ABSTRACT

GOUGING IN THE MIDWEST? AN ANALYSIS OF THE PROPANE MARKET

by Brandon Andrew Miller

The Midwestern United States in the winter of 2013-14 experienced a 42% increase in the real price of propane from the previous year’s winter. I explore whether this increase may have been partially attributable to firms opportunistically exporting to Japan. After developing a novel theoretical competitive model of supply, I use instrumental variables to estimate supply and demand for the Midwestern propane market using annual data. I then perform a residual analysis that suggests that competitive market factors are most likely the cause of the increase in prices. I repeat this analysis with a more granular data set under a different identification strategy. Further residual analysis predicts that the Midwest did experience a propane reduction in the winter of 2013-14 of about 16%; however, this could have been caused by either opportunistic market power or long-term energy contracts.
GOUGING IN THE MIDWEST? AN ANALYSIS OF THE PROPANE MARKET

Thesis Report

Submitted to the

Faculty of Miami University

in partial fulfillment of

the requirements for the degree of

Master of Financial Economics

by

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2017

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This Thesis report titled

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has been approved for publication by

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# Table of Contents

List of Tables iv  
List of Figures v  
Dedication vi  
Acknowledgements vii  
Introduction 1  
Literature Review 4  
Competitive Theory Model 6  
Data 9  
Method 11  
Results 14  
Residual Analysis 20  
Conclusion 21  
Mathematical Appendix 23  
Table Appendix 27  
Figure Appendix 32  
References 38
## List of Tables

### Initial Analysis
- Summary Statistics: Levels 27
- Summary Statistics: Logs 27
- First Stage Regressions 28
- Demand Structural Regressions 29
- Supply Structural Regressions 29

### Extended Analysis
- Summary Statistics 28
- First Stage Regressions 30
- Demand Structural Regressions 30
- Supply Structural Regressions 31
List of Figures

Regional Sales and Deliveries of Propane 32
Year Over Year Propane Price % Change 32
US Weekly Propane Production Estimates 33
CPI Adjusted Weighted Average Residential Propane Price 33
Japanese Energy Production 34
Regional Share of Total Exports-Propane 34
U.S. Exports of Propane to Japan 35
Winter Accumulative Heating Degree Days 35
Midwest Propane Supplied to the Midwest-Winter Months 36
Residuals-Propane Supply: Initial Analysis 36
Supply Residuals Oct 2010-March 2016: Extended Analysis 37
Dedication

I dedicate this paper to Kevin, Julie, and Logan Miller, who gave me the inspiration and taught me the work ethic required to successfully compete this project.
Acknowledgements

I would like to acknowledge and thank Dr. Charles Moul for his constant support and guidance throughout the entire project. His knowledge of the field and econometric expertise was invaluable to my success.

I would like to acknowledge and thank Dr. James Brock for his guidance and wisdom throughout the project. I am honored to work with a man with such acclaim and practical experience in the field.

I also would like to acknowledge and thank Dr. Gerald Granderson for his inspiring optimism throughout my time at Miami. I have always found our conversations to be reassuring and uplifting.

I lastly would like to thank the entire economics faculty, especially Dr. George Davis for his suggestion on how to switch from annual to monthly data.
I Introduction

The winter of 2013-4 was the Midwest’s coldest since 2002 and one of the most severe since the 1970s. Over December 6-10 alone, more than 100 snowfall records were broken across the United States. Intense cold and blizzard warnings were frequent, and such abnormalities occurred deep into March of 2014, even pushing into April. Given these conditions, Midwestern residents in the most rural areas relied heavily on their most prominent source of off-the-grid home heating: Propane. The Midwestern states use this energy source more than any other part of the country, averaging almost a third of the national propane consumption despite having only one-fourth of the nation’s population (See Figure 1). Increases in the price of propane during such a severe winter were to be expected, but the extent of this price surge was still a surprise. The real price of propane in the Midwest increased by an astounding 42%, reaching record levels (See Figure 2). An increase to this level suggest the possibility of other forces at play, perhaps opportunistic supply restrictions on the part of propane retailers and producers. My research aims to provide evidence as to whether this type of manipulation occurred in the winter of 2013-14.

I a. Market Conditions

Propane is a byproduct in the refining process of both crude oil and natural gas, and thus its supply has fluctuated with the market for these commodities (See Figure 3). The relationship between propane, crude oil, and natural gas supply is dictated by chemistry and technology and so has been relatively constant over time. With the introduction of hydraulic fracturing (fracking), natural gas and crude oil production has increased substantially in the last ten years. Average per-month crude oil production has increased by 28% since 2010 in the United States, and average per-month natural gas production has grown by 24% in the same period. Propane production has followed a similar course: Average per-month production in the United States has increased by 26% in the same period.
On the demand side, the market for off-the-grid (outside of the area serviced by gas heating capabilities) home heat in the Midwestern states was dominated by retail propane distributors not too long ago. In recent years, though, companies such as Duraflame and EdenPURE have developed “space” heaters. These products are powered by electricity, unlike previous such heaters, and are designed to heat rooms in a house at a time. Another group of companies are developing renewable energy heating systems such as wind and sunlight energy to heat homes, though these sources have not expanded to the level of Duraflame or EdenPure. At any rate, new, innovative, and potentially less expensive sources of heat have weakened the market share of propane retailers across the Midwest by creating a more competitive atmosphere for people to make choices regarding home heating. According to the Propane Education and Research Council, demand for space heaters will continue to increase due to an influx of new house building in the coming future. Thus, demand for propane has dipped on trend in recent years, to the tune of a 11% decrease in the Midwestern propane sales and deliveries from the previous two decades to the current decade.

I b. Motivation

The previous market picture of increased supply and decreased demand has a seemingly strong theoretical downward prediction for the direction of prices in the Midwestern propane market. This, however, has not been the case. The Midwestern propane price has been steadily increasing by around 4% per year from 2001 to 2013 (See Figure 4). This general trend was capped during the winter of 2013-2014 when the real winter price of residential Midwestern propane increased by an extreme 42% from the previous winter. This apparent contradiction with theory is the question that I am exploring in this study. While I believe that both supply and demand factors are at play, my aim is to determine whether the price increase was brought about by purely competitive economic factors or whether there was also a source of market power in Midwestern propane production that exacerbated the problem.

Before exploring the elasticities of supply and demand to determine the cause of the Midwestern propane price increase, I must first develop intuition on what economic
factors might have led to such a price elevation. The primary factor that I propose as the source for the price increase is the Fukushima nuclear disaster in Japan. On March 11, 2011, a 15-meter tsunami weakened the power supply and cooling systems of three nuclear reactors at the Fukushima Daiichi location, causing all three cores to melt within three days. Shortly after the incident, the Japanese government began shutting down nearly all of its other reactors, a move that ultimately cost Japan almost two-thirds of its domestic energy production (See Figure 5). Given this circumstance, Japan required a new source of energy practically overnight. At that point the United States, especially the Midwest, began exporting propane at a much higher rate (See Figures 6 and 7). The competitive null hypothesis posits that it was the combination of this increased demand from Japan and the onset of one of the coldest winters on record that caused a market-driven storm leading to the price increase that the Midwest observed.

To expand my hypothesis, I first develop a theoretical price-taking model for a propane producer in the Midwest. Using the assumption of increasing marginal cost of production and knowledge of the Japanese Energy market, I predict that the quantity of propane supplied to the Midwest changes negatively with Japan’s propane price. Next, I estimate elasticities of yearly supply and demand for Midwestern propane using a simultaneous equation approach with instrumental variables to control for the endogenous price. I perform a residual analysis to provide evidence in support of a competitive story rather than one of market power. I then repeat this analysis by expanding to monthly data rather than yearly. I accomplish this by creating a dummy variable to represent the extreme reduction in energy production in Japan after Fukushima. I then perform residual analysis of the supply residuals and find negative residuals in February and March of 2014 that are both one standard deviation below the mean of 0. This suggests that the Midwest did experience a reduction of supply in the winter of 2013-14; however, this reduction could have been caused by either opportunistic market power or energy contracts that prevented the change in propane distribution from Japan to the Midwest.
II Literature Review

The central idea of my research is attempting to estimate supply and demand of a competitive fossil fuel market using the simultaneous equation method to solve identification problems within the relationship between the propane price and the product supplied and demanded. Because both sides of the market determine price, there exists simultaneity bias when using OLS for estimation. This bias tends to generate elasticities upward for demand and downward for supply because the prices may be correlated with error terms. Using IV estimation allows me to remove this bias and find the true causal effect of prices on supply and demand. This method has been employed often within the literature to estimate supply and demand; however, no work has been done in the realm of propane. There, however, have been a few who have developed similar models to mine to estimate price elasticities of other fossil fuels.

Lin (2011) attempts to estimate world oil supply and demand using four main econometric techniques, one being a simultaneous-equation two stage least squares method. Lin’s motive is to use this technique to account for the identification problem that one faces when estimating supply and demand and to apply the method to the oil market. She also utilized a three stage least squares method to provide both identification and efficiency. She makes the assumption that the world oil market is perfectly competitive and static in order to test whether the market behaves in purely competitive fashion or whether it displays characteristics of an oligopoly nature. Her results are mixed. The OLS and 2SLS estimates of the price elasticity of demand for world oil are negative; however, the OPEC price specification in the 3SLS estimates returns a positive demand elasticity. When estimating supply, price elasticity coefficients using the OLS method return negative signs, while 2SLS and 3SLS estimators show insignificant positive signs, consistent with perfectly inelastic supply. These results, especially those on the supply side, support the use of instrumental variables as a method for correcting simultaneity bias. The sign of the price elasticity of supply coefficient shifted from being inconsistent with theory to consistent with theory after implementing IV estimation.

Krichene (2005) attempts a similar analysis to Lin, developing price elasticities of supply and demand in the world oil market using a simultaneous equation framework to
account for bias. Like Lin, he also assumes perfect competition; however, Krichene links elasticities of supply and demand for oil to interest rates and exchange rates. His studies find very low elasticities of supply (0.02) and demand (-0.04) for world oil. This suggests very inelastic supply and demand for crude oil, which is consistent with other estimates in the literature. His study is valuable to mine because he confirms the inelastic supply and demand of fossil fuels that has been the general consensus in the literature. My estimates for supply and demand elasticities are more elastic than Krichene’s estimates; however, propane’s byproduct nature possibly explains this difference on the supply side.

Hughes, Knittel, and Sperling (2006) also attempt to estimate supply and demand of a fossil fuel using instrumental variables. They apply the technique to gasoline prices across two different time periods to estimate whether consumer behavior has changed over the years. An important aspect of their analysis was to determine whether changes in price were supply or demand driven, which I do in my study when estimating the relationship between the supply shock in the Japanese energy production and change in Japanese propane prices. In their IV analysis, they find price elasticities of demand of around -0.07 in the United States. This is much more inelastic than my estimates for the Midwestern propane market; however, this is expected because of the greater number of options or substitutes in the home heating industry than in the market for automobile fuel. As in Krichene, Hughes et al. (2006) demonstrates that fossil fuel price elasticities can be estimated using instrumental variable techniques to remove simultaneity bias.

Borenstein, Bushnell, and Wolak (2002) provides an example of a paper that examines a similar question to mine. They study the wholesale electricity market from June 1998 to October 2000 in California to analyze a period of pricing levels far greater than one would expect of a competitive market. These increasing prices occurred in the summer months when demand for electricity is at its peak. This story is similar to my study examining winter months in the Midwest when propane demand is at its greatest levels. They try to determine if there is evidence of unilateral market power on display in the hands of the wholesale producers of electricity in California. Through a process of decomposition of wholesale electricity payments into different operating costs and market power, they find that 59% of the price increase in the summers of 1998 through 2000 in California was due to unilateral market power being exerted on the market by
electricity producers. This paper provides good insight for my examination of the Midwestern propane producers and their potential unilateral market power exertion in the winter of 2013-14.

From the literature, I gain confidence that using a simultaneous-equations method will be a sufficient approach to estimating price elasticities of supply and demand in the Midwestern propane market. The papers that I have referenced all employ this technique and mitigate bias as expected, and my results for the movement of coefficients from OLS to IV estimation are consistent with the previous papers, especially Lin (2011) on the supply side. Previous work is also valuable to me given their assumptions of perfectly competitive markets, which my research is exploring in the context of the Midwestern propane market. I begin my analysis with a discussion of a model for the competitive theory, followed by a discussion of data collected and the empirical results that I estimate.

III Competitive Theory Model

My model aims to explain the production and distribution decision facing a representative price-taking propane producer in the Midwest. The firm must first decide the total amount of propane to produce. Following the production decision, the producer must determine the quantity of propane to distribute to the Midwest and to Japan. I assume that production (refining) costs do not depend on the destination of the product and that the production of propane exhibits increasing marginal costs. The difference in cost arises on the distribution side, where we allow shipment of product to Japan differ from (presumably be costlier than) shipment of the product to local retailers for Midwestern sales and deliveries. We assume that all cost functions are increasing and convex, and thus that there are increasing marginal costs to produce propane and to distribute it.

The producer’s objective function can be modeled as:

$$\max_{q_{MW}, q_J} \pi = p_{MW} q_{MW} + p_J q_J - C(q_{MW} + q_J) - c^D_{MW}(q_{MW}) - c^D_J(q_J) \quad (#1)$$
in which the overall profit of the natural gas producer from the production of propane is equal to the revenue from both Midwestern and Japanese propane sales less the cost of production of the combined supply and less the (potentially differing) costs of distribution of propane to the Midwest and Japan. The decision by the producer shapes the difference between the amount of propane that is produced in the Midwest and the amount that remains in the Midwest for consumption after distribution to Japan.

My goal in this model is to estimate how the Midwestern quantity supplied affects the Midwestern propane price and also how the Japanese energy market affects the Midwestern quantity of propane. Given this, I am primarily interested in two comparative statics:

1. the change in Midwestern quantity with a change in Midwestern price \( \frac{dq_{MW}}{dp_{MW}} \), and
2. the change in Midwestern quantity with a change in the Japanese propane price \( \frac{dq_{MW}}{dp_J} \).

I obtain these relationships by finding and totally differentiating the first order conditions and then employing Cramer’s rule to compute the comparative statics. This work can be found in the mathematical appendix.

The resulting comparative statics are as follows:

\[
\frac{dq_{MW}^*}{dp_{MW}} = \frac{C''(q_{MW}^* + q_J^*) + c_J''(q_J^*)}{[C''(q_{MW} + q_J)] \ast [c_J''(q_J^*) + c_{MW}''(q_{MW}^*)] + [c_{MW}''(q_{MW}^*) \ast c_J''(q_J^*)]} > 0 \tag{2}
\]

in which I show that, based upon my model, the Midwestern quantity supplied of propane is increasing in the Midwestern propane price. The denominator is the determinant of the matrix of second derivatives with respect to the Midwestern and Japanese quantity supplied; it is strictly positive given an interior optimum which is guaranteed by the assumption that production cost functions and distribution cost functions are both strictly convex. This result is intuitive: when offered a higher Midwest price, the producer finds it profitable both to increase production and to shift propane from Japanese exports to the Midwest, thus reducing marginal costs of distribution to Japan.
My second comparative static of interest is:

\[
\frac{dq_{MW}}{dp_J} = \frac{-C''(q_{MW} + q_J)}{[C'(q_{MW} + q_J)] + [C''(q_{MW}) + C''(q_J)]} < 0 \quad (3)
\]

The Midwest quantity of propane distributed to the Midwest is decreasing in the Japanese propane price, as increasing marginal costs of production cause increased exports to Japan to crowd out propane retained for the Midwest.

As I described earlier, Japanese energy production plummeted after the Fukushima nuclear disaster in March of 2011, decreasing the domestic energy supply in Japan by almost two-thirds. Because a price increase in the Japanese propane market can be justified as a purely supply driven occurrence given the magnitude of the reduction in energy production, using Japanese Energy production as an inverse proxy for the Japanese propane price is not unreasonable. The average temperature in Japan over the past 20 years in the month of January is 42 degrees Fahrenheit with a standard deviation of about 1.6 degrees. February temperatures are similar, with a 20 year average of 44 degrees Fahrenheit with a standard deviation of 1.6 degrees. Given fairly constant winter temperatures over time in Japan, I can predict that any changes to the Japanese propane price stem from supply rather than demand factors. Using the comparative static found above \(\left(\frac{dq_{MW}}{dp_J} < 0\right)\), I show that as long as there are increasing marginal costs of producing propane that forces exports to Japan to crowd out shipments to the Midwest, I should see a decrease in quantity supplied to Midwestern consumers with the sharp decrease in the Japanese energy production after the Fukushima disaster. I will now describe the data and methodology used to investigate the merit of this theory.
IV Data

IV. a. Initial Analysis

I collected yearly data from 1999 to 2016. For all variables besides price and Japanese energy production, data are accumulated from the heating months in each year (October through March) and listed with the year in which that winter began. Japanese energy production data is collected by calendar year. Price data are developed using a weighted average of the price in each heating month multiplied by the amount of sales and deliveries of propane that occurred in each month. Each weighted price is divided by the CPI to find real prices. The data come from the Energy Information Administration, except for Heating Degree Days which are gathered from weatherdatadepot.com. The reason for the coarse unit of observation (year) and consequently small sample is that Japanese energy production data is limited to yearly observations. Summary statistics for the data are displayed in Table 1.

The first variable listed is Quantity Supplied to the Midwest (Figure 9), which denotes the amount of propane in thousands of gallons that are available for Midwestern consumption after exports to other countries and regions within the United States. The second variable is the Quantity Demanded variable, which can be described as prime supplier sales and deliveries of propane to Midwestern consumers for final use. The mean value of these two variables do not match because producers maintain reserve supply in the form of inventories. The third variable listed in the table is Real Propane Price. The fourth variable is Heating Degree Days, which is a proxy for how much heating energy was used at a location during a time period. A greater number of Heating Degree Days indicates a colder winter (Figure 8). I use the heating degree days from the Lima, OH, weather station because all considered Midwestern weather stations were highly correlated, and I am most familiar with this location. The fifth and final variable in the table is Japanese Energy Production (Figure 5), which is measured in quadrillions of British thermal units. I have log transformed all of the variables in order to find elasticities.
of supply and demand. I will be using the log-transformed variables for all results, and the summary statistics for the log variables are in Table 2.

**IV. b. Extended Analysis**

In my secondary analysis, I collect data monthly data from 1999 to 2016. Summary statistics for these variables are listed in Table 3. Most variables are the same as my original analysis, but there are a few exceptions. The propane prices are now indexed to the price from January of 1999 using the Midwest regional consumer price index from the Bureau of Labor Statistics. *Japanese Energy Production* has been replaced by a binary variable called *Tsunami* that holds a value of 1 for every month equal to or after March of 2011. The variable holds a value of 0 for all previous months. I am able to use this type of variable because of the seemingly on-off relationship between *Japanese Energy Production* before and after the Fukushima nuclear disaster in March of 2011. Leveraging this type of variable also allows me to use monthly observations rather than yearly. There are, however; a few drawbacks of using a dummy variable in this case. Given that the change from the peak of Japanese energy production to total reduction is not instantaneous but rather over a period of two years, there are likely negative implications of treating this gradual decrease in production as binary. This has the potential to weaken the IV estimation. Another drawback to this method is losing some mild continuous variation in the Japanese energy production over time. This could cause a loss in potential precision which could also weaken the IV estimation. Despite these negative consequences, the benefit of a more robust dataset outweighs the potential incremental losses from turning a continuous variable into a dummy variable.

I include the variable *Midwestern Natural Gas Residential Price* to capture the substitution effect between propane and natural gas in the Midwest. This variable is log transformed in my model. *Midwestern Natural Gas Withdrawals* is also included to control for the effect of natural gas production on propane production and is also log transformed. Oil prices and production are not included in the model because heating oil is very rarely used in the Midwest for home heating. I also develop a quadratic term for the \( \ln(\text{Heating Degree Days}) \) variable that was used in my original specification. This is
to account for potential non-linear relationships between propane demand and heating degree days. Monthly fixed effects and a yearly time trend variable are not used because the amount of propane demanded by consumers is not in response to a specific month, but rather to the temperature. Therefore, accounting for more of the variation in demand using polynomial terms of degree days is a more realistic estimation than month or year dummies.

V Method

V. a. Initial Analysis

Following the literature, the method that I use for my analysis is a two stage least squares model of simultaneous equations. I use this model to solve the identification issues that arise when estimating demand and supply when facing an endogenous price. I first run first stage regressions with the Quantity Supplied to the Midwest, Quantity Demanded, and Real Propane Prices as dependent variables regressed on Japanese Energy Production and Heating Degree Days.

Our First Stage regression equations are listed below:

\[
\ln Price_t = \rho_0^P + \rho_1^P \times \ln Heating Degree Days_t + \rho_2^P \times \ln Japanese Energy Production_t + u_t^P
\]

\[
\ln Q_t^D = \rho_0^D + \rho_1^D \times \ln Heating Degree Days_t + \rho_2^D \times \ln Japanese Energy Production_t + u_t^D
\]

\[
\ln Q_t^S = \rho_0^S + \rho_1^S \times \ln Heating Degree Days_t + \rho_2^S \times \ln Japanese Energy Production_t + u_t^S
\]

These equations reveal the reduced form relationship between the endogenous variables and the exogenous ones. That is, \( \rho_1 \) in each of the equations estimates the associative relationship between the endogenous variable and \( \ln(Heating Degree Days) \). Also, \( \rho_2 \) in each of the equations estimates the associative relationship between the endogenous variable and \( \ln(Japanese Energy Production) \). I will use the fitted (log) real price values from this first stage regression to estimate supply and demand in the structural forms listed at the top of the next page.

I use the following equations to estimate the Midwest’s demand and supply of propane:

\[
\ln Q_t^D = \alpha_0^Y + \alpha_1^Y \times \ln Price_t + \alpha_2^Y \times \ln Heating Degree Days_t + \varepsilon_t^D
\]

\[
\ln Q_t^S = \beta_0^Y + \beta_1^Y \times \ln Price_t + \beta_2^Y \times \ln Japanese Energy Production_t + \varepsilon_t^S
\]

Demand is explained by the Midwest’s propane price, as well as the winter’s severity. The same price variable also affects \(\ln(Quantity Supplied)\), and I control for \(\ln(Japanese Energy Production)\). The parameters \(\alpha_1^Y\) and \(\beta_1^Y\) in the demand and supply equations respectively estimate the causal effect of a change in price on the change in demand and propane supplied to the Midwest. The parameter \(\alpha_2^Y\) in the demand equation estimates the causal effect of a change in the amount of heating degree days that the Midwest faces on the quantity of propane demanded in the Midwest. The parameter \(\beta_2^Y\) estimates the causal effect of a change in the amount of energy produced by the Japanese on the quantity of propane supplied to the Midwest.

V. b. Extended Analysis

Similar to my original analysis, the method that I use for my extended dataset is a two stage least squares model of simultaneous equations. I use this model to solve the identification issues that arise when estimating demand and supply using price, which is an endogenous variable in this case. My first stage regressions are very similar to those from my original analysis, although they include some extra controls. I include \((\ln(Heating Degree Days))^2\) and Tsunami (replacing Japanese Energy Production) variables as predictors of \(\ln(Propane Price)\). The variable \(\ln(Natural Gas Withdrawals)\) is used as an additional control on the supply side, and \(\ln(Natural Gas Price)\) is used as an additional control on the demand side.

The simultaneous structure equations that I will be using in this extended analysis are listed below:
\[
\ln(Q^D_t) = \alpha_0^M + \alpha_1^M \cdot \ln(\text{PropanePrice}_t) + \alpha_2^M \cdot \ln(\text{Heating Degree Days}_t) \\
+ \alpha_3^M \cdot (\ln(\text{Heating Degree Days}_t))^2 + \alpha_4^M \cdot \ln(\text{Natural Gas Price}_t) + \varepsilon^D
\]

\[
\ln(Q^S_t) = \beta_0^M + \beta_1^M \cdot \ln(\text{PropanePrice}_t) + \beta_2^M \cdot \text{Tsunami}_t \\
+ \beta_3^M \cdot \ln(\text{Natural Gas Withdrawals}_t) + \varepsilon^S
\]

Demand is explained by the propane price in the Midwest, as well as a control for heating degree days and its square and \( \ln(\text{Natural Gas Price}) \). I include the natural gas price because of the expected substitute relationship between propane and natural gas in homes that have the capability of switching one for the other. Quantity supplied is explained by the propane price along with controls for Tsunami and \( \ln(\text{Natural Gas Withdrawals}) \). The parameters \( \alpha_1^M \) and \( \beta_1^M \) in the demand and supply equations respectively estimate the causal effect of a change in price on the change in demand and propane supplied to the Midwest. The parameters \( \alpha_2^M \) and \( \alpha_3^M \) in the demand equation jointly estimate the causal effect of a change in the amount of heating degree days that the Midwest faces on the quantity of propane demanded in the Midwest. The parameter \( \alpha_4^M \) estimates the causal effect of a change in the natural gas price on the demand. The parameter \( \beta_2^M \) estimates the causal effect of the tsunami that caused the Fukushima nuclear disaster on the supply to the Midwest. The parameter \( \beta_3^M \) estimates the causal effect of a change in the natural gas withdrawals on the supply to the Midwest.

To return estimates that both provide the identification that I am seeking and are efficient, I will also implement a three-stage least squares method similar to Lin (2011). These results will be listed alongside my two-stage results, and will further aid my analysis.
VI Results

VI a. Results: Initial Analysis

VI a. a. First Stage Results

I present the first stage regression results in Table 4. I find that both exogenous controls are strong predictors of both quantity supplied and quantity demanded; however, they do not explain price in a statistically significant way. This result is consistent with the theoretical assumptions made when evaluating a perfectly competitive market. Theory suggests that quantity supplied by producers and demanded by consumers will adjust given changes in exogenous factors, resulting in an equilibrium quantity and price in the market. Given this assumption, it is believable that the quantities would be more associated with the control variables than would price, and that the quantity supplied and demanded would be equal at the market equilibrium and establish an appropriate market price.

VI a. b. Second Stage Results

I estimate second stage structural results using the fitted (log) real prices from the first stage regression. This solves the identification problem when estimating supply and demand and allows us to estimate the purely causal effect of prices on propane supply and demand. The second stage results for supply are shown in Table 5, and the second stage results for demand are shown in Table 6. These results include p-values that are adjusted for small sample size and standard errors that are robust to heteroskedasticity. Both tables include three columns of results. The first column contains the OLS estimates. The second column is also an OLS estimate but only uses the observations that match the years for which I have collected heating degree days and Japanese energy production data (i.e., those for which IV estimation is possible). This is done to show that the IV
estimation is not only significant due to a reduction in data. The third column contains the results of the 2SLS estimator.

In the second stage supply result, the price elasticity of propane supplied is now statistically significant and very elastic in magnitude. This highly elastic IV estimate of 2.72 is intuitive. Propane is a byproduct by nature and therefore is produced at every occurrence of crude and natural gas production. Producers will simply develop a stricter quality tolerance and burn off more unwanted supply when the price is low. If the market price of propane increases, producers will optimally capture more supply to sell in the market by relaxing the quality tolerance. The coefficient implies that a 10% change in price of propane in the Midwest causes the producers of propane in the Midwest to supply 27.2% more propane to consumers in the Midwest to take advantage of the higher price. I also note that the coefficient of *Japanese Energy Production* is statistically significant and positive. This is consistent with our theoretical model’s prediction that propane supply to the Midwest has a positive relationship with the movement of Japanese energy production through the Japanese propane price. The *Japanese Energy Production* coefficient also has a much greater effect than in either OLS estimation. This suggests that Japanese energy production and propane supplied to the Midwest potentially have a stronger relationship than one might have predicted from casual observation. This makes sense because the OLS results would take into account endogenous demand side effects that arise because of simultaneity, and the IV estimates allow for a pure effect on propane supplied to the Midwest after removing the endogenous effect of price.

One concern when estimating the relationship between the Japanese and Midwestern propane markets is the effect of exchange rates. If the yen-dollar relationship experiences a large shift in magnitude, incentives for Midwestern producers to distribute propane supply to Japan could be affected if they no longer could generate enough of a profit. In the context of this study, the exchange rate at the time of the Fukushima disaster was 83¥ to $1. This meant that the yen was strong and the Japanese people had greater purchasing power. However, by 2013 the rate became larger at 101¥ to $1. This weakened the purchasing power of the Japanese people with respect to American goods. A weak yen would only strengthen the market position of the Midwestern producers, allowing them to generate a greater profit from propane distributed to Japan. Because Midwestern
producers would have been helped by a weak yen in 2013, I believe that the exchange rate would have only exacerbated any unilateral market power exerted by Midwestern producers, and thus my estimates would be understating the true magnitude of such market power.

On the demand side, results are consistent with expectations and the literature. The IV results indicate an inelastic demand for Midwestern propane, which is consistent with the intuition that relevant Midwestern consumers are very reliant on propane to heat their homes. The coefficient can be interpreted as a 10% increase in the Midwestern propane price causes a 7.6% decrease in propane demanded in the Midwest. The coefficient becomes less inelastic, however, from the OLS estimates to the IV estimation, which is consistent with price capturing unobserved demand shocks. I also observe a significant \( \ln(\text{Heating Degree Days}) \) coefficient, which is also consistent with our theories. If people in the Midwest endure colder weather, they will demand a greater amount of propane to heat their homes. This coefficient becomes larger from the OLS estimates to the IV estimation. This is because the IV estimation removes any supply-side effects and allows for a pure relationship between degree days and propane demand. In other words, the IV estimation accounts for how consumers change their demand for propane with the onset of colder weather, regardless of supply-side uncertainties. This result is consistent because for price-sensitive consumers the heating degree days must have a larger impact on demand to offset the larger impact from the price increase.

**VI b. Results: Extended Analysis**

Similar to my original analysis, I estimate second stage structural results using the fitted (log) prices from the first stage regressions. This solves the identification problem when estimating supply and demand and allows us to observe the purely causal effect of prices on propane supply and demand. My first stage regression results can be found in Table 7. They are very similar to my initial analysis including a few more control variables. The second stage results for my extended analysis of demand are shown in Table 8, and the second stage results for supply are shown in Table 9. These results
include t-values and standard errors adjusted for serial correlation using Newey-West errors with a one period lag.

**VI b. a. Demand Results**

The Demand table includes seven columns. The first and second show the difference in coefficients and significance between demand and the price in the OLS and IV specification including only the heating degree days as a control. Moving from OLS to IV estimation, our propane price elasticity coefficient changed substantially and became highly statistically significant. The third column displays the specification in which I first include the quadratic heating degree days. This variable is included to better accommodate any potential non-linear relationship between demand and heating degree days. Because the coefficient on the squared term is significant, I determine that such a non-linear relationship does exist. The fourth column attempts to include a cubed \( \ln(\text{Heating Degree Days}) \) term to account for more variation; however, including this variable greatly worsens precision. Given this result, I will not include the cubed term in my final demand specification. In the fifth column, I include my final control for demand, the natural gas residential price. This coefficient is statistically significant and will be included in our final specification for demand. The sixth column adds \( (\ln(\text{Heating Degree Days}))^3 \), and again results are unsatisfactory. The seventh column includes my 3SLS results. I conclude that the fifth column will be my final estimates of demand.

The preferred demand results point to similar conclusions of my original analysis, and the 3SLS results further affirm my original results. The coefficient on price estimates the price elasticity of demand, which in this case displays a statistically significant inelastic demand. This is consistent with my original analysis’s price elasticity of demand, as people in the Midwest who are off of the electricity grid rely on propane for their home heat. In many situations, a propane heating system is built into their homes, so they do not have the capability to switch fuel types. This coefficient can be interpreted as a 10% increase in the real propane price causes a 6% decrease in the amount of propane demanded in the Midwest.
The impact of heating degree days is more difficult to interpret in this case because of the squared term. We generally assume that, as the number of heating degree days increases, the demand for propane also increases. Since coefficients on \(\ln(\text{Degree Days})\) and \((\ln(\text{Degree Days}))^2\) are both significant, I know that there is a non-linear relationship between the heating degree days and demand. To interpret this relation, I first take the partial derivative of the (log) demand function with respect to (log) heating degree days:

\[
\frac{d\ln(Q_t)}{d\ln(\text{HDD})}.
\]

Using the mean monthly heating degree days of my sample \(E(\ln(\text{HDD})) = 6.66\) and solving yields a mean elasticity of 0.73. The squared term’s positive coefficient can be interpreted as Midwestern people being more sensitive to winter as the winter gets worse.

The natural gas price coefficient, however, can easily be interpreted as a 10% increase in the natural gas price causes a 4.7% increase in the amount of propane demanded. This is consistent with theory because, for people who are able to switch between fuel sources, natural gas and propane would be substitutes. As the price of natural gas increases, consumers will start to switch to propane given that the propane price is unchanged, and vice versa. This relationship is represented by our results quite nicely.

**VI b. b. Supply Results**

The supply table includes four columns. The first two simply show the impact that the instrumental variables have when estimating the price elasticity of supply while including only the control for the tsunami. The IV results in the second column includes a price elasticity of supply that is much more elastic and statistically significant than the same measure in the OLS specification. This shows that the IVs have a large impact. The third column includes the control for natural gas withdrawals. The fourth column provides 3SLS results affirming my analysis. The third specification is the one that I use as my final specification for residual analysis.

The price elasticity of supply is very elastic. It can be interpreted as a 10% increase in the propane price causes a 30.5% increase in the amount of propane available to the Midwest for purchase. This estimate is consistent with intuition as well. Because propane
is a byproduct of crude and natural gas production, producers can determine the tolerance specification of the propane that they keep to sell in the market. The excess supply that is not stored is simply burned off. Given the ease with which propane can be disposed, the producer has the ability to widen or shrink the tolerance depending on the quantity of propane that he wishes to keep for sale. The elastic relationship between price and propane supplied represents such a producer decision.

The coefficient on Tsunami can be interpreted as, holding both the price and natural gas withdrawals constant, post-tsunami propane supply is 70% less per month in the Midwest than it was pre-tsunami. This seems fairly extreme; however, when one examines how closely the price of propane influences supply, holding supply constant when interpreting the tsunami coefficient is probably the primary cause of the extreme coefficient magnitude. This coefficient still suggests, nonetheless, that there was a significant average per-month decrease in the amount of propane available for Midwestern consumption after the tsunami caused the Fukushima nuclear disaster.

The coefficient on natural gas withdrawals term can be interpreted as a 10% increase in the amount of natural gas withdrawals in the Midwest causes a 12% increase in the amount of propane supplied to the Midwest for purchase. I would expect this coefficient to be almost equal to one since the ratio of propane produced for every unit of natural gas produced does not change. One explanation for why it is not perfectly unit elastic is that this coefficient could also be representing the amount of propane brought into the market by crude oil production as well, as oil production and natural gas production are positively correlated. Even though the Midwest does not generally see oil as a substitute for propane in the home heating market, there still would be some residual propane produced and brought to market from the crude oil production process.
VII Residual Analysis

VII. a. Initial Residual Analysis

At the outset of this study, I suggest that the upward trend and peak in the propane price in the Midwest could be a result of either purely competitive factors or of unilateral market power being exerted by producers through opportunistic exporting. To test whether there is any evidence of market power at play, I plot the residuals of the IV estimate of propane supply over time. These residuals are displayed in Figure 10. If the situation that I have described is consistent with the market power theory, then the residuals of the supply regression would be very negative in 2013. This is because a negative residual implies that the Midwest had access to less supply than the model predicts. In reality, the residuals from the yearly data tell a story that is consistent with purely competitive factors. The residual in 2013 is positive on the supply side. That is, the model predicts less propane supplied than what the Midwest observed in the winter of 2013. These results suggest that the drastic price increase for propane in the winter of 2013 in the Midwest was driven by competitive market factors rather than any producer market power. Much research still needs to be performed, however, to be sure that market power did not play any role. My extended residual analysis below offers such additional research that may be able to better explain the phenomenon in the Midwest during the winter of 2013-14.

VII b. Extended Residual Analysis

To provide a more robust answer to my question regarding the propane price in the winter of 2013-14, I analyze the residuals of my extended analysis’s final supply regression. The residual plot can be found in Figure 11. This figure displays the supply residuals for winter years 2012 through 2015. The vertical black lines identify the winter of 2013-14 that is the target of my analysis. The red lines display one standard deviation
of the residuals both above and below zero. As I explained earlier, a negative residual suggests that the Midwest experienced especially low supply; that is, it received less propane available to purchase than my model predicted. Figure 11 shows that January, February, and March of 2014 had negative residuals, with February and March being below one standard deviation negative. The negative residuals indicate that the Midwest received less propane than the model predicts. To be precise, the model predicts that in February of 2014 the Midwest had 16% less propane available for purchase than needed, which is below one negative standard deviation of the residuals.

This result suggests opportunistic market power could have caused the price increase through an artificial supply reduction. Another possible cause of the substantial supply shortage are long term energy contracts that cannot be changed regardless of the level of demand. To guarantee supply, consumers (primarily governmental, commercial, or foreign) will enter into long-term energy contracts with producers to supply them with a certain quantity of energy over a period of time settled upon by the two parties. This can be a positive deal for both sides, as the consumer is sure to have access to supply and producers are guaranteed steady cashflows; however, this type of contract reduces the amount of distribution flexibility on the part of the producer. Producers may consequently not be able to temporarily remove themselves from the contract given a weather abnormality such as the cold winter in the Midwest in 2013-14, thus leaving the afflicted area with little access to an emergency supply of energy. With either cause, this extended analysis confirms that the Midwest did in fact experience a substantial propane supply reduction in the winter of 2013-14 that potentially was not caused by natural market forces.

VIII Conclusion

After analyzing the Midwestern propane market, I find evidence that the drastic increase in the propane price in the winter of 2013 was potentially not due entirely to market forces, but rather in part to opportunistic market power by producers or long term energy contracts. I use simultaneous equation models with instrumental variables to
estimate the elasticities of supply and demand in the Midwestern propane market. I also show that heating degree days and Japanese energy production (*Tsunami*) are significant determinants of propane demand and propane supplied respectively. There could potentially be other factors that could affect propane supplied and demand in the Midwest for propane; however, our estimates seem to be consistent with theory and with the broader energy literature. I also show that the theory developed by our price-taking model of a Midwestern propane producer is consistent with our empirical study of the market. I acknowledge that there is still much more research that needs to be done in the future to more accurately estimate demand and supply elasticities of propane, potentially on a larger scale.
Mathematical Appendix: Theoretical Model Derivation

I would like to especially thank Dr. Charles Moul for assistance with the intuition behind this model.

A profit-maximizing natural gas producer in the Midwest is a price-taker in the propane market. The firm must decide how much of its produced propane it will distribute to Midwestern consumers and how much it will distribute to Japanese consumers. Cost of producing propane does not depend on its final destination; however, distribution costs may differ between the Midwest and Japan. We assume that distribution to Japan is costlier than distribution to the Midwest on a per unit basis. All cost functions in this model are increasing and convex. Assume the following objective function below:

\[
\max_{q_{MW}, q_J} \pi = p_{MW}q_{MW} + p_Jq_J - C(q_{MW} + q_J) - c_{MW}^D(q_{MW}) - c_J^D(q_J)
\]

in which \(p_{MW}\) and \(p_J\) are market prices of propane in the Midwest and Japan respectively and \(q_{MW}\) and \(q_J\) are quantities distributed to the Midwest and Japan respectively, \(C(q_{MW} + q_J)\) accounts for the combined production cost of the quantities shipped to the Midwest and to Japan, and \(c_{MW}^D(q_{MW})\) and \(c_J^D(q_J)\) are distribution costs for both the Midwest and Japan dependent on the quantity of propane distributed to each location. Taking the first order conditions of the above equation with respect to both quantities yields:

\[
FOC_{MW}: p_{MW} - C'(q_{MW}^* + q_J^*) - c_{MW}^D(q_{MW}^*) \equiv 0
\]
\[
FOC_J: p_J - C'(q_{MW}^* + q_J^*) - c_J^D(q_J^*) \equiv 0
\]

I am most interested in two specific comparative statics \(\frac{dq_{MW}}{dp_{MW}}, \frac{dq_{MW}}{dp_J}\), which I will construct with two separate applications of Cramer’s Rule.

The first application will be for \(\frac{dq_{MW}}{dp_{MW}}\), and I totally differentiate both first order conditions with respect to \(q_{MW}, q_J\), and \(p_{MW}\). This yields the following equations:
\[
(-C''(q_{MW} + q_j) - c''_{MW}''(q_{MW})) dq_{MW} - C''(q_{MW} + q_j) dq_j + 1p_{MW} = 0
\]
\[-C''(q_{MW} + q_j) dq_{MW}^* + (-C''(q_{MW} + q_j^*) - c''_j''(q_j)) dq_j^* + 0p_{MW} = 0
\]

Once I rearrange these equations and put them into matrix form, they become:

\[
\begin{bmatrix}
C''(q_{MW}^* + q_j^*) + c''_{MW}''(q_{MW}^*) & C''(q_{MW}^* + q_j^*) \\
C''(q_{MW}^* + q_j^*) & C''(q_{MW}^* + q_j^*) + c''_j''(q_j^*)
\end{bmatrix}
\begin{bmatrix}
dq_{MW}^*
dq_j^*
dp_{MW}
dq_{j}^*
\end{bmatrix} = \begin{bmatrix} 1 \\ 0 \end{bmatrix}
\]

Given my assumption that production cost functions and distribution cost functions are both strictly convex, the left-hand side matrix is positive definite with a determinant \(A > 0\), defined below.

\[
A = [C''(q_{MW}^* + q_j^*)] * [c''_{j}''(q_j^*) + c''_{MW}''(q_{MW}^*)] + [c''_{MW}''(q_{MW}^*) * c''_j''(q_j^*)]
\]

Now I apply Cramer’s Rule for the comparative static that I seek:

\[
\frac{dq_{MW}^*}{dp_{MW}} = \frac{C''(q_{MW}^* + q_j^*) + c''_j''(q_j^*)}{A} > 0
\]

This result shows that Midwest supply is increasing in the Midwest price because of both increasing marginal costs of production and increasing marginal costs of distribution to Japan. Increasing marginal cost of production will force the producer to choose a limited amount of propane to supply. She will then divide that supply between Japan and the Midwest optimally to maximize profits. Given an increase in Midwestern prices, the producer may be more inclined to sell more propane in the Midwest and vice versa. This would increase the propane supply in the Midwest for purchase by consumers. The producer would also determine an optimal amount of propane to distribute to Japan given increasing marginal distribution costs. This optimal amount of Japanese propane distribution would theoretically decrease given a price increase in the Midwest, resulting in greater supply for the Midwest.
In my second distinct Cramer’s Rule application, I differentiate both first order conditions with respect to $q_{MW}, q_j$, and $p_j$. This yields the following equations:

$$\left(-C''(q_{MW}^* + q_j^*) - c_{MW}''(q_{MW}^*)\right) dq_{MW}^* - C''(q_{MW}^* + q_j^*) dq_j^* + 0p_j = 0$$

$$-C''(q_{MW}^* + q_j^*) dq_{MW}^* + \left(-C''(q_{MW}^* + q_j^*) - c_j''(q_j^*)\right) dq_j^* + 1p_j = 0$$

Once I rearrange these equations and put them into matrix form, they become:

$$\begin{bmatrix}
C''(q_{MW}^* + q_j^*) + c_{MW}''(q_{MW}^*) & C''(q_{MW}^* + q_j^*) \\
C''(q_{MW}^* + q_j^*) & C''(q_{MW}^* + q_j^*) + c_j''(q_j^*)
\end{bmatrix} \begin{bmatrix}
dq_{MW}^* \\
\frac{dp_j}{dq_j^*}
\end{bmatrix} = \begin{bmatrix}
0 \\
1
\end{bmatrix}$$

Now I apply Cramer’s Rule for the comparative static that we seek:

$$\frac{dq_{MW}^*}{dp_j} = \frac{-C''(q_{MW}^* + q_j^*)}{A} < 0$$

This result explains that Midwest supply is decreasing in the Japanese propane price. This is intuitive because as the price of Japanese propane increases, producers in the Midwest will be more inclined to distribute more propane to Japan to take advantage of the increased revenue potential. Midwestern consumers would have access to a lesser supply of propane in such a situation given increasing marginal costs of propane production that restricts overall production.

Given market conditions in Japan in the energy market, I argue that Japanese energy production can be used as an inverse proxy for the Japanese propane price. Japanese energy production fell by two-thirds after the Fukushima disaster in March of 2011, and so this negative supply shock would naturally cause a drastic increase in Japanese propane prices. Given that temperatures over time in Japan are relatively constant, I assume that propane demand has been relatively constant across years. Because data are very limited on Japanese fuel source pricing and because the Japanese use myriad fuel sources, it is nearly impossible to gather the data for the Japanese propane price. Given this difficulty, the Japanese energy production is a good inverse proxy for the Japanese propane price.
Table Appendix

Table 1: Summary Statistics-Levels
Data Collected Yearly, Accumulated during Heating Months (Oct-Mar)

<table>
<thead>
<tr>
<th>VARIABLES</th>
<th>N</th>
<th>Mean</th>
<th>Standard Deviation</th>
<th>Min</th>
<th>Max</th>
</tr>
</thead>
<tbody>
<tr>
<td>Propane Supplied (Thousands of Barrels)</td>
<td>26</td>
<td>75869</td>
<td>9744</td>
<td>54131</td>
<td>91432</td>
</tr>
<tr>
<td>Propane Demanded (Thousands of Barrels)</td>
<td>26</td>
<td>90426</td>
<td>11590</td>
<td>66904</td>
<td>113797</td>
</tr>
<tr>
<td>Real Propane Price (Cents/Gallon)</td>
<td>26</td>
<td>0.73</td>
<td>0.19</td>
<td>0.45</td>
<td>1.08</td>
</tr>
<tr>
<td>Winter Heating Degree Days</td>
<td>18</td>
<td>5056</td>
<td>482</td>
<td>4076</td>
<td>5776</td>
</tr>
<tr>
<td>Japanese Energy Production (Quadrillion BTU)</td>
<td>25</td>
<td>3.77</td>
<td>0.89</td>
<td>1.625</td>
<td>4.67</td>
</tr>
</tbody>
</table>

Table 2: Summary Statistics-Logs
Data Collected Yearly, Accumulated during Heating Months (Oct-Mar)

<table>
<thead>
<tr>
<th>VARIABLES</th>
<th>N</th>
<th>Mean</th>
<th>Standard Deviation</th>
<th>Min</th>
<th>Max</th>
</tr>
</thead>
<tbody>
<tr>
<td>In Propane Supplied</td>
<td>26</td>
<td>11.23</td>
<td>0.14</td>
<td>10.899</td>
<td>11.42</td>
</tr>
<tr>
<td>In Propane Demanded</td>
<td>26</td>
<td>11.4</td>
<td>0.13</td>
<td>11.11</td>
<td>11.64</td>
</tr>
<tr>
<td>In Real Price (Cents/Gallon)</td>
<td>26</td>
<td>-9.56</td>
<td>0.27</td>
<td>-10.00</td>
<td>-9.14</td>
</tr>
<tr>
<td>In Winter Heating Degree Days</td>
<td>18</td>
<td>8.52</td>
<td>0.10</td>
<td>8.31</td>
<td>8.66</td>
</tr>
<tr>
<td>In Japanese Energy Production</td>
<td>25</td>
<td>1.29</td>
<td>0.32</td>
<td>0.486</td>
<td>1.54</td>
</tr>
</tbody>
</table>
### Table 3: Summary Statistics-Logs

Data Collected Monthly, Accumulated during Heating Months (Oct-Mar)

<table>
<thead>
<tr>
<th>VARIABLES</th>
<th>N</th>
<th>Mean</th>
<th>Standard Deviation</th>
<th>Min</th>
<th>Max</th>
</tr>
</thead>
<tbody>
<tr>
<td>In Propane Supplied</td>
<td>105</td>
<td>9.49</td>
<td>0.22</td>
<td>8.93</td>
<td>9.95</td>
</tr>
<tr>
<td>In Propane Demanded</td>
<td>105</td>
<td>9.56</td>
<td>0.26</td>
<td>8.76</td>
<td>10.05</td>
</tr>
<tr>
<td>In Real Price</td>
<td>105</td>
<td>0.27</td>
<td>0.24</td>
<td>-0.29</td>
<td>0.90</td>
</tr>
<tr>
<td>In Natural Gas Withdraws</td>
<td>105</td>
<td>12.20</td>
<td>0.18</td>
<td>0.18</td>
<td>12.79</td>
</tr>
<tr>
<td>In Real Natural Gas Price</td>
<td>105</td>
<td>2.00</td>
<td>0.25</td>
<td>0.25</td>
<td>2.87</td>
</tr>
<tr>
<td>In Winter Heating Degree Days</td>
<td>105</td>
<td>6.66</td>
<td>0.43</td>
<td>5.34</td>
<td>7.25</td>
</tr>
<tr>
<td>In Winter Heating Degree Days Squared</td>
<td>105</td>
<td>44.59</td>
<td>5.54</td>
<td>28.54</td>
<td>52.67</td>
</tr>
<tr>
<td>Tsunami</td>
<td>105</td>
<td>0.30</td>
<td>0.46</td>
<td>0</td>
<td>1</td>
</tr>
</tbody>
</table>

### Table 4: First Stage Regressions

<table>
<thead>
<tr>
<th>VARIABLES</th>
<th>(\ln(Q^S))</th>
<th>(\ln(Q^D))</th>
<th>(\ln(P^{Pro}))</th>
</tr>
</thead>
<tbody>
<tr>
<td>In Winter Heating Degree Days</td>
<td>0.76*</td>
<td>0.84**</td>
<td>0.28</td>
</tr>
<tr>
<td></td>
<td>(0.38)</td>
<td>(0.23)</td>
<td>(0.69)</td>
</tr>
<tr>
<td></td>
<td>(0.07)</td>
<td>(0.00)</td>
<td>(0.69)</td>
</tr>
<tr>
<td>In Japanese Energy Production (Quadrillion BTU)</td>
<td>0.26**</td>
<td>0.14**</td>
<td>-0.19</td>
</tr>
<tr>
<td></td>
<td>(0.06)</td>
<td>(0.05)</td>
<td>(0.15)</td>
</tr>
<tr>
<td></td>
<td>(0.00)</td>
<td>(0.01)</td>
<td>(0.22)</td>
</tr>
<tr>
<td>Observations</td>
<td>17</td>
<td>17</td>
<td>17</td>
</tr>
<tr>
<td>Adjusted R-Squared</td>
<td>0.50</td>
<td>0.52</td>
<td>-0.02</td>
</tr>
</tbody>
</table>

Notes: Significant coefficients are denoted with ** or * depending on significance at the 95% or 90% level. Coefficients are listed with heteroskedasticity robust standard errors and small-sample corrected p-values listed below in parentheses.
### Table 5: Log Quantity Supplied
Data Collected Yearly, Accumulated during Heating Months (Oct-Mar)

<table>
<thead>
<tr>
<th>VARIABLES</th>
<th>OLS (All Data)</th>
<th>OLS (Only 17 Years)</th>
<th>IV</th>
</tr>
</thead>
<tbody>
<tr>
<td>ln($P^{Pro}$)</td>
<td>0.03</td>
<td>-0.07</td>
<td>2.72*</td>
</tr>
<tr>
<td></td>
<td>(0.09)</td>
<td>(0.12)</td>
<td>(1.36)</td>
</tr>
<tr>
<td></td>
<td>(0.77)</td>
<td>(0.59)</td>
<td>(0.07)</td>
</tr>
<tr>
<td>ln Japanese Energy Production</td>
<td>0.22**</td>
<td>0.20**</td>
<td>0.77**</td>
</tr>
<tr>
<td>(Quadrillion BTU)</td>
<td>(0.06)</td>
<td>(0.06)</td>
<td>(0.30)</td>
</tr>
<tr>
<td></td>
<td>(0.00)</td>
<td>(0.00)</td>
<td>(0.02)</td>
</tr>
<tr>
<td>Observations</td>
<td>25</td>
<td>17</td>
<td>17</td>
</tr>
<tr>
<td>Adjusted R-Squared</td>
<td>0.20</td>
<td>0.25</td>
<td>---</td>
</tr>
</tbody>
</table>

Notes: Significant coefficients are denoted with ** or * depending on significance at the 95% or 90% level. Coefficients are listed with heteroskedasticity robust standard errors and small-sample corrected p-values listed below in parenthesis. Instrumental Variable used in IV Results column is ln(Heating Degree Days).

### Table 6: Log Quantity Demanded
Data Collected Yearly, Accumulated during Heating Months (Oct-Mar)

<table>
<thead>
<tr>
<th>VARIABLES</th>
<th>OLS (All Data)</th>
<th>OLS (Only 17 Years)</th>
<th>IV Results</th>
</tr>
</thead>
<tbody>
<tr>
<td>ln($P^{Pro}$)</td>
<td>-0.11</td>
<td>-0.13*</td>
<td>-0.76**</td>
</tr>
<tr>
<td></td>
<td>(0.08)</td>
<td>(0.07)</td>
<td>(0.27)</td>
</tr>
<tr>
<td></td>
<td>(0.21)</td>
<td>(0.08)</td>
<td>(0.01)</td>
</tr>
<tr>
<td>ln Winter Heating Degree Days</td>
<td>0.92**</td>
<td>0.75**</td>
<td>1.05**</td>
</tr>
<tr>
<td></td>
<td>(0.20)</td>
<td>(0.21)</td>
<td>(0.28)</td>
</tr>
<tr>
<td></td>
<td>(0.00)</td>
<td>(0.00)</td>
<td>(0.00)</td>
</tr>
<tr>
<td>Observations</td>
<td>18</td>
<td>17</td>
<td>17</td>
</tr>
<tr>
<td>Adjusted R-Squared</td>
<td>0.44</td>
<td>0.36</td>
<td>---</td>
</tr>
</tbody>
</table>

Notes: Significant coefficients are denoted with ** or * depending on significance at the 95% or 90% level. Coefficients are listed with heteroskedasticity robust standard errors and small-sample corrected p-values listed below in parenthesis. Instrumental Variable used in IV Results column is ln(Japanese Energy Production).
Table 7: First Stage Results
Data Collected Monthly, Accumulated during Heating Months (Oct-Mar), 105 Obs

<table>
<thead>
<tr>
<th>VARIABLES</th>
<th>ln(P&lt;sub&gt;Prev&lt;/sub&gt;)</th>
<th>ln(Q&lt;sub&gt;1&lt;/sub&gt;)</th>
<th>ln(Q&lt;sub&gt;2&lt;/sub&gt;)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tsunami</td>
<td>0.29**</td>
<td>-0.15**</td>
<td>-0.07</td>
</tr>
<tr>
<td></td>
<td>(0.07)</td>
<td>(0.04)</td>
<td>(0.05)</td>
</tr>
<tr>
<td>In Heating Degree Days</td>
<td>-0.36</td>
<td>-5.15**</td>
<td>-4.43**</td>
</tr>
<tr>
<td></td>
<td>(1.13)</td>
<td>(1.06)</td>
<td>(1.09)</td>
</tr>
<tr>
<td>(In Heating Degree Days)&lt;sup&gt;2&lt;/sup&gt;</td>
<td>0.05</td>
<td>0.43**</td>
<td>0.37**</td>
</tr>
<tr>
<td></td>
<td>(0.09)</td>
<td>(0.08)</td>
<td>(0.08)</td>
</tr>
<tr>
<td>In Natural Gas Residential Price</td>
<td>0.70**</td>
<td>0.04</td>
<td></td>
</tr>
<tr>
<td></td>
<td>(0.11)</td>
<td>(0.06)</td>
<td></td>
</tr>
<tr>
<td>In Natural Gas Withdrawals</td>
<td>-0.17</td>
<td>-0.03</td>
<td></td>
</tr>
<tr>
<td></td>
<td>(0.14)</td>
<td>(0.11)</td>
<td></td>
</tr>
<tr>
<td>R Squared</td>
<td>0.47</td>
<td>0.62</td>
<td>0.61</td>
</tr>
</tbody>
</table>

Notes: Significant coefficients are denoted with ** or * depending on significance at the 95% or 90% level. Coefficients are listed with Newey-West standard errors listed below in parenthesis.

Table 8: Log Quantity Demanded
Data Collected Monthly, Accumulated during Heating Months (Oct-Mar), 105 Obs

<table>
<thead>
<tr>
<th>VARIABLES</th>
<th>OLS</th>
<th>IV</th>
<th>IV</th>
<th>IV</th>
<th>IV</th>
<th>3LS</th>
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</thead>
<tbody>
<tr>
<td>ln(P&lt;sub&gt;Prev&lt;/sub&gt;)</td>
<td>(1)</td>
<td>(2)</td>
<td>(3)</td>
<td>(4)</td>
<td>(5)</td>
<td>(6)</td>
</tr>
<tr>
<td></td>
<td>0.08</td>
<td>0.46</td>
<td>0.44</td>
<td>0.44</td>
<td>0.18</td>
<td>0.18</td>
</tr>
<tr>
<td>ln(HDD)</td>
<td>0.40***</td>
<td>0.54**</td>
<td>-8.62**</td>
<td>-5.39</td>
<td>-5.26**</td>
<td>8.88</td>
</tr>
<tr>
<td></td>
<td>(0.06)</td>
<td>(0.07)</td>
<td>(1.37)</td>
<td>(16.39)</td>
<td>(1.06)</td>
<td>(14.92)</td>
</tr>
<tr>
<td>(ln(HDD))&lt;sup&gt;2&lt;/sup&gt;</td>
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<td></td>
<td></td>
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<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>0.71**</td>
<td>0.2</td>
<td>0.45**</td>
<td>-1.76</td>
<td>0.61**</td>
<td></td>
</tr>
<tr>
<td></td>
<td>(0.11)</td>
<td>(2.54)</td>
<td>(0.08)</td>
<td>(2.34)</td>
<td>(0.07)</td>
<td></td>
</tr>
<tr>
<td>(ln(HDD))&lt;sup&gt;3&lt;/sup&gt;</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>0.03</td>
<td>0.11</td>
<td></td>
<td></td>
<td></td>
<td></td>
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<tr>
<td></td>
<td>(0.13)</td>
<td>(0.12)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>ln(P&lt;sub&gt;NG&lt;/sub&gt;)</td>
<td></td>
<td></td>
<td></td>
<td></td>
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<td></td>
</tr>
<tr>
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<td>0.47**</td>
<td>0.47**</td>
<td>0.48**</td>
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<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>(0.12)</td>
<td>(0.12)</td>
<td>(0.10)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>R Squared</td>
<td>0.43</td>
<td>...</td>
<td>...</td>
<td>...</td>
<td>...</td>
<td>...</td>
</tr>
</tbody>
</table>

Notes: Significant coefficients are denoted with ** or * depending on significance at the 95% or 90% level. Coefficients are listed with Newey-West standard errors listed below in parenthesis. Instrumental Variable used in IV column specifications is Tsunami.
<table>
<thead>
<tr>
<th>VARIABLES</th>
<th>OLS</th>
<th>IV</th>
<th>IV</th>
<th>3SLS</th>
</tr>
</thead>
<tbody>
<tr>
<td>ln(P^Pro)</td>
<td>0.02</td>
<td>3.94**</td>
<td>3.05**</td>
<td>3.05**</td>
</tr>
<tr>
<td></td>
<td>(0.09)</td>
<td>(0.41)</td>
<td>(0.33)</td>
<td>(0.29)</td>
</tr>
<tr>
<td>Tsunami</td>
<td>-0.10*</td>
<td>-0.44**</td>
<td>-0.70**</td>
<td>-0.72**</td>
</tr>
<tr>
<td></td>
<td>(0.05)</td>
<td>(0.05)</td>
<td>(0.09)</td>
<td>(0.07)</td>
</tr>
<tr>
<td>ln(Q^NG)</td>
<td></td>
<td></td>
<td>1.23**</td>
<td>1.29**</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>(0.20)</td>
<td>(0.14)</td>
</tr>
<tr>
<td>R Squared</td>
<td>0.04</td>
<td>---</td>
<td>---</td>
<td>---</td>
</tr>
</tbody>
</table>

Notes: Significant Coefficients are denoted with ** or * depending on significance at the 95% or 90% level. Coefficients are listed with t-statistics and Newey-West standard errors listed below in parenthesis. Instrumental Variables used in IV column specifications are ln(HDD) and (ln(HDD))^2.
Figure Appendix

Figure 1: Regional Sales and Deliveries of Propane

Note: Displays Regional Sales and Deliveries of Propane in thousands of barrels. The x axis provides reference dates, and the y axis provides propane in thousands of barrels.

Figure 2: Year Over Year Propane Price % Change

Note: Displays year over year percent changes in the CPI adjusted, weighted average winter propane price in the Midwestern United States.
Note: Figure above show the trends of Crude Oil and Propane production. Figure is labeled with Crude Oil Production in thousands of barrels on the left vertical axis, and Propane Production in thousands of barrels on the right vertical axis. Dates are listed on the x-axis.

Note: Displays the Real Winter Propane Price for the past fifteen years in the Midwest. The vertical axis describes the price, and the horizontal axis displays the year reference.
Figure 5: Japanese Energy Production (Quadrillion BTU)

Note: Displays Japanese Energy Production by year in quadrillion British thermal units. The vertical axis describes Japanese Energy Production in quadrillion btu, and the horizontal axis provides year references.

Figure 6: Regional Share of Total Exports-Propane

Note: Displays Regional Share of total exports of propane out of the United States. The horizontal axis displays the date, and the vertical axis displays propane exported in thousands of barrels.
Note: Displays United States exports of propane to Japan. The vertical axis describes exports of propane to Japan in thousands of barrels, and the horizontal axis provides a date reference.

Note: Displays accumulated Winter Heating Degree Days for each winter beginning in the year displayed on the horizontal axis. The vertical axis displays accumulated winter heating degree days, and the horizontal axis displays a year reference.
Note: Displays Propane Supplied to the Midwest during each year’s winter months. The vertical axis describes the supply of propane in the Midwest, and the horizontal axis provides a year reference.

Note: Displays residuals gathered from IV estimated Propane Supplied regression results. The vertical axis provides the level of the residuals, while the horizontal axis describes the year.
Note: Displays residuals gathered from IV estimated Propane Supplied regression results. The vertical axis provides the level of the residuals, while the horizontal axis describes the month and year. The black lines direct attention to the winter of 2013-14, and the red lines are one standard deviation of the residuals positive and negative.
References


