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Workshop: Natural Gas Demand in the Industrial and Power Generation Sectors

Part of a study investigating:
The Relationship between Crude Oil and Natural Gas Prices

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Agenda

9:00 – 9:15 am: Welcome and Introductions
- Introductions
- Background and purpose of the study

9:15 – 9:30 am: Motivation with a brief overview of recent trends
- Market price
- Power generation sector
- Industrial sectors

9:30 – 10:30 pm: A focus on demand – a methodology and preliminary results
- Power generation sector
- Detail the steps taken in this study to date
- Preliminary results
- Discussion

10:30 – 10:45 am: Break

10:45 – 12:00 pm: A focus on demand – a methodology and preliminary results (cont.)
- Industrial sector
- Detail the steps taken in this study to date
- Preliminary results
- Discussion

12:00 – 1:00 pm: Lunch

1:00 – 2:00 pm: Fuel switching and the natural gas-crude oil price relationship
- Past, present and future
- Possible modeling approaches
- Discussion

2:00 – 2:30 pm: Comments and suggestions

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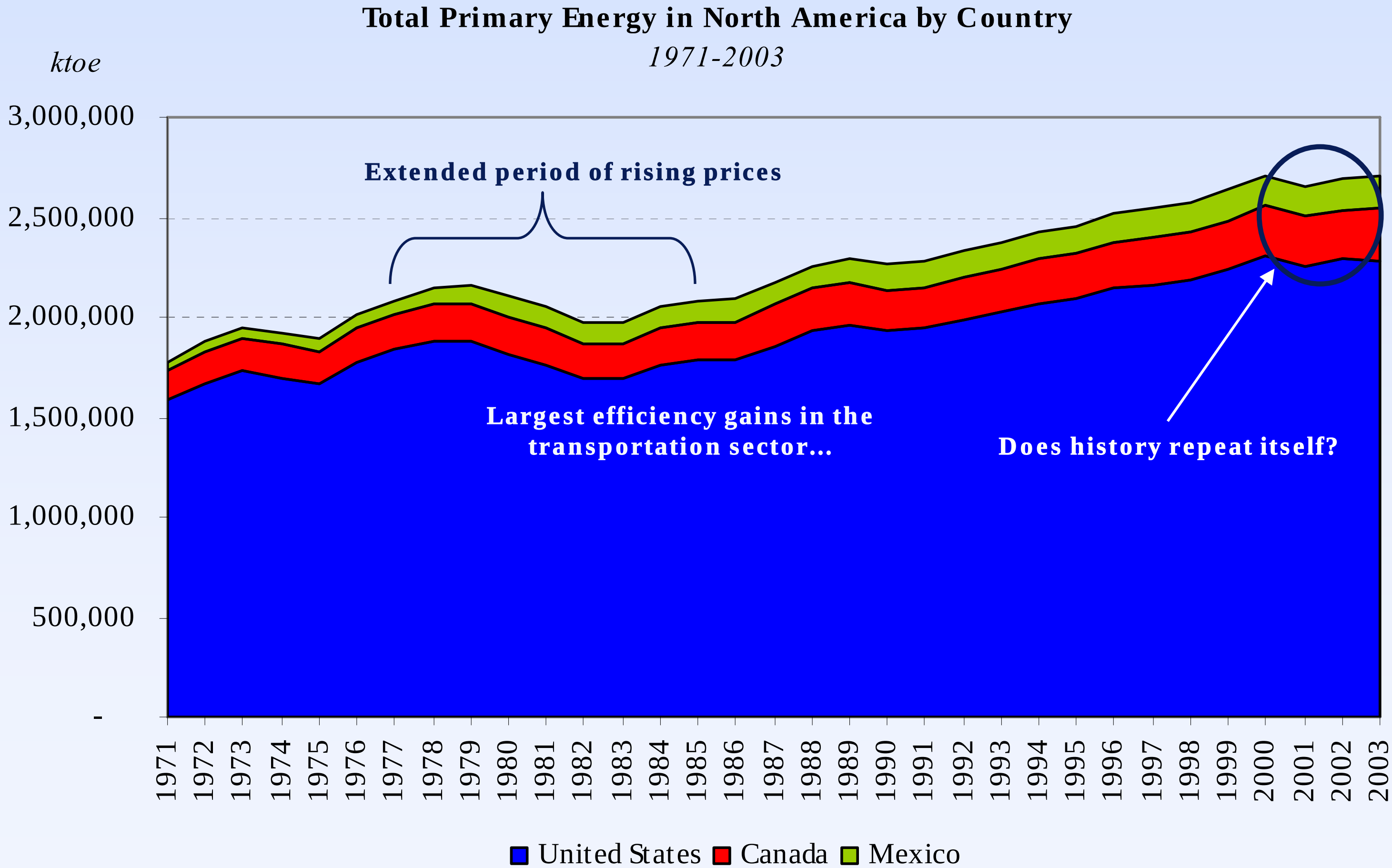
A General Comment on Energy Demand in North America

- Energy demand has grown substantially over the past 30 years, with periods of decline due to conservation/efficiency encouraged by periods of high prices.



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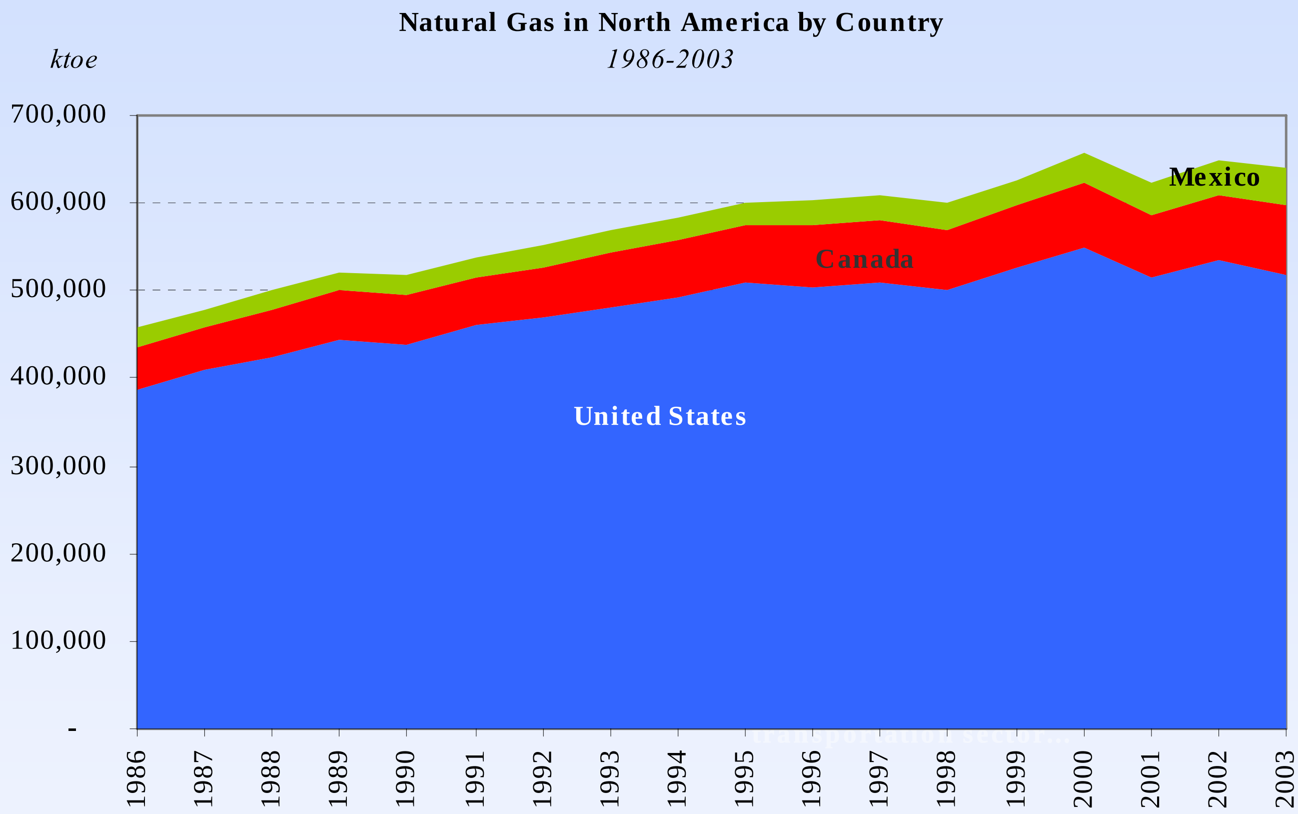
Historical Natural Gas Demand, 1986-2003

- Focusing on one time frame gives one indication as to the nature of growth in natural gas demand…



- North America – 2.00% per year
  - US – 1.73% per year; Canada – 2.99% per year; Mexico – 4.11% per year

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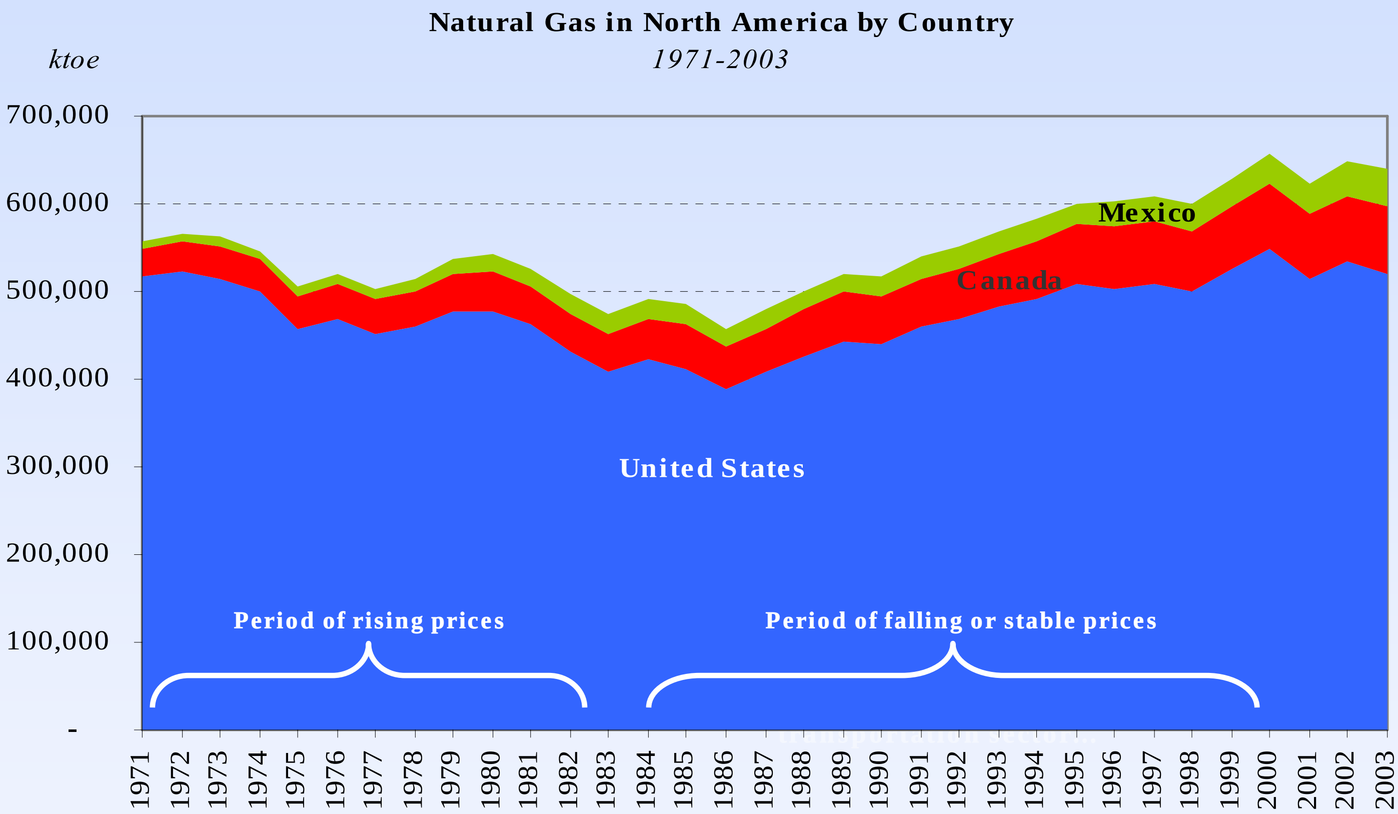
Historical Natural Gas Demand, 1971-2003

- Focusing on another time frame gives a completely different indication as to the nature of growth in natural gas demand…



- North America – 0.42% per year
  - US – 0.01% per year; Canada – 2.87% per year; Mexico – 4.86% per year

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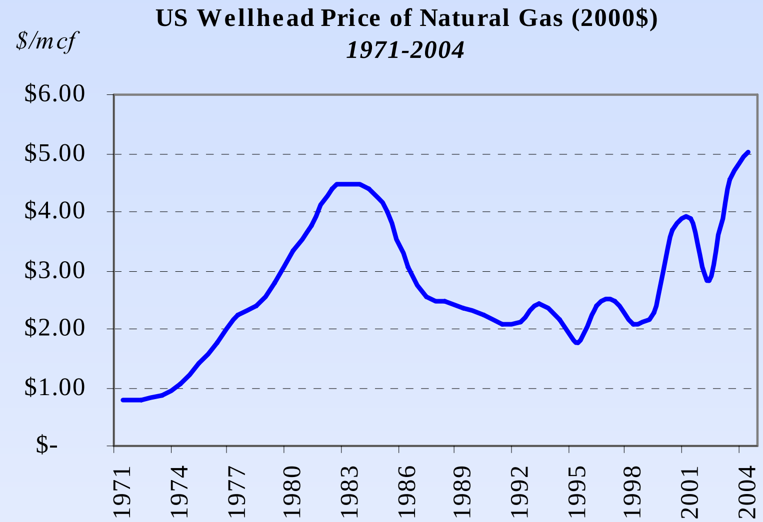
Historical Natural Gas Demand, 1971-2003 (cont.)

- One potential explanation is price…



- Of note:
  - US natural gas demand is only slightly above where it was 35 years ago.
  - We typically focus on the period 1986-present.
    - Regulatory reform in Canada – market-based procedures for determining exports rather than R/P requirements
    - NGPA (1978) decontrolled wellhead prices by 1985, allowed rents to accrue to producers
  - Prior to the mid-1990s, demand was driven largely by residential and commercial capital equipment and industrial activity. More recently, growth is driven by power generation demand.

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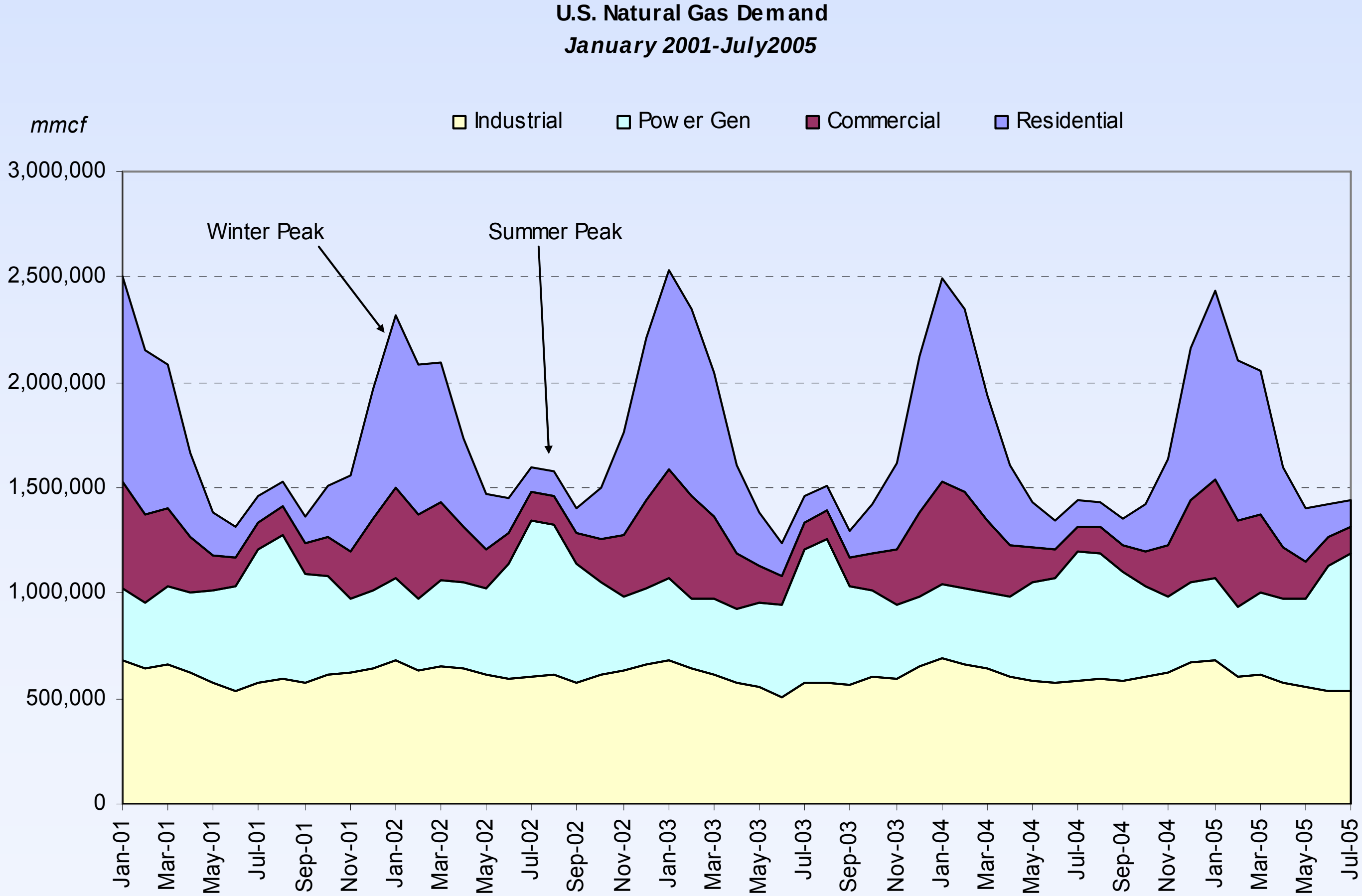
Natural Gas Demand is highly seasonal

- Residential demand has been the primary driver of seasonal variation
- The power generation sector contributes to a summer peak
- The industrial sector accounts for the largest proportion of total natural gas demand, followed by power generation sector



Natural Gas Demand for Power Gen

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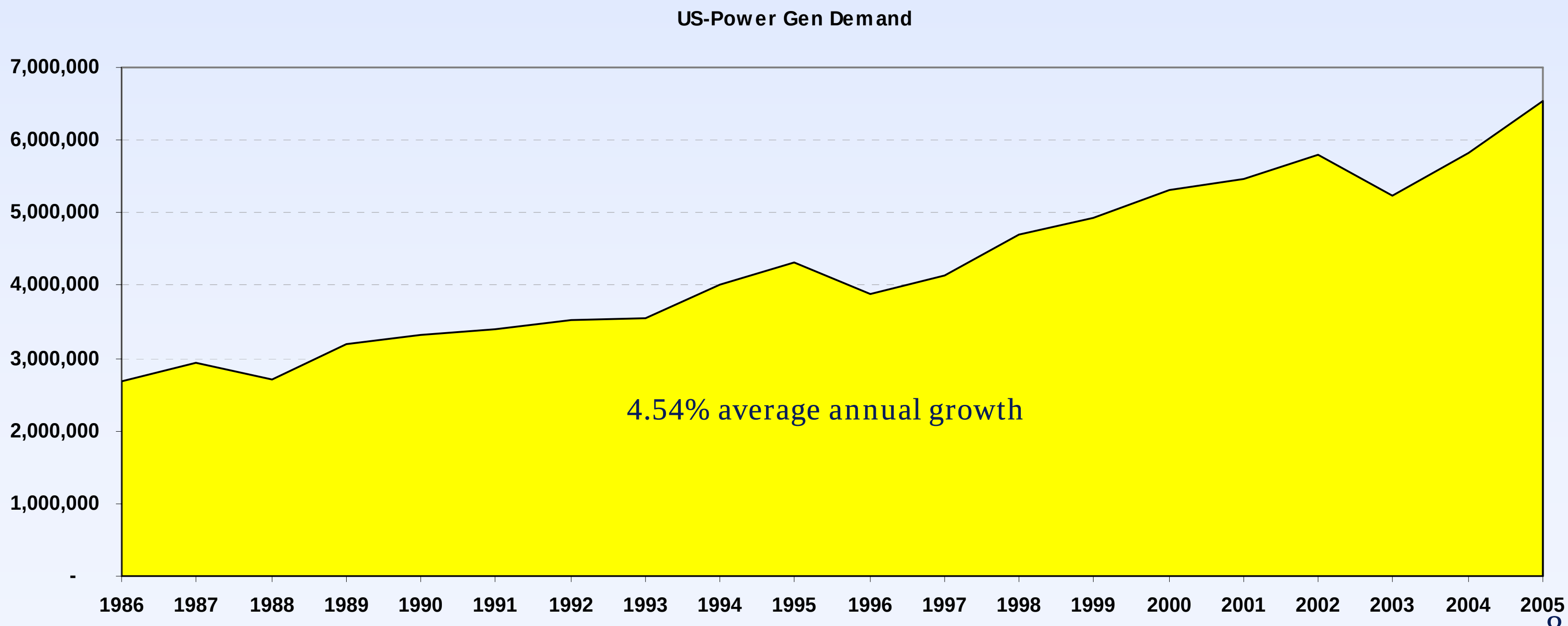
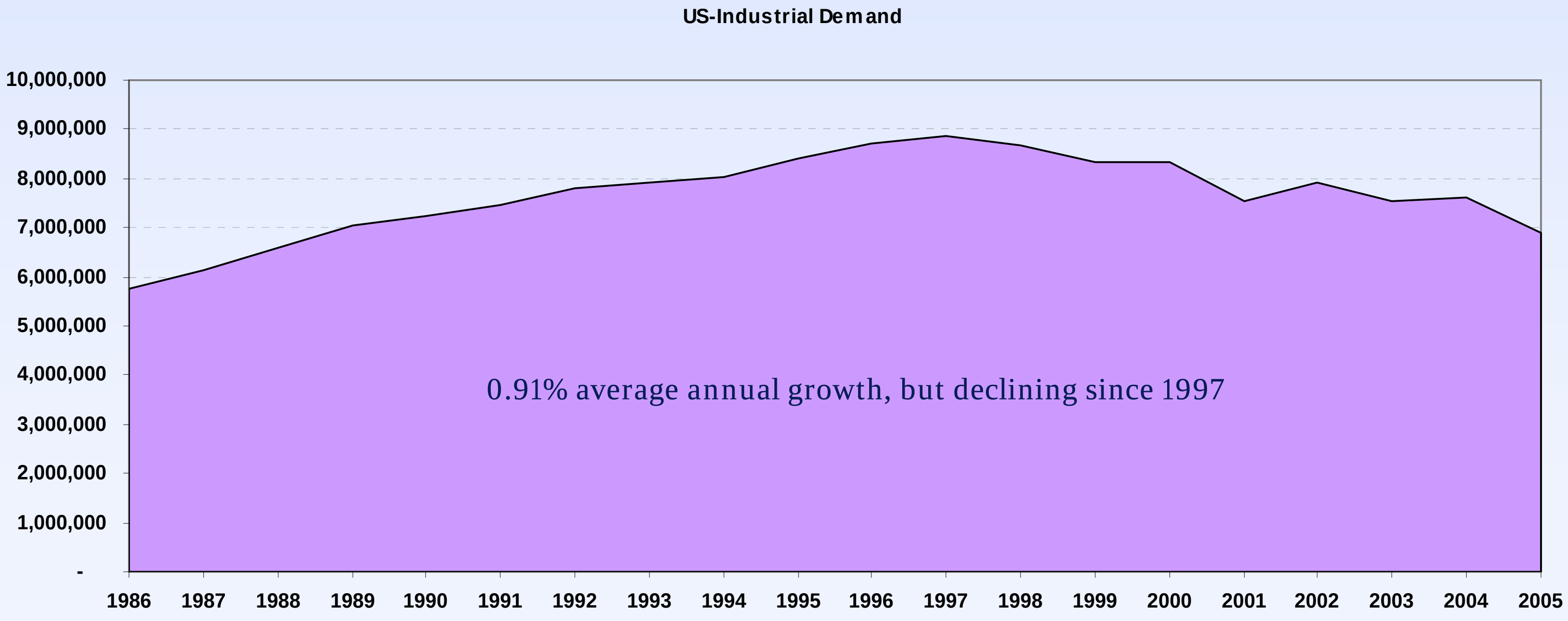
- Power generation will be the main driver of demand for natural gas…
  - Technological improvements in the use of gas to generate electricity has spurred a shift in the demand curve.
  - Much of the witnessed growth has been driven by capacity investment (long term expectations of low gas prices made NGCC competitive with coal for base load)
- … or will it? The expectation of long term low prices has since changed, and capacity investment in gas has slowed.



Industrial Natural Gas Demand

- High natural gas prices threaten to permanently disable certain portions of industrial demand
  - Fuel switching in near term is temporary. It will not necessarily drive a downward trend.
  - Long term demand "destruction" can result from things such as certain sectors relocating offshore.
  - High final product demand can allow some industrials to absorb higher prices, as the price of the finished good also rises.



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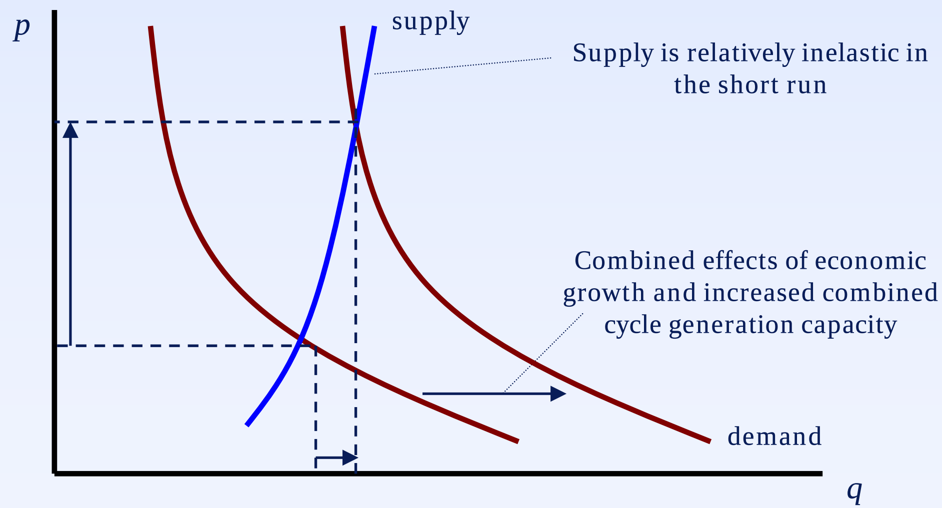
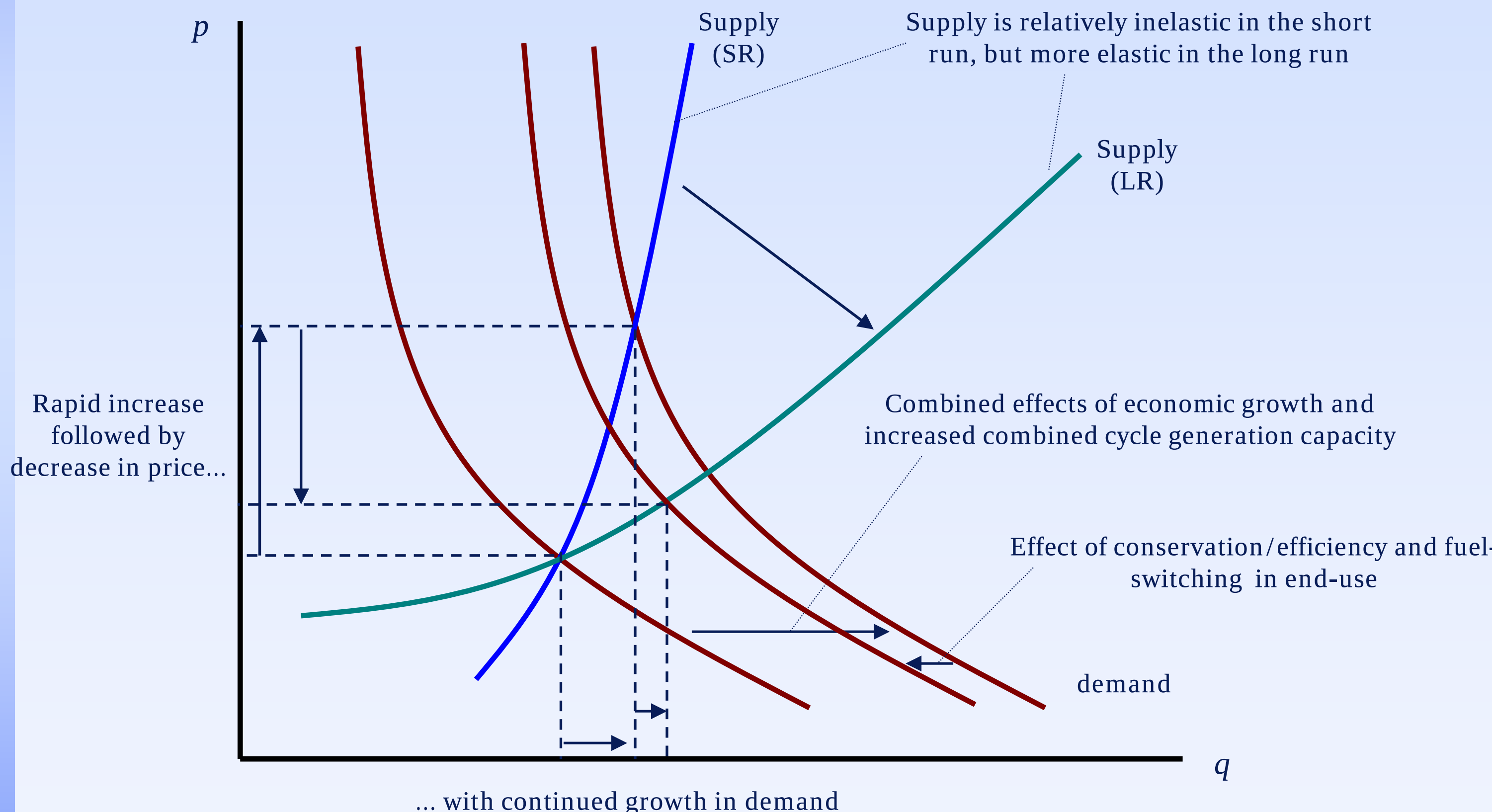
The Future of Natural Gas

- Residential and commercial demand will remain the primary driver for seasonality in demand.
- Power demand could cause Summer peaks to intensify, but price plays an important role.
- On an annual basis, demand has not apparently grown in the past few years… so what is going on?
  - Price vs. income effects
  - *Potential* demand (power sector) effects



The Future of Natural Gas (cont.)

- Long term supply is much more elastic
- High prices encourage efficiency and LR fuel switching in end-use



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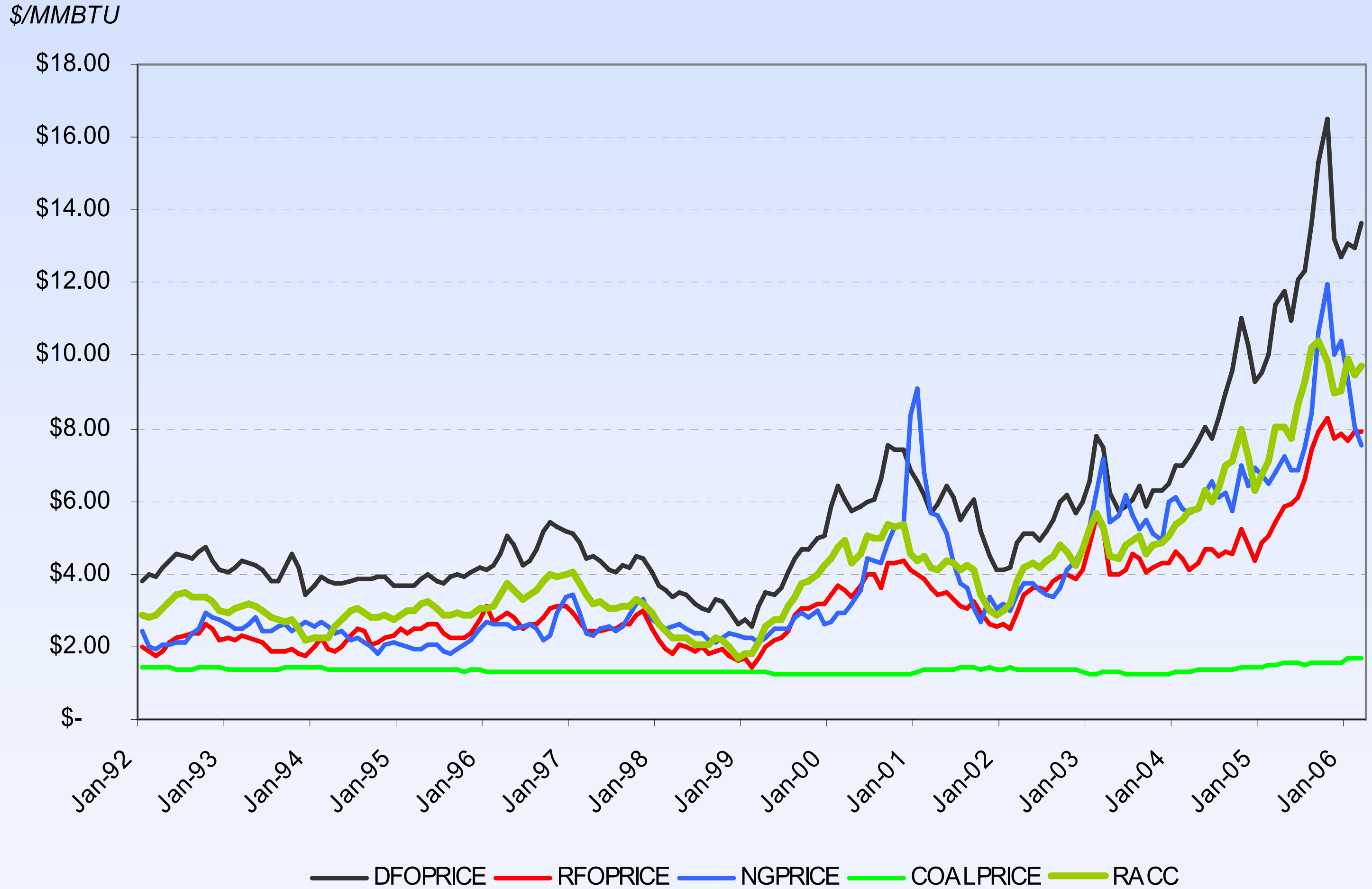
The convergence of crude oil and natural gas?

- When factors create tightness in the natural gas market, natural gas prices tend to price higher against crude.



Power Generation Demand for Natural Gas

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A Modeling Approach

- Consider a cost-minimizing agent that determines fuel consumption as an input to the production of electricity.
- This motivates a choice of variables that should be important in determining fuel choice in any given time period.
  - Cost to use fuel for power generation matters, not price. Thus, if any factor serves to reduce cost for a given price, it will favor that particular fuel.
    - Variable: Price*HeatRate
  - Total power generation will be important in determining natural gas demand since natural gas is one possible input into the production of electricity.
    - Variable: Total Electricity Generation
  - Installed capacity is a function of expectations regarding profitability. Once the fixed cost is borne and capacity is in place it should tend to influence demand.
    - Variable: Gas-fired generation capacity
  - Degree days allow for variation in peak. Thus, for a given gen set, higher CDDs should push us up the supply stack.
    - Variable: CDD, HDD
  - Hydro capacity can follow load to the extent that the capacity is available. This will tend to negate the need for gas
    - Variable: Hydro Generation

Data

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- Electricity (January 1992 – March 2006)
  - Generation: EIA-906 and EIA-920
  - Capacity: EIA Annual Electric Generator Report EIA-860
  - Heat Rates: EPA NEEDS data (v2.1, 2000, 2004)
    - Matched EPA heat rates to plants and took averages for plants built in that year when exact match not available
  - CDD and HDD: NOAA population weighted averages by NERC region – each state was assigned to a single NERC region/subregion
  - Fuel Prices: purchase price consumption weighted average by NERC region – Energy Velocity/FERC Form 423
- Gas-fired generation grouped into two major categories: Combined cycle and Other
  - Combined cycle consists of: Combined Cycle Steam Part (CA), Combined Cycle Turbine Part (CT), Combined Cycle Single Shaft – combustion turbine and steam turbine share the same generator (CS)
- Competing facilities are grouped broadly as:
  - Coal
  - Distillate Fuel Oil
  - Residual Fuel Oil

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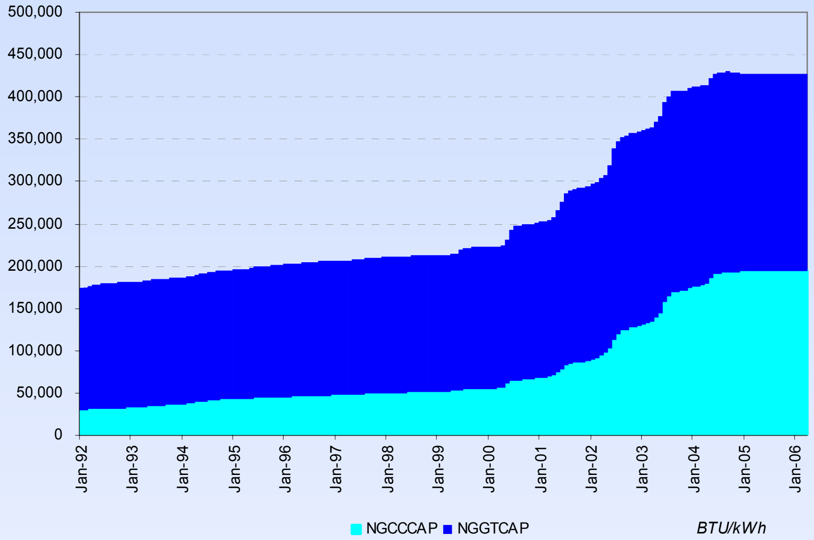
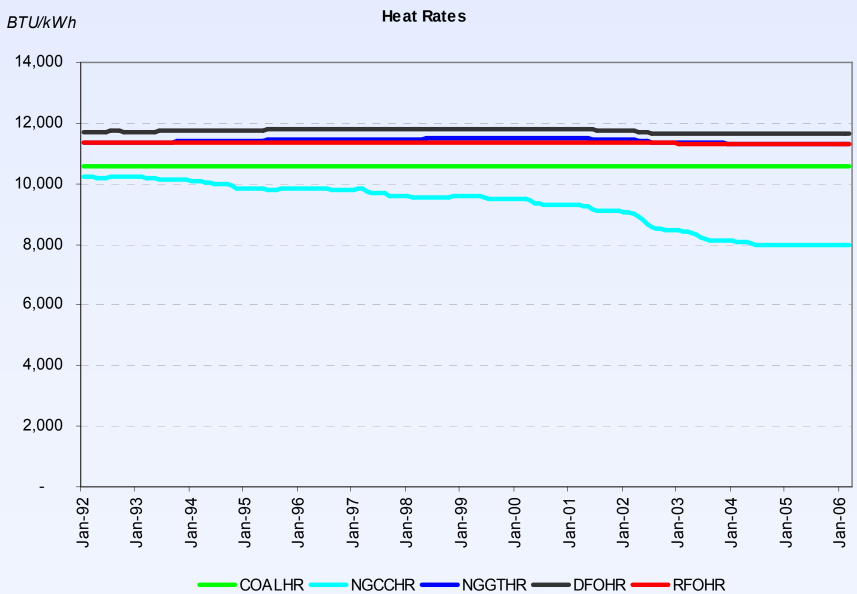
Data (cont.)

- Aggregate measure of US gas-fired capacity reveals shift to higher efficiency means of power generation





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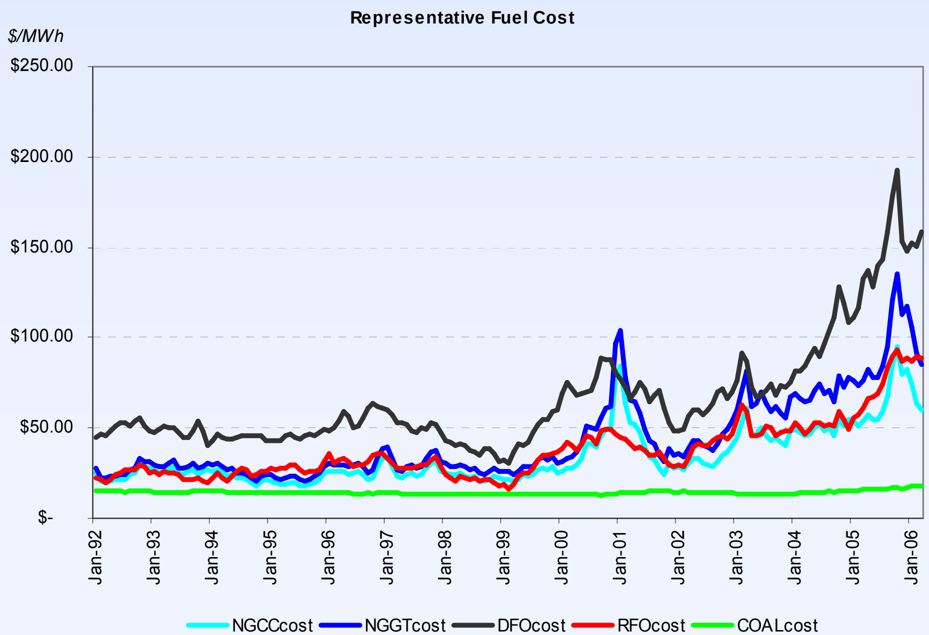
Data (cont.)

- The shift to higher efficiency has implications for the price competitiveness of natural gas with other fuels in power generation…

	Price	HR	NG Heat Rate CC 7,956	NG Heat Rate AVG 9,790	NG Heat Rate GT 11,310	
Coal	$ 1.70	10,571	$ 2.26	$ 1.84	$ 1.59	Implied Competitive NG Price
	$ 1.35	10,571	$ 1.80	$ 1.46	$ 1.27	
	$ 1.22	10,571	$ 1.62	$ 1.32	$ 1.14	
DFO	$ 16.53	11,631	$ 24.17	$ 19.64	$ 17.00	
	$ 5.64	11,631	$ 8.24	$ 6.70	$ 5.80	
	$ 2.58	11,631	$ 3.77	$ 3.07	$ 2.65	
RFO	$ 8.28	11,286	$ 11.75	$ 9.55	$ 8.27	
	$ 3.28	11,286	$ 4.66	$ 3.78	$ 3.28	
	$ 1.46	11,286	$ 2.07	$ 1.68	$ 1.45	

Implied RACC	$ 70.43
	$ 24.03
	$ 11.00



Regression Analysis

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- Estimate longitudinal dataset:
  - 14 NERC regions
    - ECAR, ERCOT, FERC, MAAC, MAIN, MAPP, NPCCI, NPCCN, SERC, SPPN, SPPS, VACAR, WECC, WECC-C
  - Monthly data span January 1992 through March 2006
    - Allows for significant variation in price
    - Allows for substantial capacity additions in NGCC in particular
- Using the cost minimizing agent as motivation, we allow for fuel competition, region-specific variation based on month, own price effects, weather related effects, capacity influence, technological change, total generation requirement, hydro effects
  - Switching is possible at the plant level or at the system level. The latter is an important aspect of the grid that provides flexibility to minimize system costs.
- Important caveat: Monthly data do not allow analysis of hourly dispatch decisions dictated by a position in the supply stack. Thus, the cumulative effect of all dispatch when measured against a monthly price may not yield what one might otherwise expect.

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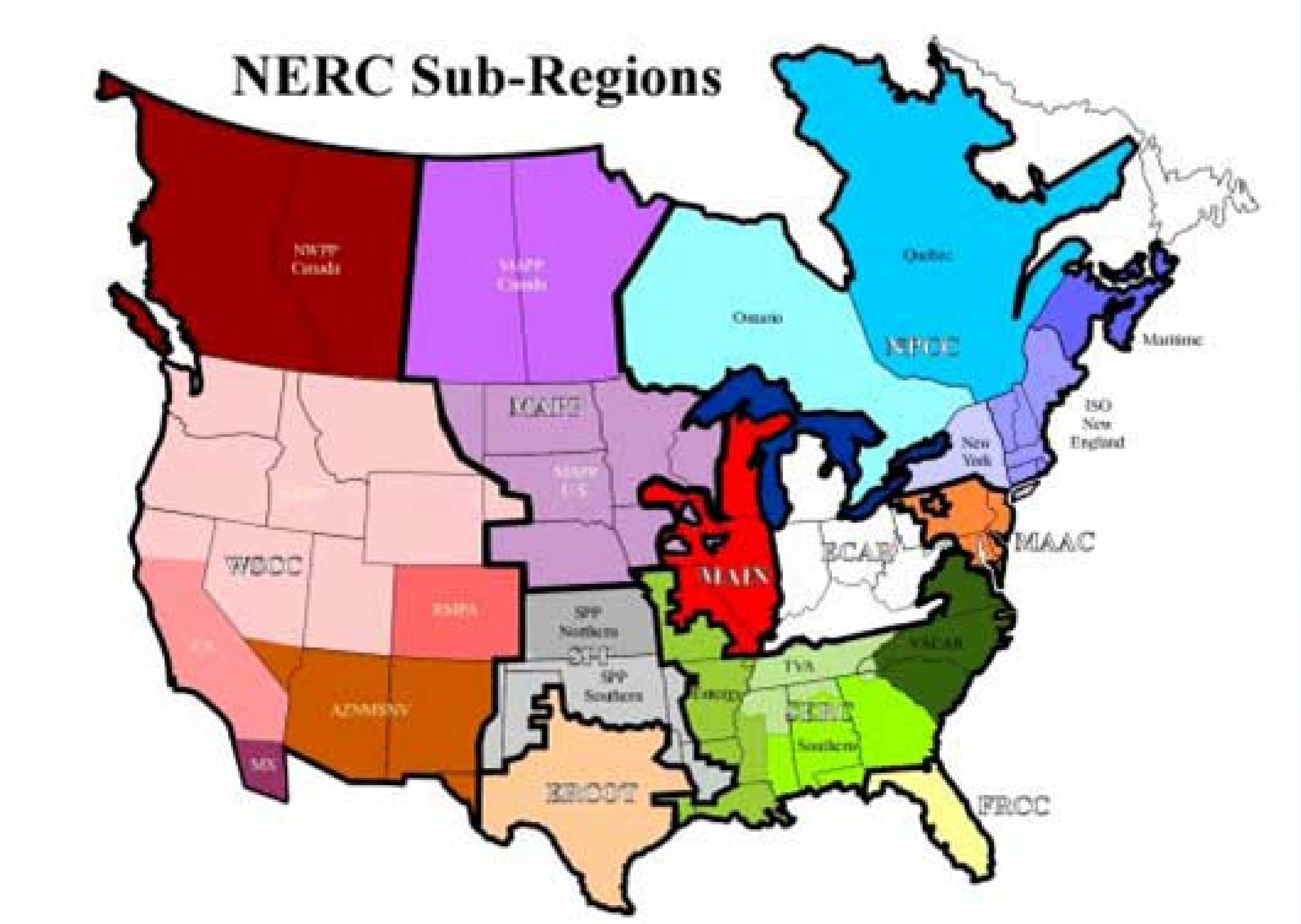
Regression Analysis (cont.)



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Regression Results

- Total gas-fired variable yields the best fit
- Gas-fired capacity additions push demand up
- Hydro availability dampens the need for gas
- Cost variables have better explanatory power than price alone
- DFO seems to capture switching
  - One explanation is that in monthly time series the competition between gas and RFO is infra-marginal. In fact, the “cost” variable implies a general ranking of facility type – COAL, NGCC, RFO, NGGT, DFO
  - The data do not indicate any statistically significant influence from coal
- CDDs demonstrate a non-linear effect on gas burn
- R-squared = 0.9719

lnngcon	Coef.	Panel-corrected Std. Err.	t	P>|t|	[95% Conf. Interval]	
lnegen	0.50769	0.06430	7.90	0	0.38167	0.63371
lnhydgen	-0.01295	0.00807	-1.61	0.108	-0.02876	0.00286
hdd	0.00031	0.00015	2.07	0.039	0.00002	0.00060
cdd	0.00438	0.00064	6.81	0	0.00312	0.00564
cddsq	-2.850E-06	1.010E-06	-2.82	0.005	0.00000	0.00000
lnngtotcap	0.24228	0.05249	4.62	0	0.13940	0.34516
lnngtotcost	-0.26446	0.07484	-3.53	0	-0.41115	-0.11778
lndfocost	0.12049	0.08274	1.46	0.145	-0.04167	0.28265
laglnngcon	0.69959	0.02006	34.87	0	0.66027	0.73891

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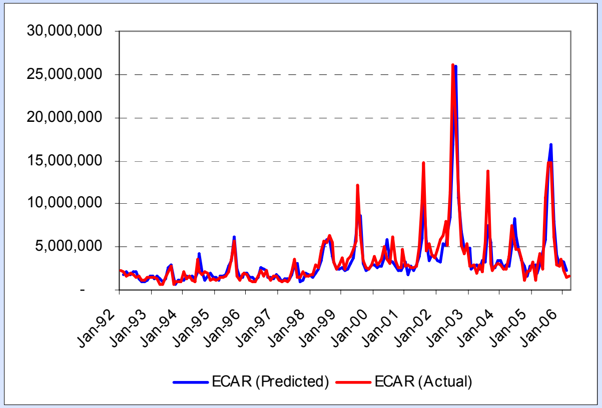
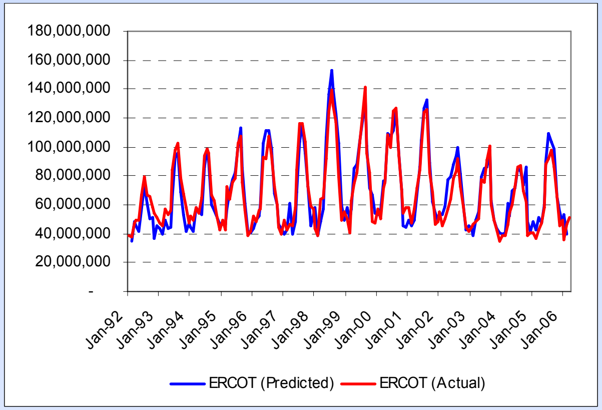
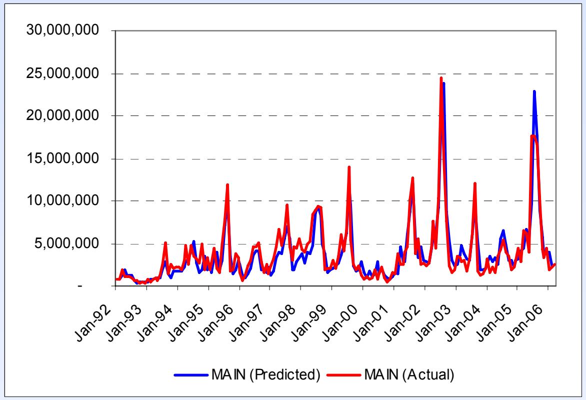
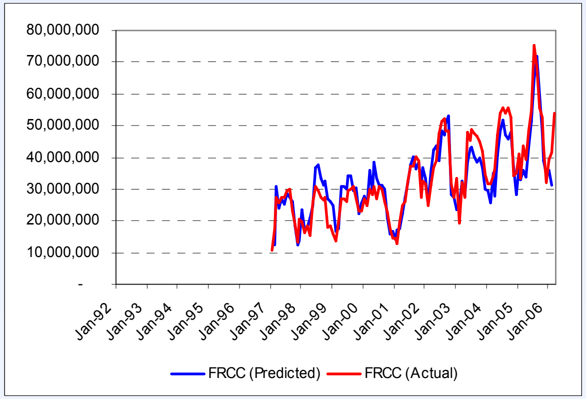
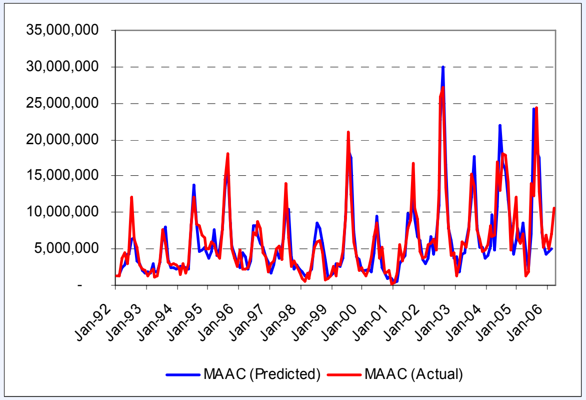
Regression Results: Fitted vs. Actual











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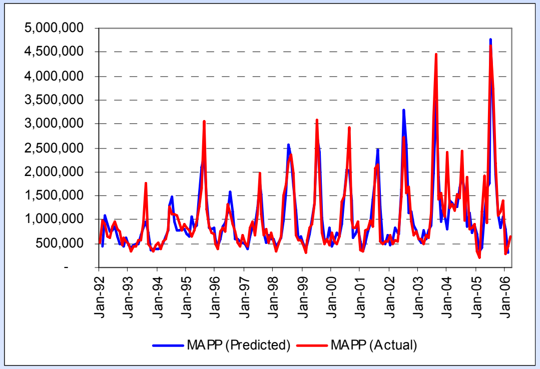
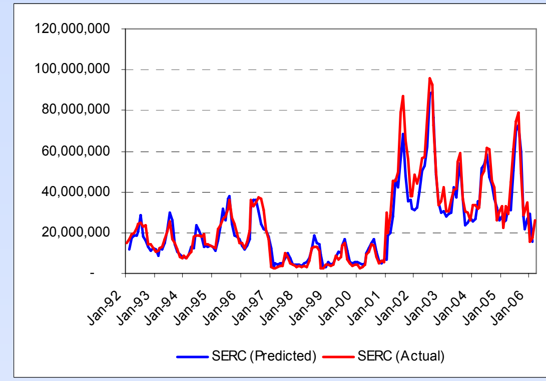
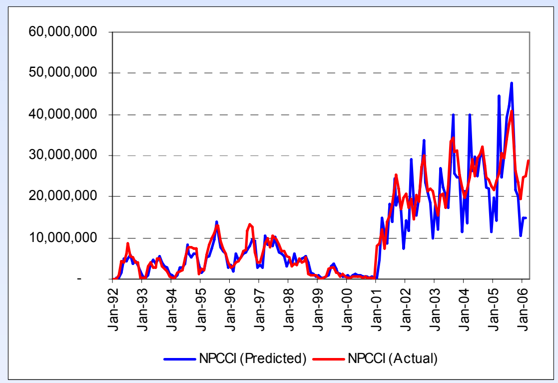
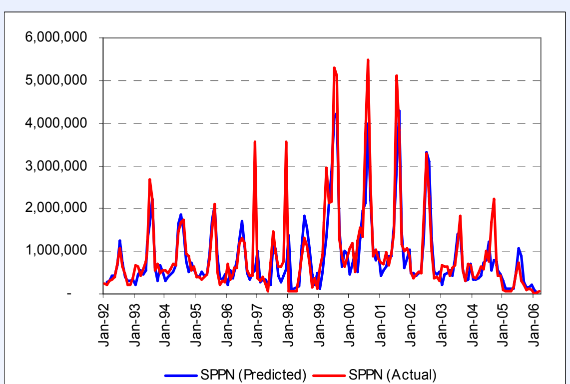
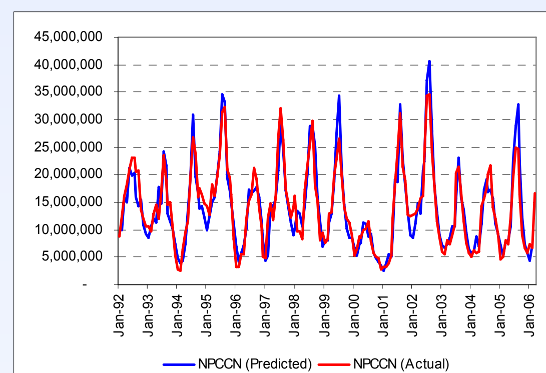
Regression Results: Fitted vs. Actual (cont.)











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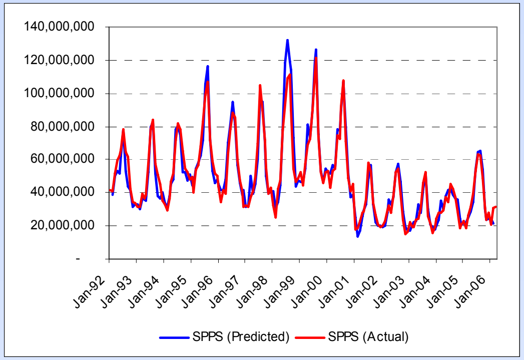
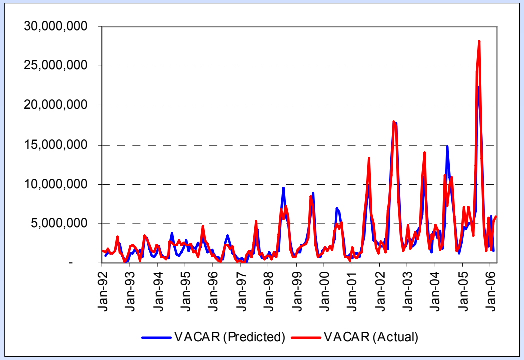
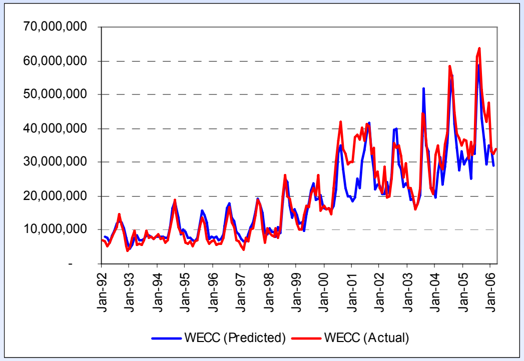
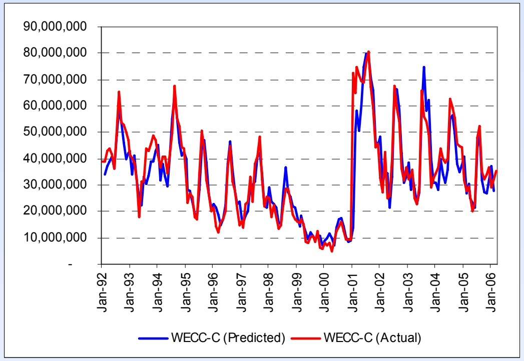
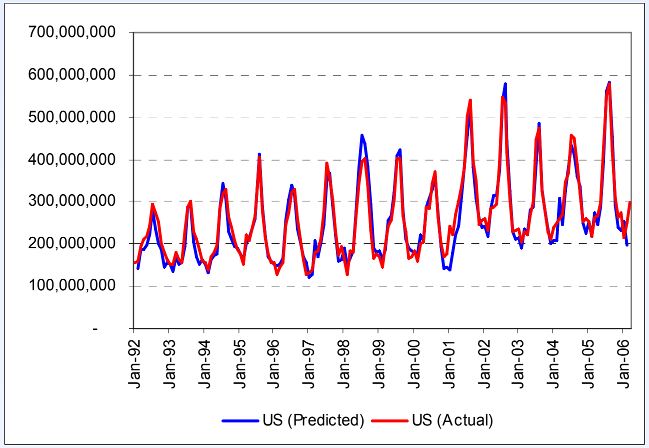
Regression Results: Fitted vs. Actual (cont.)











US constructed as a sum of all NERC regions

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Future Work

- Investigate a more non-linear approach to better approximate the "on-off" nature of switching
- Analyze a sub-sample of facilities with dual-fuel capability. How (and why) might this differ from system-wide switching capability?
- Time series approach to NERC region data to separate and identify important aspects (as they may vary) of different regions
  - Dual-fired capacity is variable across regions. Does this ultimately matter?
- What are the decision variables for long term and short term switching?
  - Capacity investment vs. dispatch alternatives
- Comments or suggestions???

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Industrial Demand for Natural Gas

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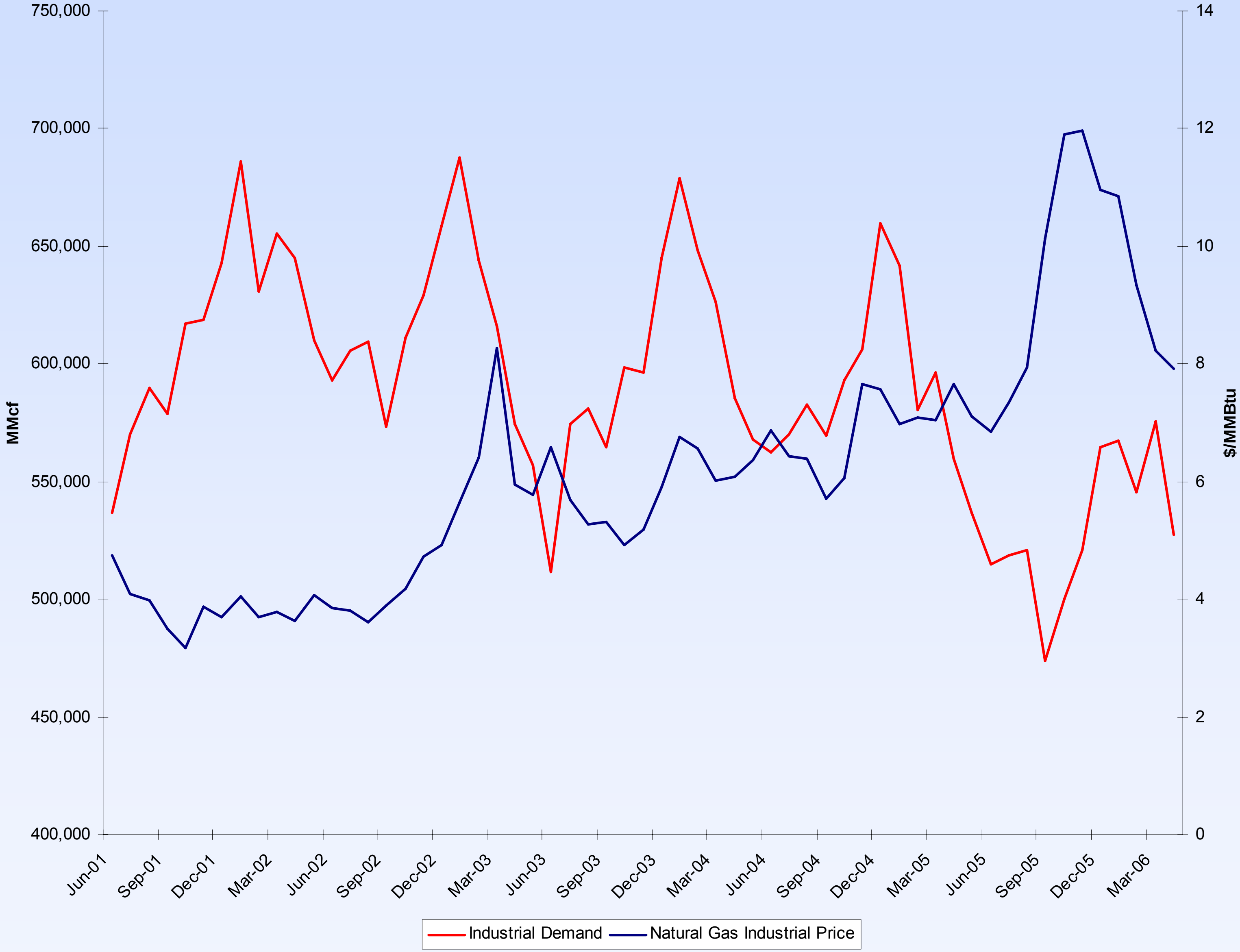
US Industrial Demand for Natural Gas



NPC Study

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- Demand for natural gas is not expected to change dramatically in the industrial sector, but some industries will be more responsive to prices.
- Used MECS data to focus on 6 most gas-intensive industries comprising 80% of industrial natural gas demand.
- Main drivers:
  - Industrial production
  - Energy prices
  - Technology
  - Fuel switching
  - Regionality
  - Seasonality
- This study focuses on similar industry groups using econometric analysis to determine long run and short run sector level price responses.

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A Structural Model as Motivation

- Similar to that used for power generation sector
- Independent Variables
  - Industrial Production
  - Production Price Index
  - Fuel Prices
    - Natural Gas
    - Distillate
    - Residual Fuel
    - Electricity
  - Lagged Dependent Variable
  - Monthly Dummies

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Data

- Monthly industrial consumption by state, June 2001 – April 2006 (EIA)
- Industrial Production Indices (Federal Reserve Bank)
- Producer Price Index (Bureau of Labor Statistics)
- Prices
  - Natural Gas – prompt month contract (EIA/NYMEX), spot price for industrial consumers
  - Petroleum Products – spot price for distillate and residual fuel, futures price for crude oil (EIA/NYMEX)
  - Electricity – ICE Entergy Price via Energy Velocity

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More on Prices

- Different prices used to account for contracting behavior
  - Spot Prices
    - First day of the month
    - Average
  - Futures Prices
    - First day of the month
    - Average of days 10 – 20
    - Last week of the month average
- Normalization using the PPI
  - Shows input price relative to output price

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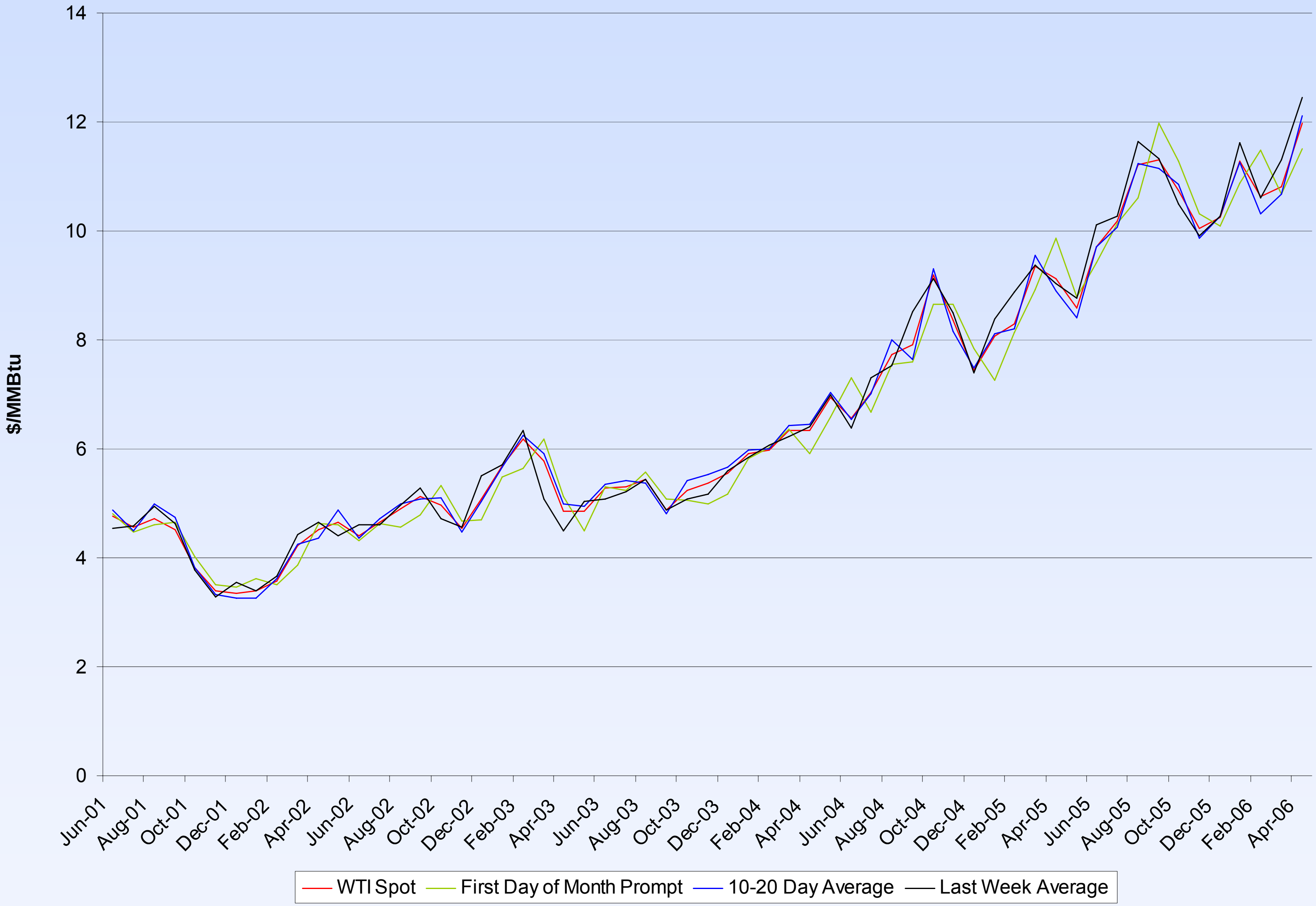
Monthly Crude Oil Price Measurements



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Estimated Regression

$$\ln NG_{i,t} = \alpha_i + \beta_0 + \beta_1 \ln NGPrice_{i,t} + \beta_2 \ln DieselPrice_{i,t} + \beta_3 \ln ResidPrice_{i,t}$$
$$+ \beta_4 \ln ElecPrice_{i,t} + \beta_5 \ln IPI_{i,t} + \beta_6 \ln NG_{i,t-1} + \sum_j \beta_j Month_{j,t}$$

- Instruments are used as a proxy for lagged natural gas consumption
- Coefficients estimate price elasticities of demand

Preliminary Results

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- Found that real natural gas price was significant, but not other fuel prices

$$\ln NG_{i,t} = \alpha_i + 0.397 + 0.837 * \ln NG_{i,t-1} - 0.063 * \ln(NGPrice_{i,t})$$
$$- 0.08 * Feb - 0.06 * Mar - 0.12 * Apr - 0.13 * May$$
$$- 0.13 * June - 0.10 * Jul - 0.04 * Aug - 0.09 * Sep$$
$$+ 0.02 * Oct + 0.04 * Dec$$

Results indicate significant persistence in industrial demand and an own price elasticity of approximately 0.063.

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Disaggregate Industrial Sector Analysis

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Industry Sectors

- Testing different industry sectors allows us to determine where the price response comes from
  - Refining (NAICS 324)
  - Chemicals (NAICS 325)
  - Pulp and Paper (NAICS 322)
  - Primary Metals (NAICS 331)
- Industry level consumption data is not easily available except in MECS
  - Published every four years, this does not give us enough data to discern short run response

Energy Velocity Pipeline Data

- Consumption data at metering stations along natural gas pipelines
- Daily reports of scheduled deliveries and capacity
- Flow points are assigned an NAICS code to designate their industry
  - Sorted by three digit NAICS code for regression analysis
- Some pipeline data goes back as far as 2000, others go back to 2004
  - Estimating a regression for each pipeline separately will allow us to use all the data

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Pipelines for analysis

- ANR
- Columbia
- Centerpoint
- Dominion
- El Paso
- Florida Gas
- Gulf South
- Gas Transmission Northwest
- Mississippi River Transmission
- Northern Border
- NGPL
- Northwest
- Panhandle Eastern
- Portland
- Tennessee
- Texas Eastern
- Texas Gas
- Transco
- Trunkline

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Gulf South Pipeline

- Data from May 2001 – July 2006
- Includes consumption in Texas (<1%), Louisiana (7%), Alabama (2%), Florida (12%), and Mississippi (6%)
- Aggregated the daily data into monthly and daily time series by three digit NAICS code for each industry of interest and ran separate regressions for each

Industrial Demand on Gulf South vs. Price

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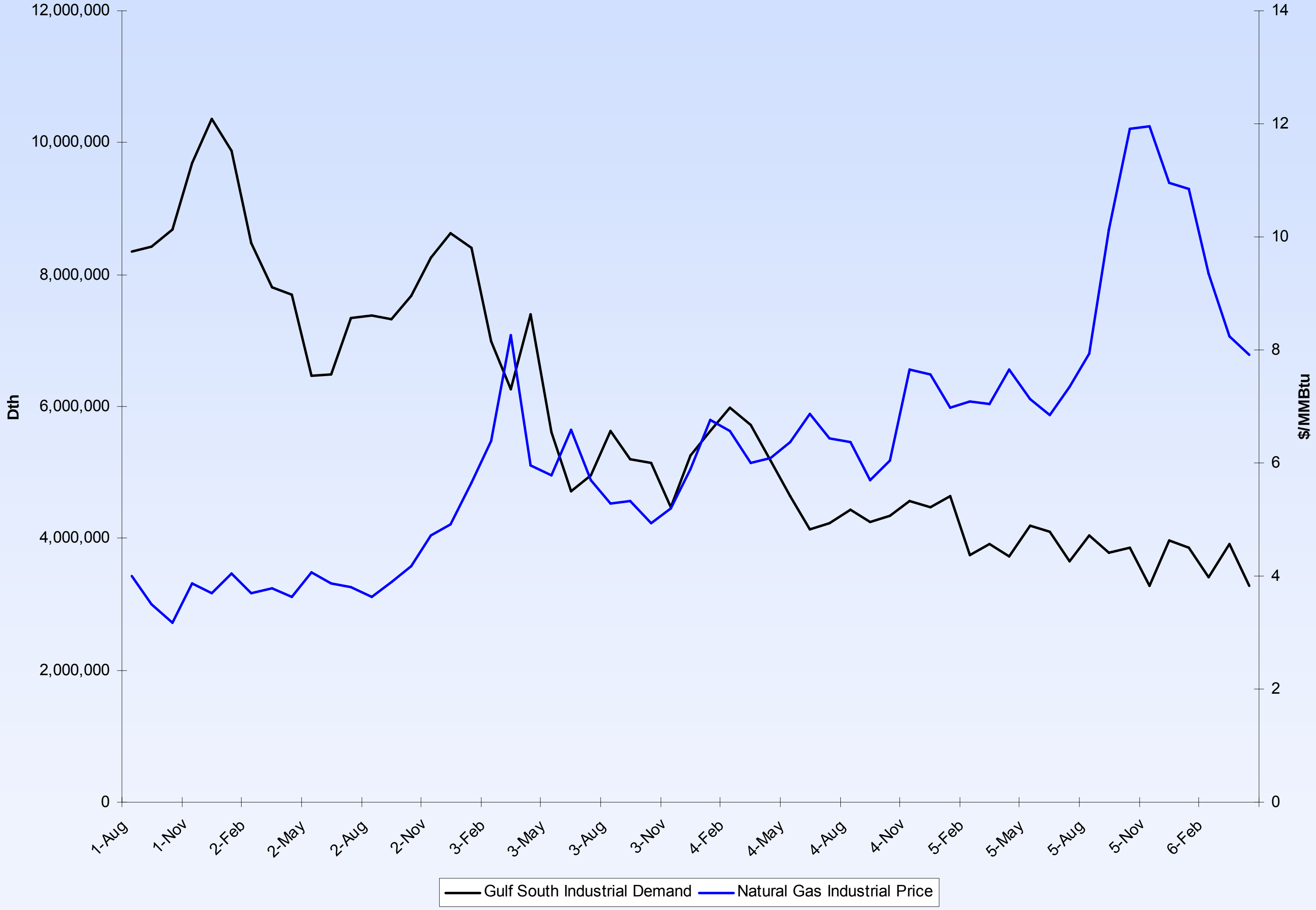

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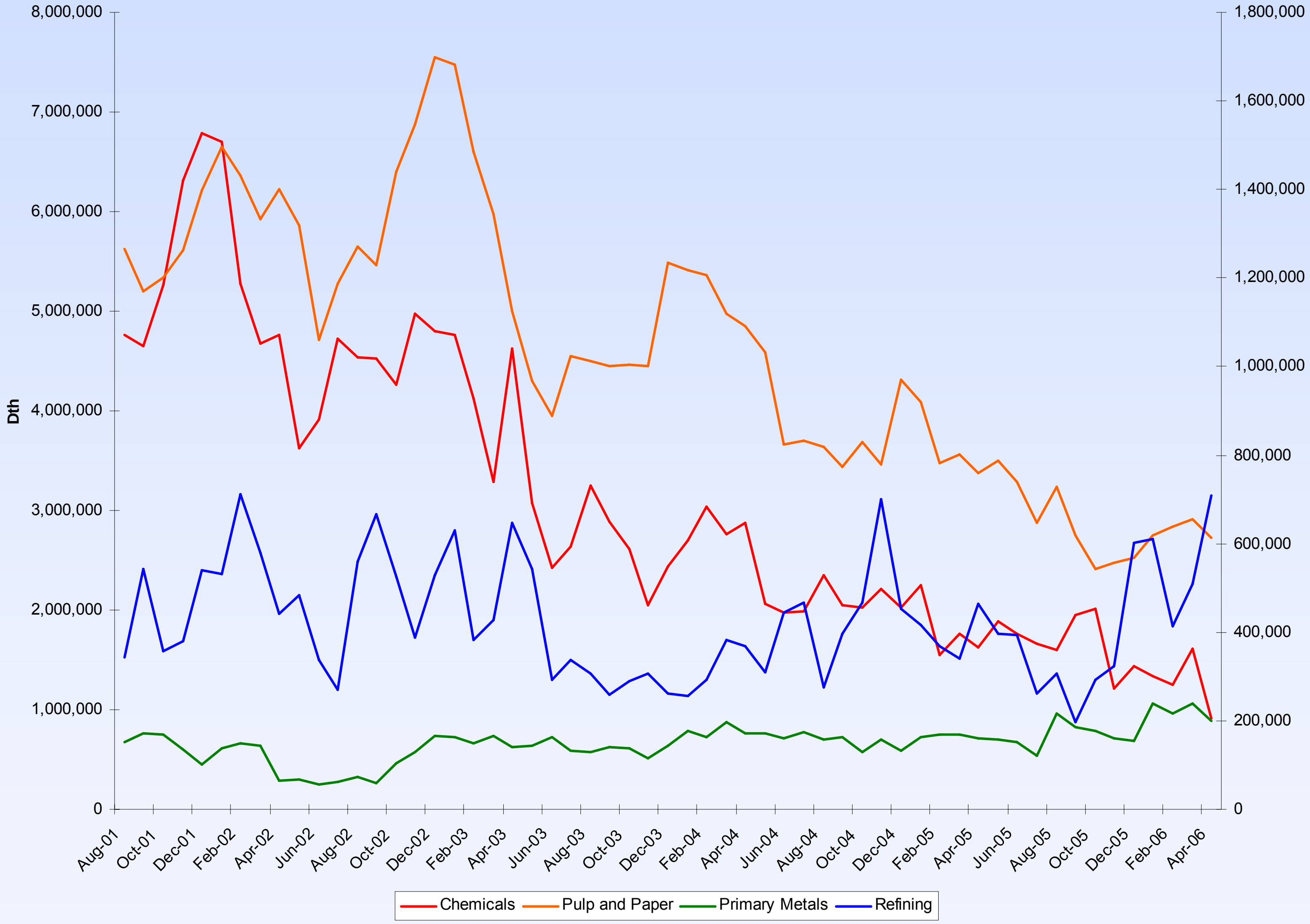
Gulf South Pipeline: Monthly Consumption by Industrial Sector



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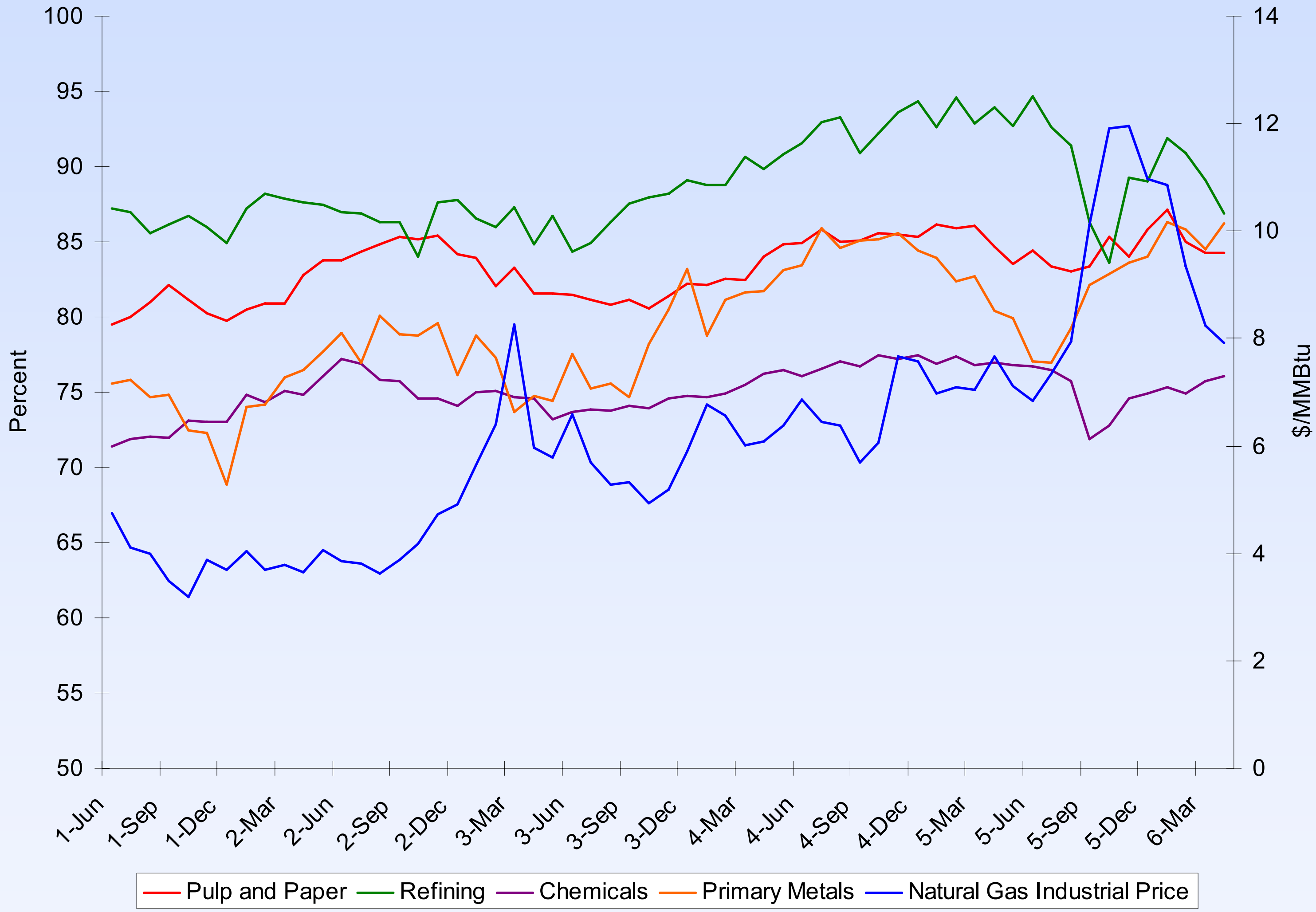
Capacity Utilization



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Gulf South Pipeline: Regression Analysis

- Estimated Equation

$$\ln NG_t = \beta_0 + \beta_1 \ln NGPrice_t + \beta_2 \ln DieselPrice_t + \beta_3 \ln ResidPrice_t$$
$$+ \beta_4 \ln ElecPrice_i + \beta_5 \ln IPI_i + \sum_j \beta_j Month_{j,t}$$

- Fuel choice for each industry sector based on switching in the industry (NPC)
  - Chemicals – natural gas, petroleum products
  - Primary metals – natural gas
  - Refining – natural gas
  - Pulp and paper – natural gas
- Mixed results in terms of significance of coefficients and magnitude of effects

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Gulf South Pipeline: Total Industry

- Results show persistence and an own price elasticity of 0.35
- Cross price elasticity of electricity was marginally significant at 0.14
- Independent variables explained 94% of the natural gas demand

$$\ln NG_t = 3.06 + 0.811*\ln NG_{t-1} – 0.350*\ln(NGPrice_t)$$
$$– 0.14*Feb – 0.05*Mar – 0.11*Apr – 0.17*May$$
$$– 0.17*June – 0.10*Jul – 0.02*Aug – 0.12*Sep$$
$$– 0.06*Oct – 0.03*Nov + 0.05*Dec$$

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Gulf South Pipeline: Pulp and Paper

- Results indicate significant persistence and an own price elasticity of 0.18
- Cross price elasticities were insignificant

$$\ln NG_t = 2.88 + 0.818 * \ln NG_{t-1} - 0.181 * \ln(NGPrice_{t,I})$$
$$- 0.08 * Feb - 0.07 * Mar - 0.10 * Apr - 0.10 * May$$
$$- 0.20 * June - 0.01 * Jul - 0.03 * Aug - 0.13 * Sep$$
$$- 0.05 * Oct + 0.08 * Dec$$

Gulf South Pipeline: Chemicals

- Also persistent with and own price elasticity of 0.38
- Cross price elasticities were insignificant

$$\ln NG_t = 4.46 + 0.749*\ln NG_{t-1} - 0.377*\ln(NGPrice_{t,I})$$
$$- 0.17*Feb - 0.07*Mar - 0.13*Apr - 0.27*May$$
$$- 0.17*June - 0.08*Jul + 0.02*Aug - 0.11*Sep$$
$$- 0.10*Oct - 0.11*Nov$$

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Regression Analysis using Daily Data

- Same idea, but only prices are included as independent variables
- No controls in place for production, seasonality, and production price indices
- Data – Gulf South pipeline production by NAICS code, residual fuel and diesel spot prices, and natural gas prompt month contract price
- Results:
  - Lower own price elasticity on total demand than in the monthly data
  - Consumption largely dependent on consumption from the previous day
  - Primary Metals show no significant results while Chemicals, Pulp and Paper, and Refining have significant negative own price elasticities
- Next steps:
  - Analyze more pipelines and aggregate by state or region
  - Separate out single large users to determine price responsiveness

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Some Comments on the Relationship between Crude Oil and Natural Gas Prices

Micro Analyses and Dynamic Responses

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- The analyses discussed earlier in the day should help us understand the critical determinants of substitution between natural gas and other fuels
- Such substitution should link the prices of different fuels
- One key question we are interested in is how *fast* the adjustment occurs
- One could aggregate the microeconomic models of individual sectors to get a model of how overall demand responds to price changes
  - This is feasible and something that we intend to pursue
- However, the overall dynamic price response may also depend on supply factors

A Role for Time Series Analysis

- It may also be useful to approach the problem from the "other direction"
  - That would involve modeling the dynamic relationships using aggregate time series data
- The time series approach makes fewer assumptions about firm behavior or market structures
  - It could be seen more as a way to "summarize the data"
  - It thus provides another "triangulation" on how the aggregated micro models should behave
- Time series analysis can facilitate looking at more complicated dynamic responses
- Time series approach also has weaknesses
  - Especially, without theory, it is difficult to choose functional form or to say which parameters should be relatively stable
- It also is more difficult to understand why the results are what they are and how the model might change out of sample

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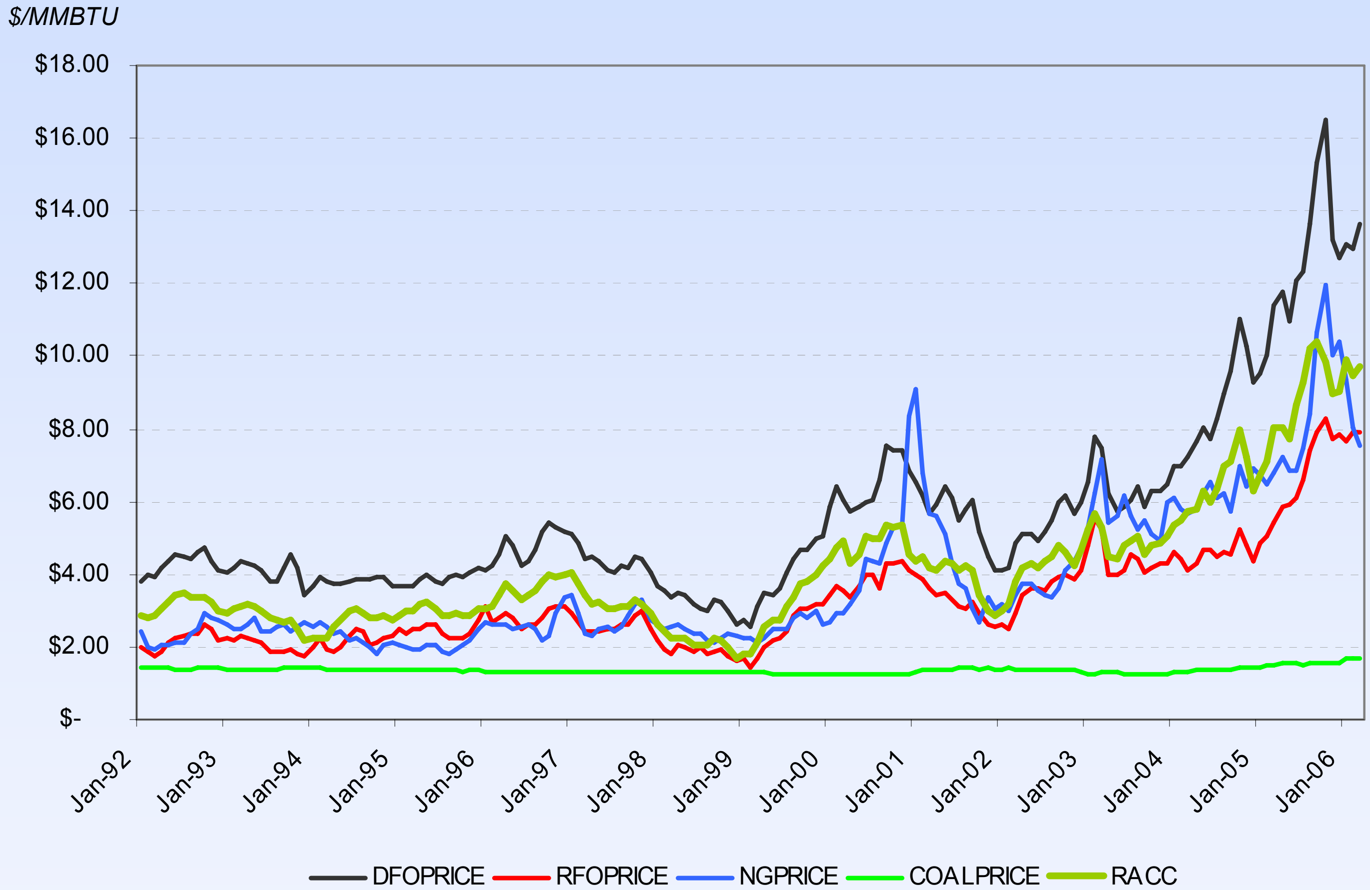
Analysis of Price Relationships

- Most previous analyses have used "benchmark" prices like WTI for oil and Henry Hub for natural gas
- Micro level analyses can suggest which prices are most relevant
- Firms respond to local gas prices, which include premiums for pipeline constraints
  - Responses to capacity constraints might differ from responses to other sources of price shocks
  - A similar argument applies to predictable shocks – like seasonal weather – versus less predictable ones
  - A consumption weighted average price is also not necessarily the best thing to look at
- Also need to take account of technological change – such as changes in heat rates

Natural Gas, Petroleum and Coal Prices



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Why the would oil and gas prices be correlated?

- Substitutability
  - Dual fueled electricity generation
  - Competition on the electricity supply stack
  - But over the long term – technological changes are likely to change the relationship
- Supply-side issues
  - Use of natural gas to extract oil (EOR)
  - Associated gas
  - Unconventional oil
  - Gas to liquids
- Financial markets
  - Expectations of a linkage affect arbitrage, storage decisions
- Development of global LNG market
  - Should make gas prices more closely tied to shorter term market conditions

Modeling Approach

- Real oil and gas prices may tend to "drift" over time
  - Hotelling model of resource extraction, combined with non-stationary changes in technologies and costs
- Handling non-stationarity
  - In the equation, $y_t = \rho y_{t-1} + e_t$, a unit root exists if ρ is not statistically different than 1.
  - Tests for unit root
    - Dickey-Fuller, Augmented Dickey-Fuller, Phillips-Perron (allows specification of structural changes)
- Cointegration
  - Two I(1) variables, y_t, x_t are considered cointegrated if there exists a cointegrating vector, β, such that

$$y_t - \beta_0 - \beta_1 x_t = u_t$$

    where u_t is I(0).
  - Tests for cointegration
    - Johansen MLE to estimate relationship
    - OLS
    - VAR for multivariate cointegration

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Vector Autoregression (VAR)

- With multiple price series we can use a vector autoregression (VAR) to investigate the long run relationships among variables.
- Each endogenous variable is regressed on lagged values of itself and the other endogenous variables in the system.
- Appropriate lag time can be determined using AIC or other criterion.
- The VAR(r) long run relationship can be written

$$\mathbf{p}_t = \prod_1 \mathbf{p}_{t-1} + \ldots + \prod_r \mathbf{p}_{t-r} + \mathbf{B}x_t + u_t$$

Error Correction Model (ECM)

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- Once a long run relationship is determined by the cointegrating vector, the ECM looks at how quickly and through what variable an adjustment back to the long run equilibrium occurs.
- In a multivariate setting, we can use the VAR to determine the cointegrating relationships. Then, the estimated residuals are used as a regressor for the differenced endogenous variables in the Vector ECM (VECM). The VECM looks at a system of equations of the form:

$$\Delta p_t = \alpha_1 + \alpha_2 \widehat{u}_t + \sum_{j-1}^{r} \alpha_{11} \Delta p_{t-j} + \varepsilon_t$$

- The variable α_2 measures how quickly prices move back to their long run equilibrium relationship. We expect the sign to be negative.
- A note on causality
  - Granger causality is demonstrated by positive coefficients for the independent variable on the lagged differences of the other variables in the system.
  - Additionally, a value of α_2 statistically different from zero indicates that it is the dependent variable that adjusts to movements away from the long run equilibrium.

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Some previous literature

- Serletis and Herbert (1999)
  - Used daily data from October 1996 – November 1997 for Henry Hub and Transco Zone 6 natural gas, PJM electricity prices, and NYMEX NY harbor heating oil contract.
  - Checked for correlation between prices, integration in the series, shared price trends, and causality.
  - Found a strong overall correlation between logged levels and first differences, but with a smaller relationship between PJM and the others.
  - Augmented Dickey-Fuller test to check the integration of the series and found that all price series were integrated except PJM.
  - Engle-Granger cointegration tests (tests to see if the OLS residuals have a unit root) and found that there is a cointegrating vector between Henry Hub TZ6, and fuel oil.
  - Short run dynamics can be described by an Error Correction Model (ECM).
  - Using a bivariate VAR with the error correction terms found that Henry Hub causes TZ6 prices, but causality does not move in the opposite direction.

Some previous literature (cont.)

- Serletis and Herbert (2002)
  - Goal was to assess the strength of shared dynamics between North American energy markets after deregulation (occurred in the natural gas market in 1989).
  - Looked at shared trends and cycles between WTI and Henry Hub as well as Henry Hub and AECO Alberta natural gas.
  - Concluded that there has been a de-coupling of oil and natural gas price cycles since deregulation, but North American natural gas markets continue to move together.

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Some previous literature (cont.)

- Brown and Yucel (1993)
  - An analysis of upstream and downstream natural gas pricing in the United States.
  - They examined:
    - Integration, Cointegration, Causality, Adjustment to equilibrium error (ECM), Impulse response, Long run sources of variance
  - Found integration in seven series using ADF and Phillips-Perron.
  - Using the Johansen MLE procedure found linear significant, but different, cointegrating relationship between wellhead prices and electrical, industrial, city gate, and commercial prices.
  - Causality runs from upstream price to downstream price in all tests and from downstream to upstream when looking at electrical, industrial, and city gate.
  - Used and ECM to evaluate adjustments to equilibrium error and found that for some markets upstream prices adjust and for some markets downstream prices adjust.

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Some previous literature (cont.)

- Villar (2006)
  - Looks at the statistical relationship between Henry Hub natural gas and WTI January 1989 – December 2005.
  - Used a VAR and VECM to look at the long and short run relationships between the prices.
  - Addition of this research is the use of some exogenous control variables.
  - As with others, showed the I(1) nature of prices. The persistence of autocorrelations are consistent with this finding.
  - VAR regresses an endogenous variables on lagged value of itself and other endogenous variables in the system.
  - Used a VAR(2) found that the estimated residuals are non-normal and possibly heteroskedastic.
  - Added several exogenous variables in order to improve the fit of the model: heating degree days, monthly dummy variables, lagged value of the difference between storage and the 5-year minimum, pulse dummy variables.

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Preliminary Analysis

- Used monthly price data from June 1986 to December 2005 for natural gas, residual fuel oil, and heating oil prices.
- Exogenous variables
  - Inventory/Consumption
    - an improvement on Villar's use of Inventory and HDD as separate variables
  - Heat rate for DFO, RFO, and NG plants
    - much of the literature has concluded a de-coupling of prices. Is this a function of natural gas electricity generation becoming more efficient?
  - Monthly dummy variables
    - accounts for seasonal factors influencing prices

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Preliminary Analysis (cont.)

- Cointegration analysis
  - Natural logarithm of variables

	Test Statistic			
	ADF	Phillips-Perron		Conclusion
	Z(t)	*Z(rho)*	*Z(t)*	
Natual Gas	-0.397	-0.596	-0.184	I(1)
Residual Fuel Oil	-0.645	-4.595	-1.13	I(1)
Distillate Fuel Oil	-0.574	-3.031	-0.862	I(1)
Heating Oil	-1.085	-4.792	-1.198	I(1)

  - Log returns of variable

	Test Statistic			
	ADF	Phillips-Perron		Conclusion
	Z(t)	*Z(rho)*	*Z(t)*	
Natual Gas	-12.591	-159.555	-12.776	I(0)
Residual Fuel Oil	-10.38	-130.865	-10.059	I(0)
Distillate Fuel Oil	-10.838	-133.999	-10.459	I(0)
Heating Oil	-12.799	-171.23	-12.626	I(0)

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Preliminary Analysis (cont.)

- VAR analysis (prices only)
  - Variables: LNPNG, LNPRFO, LNPDFO, LNPHO
  - Optimal lag of three periods selected based on the AIC.
- Natural gas price equation results:

	Coef.	Std. Err.	z	P>z
LNPNG				
lnpng				
L1.	1.028	0.066	15.540	0.000
L2.	-0.386	0.093	-4.170	0.000
L3.	0.233	0.065	3.590	0.000
lnprfo				
L1.	0.046	0.132	0.350	0.729
L2.	-0.027	0.189	-0.140	0.886
L3.	0.033	0.126	0.260	0.796
lnpdfo				
L1.	-0.090	0.224	-0.400	0.688
L2.	0.857	0.282	3.050	0.002
L3.	-0.375	0.199	-1.880	0.060
lnpho				
L1.	0.438	0.148	2.950	0.003
L2.	-0.743	0.168	-4.420	0.000
L3.	0.055	0.153	0.360	0.722
_cons	-0.709	0.195	-3.640	0.000

- Test for normality of VAR residuals using the Jarque Bera test does not reject the null that the disturbances are normally distributed, except in the case of LNPDFO.

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Preliminary Analysis (cont.)

- VAR analysis with exogenous variables
  - Seasonal dummies, heat rate, inventory/consumption.
  - Two VAR models – one with RFO, one with HO.
  - Chose lag of two periods based on AIC.
- Natural gas price equation results:

Model with RFO

	Coefficient	Standard Error	z	P>z
LNPNG				
lnpng				
L1.	0.9425950	0.0701729	13.43	0.000
L2.	-0.1039345	0.0674891	-1.54	0.124
lnprfo				
L1.	0.3395874	0.09244	3.67	0.000
L2.	-0.2102098	0.0926443	-2.27	0.023
constr	-0.0100617	0.006912	-1.46	0.145
hrng	-0.0000520	0.0000178	-2.92	0.003
hrpet	-0.0000123	0.0000239	-0.52	0.606
jan	0.1058900	0.0303624	3.49	0.000
mar	0.0991395	0.030449	3.26	0.001
apr	0.1127435	0.0308399	3.66	0.000
may	0.1495425	0.0358319	4.17	0.000
jun	0.1644365	0.0504613	3.26	0.001
jul	0.1793854	0.0629362	2.85	0.004
aug	0.2100776	0.0730432	2.88	0.004
sep	0.2116101	0.0758915	2.79	0.005
oct	0.2070264	0.0546222	3.79	0.000
nov	0.1643608	0.0373112	4.41	0.000
dec	0.1589530	0.0307438	5.17	0.000
_cons	0.2081383	0.3382423	0.62	0.538

Model with HO

	Coefficient	Standard Error	z	P>z
LNPNG				
lnpng				
L1.	0.9464720	0.0638644	14.820	0.0000
L2.	-0.0899772	0.0611714	-1.470	0.1410
lnpho				
L1.	0.4382131	0.0717622	6.110	0.0000
L2.	-0.3262390	0.0734177	-4.440	0.0000
constr	-0.0114274	0.0066528	-1.720	0.0860
hrng	-0.0000491	0.000017	-2.880	0.0040
hrpet	-0.0000146	0.0000223	-0.660	0.5120
jan	0.1061871	0.0286753	3.700	0.0000
mar	0.0974767	0.0289588	3.370	0.0010
apr	0.1070907	0.0290101	3.690	0.0000
may	0.1509081	0.0340608	4.430	0.0000
jun	0.1877196	0.0485324	3.870	0.0000
jul	0.2020967	0.0604943	3.340	0.0010
aug	0.2229399	0.0702278	3.170	0.0020
sep	0.2111372	0.0729091	2.900	0.0040
oct	0.2027337	0.0521683	3.890	0.0000
nov	0.1700492	0.0356216	4.770	0.0000
dec	0.1666191	0.0292373	5.700	0.0000
_cons	0.2175743	0.3210996	0.680	0.4980

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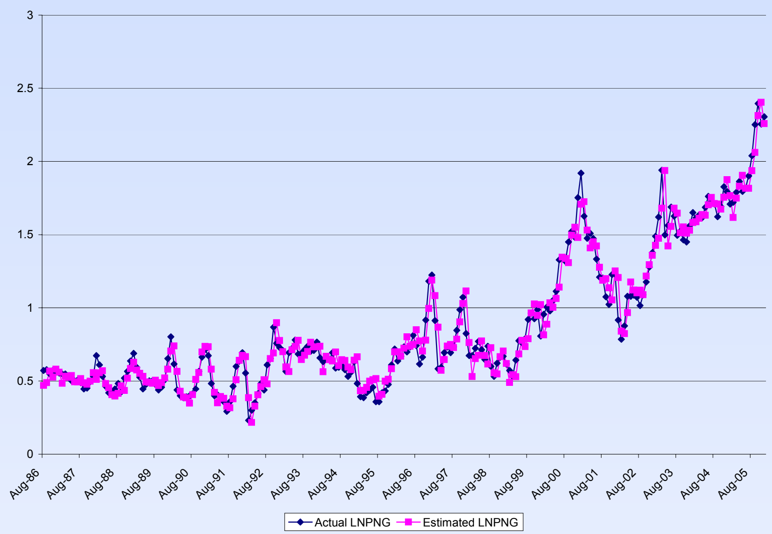
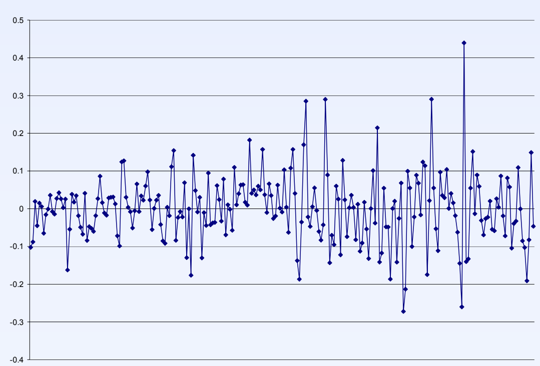
Preliminary Analysis (cont.)

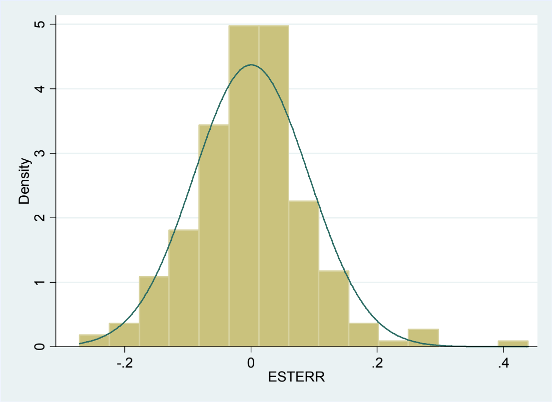
- VAR analysis with exogenous variables (cont.)

Fitted Values



Estimated Residuals





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Preliminary Analysis (cont.)

- VECM Analysis
  - Included variables:
    - LNPNG, LNPRFO, LNPHO, Exogenous Variables
  - Test significance of coefficient on the estimated residual from the VAR.
- Results:
  - Coefficient is negative and significant for natural gas and positive and significant for residual fuel oil, but not significant for heating oil.
- Next Steps:
  - Disaggregate heat rate data
  - Include an international market component
  - Test for Granger causality
  - Add pulse dummy variables for significant events