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Temperature, Storage and Natural Gas Prices

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Goal of the analysis

- We examine the *simultaneous* influence of temperature shocks and storage surprises on *both* the mean and variance of natural gas futures prices in the US
- There is an extensive literature on this – although fewer papers jointly estimating both mean effects and effects on price variability
- Our main focus: The appropriate way to measure temperature shocks
  - Previous authors have used the National Oceanic and Atmospheric Administration (NOAA) definitions of heating (HDD) and cooling (CDD) degree days
  - We instead derive our own measures from raw temperature data and test to see if alternative measures may better predict natural gas prices
- Also, we depart from most previous papers in the ways that we:
  - Measure storage surprises;
  - Forecast expected degree-day measures; and
  - Weight local HDD and CDD measures to get national ones

The standard HDD and CDD measures

- The standard measures compare the average of the daily maximum and minimum temperatures (the so-called *daily mean*), $\bar{T}$, to 65°F (18.33°C)
  - For each day, $\text{CDD} = (\bar{T} - 65) * I(\bar{T} > 65)$ and $\text{HDD} = (65 - \bar{T}) * I(\bar{T} < 65)$
- To model and project energy consumption for the US and for US Census regions and divisions, the EIA weights these measures by population
- NOAA also calculates "gas home heating customer weighted degree days" by using "the number of residential customers heating with gas" in each region (according to the 2000 census) as weights

Some concerns with the standard measures

- The daily mean temperature may be a poor indicator of heating or cooling services demand
  - Consider, for example, a day affected by passage of a cold front
- Temperature departures from 65°F could be for 6 hours (0.25 of a day) for one day and 12 hours (0.5 of a day) on another
  - The fraction of the day would not matter statistically if were the same amount of time each day, but more generally the fraction will matter
- 65°F may not be the most appropriate threshold for predicting natural gas demand, while thresholds for CDD and HDD could differ

An alternative approach

- We use *hourly* temperatures from the quality-controlled US Climate Reference Network (USCRN) to calculate our HDD and CDD measures
  - USCRN calculates 5-minute average temperature values using independent 10-second measurements from multiple co-located temperature sensors
  - To get a long series, we select one weather station for each (lower-48) state, choosing the station closest to the largest city
- Hourly temperature readings also allow us to more accurately align the temperature variations to the time of day that the prices are measured
  - Technically, the daily maximum or minimum will not be known for sure until the end of the 24-hour period to which they pertain
- Since we are forming our own measures we can also test for different thresholds than 65°F for CDD or HDD

Weighting for natural gas demand

- We weight the temperature measures using *forecasted* natural gas consumption shares of each lower 48 state as weights:
  - CDD with natural gas used for electricity generation; and
  - HDD with natural gas used by residential and commercial customers
- Consumption information is released periodically and with a 2-month lag
  - We develop a model to forecast consumption shares for months after the data become available

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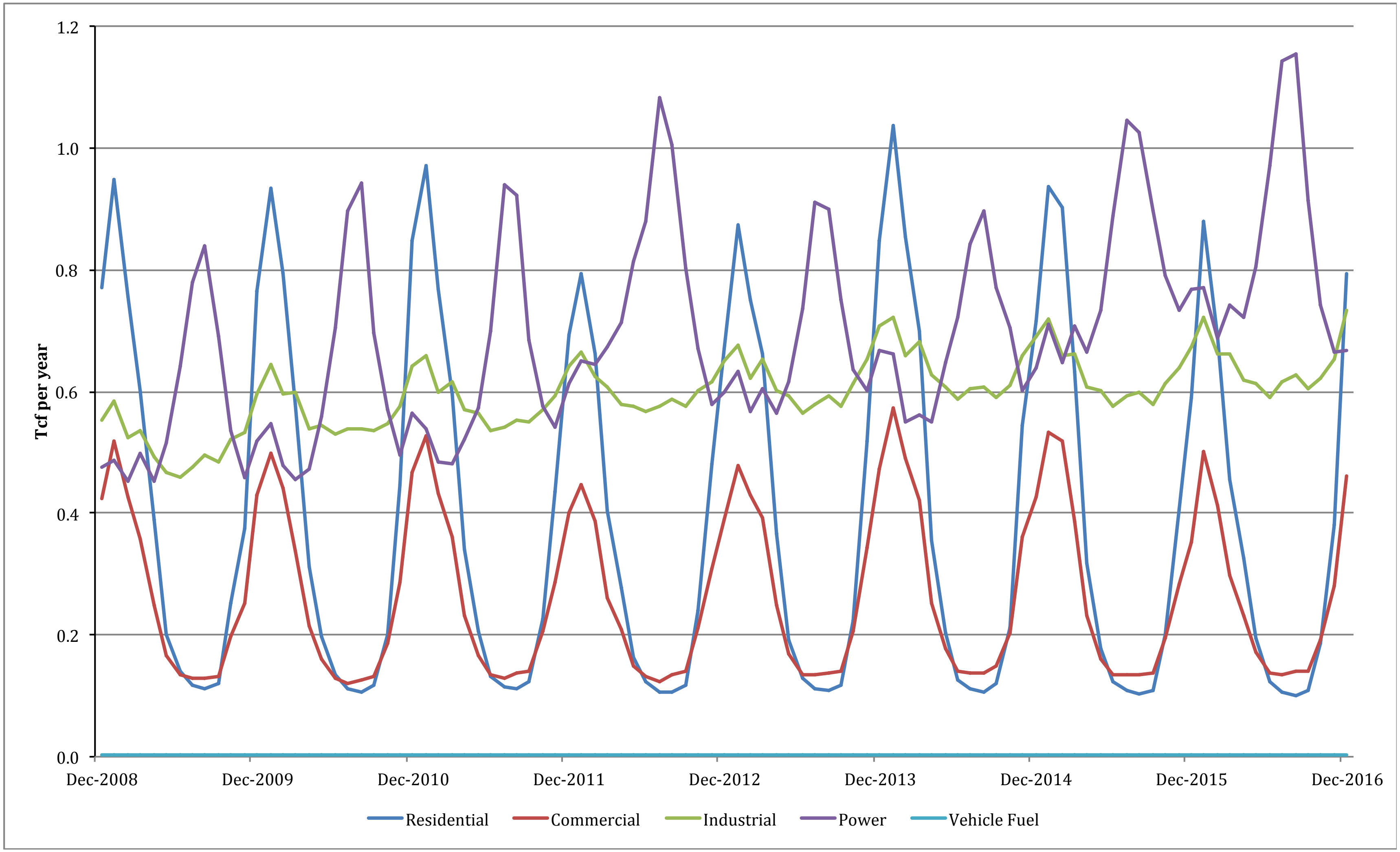
US natural gas consumption in our period



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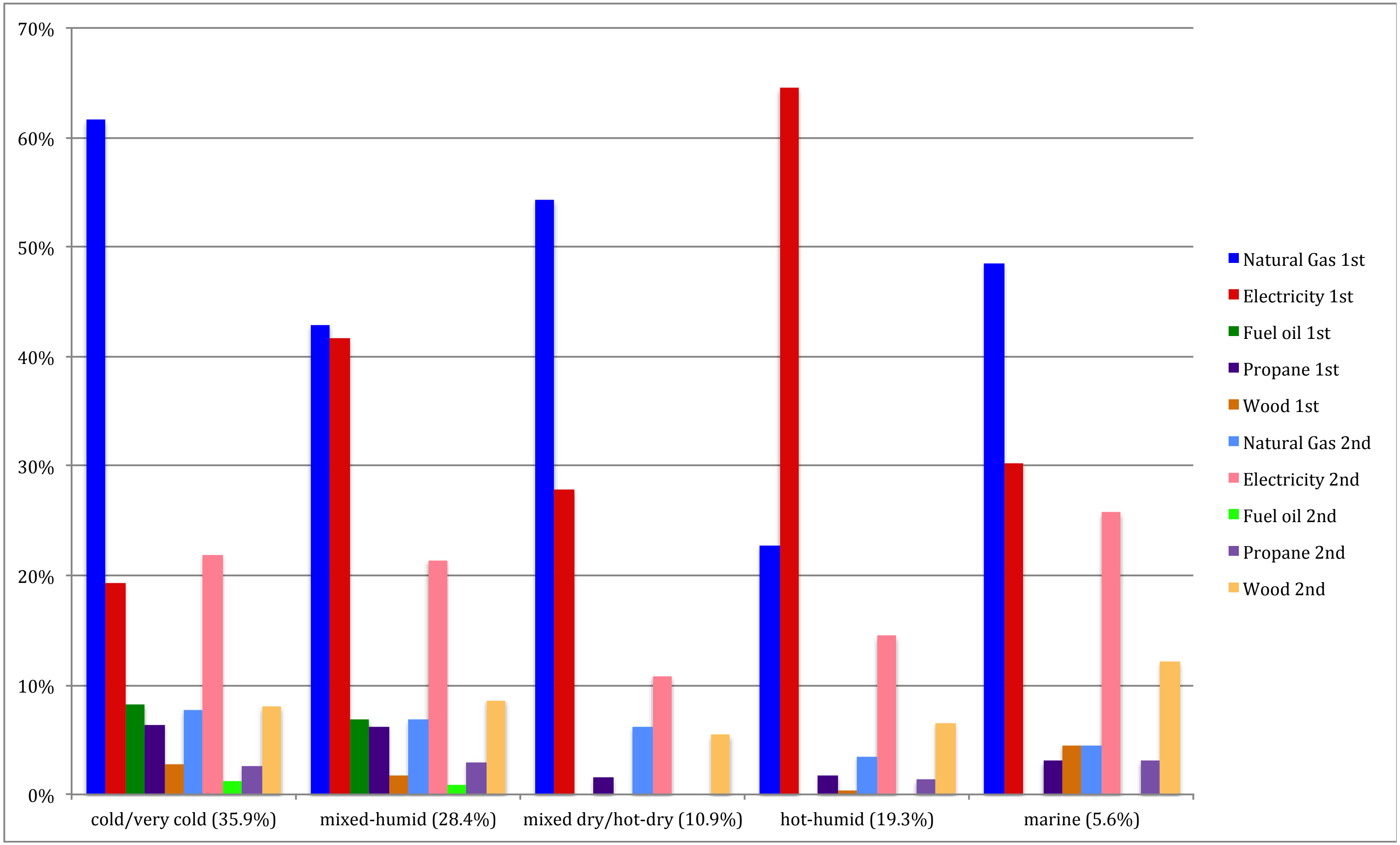
Use of natural gas for space heating



Source: EIA, 2015 Residential Energy Consumption Survey

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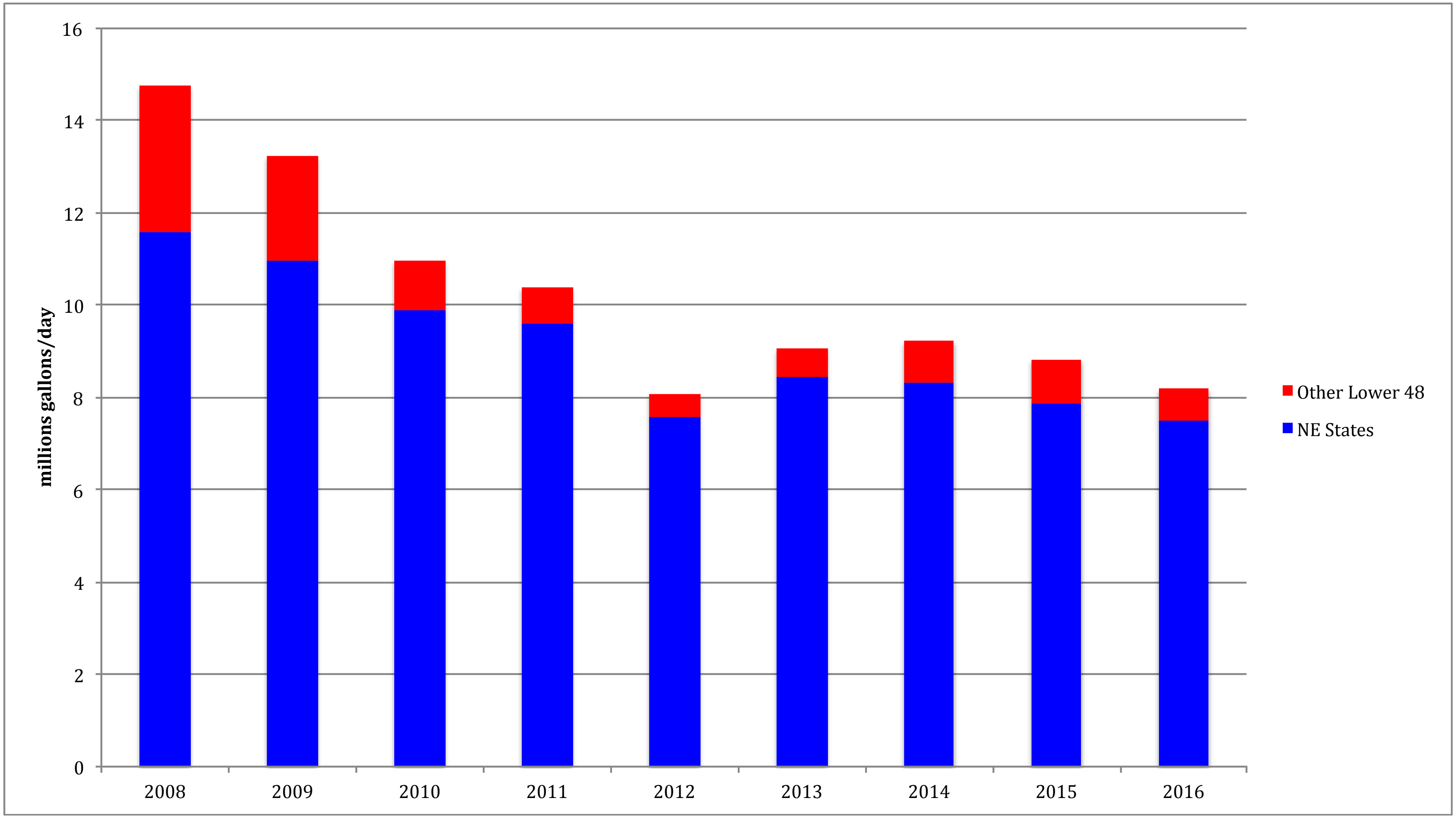
Annual sales of fuel oil #2, lower-48



Source: EIA

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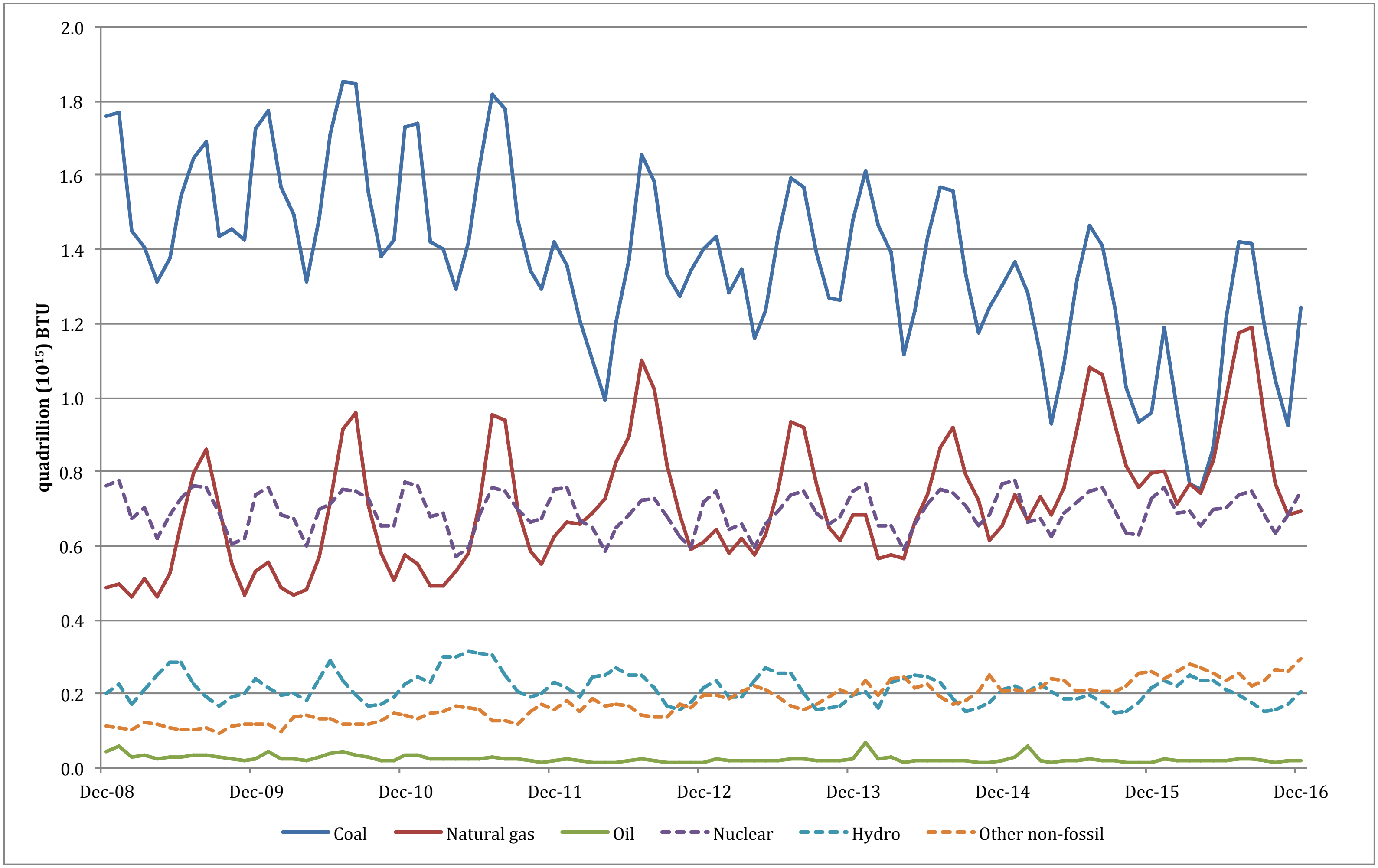
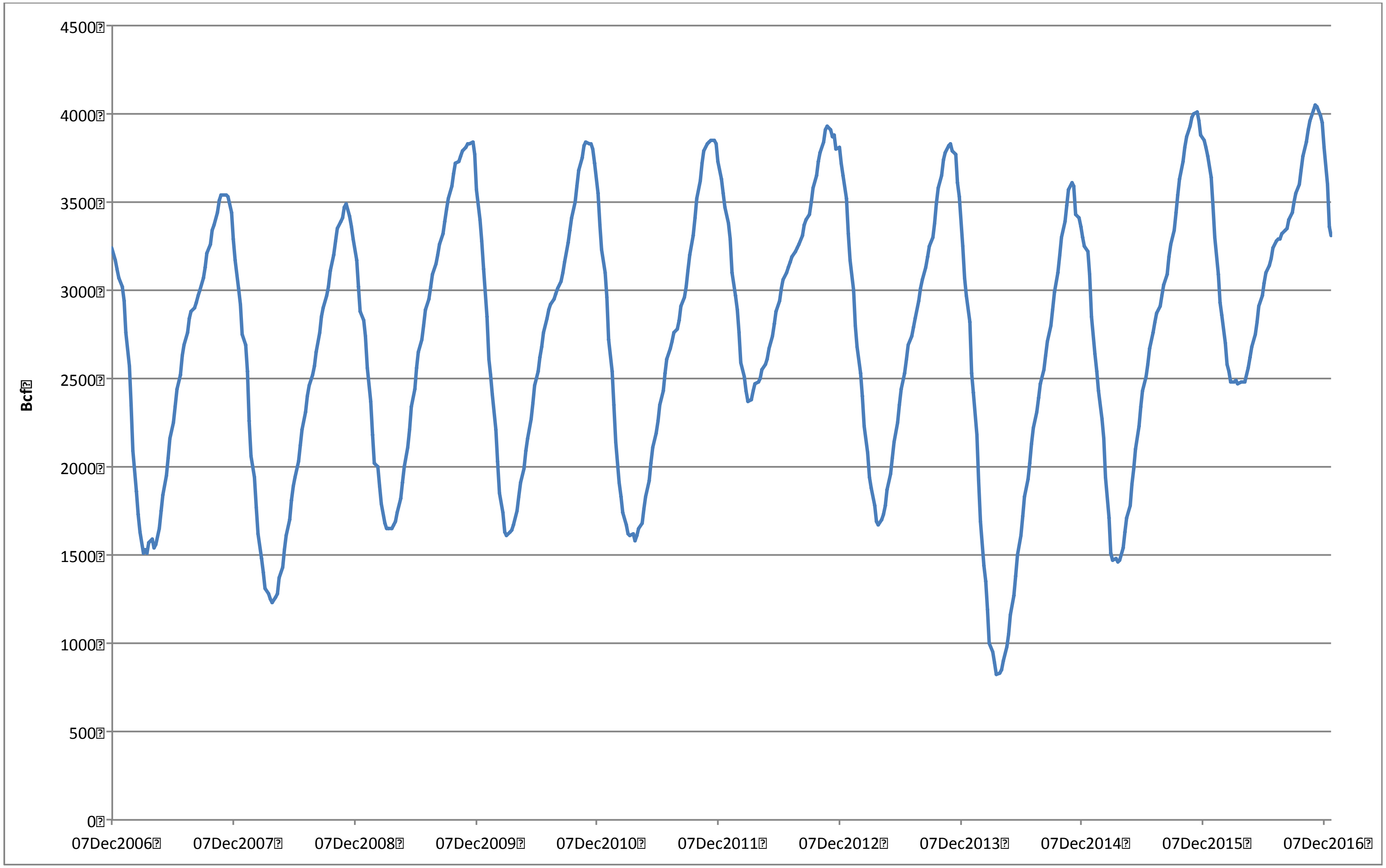
Electric power sector energy consumption



Source: EIA

Weekly natural gas underground storage (lower 48)



Source: EIA

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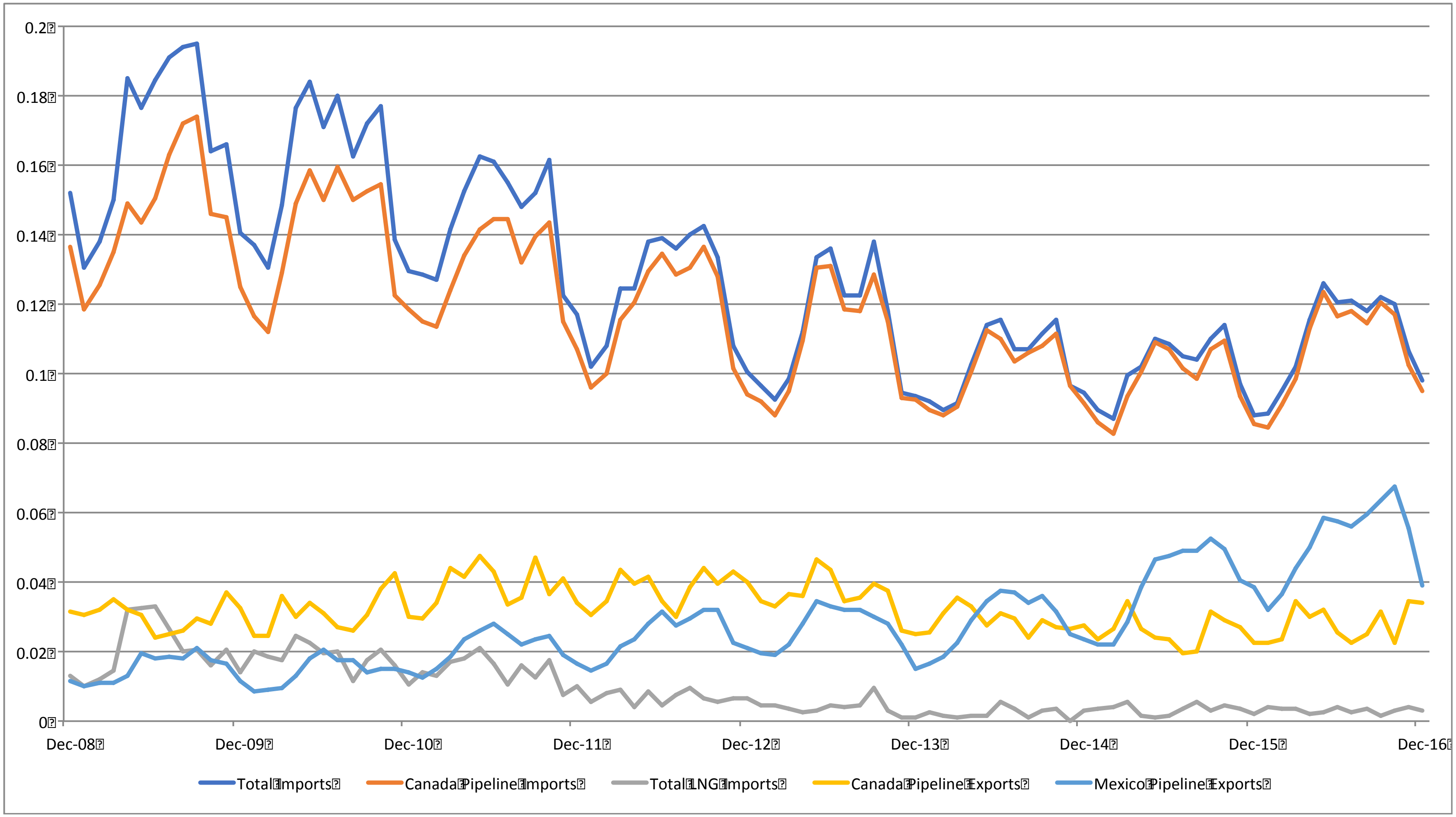
Natural gas trade relative to consumption



Source: EIA

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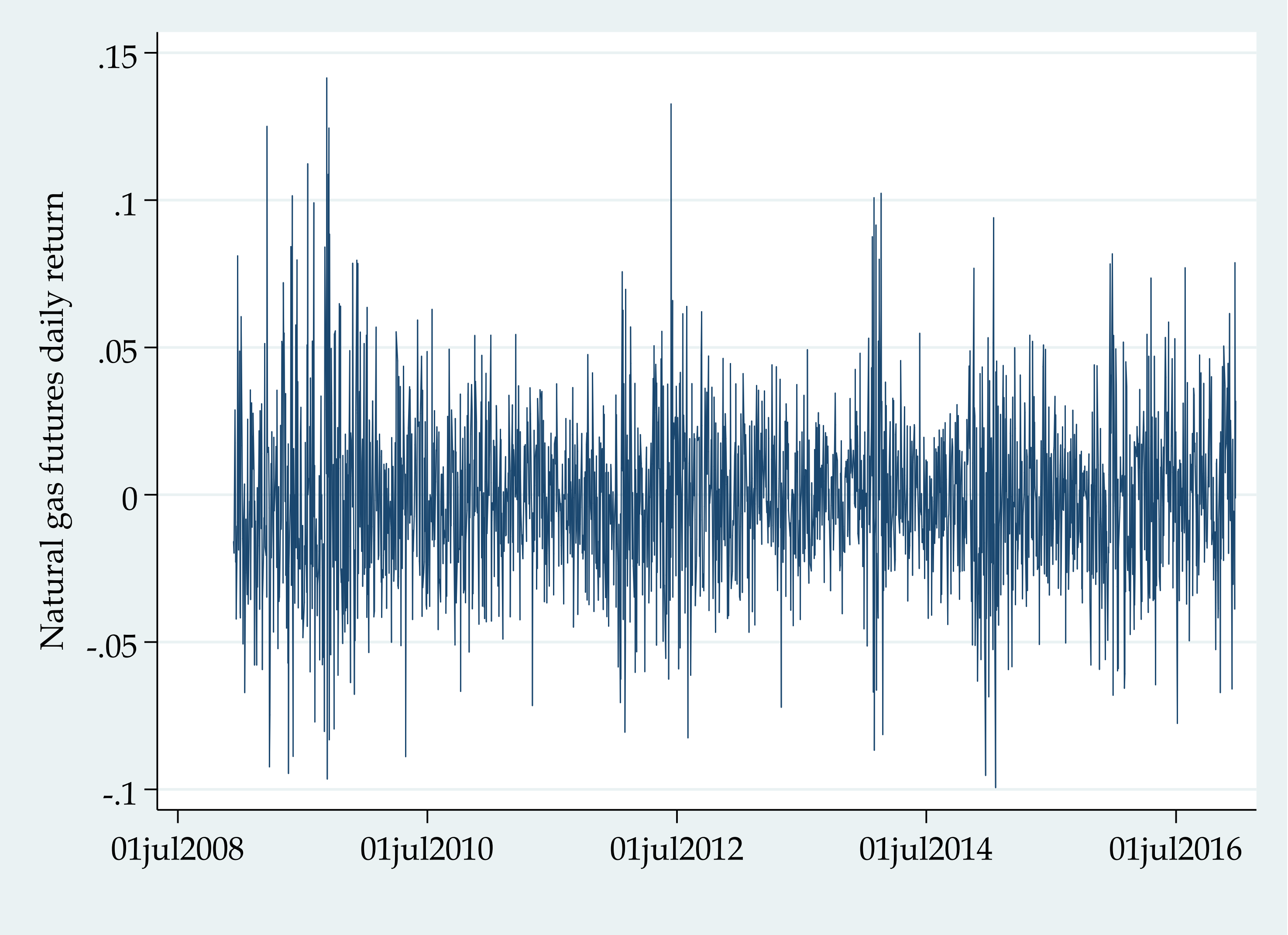
Dependent variable of interest



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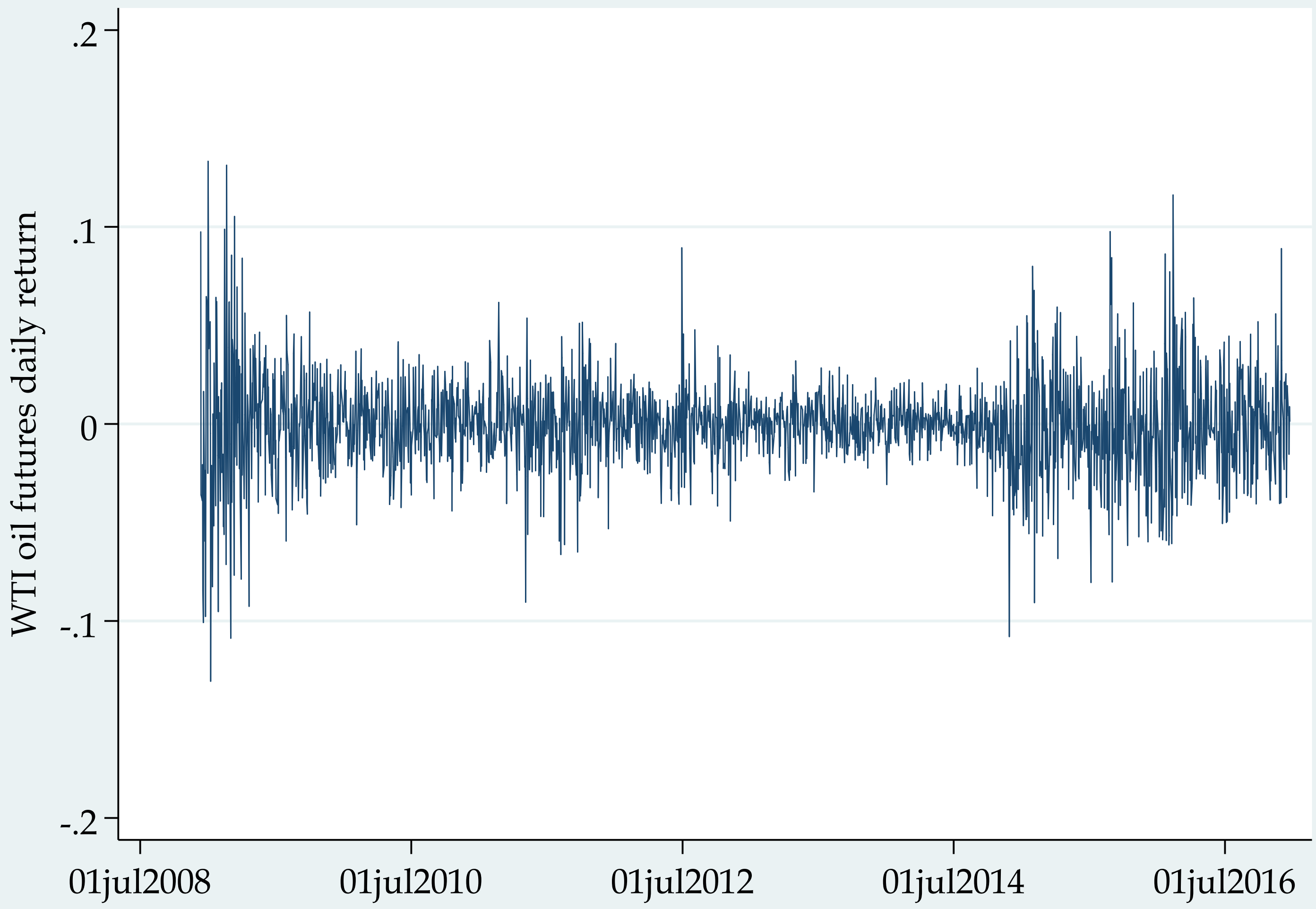
Corresponding oil futures return



Rolling degree-day forecasts

- We calculate *DD* measures in 4-hour blocks starting 10am Thursdays to allow for different release times for storage levels and prices
- Forecasts of the 2 *DD* measures in six 4-hour time blocks are based on Tobit models (to allow for zero truncations) with explanatory variables:
  - Immediately preceding *m* 4-hour time blocks,
  - Same 4-hour time block on previous *n* days, and
  - Historical 5-year NOAA degree day measures for the same day of the year

$$DD^{*}_{dh} = \gamma^{H}_{h0} + \sum_{j=1}^{m} \gamma^{H}_{hj} DD_{dh-j} + \sum_{k=2}^{n} \gamma^{H}_{h6+k} DD_{d-kh} + \gamma^{H}_{h15} NDD^{H}_{d} + u^{H}_{dh}$$

- We found that the coefficient on *NDD* was generally statistically significant, *m* was 7 and *n* was generally 4, 5 or 6

Rolling storage forecasts

- The change in weekly storage levels (week *w*–1 to week *w*) were regressed on
  - The weekly, accumulated, US degree day measures (six 4-hour time slots each day for 7 days, except for non-standard announcement days)
  - The 5-year historical average change in storage between weeks *w* and *w*–1
- The error term was allowed to follow an ARMA process

$$\Delta Stor_w = \beta_{w0} + \beta_{w1} \sum_{d=1}^{7} \sum_{h=1}^{6} HDD_{dh} + \beta_{w2} \sum_{d=1}^{7} \sum_{h=1}^{6} CDD_{dh} + \beta_{w3} \Delta \bar{S}_w + u_{Sw}$$

- We found cut-off temperatures of 22°C for *CDD* and 10°C for *HDD* were best for forecasting weekly storage changes
- Generally, while the 5-year historical average change in storage was statistically significant, the *DD* variables also improved the forecast

Rolling consumption share forecasts

- For weighting *CDD*, we forecast the logs of state shares of natural gas consumption for electricity generation using ARMAX models
  - Exogenous variables are logs of (either) winter or summer state-level natural gas-fired capacity shares, monthly dummies and a slow-moving time trend
- For weighting *HDD*, we forecast the logs of state shares of residential plus commercial natural gas consumption using ARMAX models
  - Exogenous variables are monthly dummies and a slow-moving time trend
- After shares were forecast for each state, they were divided by the sum across states to ensure the weights summed to 1

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Proposed pricing equations

$$RNG_{wd} = \delta_0 + \delta_1[Stor_w - \widehat{Stor_w}] + \delta_2[\widehat{Stor_w} - Stor_{w-1}] + \delta_3 \sum_{k=1}^{d-1}\sum_{h=1}^{6} HDD_{kh}$$
$$+\delta_4 \sum_{h=1}^{6} HDD_{dh} + \delta_5 \sum_{k=1}^{d-1}\sum_{h=1}^{6} CDD_{kh} + \delta_6 \sum_{h=1}^{6} CDD_{dh} + \delta_7 \sum_{k=1}^{7}\sum_{h=1}^{6} \widehat{HDD}_{d+kh}$$
$$+\delta_8 \sum_{k=1}^{7}\sum_{h=1}^{6} \widehat{CDD}_{d+kh} + \delta_9 RCO_{wd} + \delta_{10} MR_{wd} + \delta_{11} Tbill_{wd} + \frac{1+\theta L}{1-\rho L}\varepsilon_t$$

with $\varepsilon_t \sim N(0, \sigma_t^2)$ and

$$(1-\beta L)\sigma_t^2 = c + \alpha_1 \varepsilon_{t-1}^2 + \gamma_1[Stor_w - \widehat{Stor_w}]^2 + \gamma_2[\widehat{Stor_w} - Stor_{w-1}]^2 +$$
$$\gamma_3\left[\sum_{k=1}^{d-1}\sum_{h=1}^{6} HDD_{kh}\right]^2 + \gamma_4\left[\sum_{h=1}^{6} HDD_{dh}\right]^2 + \gamma_5\left[\sum_{k=1}^{d-1}\sum_{h=1}^{6} CDD_{kh}\right]^2 + \gamma_6\left[\sum_{h=1}^{6} CDD_{dh}\right]^2$$
$$+\gamma_7\left[\sum_{k=1}^{7}\sum_{h=1}^{6} \widehat{HDD}_{d+kh}\right]^2 + \gamma_8\left[\sum_{k=1}^{7}\sum_{h=1}^{6} \widehat{CDD}_{d+kh}\right]^2 + \gamma_9 Oil\,Vol_t$$

Announcement day equations

- Trades on announcement days (mostly Thursdays) will involve fewer additional hours of temperature observations since the last storage announcement (made that morning)
- Also, there may be additional anticipated and unanticipated storage shocks:
  - The prices on Wednesday and Thursday afternoons would be based on different storage level information – both could be relevant

Preliminary Results

- The best HDD and CDD measures for predicting price changes had cutoff temperatures of 14°C and 22°C respectively
  - For forecasting storage changes, the best CDD measure also has a threshold of 22°C, but the best threshold for HDD is 10°C
  - Forecast HDD values are much more important than forecast CDD values in explaining prices
- *Other* variables that appear important for explaining the daily return on the natural gas futures are the return on the oil futures and the lagged unexpected storage shock on announcement day
  - The AR and MA coefficients are also significant
  - *Tbill* return has a weak effect, but market return is tiny and insignificant
- In the variance equation, the squares of forecast HDD and unexpected and expected storage shocks have the biggest effects
  - The ARCH and GARCH coefficients are also significant