Temperature Effects on Residential Natural Gas Demand

Jack Hardiman

Department of Economics

ECO 321: Econometrics

Aneesh Arora

December 7, 2025

1. Introduction

Residential energy demand plays a large role in regional energy markets, household budgeting, and climate policies. Among household energy sources, natural gas remains the dominant fuel type for space heating in the Midwest of America. And because the Midwest has a lot of temperature variation, it makes residential demand highly sensitive to these short-run weather fluctuations. In Illinois, for example, month-to-month variations in temperature generate large swings in heating needs. This then creates substantial changes in natural gas consumption. Understanding this magnitude of this weather-demand relationship is important for energy providers, energy traders, policy makers, and risk managers.

From an economic perspective. Short-run residential natural gas demand is shaped by both exogenous weather shocks, and market prices of the gas. While the prices of natural gas influence the consumption through standard demand models, the temperature fluctuations are largely outside the control of the homeowners, and provides a natural source of quasi-experimental variation. Heating and cooling degree days (HDD and CDD) are widely used by meteorologists and energy traders to summarize measures of temperature that go directly into heating and cooling needs. A degree day compares the mean of the high and low outdoor temperature for a location to a standard temperature, usually of 65℉ in the United States. The more extreme the outside temperature is, the higher the number of degree days. For example, if the high temperature for a particular day was 90℉ and the low temperature was 66℉, the temperature mean for that day was:

$$(90°\mathrm{F} + 66°\mathrm{F})/2 = 78°\mathrm{F}$$

Because the result above is above 65℉:

$$78°\mathrm{F} - 65°\mathrm{F} = 13\ \mathit{Cooling\ Degree\ Days}$$

The same structure is for heating degree days, except the it would be the subtraction of the mean temperature from 65℉. So, HDD captures the intensity of cold conditions that drive the space heating demand, while CDD reflects the warm conditions that shift household energy use toward electricity for air conditioning and away from natural gas. The combination of CDD and HDD provide a clean framework for isolating the short-run causal impact of weather on energy consumption.

This paper studies the effect of short-run temperature shocks on residential natural gas demand in the state of Illinois using monthly data from 1989 to 2025. Specifically, this paper asks: By how much does residential natural gas consumption change in response to one-standard deviation increase in monthly heating or cooling degree days, after controlling for prices and seasonal and time effects? To answer this, I estimate a log-linear demand model in which the logarithm of residential natural gas consumption depends on HDD,CDD, the logarithm of the residential gas price, and a full set of month and year fixed effects. These terms allow the effects of the weather to be interpreted as short-run semi-elasticities while flexibly controlling for seasonality and long-run structural shifts in consumption.

The results show that cold weather is the dominant driver of residential natural gas demand in Illinois. Heating degree days exert a large, positive, and highly statistically significant effect on gas consumption, while cooling degree days have a smaller but statistically significant negative effect. This reflects the substitution toward electricity during hot months. The estimated price elasticity of demand is negative and inelastic in magnitude, consistent with natural gas being a short-run necessity for households in CDD dominant times. Together, these findings highlight the importance of weather in shaping short-run residential gas demand and underscores the vulnerability of energy systems to temperature volatility.

The remainder of this paper proceeds as follows. Section 2 describes the data and sources. Section 3 presents exploratory data analysis and visualizations. Section 4 outlines the econometric model and identification strategy. Section 5 reports the regression results and economic interpretations. Section 6 concludes with implications for energy planning and climate-driven demand risk.

2. Data Description:

All data used in this study were obtained through publicly available U.S. government sources. Residential natural gas consumption and residential natural gas prices for Illinois were obtained from the U.S. Energy Information Administration (EIA). Monthly heating degree days (HDD) and cooling degree days (CDD) were obtained through the National Oceanic and Atmosphere Administration (NOAA) nClimDiv dataset.

- NOAA Heating and Cooling Degree Days (HDD,CDD):
  https://www.ncei.noaa.gov/access/monitoring/climate-at-a-glance/statewide/time-series
  (Statewide → Illinois → Degree Days → Monthly)

- EIA Residential Natural Gas Consumption (Illinois):
  https://www.eia.gov/dnav/ng/ng_cons_sum_a_EPG0_VRS_mmcf_m.htm

- EIA Residential Natural Gas Price (Illinois):
  https://www.eia.gov/dnav/ng/ng_pri_sum_a_EPG0_PRS_dolmcfe_m.htm

All series were downloaded at a monthly frequency and merged by date.

Unit of Observation

The unit of observation is the state-month. Each observation represents one calendar month of residential natural gas activity in the state of Illinois.

Sample Size and Time Period

The sample covers the period from January 1989 through July 2025. This yielded a total of

- 439 monthly observations

This long time span allows for the identification of both short-run weather-driven demand fluctuations and long-run structural shifts in residential gas consumption.

Key Variables:

Dependent Variable

- Residential Natural Gas Consumption (Consumption)

  Measured in million cubic feet (MMcf) for the residential sector in Illinois. For estimation, the natural logarithm of consumption, log(Gas), is used to stabilize variance and allow for percentage-based interpretation.

Main Independent Variables

- Heating Degree Days (HDD)

  Monthly heating degree days for Illinois, constructed by NOAA based on deviations below 65°F. HDD captures cold-weather heating requirements and is the primary weather driver of residential gas demand.

- Cooling Degree Days (CDD)

  Monthly cooling degree days for Illinois, constructed by NOAA based on deviations above 65°F. CDD captures warm-weather cooling needs and is expected to reduce gas consumption due to substitution toward electricity.

Control Variable

- Residential Natural Gas Price (Price)

  Monthly average residential natural gas price for Illinois, measured in dollars per thousand cubic feet ($/Mcf).

  The natural logarithm of price, log(Price), is used so the coefficient can be interpreted as a price elasticity of demand.

3. Data Construction

All series were converted to a common monthly time format and merged by date. The dependent variable and price were transformed into logarithms. Additional time variables (year and month indicators) were constructed to implement fixed effects that control for seasonality and long-run time trends.

Data Cleaning and Preparation

Data Cleaning Procedures

All datasets were merged at the monthly frequency using a common data variable. After merging the residential natural gas consumption, the residential natural gas price, and the HDD and CDD, the dataset was inspected for missing values and inconsistencies. After fully checking across all the key variables, it was revealed that no missing values were in the final merged dataset. So, no imputation or row deletion was required.

The dataset was also sorted chronologically to ensure correct time ordering. Basic validity checks confirmed that all observations were economically reasonable: residential gas consumption, prices, and degree days were strictly nonnegative. Also, no implausible spiked or structural breaks were observed that would require an outlier to be removed. As a result, no outliers were removed from this sample. All 439 monthly observations from January 1989 through July 2025 were retained for analysis.

Variable Construction

Several new variables were constructed to prepare the data for econometric estimation:

1. Logarithmic Transformations

   The natural logarithm of residential natural gas consumption was created to stabilize variance and allow for percentage-based interpretation of coefficients:

   $$log\_gas_t = ln(Consumption_t)$$

   The natural logarithm of residential natural gas prices was created so that the price coefficient could be viewed as an elasticity

   $$log\_price_t = ln(Price_t)$$

2. Time Variables for Fixed Effects

   To control for seasonality and long-run trends, calendar time indicators were constructed:

- Month indicators (1-12) to capture seasonal demand patterns
- Year indicators (1989-2025) to capture long-run structural changes in residential energy use.

3. Final Estimation Variables

The final set of variables used in the regression analysis consists of

- Log of residential natural gas consumption (dependent variable)
- Heating degree days (HDD)
- Cooling degree days (CDD)
- Log of residential natural gas price
- Month and year fixed effects

Summary Statistics

Table 1 reports summary statistics for the mean variables used in the analysis. Residential natural gas consumption displays substantial variation across months, showing strong seasonal heating demand in winter months. Heating degree days show a wide dispersion, while cooling degree days display a narrower distribution consistent with Illinois' summer climate. Residential natural gas prices also vary considerably over time, which show a changing market and regulatory environments.

	mean	std	min	max
Consumption	36456.870	27065.722	7170.000	104083.000
HDD	504.804	455.724	0.000	1540.000
CDD	74.597	107.307	0.000	476.000
Price	9.954	4.744	4.100	31.770
log_gas	10.176	0.850	8.878	11.553
log_price	2.198	0.439	1.411	3.459

Table 1. Summary Statistics (Monthly Illinois Data, 1989-2025)

The summary statistics confirm that the variables here exhibit sufficient variation to support econometric estimation and that the log transformations meaningfully compress the scale of the consumption and price variables.

4. **Exploratory Data Analysis (EDA)**

This section explores the main features of the data prior to econometric estimation. Visual inspection helps assess the distribution of the dependent variable and the raw relationship between residential natural gas consumption and weather conditions.

Distribution of Residential Natural Gas Consumption

To examine the distribution of the dependent variable, a histogram of the logarithm of the monthly residential natural gas consumption in Illinois was constructed (Figure 1). The log transformation compresses the scale of the data and reduces the strong right-skew that is present in gas consumption measured in levels. This histogram shows that the logarithm of gas consumption is symmetric and bell-shaped after transformation. This supports the use of a log specification in the regression model, because this stabilizes the variance and reduces the influence of extreme winter demand spikes. The absence of unusual points or any extreme outliers is a sign that the data are well-behaved for linear regression analysis.

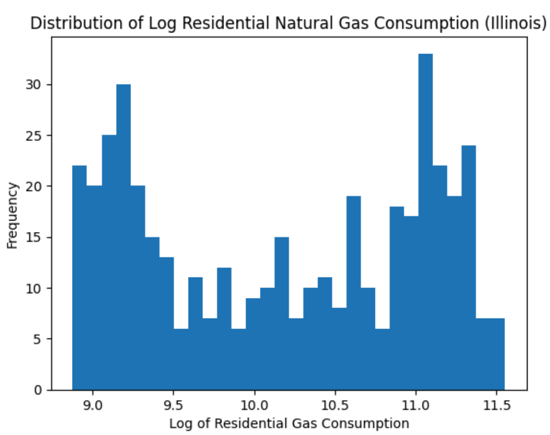

Figure 1. Histogram of the logarithm of monthly residential natural gas consumption in Illinois.

Relationship Between Gas Consumption and Heating Degree Days

The scatter plot reveals a strong positive relationship between HDD and residential gas consumption. Months with low HDD (warmer months) are associated with substantially lower gas usage. High HDD months (cold winter months) are associated with much higher gas consumption. This clear upward trend provides a strong visual evidence that colder temperatures are a dominant driver of residential natural gas demand in Illinois.

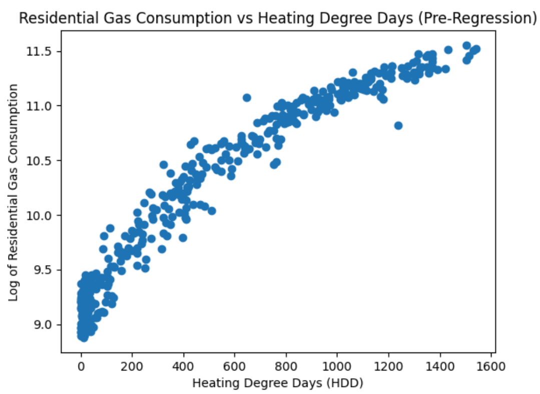

Figure 2. Scatter plot of heating degree days (HDD) versus the logarithm of residential natural gas consumption in Illinois.

Together, the exploratory visualizations confirm several important features of the data. First, the distribution of residential natural gas consumption supports the use of a log transformation. Secondly, there is a strong positive raw correlation between cold weather (HDD) and gas demand, which is consistent with the economic intuition regarding space heating needs. These patterns provide a clear motivation for the econometric specification used in the regression analysis.

5. Model Specification, Regression Results, and Interpretation

Model Specification

To estimate the short-run effect of weather, I estimate the following multivariate log-linear regression model at the monthly frequency

$$ln(Gas_t) = \beta_1 HDD_t + \beta_2 CDD_t + \beta_3 ln(Price_t) + \gamma_m + \delta_y + \varepsilon_t$$

Where:

- $ln(Gas_t)$ is the natural logarithm of monthly residential natural gas consumption
- HDD_t is monthly heating degree days
- CDD_t is the monthly cooling degree days
- $ln(Price_t)$ is the natural logarithm of the residential natural gas price
- γ_m are month fixed effects
- δ_y are year fixed effects
- ε_t is the error term

Residential natural gas price is included to allow estimation of the price elasticity of demand. Month fixed effects control for recurring seasonal patterns, while the year fixed effects control for long-run structural changes in baseline consumption due to efficiency improvements, demographic change, or fuel substitution.

Regression Output

Table 2 reports the regression results estimated using Ordinary Least Squares with heteroskedasticity-robust (HC1) standard errors.

```
                            OLS Regression Results
==============================================================================
Dep. Variable:                log_gas   R-squared:                       0.992
Model:                            OLS   Adj. R-squared:                  0.991
Method:                 Least Squares   F-statistic:                     1852.
Date:                Sun, 07 Dec 2025   Prob (F-statistic):               0.00
Time:                        21:01:35   Log-Likelihood:                 507.19
No. Observations:                 439   AIC:                            -912.4
Df Residuals:                     388   BIC:                            -704.1
Df Model:                          50
Covariance Type:                  HC1
```

Table 2. Regression Results for Residential Natural Gas Demand in Illinois

Key model statistics:

- R-squared: 0.992
- Adjusted R-Squared: 0.991
- F-statistic: 1852 (p<0.001)

The high R-squared value indicates that the model explains nearly all of the variation in monthly residential gas consumption

Interpretation of Results:

HDD

The estimated coefficient on HDD is $\hat{\beta}HDD = 0.0009\ (p < 0.001)$

This implies that a one-unit increase in monthly HDD is associated with a 0.09% increase in residential natural gas consumption, holding everything else constant. The coefficient is highly statistically significant at the 1% level. This confirms that cold weather has a strong positive effect on residential gas demand.

CDD

The estimated coefficient on CDD is $\hat{\beta}CDD =- 0.0005\ (p < 0.001)$

This implies that a one-unit increase in monthly CDD is associated with a 0.05% decrease in residential natural gas consumption, holding everything else constant. The coefficient is statistically significant at the 1% level. The standard deviation of CDD is 107.3, implying that a one standard deviation increase in CDD leads to an approximate -5.1% decrease in residential natural gas consumption. This negative effect reflects household substitution away from natural gas toward electricity during the hotter months.

Residential Natural Gas Price

The estimated coefficient on the logarithm of price is $\hat{\beta}Price =- 0.235\ (p < 0.001)$

Because both demand and price are in log, this coefficient represents the price elasticity of demand. It shows that a 1% increase in the residential natural gas price is associated with a 0.235% decrease in residential gas consumption, holding weather and time fixed effects constant.

6. Conclusion

The results from this study strongly support the original hypotheses. HDD have a positive effect on gas consumption, while CDD have a smaller but statistically significant negative effect. A one-standard deviation increase in HDD raised residential gas demand by 41%. A similar increase in CDD reduced the demand by 5%. Residential gas demand is also found to be price inelastic, with a price elasticity of -0.24. Overall, the data confirm that cold weather variation is the dominant driver of short-run residential natural gas in Illinois.

This regression analysis has several limitations. This model may be subject to omitted variable bias, as it does not control for factors such as household income, household characteristics, or energy efficiency improvements from years apart. The future research could improve this regression analysis by performing across multistates in regions similar, and take more factors meteorologically into effect.