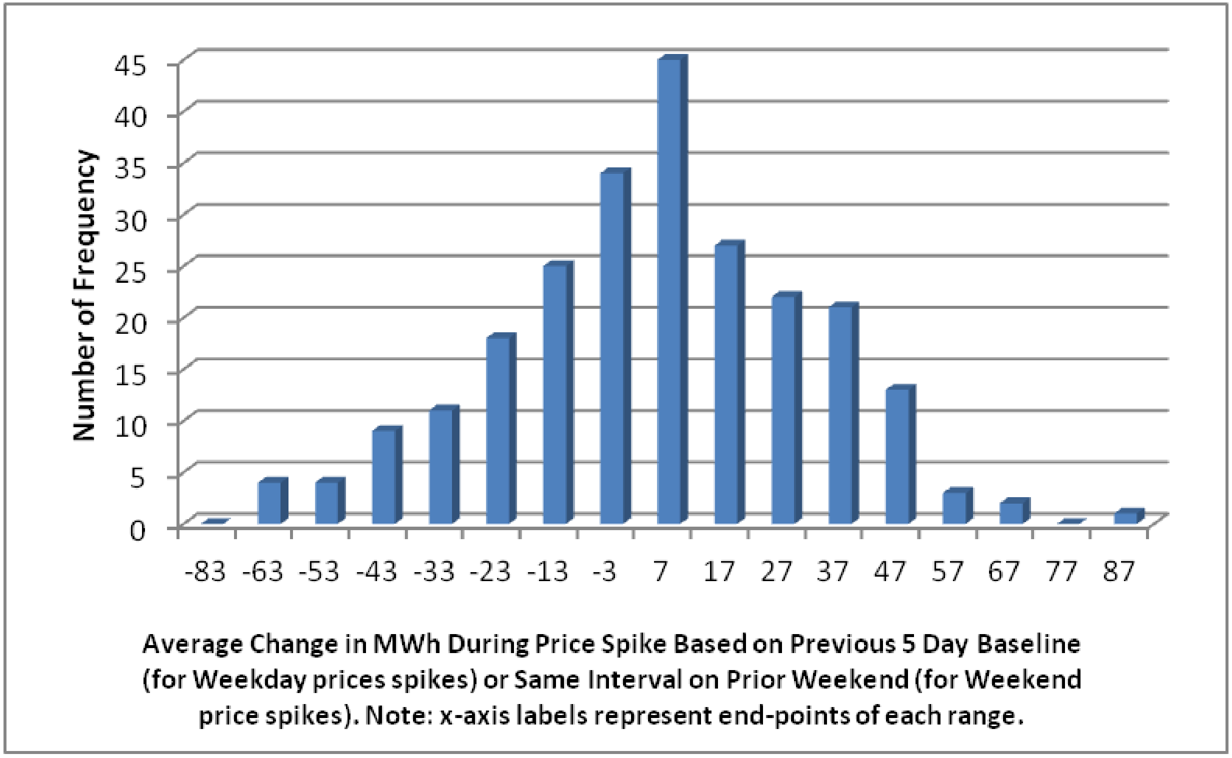


Figure 6 shows the change in energy consumption by energy consumers served at transmission voltage during every price spike since January 1, 2007 and further demonstrates how difficult it is to detect any response by large industrial energy consumers to price changes in the ERCOT market. The vertical axis measures the increase or decrease in consumption by this group of consumers, relative to their average consumption during the same intervals of the five previous weekdays (if the price spike fell on a weekday) or the one interval of the previous weekend (if the price spike fell on a weekend). The horizontal axis shows the price level on the first interval of the price spike. Often when consumption goes up during a price response, a rational response would be to reduce consumption. Presumably, many of these industrial energy consumers are not exposed to wholesale market prices and have no incentive to respond.

Figure 6

Average Reduction for Energy Consumers served at Transmission Voltage Based on Previous 5 Day Baseline or Same Interval as Previous Weekend Day if Weekend for all Price Spikes Since January 2007

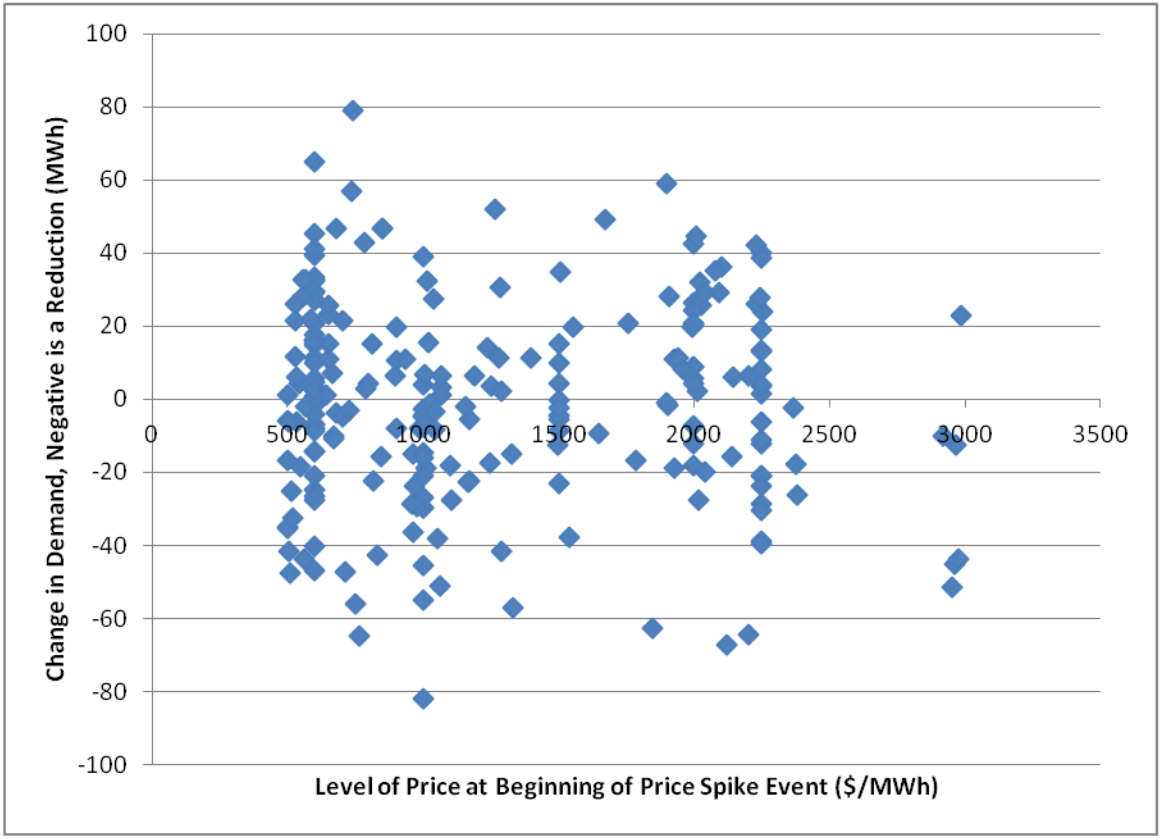
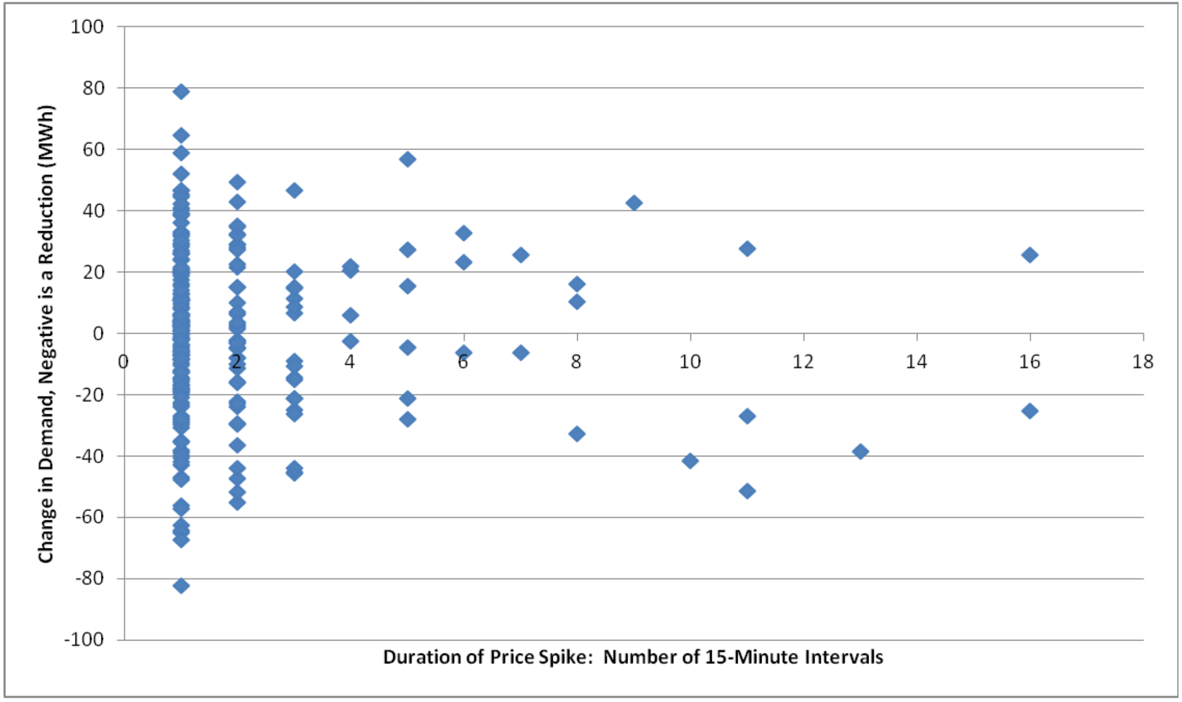


Figure 7 provides further evidence that any relationship between the demand reduction achieved and the length of a price spike is very weak.

Figure 7

Average Reduction for Energy Consumers served at Transmission Voltage based on Previous 5 Day Baseline or Same Interval as Previous Weekend if Weekend vs. Length of Price Spike Event for all Price Spikes Since January 2007



A regression model was used to determine whether there was any relationship between demand by large industrial consumers and wholesale price spikes. The observations used in the estimation were 15-minute intervals from Jan. 2007 through mid-2012 where the wholesale electricity price was greater than $500 /MWh in the North (largest) Zone in the ERCOT market and that did not coincide with deployment of responsive reserves or a system emergency. Representing the Price in the North Zone at the Start of the Price Spike, the duration in 15-minute intervals of the price spike and the Transmission kWh at the Start of the Price Spike were also included.

As can be seen from Table 1, there is no statistically significant relationship between changes in demand during a price spike, and the level of prices during the spike or the duration of the price spike.

Table 1

Demand Reduction as a function of Price Level, Duration of Spike, and Demand Level at Beginning of Price Spike

Regression Statistics	
Multiple R	0.305833
R Square	0.093534
Adjusted R Square	0.081962
Standard Error	26043.44
Observations	239

ANOVA

	df	*SS*	*MS*	*F*	*Significance F*
Regression	3	1.64E+10	5.48E+09	8.082852	3.8E-05
Residual	235	1.59E+11	6.78E+08		
Total	238	1.76E+11			

	Coefficients	*Standard Error*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*
Intercept	-91563.1	19901.37	-4.60085	6.88E-06	-130771	-52355.2
Price in North Zone at Start of Price Spike	-1.5023	2.508742	-0.59883	0.549865	-6.4448	3.440197
Duration in Intervals	-1046.44	730.9182	-1.43168	0.153563	-2486.43	393.545
Transmission kWh at Interval at Start of Price Spike	0.115066	0.023775	4.839831	2.35E-06	0.068227	0.161905

Analysis Using a Baseline Reflecting Consumption in Interval Prior to Price Spike

Frontier also analyzed the period prior to a spike as the baseline from which to calculate the amount of demand reduction during a price spike. The picture is no clearer, as can be seen from Figure 8. There is no relationship between the demand reduction achieved and the length of a price spike.

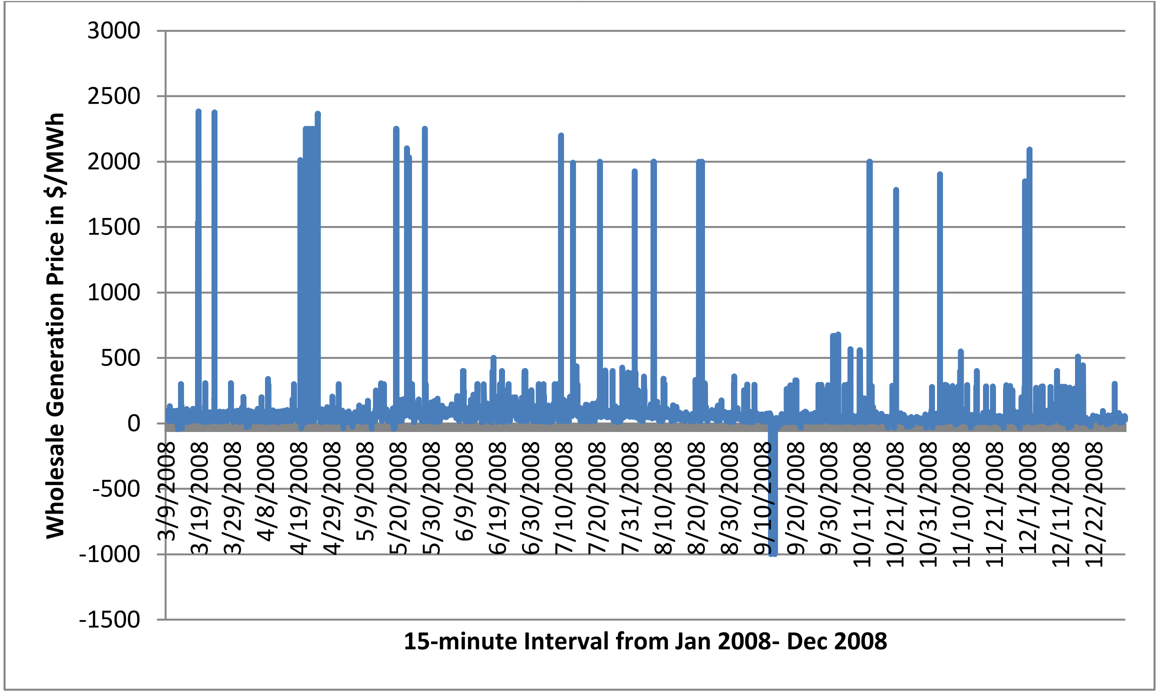
Figure 8

Change from Previous Interval to First Interval of Price Spike, for Energy Consumers served at Transmission Voltage for all Price Spikes Since January 2007

Additionally, our data suggested that price spikes can occur at any time. Figure 9 represents the randomness of price spikes (prices rise over $500/MWh in a 15-minute interval) in a sample year 2008.

Figure 9

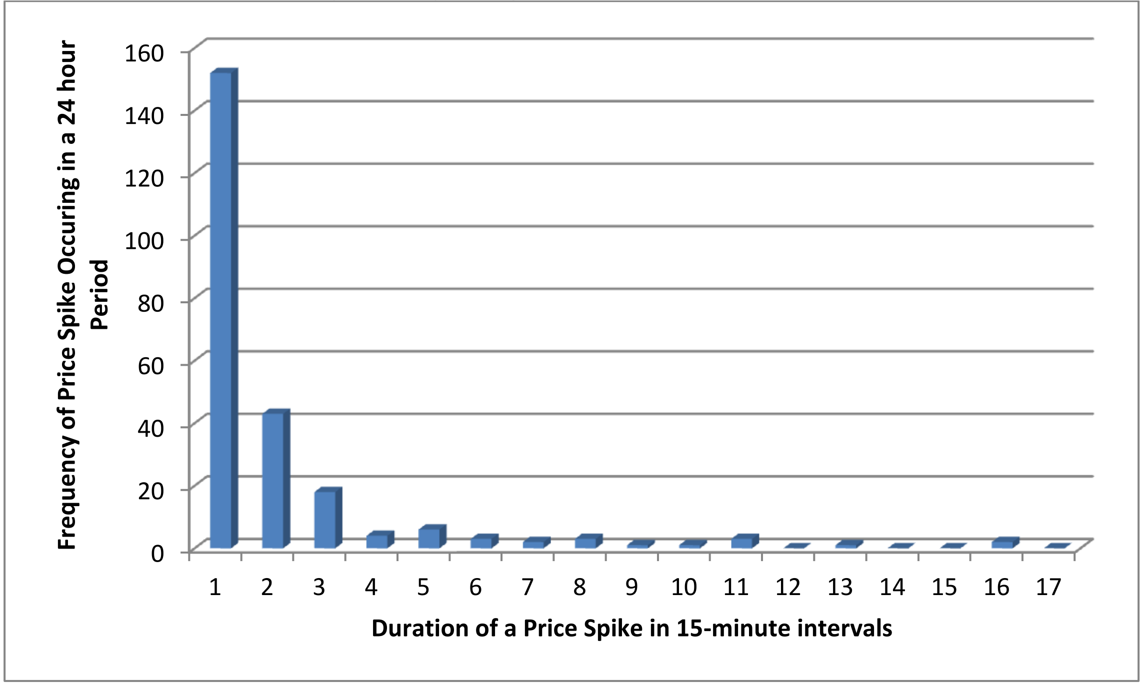
Wholesale Generation Prices May Spike at Any Time



Finally, Figure 10 below shows that the duration of a price spike can be any length of time, from a single 15-minute interval, to over a day in length.

Figure 10

Duration of Price Spikes May be Any Length



Conclusions

Our research has illustrated that most industrial energy consumers served at transmission voltage do not significantly reduce their energy consumption in response to a price spike in the wholesale market. To these customers, the savings from reducing consumption during a price spike in wholesale generation prices is difficult to estimate, and with the implementation of the nodal market, hard to predict. Because of these uncertainties, many (if not, most) large energy consumers hedge their price risk with fixed price contracts, and thus have little incentive to respond to wholesale generation prices. In contrast, wholesale generation prices may spike at any time of the year, as Figure 9 exhibits using data for 2008 as an example, and at any time of the day. The duration of most price spikes is typically a single 15-minute interval, as is evident from Figure 10. This makes it very difficult to respond to wholesale generation price signals, especially now that advance notice of settlement prices has been eliminated.