Industrial Natural Gas Consumption in the United States: An Empirical Model for Evaluating Future Trends

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Abstract

This study develops a statistical model of industrial US natural gas consumption based upon historical data for the 1958-2003 period. The model specifically addresses interfuel substitution possibilities and changes in the industrial economic base. Using a relatively simple approach, the framework can be simulated repeatedly with little effort over a range of different conditions. It may also provide a valuable input into larger modeling exercises where an organization wants to determine long-run natural gas prices based upon supply and demand conditions.

Projections based upon this demand framework indicate that industrial natural gas consumption may grow more slowly over the next 20 years than being projected by the U.S. Energy Information Administration (EIA). This conclusion is based upon the assumption that natural gas prices will follow oil prices, as they have done over recent decades. If natural gas prices should lag well below oil prices, as envisioned by the latest EIA outlook, industrial natural gas consumption should rapidly expand well beyond the levels being projected by EIA.

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1. Introduction

High recent energy prices and a shifting industrial composition are transforming the US industrial consumption of natural gas. What happens to industrial consumption will have important effects on total natural gas use because this sector represents a large share of total use and has had an uneven pattern influenced by regulatory conditions and business cycles over many decades (Figure 1).

*** FIGURE 1 ABOUT HERE ***

This study develops a statistical model of industrial US natural gas consumption based upon historical data since World-War II. Its main purpose is to help policy and corporate planners think about important factors that could influence future industrial consumption trends. The model's main strengths lie in representing interfuel substitution possibilities at an aggregate level as well as the influence of changes in the industrial economic base. These two issues have important implications for future energy use trends within this sector. Although Brown (2005) and Rothwell (2005) have found recent evidence that natural gas prices has remained competitive with petroleum prices, the recent Annual Energy Outlook 2006 (US Energy Information Administration, 2006) expects that natural gas prices will compete more directly with coal prices. Energy advisors need a tractable method to trace through the implications of these two very different energy price paths. In addition to interfuel substitution possibilities, the growth of energy-intensive industries relative to other sectors has had significant effects on energy use, especially in the 1990s (e.g., see Boyd and Roop, 2004). Moving forward, there remains considerable uncertainty about how economic structure will influence future industrial natural gas demand growth.

This model has been designed to be relatively simple in order to easily simulate a number of different cases of potential interest to decisionmakers. As a compact system, the framework may provide a valuable input into larger modeling exercises where an organization wants to determine long-run natural gas prices based upon supply and demand conditions.

These benefits come at the cost of ignoring important technical and process changes, such as the emergence of electric arc furnaces and minimills in the steel industry. The major drawback of this framework is that it will be too broad to address important technology developments, processes and environmental emissions in particular industrial sectors. For evaluating the critical tradeoffs at the individual level, analysts should adopt other frameworks, such as the production-frontier approach used by Boyd et al (2002) to investigate efficiency and emissions tradeoffs in the glass container industry or the hybrid modeling approach used by Rivers and Jaccard (2005) to investigate technology decisions for industrial steam generation. Even for such detailed issues, however, the industrial model developed in this paper may provide useful insights about how industrial natural gas use may evolve over the next few decades. It is often difficult to understand future energy use patterns without having at least some appreciation of how these patterns have evolved in the past.

After describing the data in the next section, the analysis considers whether each variable moves as a stationary series in Section 3. Section 4 truncates the estimation period to the 1958-2003 years after evaluating the stability of the basic relationship between variables over the last 50 years. Section 5 addresses a range of estimation issues, including approaches for representing natural gas shortages of the 1970s, the effect of using different measures of economic activity, and the influence of different oil price variables. Key elasticities with respect to oil and natural gas prices and to economic activity are summarized in Section 6. Several projections with this framework are discussed in Section 7 to indicate how fuel price and economic composition assumptions might influence future consumption. A concluding section summarizes the results and offers a few recommended improvements for future work on this topic.

2. Industry Data Over the 1949-2003 Period

Annual data covering the 1949-2003 period were collected from primarily U.S. government sources. Table 1 summarizes the data, its construction and relevant data sources. The analysis considers total national variables representing industrial natural gas and total fossil fuel consumption, weather, economic output, capacity utilization rates, and fuel prices.

*** TABLE 1 ABOUT HERE ***

Industrial energy consumption (trillion Btus per year) represents energy use in manufacturing, mining, construction and agriculture. Weather is measured by heating and cooling degree-days, which are the daily difference between the average temperature and 65 degrees Fahrenheit, summed over all days in the year. These national climate estimates are population-weighted averages of state weather data. Since the state population weights are fixed at their 2000 levels (U.S. Energy Information

Administration 2005, Table 1.9, notes), they exclude the direct effects of the U.S. population and economic activity migrating to the south and west.

Capacity utilization rates are the percentage of total capacity used for the production of goods and services in the sector. Capacity utilization rates are available for the industrial sector beginning in 1967, but a longer series beginning in 1949 exists for manufacturing only. Both series are evaluated in this analysis. Although manufacturing is the dominant sector within industry, the shorter industrial series covers more precisely the sector whose consumption is evaluated here. Similarly, energy and economic data availability requires that output refers to the manufacturing rather than industrial sector. Total manufacturing output is measured in 2000 chain-weighted dollars. To extend the data series back to 1949, the output variable based upon the NAICS classification was spliced with older data based upon the SIC classification. [1]

A dollar increase in output in primary metals, chemicals or paper industries will have much larger effects on energy consumption than will a dollar increase in some other industries that are less energy intensive. To incorporate the changing composition of industrial activity, the study develops a structural output variable that will move more rapidly than measured output if more energy-intensive industries grow faster than other industries. Instead of simply aggregating real value added across all industries, this measure weights each two-digit industry's output by its energy intensity in 2002. As a result, it measures total energy use in all industries, if the energy intensity in each industry remains at its 2002 level. The variable continues to represent changes in output,

[1] The manufacturing sector in the national economic accounts includes SIC codes, 20-39, or NAICS codes, 311-339.

but each industry's output is weighted by energy intensity in 2002 rather than by its share of total output in each year.

Figure 2 compares the structural output variable with the GDP series for manufacturing sectors. The two series track each other closely through 1994. At that point, structural output grows considerably slower than actual output due to the slowdown in the growth and relative importance of the energy-intensive sectors.

*** FIGURE 2 ABOUT HERE

Fuel prices for coal, natural gas, total petroleum products, residual fuel oil and distillate fuel oil are measured in 2000 dollars per million Btu, after they have been deflated by the GDP price deflator (or alternatively, the producer price index for all commodities). The trends in these price series are based upon the producer price data maintained by the U.S. Bureau of Labor Statistics in order to extend the coverage to the earlier years. Separate analysis has shown that the U.S. Bureau of Labor Statistics and U.S. Energy Information Administration energy price series are reasonably consistent with each other (Klemmer and Kelley, 1998).

A special price series was developed to represent the natural gas shortage conditions that became most severe during the 1970s. During this period, wellhead price controls segmented the gas-producing industry into a jurisdictional field market, where exogenous price controls created shortages and prevented industry from operating along its true demand curve, and an intrastate field market, where prices were determined endogenously by regional demand and available supply (Huntington, 1978). As oil prices rose during this period, the price difference between these two markets began to widen substantially. As higher regional demand pulled intrastate prices higher, price controls prevented prices from rising as much in the interstate market. Figure A.1 in the appendix shows that this price distortion in the two natural gas markets is not due simply to oil price shocks but depends critically upon the presence of regulated prices in one of the markets.

The price difference was measured as the ratio of the average industrial natural gas price in Texas to the average wellhead price in the United States. Texas was the dominant state within the intrastate market, and its industrial customers bought natural gas principally from pipelines that were not under the Federal Power Commission's jurisdiction. Since short-run regional business conditions could cause temporary and small distortions in the two prices, it was necessary to focus upon large price distortions in order to represent the effects of price regulation on interstate supplies. To minimize minor fluctuations in this price ratio, the analysis defines the shortage variable to equal the price ratio only if it exceeded 1.5. Otherwise, the shortage ratio was set equal to unity, inferring that regional business conditions and other factors were creating the relatively small price distortion rather than shortages in those years. As expected, the distortion becomes relevant only during the 1974-79 period, and then dramatically so.

This variable has an advantage over a simple dummy specification for shortages. A dummy variable simply measures whether shortages exist or not. The price distortion variable allows a direct measure of the *intensity* of the shortage, which may provide additional useful information.

All variables, except the percentage of utilized capacity, are expressed as logarithms. This data transformation allows one to interpret each output coefficient as an elasticity that shows the percentage change in energy demand caused by a percentage change of any independent variable.

3. Stationary Variables

Two or more data series may move together even if there is no causality between these variables. To avoid this problem of spurious correlation, economists often test the individual data series to see if their means and standard deviations are relatively stable as more recent observations are added. Series with stable means and deviations are called stationary variables. If they are stationary, traditional econometric techniques can be applied to them, just as if the data were drawn from separate coin flips or from drawing a card from a shuffled deck. If they are not stationary, further tests must be conducted to see that these variables truly are related to each other.

Table 2 summarizes a set of augmented Dickey-Fuller tests conducted on the variables to discover whether they are stationary.[2] The tests try to reject the null hypothesis that the variable's means and deviations grow over time and are hence non-stationary. Significant tests allow us to reject this hypothesis and accept the result that they are stationary.

*** TABLE 2 ABOUT HERE ***

The reported tests demonstrate that most variables are stationary, because the test statistic exceeds the critical value established for the augmented Dickey-Fuller technique. This result means that the standard econometric techniques will be appropriate for

[2] All estimates and tests were conducted with TSP 4.5. Standard econometric texts, e.g., Johnston and DiNardo (1997, pp. 215-228), explain these tests for stationarity and the importance of specifying them correctly, as explained later in this section. This reference also provides an interesting numerical example of explaining gasoline demand with the ADL specification used later in this paper.

modeling natural gas demand if the variable list includes the stationary variables. Only fossil fuel consumption, cooling degree-days (but not heating degree-days)[3], and coal prices are non-stationary when expressed as logarithmic levels, but these variables are not used in the estimation. The output variable based completely upon the SIC classification just misses being significant at the 5% level and is significant at the 10% level.

Considerable care must be taken in conducting these tests for several reasons. It is often easy to accept the null hypothesis that variables are not stationary, because the econometric test is not very powerful when there are too few observations. This potential problem means that the tests should be specified carefully and with considerable judgment. For example, time trends should be incorporated in tests of the output and structural output variables, the manufacturing capacity utilization variable, and many of the energy price variables. Time trends are not necessary for the other variables and often detract from the power of the test in these cases.

Another problem is that a structural shift may cause a variable to appear non-stationary when in fact it is stationary. The non-stationary hypothesis could not be rejected for most energy price variables unless the tests include a one-time shift in the constant term beginning in 1974, as suggested by Perron (1989). The tests on the coal price variable show how different the approach can be for some variables. For this variable, a constant did not help explain the variable, but both a trend and a squared-trend variable were important. Even with these adjustments, the non-stationary condition could

[3] As explained in the data section, degree days are based upon fixed state population weights and do not reflect the shift in the U.S. population towards the west and south.

be rejected only at a 20% level.[4] Fortunately, fuel oil rather than coal prices appear to be the principal competitor with natural gas prices within the industrial sector.

4. Stable Relationship Between Variables

With the relevant variables being stationary, the analysis adopted a general autoregressive distributed lag (ADL) relationship comprised of current and lagged values of natural gas consumption and the independent variables. After rearranging terms (see the appendix), this formulation can be expressed as

$$dY_t = \beta_0 + \beta_1(dX_t) + (\beta_1 + \beta_2)X_{t-1} - (1-\beta_3)Y_{t-1} + \mu_t \qquad (1)$$

where *Y* and *dY* refer to the level and change in industrial natural gas consumption, *X* and *dX* to the level and change in a set of independent explanatory variables, and the subscript t indicates the year. Explanatory variables included industrial natural gas price, distillate fuel oil price, structural output, heating degree-days, and capacity utilization. The parameter *u* denotes the disturbance term, which is assumed to be normally distributed with zero autocorrelation between successive errors.

There can be additional lagged changes in these variables in the most general form of the ADL specification. Table 3 reports F-tests that show that these additional terms do not contribute significantly to the equation's explanatory power. The equation is estimated first by including current changes as well as changes lagged one and two years. The set of coefficients on the second lagged changes are jointly insignificant. When they

[4] The test for each variable also included lagged values of the change in the variable if F-tests supported their inclusion as a group.

are removed, the set of coefficients on the first lagged changes are also jointly insignificant. These tests confirm that the coefficients should be estimated based upon equation (1).

*** TABLE 3 ABOUT HERE ***

The initial demand function results in a reasonably accurate fit with significant coefficients for the key variables. Nevertheless, the historical data covered an extremely long historical period, during which regulatory policy and market conditions changed dramatically (MacAvoy 2000). There was a very real possibility that the substitution between natural gas and other fuels was not stable through this period. In addition, shifting definitions used by government data-collection organizations may have created data inconsistency over the entire period for industrial energy use and economic output.[5] Similarly, there has been a trend towards decreasing coverage in surveys collecting information on industrial prices.

A Chow (1960) test is a convenient and simple approach for testing the stability of a relationship between variables. The analyst makes an arbitrary break in the data set and estimates three equations: one covers the entire period and the other two cover the two shorter periods. If the two shorter periods produce a significantly better set of estimates than the one longer period, the analyst rejects the hypothesis that one single stable relationship applies throughout the period. Accordingly, the preferred specification would be to estimate the relationship with different coefficients on each variable, one estimate for each subperiod.

[5] An important adjustment was the federal government's decision to separate industrial energy use for generating electricity from other industrial consumption (U.S. Energy Information Administration, 2003, Appendix D).

When the break period is not known *a priori*, the critical values for the Chow test do not apply. Fortunately, Andrews (1993) and Andrews and Ploberger (1994) have developed the critical values when the break period is unknown. One conducts repeated Chow tests, where the break point is increased by one period. Each Chow test statistic is plotted along with the year when the data set was segmented, as in Figure 3.

*** FIGURE 3 ABOUT HERE ***

The dashed-line series marked by "full" shows the Chow test plot when all variables are estimated with separate coefficients for the two periods. The test statistic reaches its maximum in 1972 but is not significant at the 5% or even 10% level. Accordingly, there is no reason to reject this specification for unstable responses to either fuel prices or economic activity, despite the potential problems noted above.

The solid-line series marked by "partial" shows the F-tests when only the intercept is estimated with separate coefficients for the two periods. The partial model specification shows much more dramatic effects than the full model specification. The Chow test statistic reaches its maximum level of 7.08 in 1958 but it fails to exceed the critical value of 8.85 established by Andrews for a breakpoint that creates subsamples of 15 and 85 percent. The test fails at the 10% level, too, although just barely.

Despite these insignificant tests, it would be unsettling to begin the analysis with a specification that suggests that other factors besides demand conditions have limited industrial consumption. The 1950s were a period when large pipelines were constructed across the nation, bringing gas service to the east coast and other major regions.[6]

[6] "During the 1950s and for much of the 1960's, the gas transmission industry experienced what must be considered the greatest uninterrupted period of sustained growth ever experienced by an energy industry in the United States. Following the original post-war projects, new pipelines were extended into New

Industries in these markets went from having no access (where gas prices were essentially infinite) to situations where gas suddenly became available at a finite price. During this transformation, pipeline availability rather than demand conditions may have been the limiting factor.

The preferred approach would be to add a variable to represent the expanding access to natural gas service. However, it is much easier to measure access to natural gas service for a regionally disaggregated area than for the nation.[7] For this reason, industrial natural gas demand for the nation is estimated over the somewhat shorter, 1958-2003 period.

5. Estimation Results

Table 4 reports the estimated coefficients and their statistical significance for equation (1) over the 1958-2003 period. The top set of coefficients refers to the effect of a change in a variable, while the next set refers to the effect of a change in last year's level. It is more likely that capacity utilization will have a more immediate, short-run rather than a long-run effect, and this expectation is supported by a very weak and insignificant effect for the lagged capacity utilization level. This coefficient is not reported in Table 4.

*** TABLE 4 ABOUT HERE ***

England, the Pacific Northwest, Southern Florida, and enlarged lines to those areas already served." (US Federal Power Commission, 1973, Volume 3, p. 6).

[7] For example, see the natural gas availability index constructed by Blattenberger, Taylor and Rennhack (1983) that measures the percentage of a state's population that reside in areas served by natural gas utilities.

In the preferred specification in column (1), all coefficients are significant at the 5% level, except for the change in capacity utilization rates. The table also displays five alternative estimations that explore different specifications.

7.1. Natural Gas Shortages

During the 1970s, natural gas shortages and the curtailment of service to industrial customers became a pervasive problem. The existence of wellhead price controls on natural gas sold within the jurisdictional or interstate market prevented many industrial gas customers from operating along their demand curve. The shortage variable based upon the difference between prices in Texas and the nation, which was discussed in a previous section on the data, indicated when the shortage was most severe during the 1973-79 period.

Adding the price distortion variable to control for shortages in the 1970s (column 2) does not appreciably change the coefficients for the price variables and for most of the other variables as well. Replacing this shortage variable with a dummy variable for 1973-79 is not shown in the table but also resulted in a weak and insignificant effect on industrial natural gas consumption.

7.2. Economic Growth

If economic activity is represented by constant-dollar GDP rather than structural output, the coefficient for the change in output in column (3) becomes insignificant. This finding underscores that adjusting activity for its energy intensity appears to provide additional useful information compared to the constant dollar estimates of GDP.

The use of industrial rather than manufacturing capacity utilization rates does not appear to be a major shortcoming of the previous set of results. Industrial rates shortened the estimation horizon to the 1967-2003 period with only minor differences in the results. These results are not shown, but the coefficients on both the change and lagged capacity rate levels remained insignificant, as they were with the manufacturing utilization rates.

7.3. Competitive Fuel Prices

Natural gas competes with many types of alternative fuels depending upon the industrial process and region of the United States. Various fuel prices including different oil products, coal and fuel and power were included separately in the equation, but the cross-price effect associated with oil prices appeared to be the most promising based upon the historical data.[8] In both 1973 and 2004, natural gas and various petroleum product uses accounted for approximately 75 percent of all fuel consumption (including direct electricity sales) within the aggregate industrial sector. Although industrial oil use for direct process heat has declined over recent decades, natural gas and petroleum-based products remain important in the energy picture for the industrial sector overall. In addition, the oil-gas substitution possibility remains critical in such major sectors as the refining industry.

There are multiple types of oil products used within the industrial sector, including such products as liquefied petroleum gases (LPG) and natural gas liquids (NGL). Two important oil products whose prices are regularly forecasted by the U.S. Energy Information Administration are the cleaner-burning distillate fuel oil and the heavier residual fuel oil. Distillate fuel oil was chosen as being more representative as

[8] Moreover, the coal price was statistically not a stationary series.

the types of petroleum products that could replace natural gas, because it would be preferred for its environmental benefits compared to fuels with higher sulfur content.

If distillate fuel oil prices are replaced by residual fuel prices, Column (4) shows that the immediate short-run cross-price effect of oil prices on natural gas consumption is lower than in column (1). Representing oil prices as the average of all refined petroleum prices is an improvement over using only residual fuel prices, but the explanatory power in column (6) falls slightly lower than in column (1).

7.4. Errors and Specification Issues

At the table's bottom are reported several important statistical tests. The adjusted R-squares are large when it is recognized that the equation is explaining changes in, rather than the level of, natural gas consumption. The F-tests for the equation indicates that the set of coefficients for the independent variables are jointly significant. Most critically, the disturbance term appears properly behaved. The Jarque-Bera test does not reject that the errors are normally distributed, and the Breusch-Godfrey test does not reject zero first-order autocorrelation in the error term. The Breusch-Godfrey test for autocorrelation is preferred over the more popularly used Durbin-Watson statistic (or any of its alternatives) when a lagged dependent variable is included.

Since all of the lagged variable coefficients are statistically significant in the preferred specification (column 1), there is no justification for adopting an equation that explicitly assumes that any of them equal zero. Nevertheless, a popular approach is the partial adjustment specification (e.g., the Koyck-lag adjustment), because it represents the dynamic response in a simple and easily interpreted manner. It can be justified by assuming either that firms use adaptive expectations about future market conditions or that the capital stock is adjusted gradually over time.

In a partial adjustment specification, energy consumption levels are explained as functions of the independent variables as well as the lagged value of only the lagged consumption series (the dependent variable). The latter variable allows consumption to change gradually over time rather than immediately, as *each* independent variable changes. However, the adjustment process is the same for each independent variable and becomes weaker over time. Column (6) indicates that all the estimated coefficients are significant at the 5% level, although the explanatory power (adjusted R-squared) is lower than in column (1).[9]

6. Short and Long-Run Elasticities

What is particularly interesting in the different specifications are their effects on the various elasticities with respect to price and output, which are two variables that can cover a wide range of possible outcomes. Table 5 summarizes both the short-run and the long-run elasticities. Short-run responses are derived directly from the coefficient for the change in price or output in Table 4. Long-run responses are derived directly from the ratio of the lagged level of the explanatory variable relative to the lagged level of natural gas consumption (multiplied by –1), as shown by equation (A.4) in the appendix.

*** TABLE 5 ABOUT HERE ***

[9] The equation in column (6) has been estimated with the same dependent variable (change in consumption) as the other equations for comparability on such statistics as adjusted R-squared. Usually, the Koyck lag is estimated in levels. Estimating the equation in levels changes the adjusted R-squared but does not alter the coefficients or the tests for normality and autocorrelation of the error terms.

The price and output elasticities are similar with (column 2) and without (column 1) the shortage variable. Measuring economic activity with real GDP rather than with structural output sharply reduces the output effect (column 3), causing the short-run response to be based upon a coefficient that is not significant at the 5% level. The residual price sharply curtails the magnitude of the oil cross-price effect (column 4), relative to the distillate price. On the other hand, the average price for all refined petroleum products (column 5) produces responses very similar to the preferred specification (column 1). Finally, the partial adjustment specification (column 6) reduces the short-run and long-run elasticities for natural gas prices, distillate fuel oil prices and structural output that were estimated for the unconstrained ADL approach (column 1).

The own-price elasticity refers to the percentage change in consumption when only natural gas prices change by a given percent. The table shows that if natural gas prices rise by 10 percent and oil prices remain unchanged, the restricted Koyck-lag equation (column 6) reveals that industrial natural gas consumption would decline by 5.5 percent over the long run, while the unconstrained ADL formulation (column 1) would place the long-run response at 6.7 percent. Based upon the discussion in the last section, the latter estimates are preferred. However, natural gas prices often move with oil prices. Under these conditions, natural gas consumption would be affected by less. If both fuel prices should increase by 10 percent, there would be no interfuel substitution effect where other fuels replace natural gas. Industrial natural gas would decline by 2.8 percent over the long run with the Koyck-lag equation and by 3.4 percent with the ADL specification.

Another way to interpret the long-run natural gas price response in this specification is that a 10% increase in natural gas prices will reduce industrial natural gas consumption by 6.7%, with approximately half of the effect due to its replacement by other fuels (3.4%) and half due to substitution away from energy (3.3%=6.7%-3.4%).

7. Projected Industrial Consumption

The ADL specification shown in the first column of Table 4 was used to generate alternative projections of industrial natural gas consumption through 2030. The equation uses as inputs the following variables: industrial natural gas prices, wholesale distillate fuel oil prices, structural output, heating degree days and industrial capacity utilization. The discussion below considers alternative assumptions about the first three variables (fuel prices and structural output), holding constant the weather and capacity utilization variables at their 2003 values.

7.1. Energy Prices

Before evaluating the industrial consumption projections, it is helpful to understand the energy price projections in the AEO 2006 reference scenario (US Energy Information Administration, 2006). Natural gas prices in the AEO2006 projections begin to decouple from oil prices and compete directly against other, lower-priced fuels like coal. By 2030, natural gas prices are about $5 per million Btu (2000 prices) lower than distillate fuel oil prices, compared to $1.50 in 2003, as shown in Figure 4. In the earlier years, natural gas is competitively priced with many petroleum product types, since distillate fuel is higher quality and cleaner burning than other fuel oils. By the later years, the AEO 2006 natural gas price trend begins to depart sharply from a level where it maintains its parity with oil prices (represented by the middle line of Figure 4).

*** FIGURE 4 ABOUT HERE ***

The industrial natural gas demand projections based upon the model developed in this study are quite different for this energy price scenario than for one where distillate oil and natural gas are priced similarly on a heat-content basis. Figure 5 displays much stronger consumption growth when the AEO2006 price trends are used rather than the price-parity assumption. This stronger growth with the AEO2006 price paths reflects the significant cost advantages when natural gas prices decouple from oil prices in this sector.

*** FIGURE 5 ABOUT HERE ***

Our model's lower consumption path *from the price-parity assumption* tracks the industrial natural gas consumption path that the AEO 2006 reports in their recent outlook, which are based upon *a decoupling of oil and gas prices*. In this price-parity case, natural gas demand will not exceed its 2003 level until 2010. Through 2025, this case reveals the lowest consumption level of the three different projections in Figure 5. (The reported AEO projection in EIA's outlook is represented by a third trend in Figure 5.) By implication, the AEO 2006 expects that lower-priced fuels like coal will replace petroleum products as the major fuel competition in the industrial sector and that natural gas prices will no longer follow oil prices, as they have done historically.

Whether coal and other fuels will replace oil as the major competitor for natural gas in the industrial sector will depend upon perceptions about changes in energy markets and new technologies. The current model focuses upon existing historical trends where substitution between oil and gas production and within refineries has dominated the oil-gas price relationship. Statistical studies (Brown 2005, Rothwell 2005) have confirmed that natural gas price movements tend to follow oil price movements and that these prices tend to converge.

If oil and gas prices decouple with much lower prices for gas than for oil, our industrial model projects substantially greater industrial natural gas consumption. If our industrial model were to replace the EIA's industrial model in their total energy system, there would be more industrial natural gas demand. These developments would place additional upward pressure on natural gas prices than shown in the AEO 2006 reference case, although if natural gas prices do increase, there will be some offsetting effects as natural gas consumption declines in other sectors.

7.2. Economic Growth

A second important unknown factor is the economic growth rate and its distribution across different economic sectors. The AEO 2006 assumes that the manufacturing sector will grow by 2.4% per year. The previous year's report, AEO 2005, concluded that structural shift within the industrial sector would cause that sector's energy intensity to be about 17 percent lower by 2025. We combined these two observations to develop a trend growth in structural output (weighted by energy intensity) that increased on average by 1.6% per year. This economic assumption was used in the previous consumption paths based upon different oil and gas prices.

The plain solid line in Figure 6 shows the projected consumption path with price parity between distillate fuel oil and natural gas and the AEO assumptions about economic structure. This figure also shows two other industrial natural gas consumption paths based upon different assumptions for the growth in structural output. All three cases assume parity pricing between distillate fuel oil and natural gas prices. The higher path reflects conditions similar to the 1987-94 period, when energy-intensive sectors enjoyed reasonably strong economic growth. The lower alternative path incorporates more pessimistic conditions similar to the 1994-2003 period, when computer-oriented and other less energy-intensive sectors accounted for much more of the total industrial economic growth. By 2030, the gap between these two industrial natural gas consumption paths reaches about 3.5 trillion cubic feet.

*** FIGURE 6 ABOUT HERE ***

We can conclude from this figure that the AEO 2006 expects a trend in economic structure that resembles the 1994-2003 experience more than the earlier trend. Growth in less energy-intensive sectors is expected to be greater than growth in more energy-intensive sectors over the next several decades.[10]

8. Summary and Recommended Improvements

This study has developed a simple but useful model for tracking industrial natural gas consumption. This general dynamic specification finds that industrial natural gas consumption increases by 6.7 percent over the long run for each 10 percent decrease in natural gas prices and increases by 3.2 and 9.2 percent for each 10 percent increase in distillate fuel oil price and structural economic output, respectively. In addition to incorporating significant interfuel substitution, the model also allows changes in the industrial sector's composition either towards or away from energy-intensive sectors to influence projected industrial natural gas consumption.

[10] The paths in Figure 6 should be viewed as approximate, because it is very difficult to calibrate the AEO assumptions precisely with the available data. This problem probably explains why the AEO structure line in Figure 6 is slightly less than the 1987-94 structure path.

Several improvements are recommended if the appropriate data can be located. The most important limitation concerns the structural output and capacity utilization variables, which refer to the manufacturing rather than the industrial sector due to limited data availability. Industrial activities also include construction, mining and agriculture. Moreover, the structural output variable tracks changes in this sector's composition at the two-digit industrial level, thereby obscuring some important structural changes in more detailed industries such as nitrogenous fertilizers (which are aggregated into the chemicals industry). Although data exists for these more detailed industries, they cover much shorter time periods and are not consistent with the data sources used in the study.

A second area where improvements may be warranted lies in the merits of representing important new technologies and processes that could reshape some key sectors. If relevant information about these technologies and processes exists, the framework can incorporate these factors through the structural output variable. For example, if it is known that a certain sector will be adopting a new process that transforms its use of energy and natural gas, the analyst can adjust the energy weights in the structural output variable to reflect these new opportunities.

A third issue concerns the conceptual framework. Natural gas demand is represented as a single fuel rather than as one of several energy sources in a system of equations. It may be that a systems approach is superior for incorporating interfuel substitution responding to fuel prices or the effect of shortages. For example, constraints on natural gas use can be imposed on the system to evaluate how other fuels are affected. Although the systems approach has some advantages, it also has some disadvantages. Often, flexible functional forms are used as an approximation to the actual demand specification. These approximations frequently produce elasticities that are very large and not too stable, especially if forecast simulations cover scenarios with price ranges that differ from the historical data. An added problem for this study is that the fossil fuel use variable was not found to be stationary in the augmented Dickey-Fuller tests. Adding a non-stationary variable to the model would create additional specification issues.

Appendix: Estimated Equations

The augmented Dickey-Fuller tests are estimated to determine whether each variable is stationary. The basic estimating equation is:

$$dY_t = \alpha_0 + \alpha_1 Y_{t-1} + \alpha_2 \ t + \sum_{i=1}^{m} \gamma_{t-i} \ dY_{t-i} + \mu_t \qquad \text{(A.1)}$$

where *Y* and *dY* refer to the level and change in a particular series, the variable t is a time trend, and the subscript t indicates the year. The parameter *u* denotes the disturbance term. If the test rejects $\alpha_1=0$, the variable is stationary. As explained in the text, the presence of a constant or trend term as well as the optimal lag terms must be determined for each variable.

The regression analysis uses a general dynamic framework, whose flexibility allows a number of different specifications (Hendry, 1995, Chapter 7). Both current and lagged values of natural gas demand (Y) and independent variables (X) are included in the following specification:

$$Y_t = \beta_0 + \beta_1 X_t + \beta_2 X_{t-1} + \beta_3 Y_{t-1} + \mu_t \qquad \text{(A.2)}$$

Subtracting Y_{t-1} from both sides and adding β_{t-1} X_{t-1} - β_{t-1} X_{t-1} to the right side yields the equation estimated in this analysis:

$$dY_t = \beta_0 + \beta_1 (dX_t) + (\beta_1 + \beta_2) X_{t-1} - (1-\beta_3) Y_{t-1} + \mu_t \qquad \text{(A.3)}$$

This formulation contains an equilibrium-corrections mechanism, where natural gas consumption adjusts to disequilibrium conditions in the previous year. In long-run equilibrium, $Y^*=Y_t=Y_{t-1}$ and $X^*=X_t=X_{t-1}$, so that $dY_t=dX_t=0$. Rearranging terms provides the long-run relationship between Y* and X*

$$Y^* = [\beta_0 / (1 - \beta_3)] + [(\beta_1 + \beta_2) / (1 - \beta_3)] X^* + \mu_t \quad \text{(A.4)}$$

The long-run response of Y with respect to a change in X is based upon the estimated coefficients from Equation A.3. It equals the estimated coefficient for X_{t-1} divided by the estimated coefficient for Y_{t-1} (multiplied by –1).

Analysts sometimes use a partial-adjustment specification like the Koyck adjusted-lag model because it represents the dynamic response in a simple and easily interpreted manner. Partial adjustment equations can be justified by assuming either that firms use adaptive expectations about future market conditions or that the capital stock is adjusted gradually over time. Such a specification can be derived from the general dynamic equation by assuming $\beta_2 = 0$. The long-run response then becomes $(\beta_1)/(1 - \beta_3)$, or the estimated coefficient of X_t divided by the estimated coefficient of Y_{t-1} (multiplied by –1). Although the responses adjust at different rates in the more general dynamic specification, the responses to all independent variables adjust at the same rate in the partial adjustment specification.

These long-run response relationships are used to compute the long-run elasticities in the text's Table 5 from the coefficients reported in Table 4.

These coefficients are estimated both with and without controls for natural gas shortages during the 1970s. A dummy variable for years 1974-79 controls for whether a shortage exists or not. A variable based upon the price distortion between Texas and the U.S. wellhead controls for the intensity of the shortage. Figure A.1 plots the price distortion as a solid line. It escalates after 1973 and becomes most intense in 1975 and 1976, the years when newspaper articles repeatedly warned of job losses and other dislocations caused by inadequate supplies for industrial firms. The figure also shows that this price distortion weakened considerably between 1980 and 1985, even though the inflation-adjusted distillate fuel oil price rose sharply and stayed higher during this period. The price distortion was caused by both an increase in natural gas demand (due to higher oil prices) and the existence of price controls on interstate supplies of natural gas.

*** FIGURE A.1 ABOUT HERE ***

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Table 1: Data Explanation and Sources

Variable	Dates	Description	Source
Natural Gas Consumption	1949-2003	Industrial consumption	AER Table 2.1.d.
Fossil Fuel Consumption	1949-2003	Industrial consumption	AER Table 2.1.d.
Manufacturing Output	1949-2003	Real value added based upon NAICS beginning in 1987, trended by SIC-based estimates prior to 1987.	Post-1986 NAICS-based estimates: U.S. Bureau of Economic Analysis, http://www.bea.gov/bea/industry/gpotables/gpo_action.cfm?anon=297&table_id=10982& format_type=0. Pre-1987 SIC estimates: Nordhaus and
Manufacturing Energy-Weighted Output	1949-2003	Each 2-digit industry's value added is weighted by 'first energy use' in 2002.	US Energy Information Administration, Manufacturing Energy Consumption Survey, Table 1.2: http://www.eia.doe.gov/emeu/mecs/
Manufacturing Capacity Utilization	1949-2003	Capacity rate (%), spliced series between pre-1986 and post-1985 data sets.	Federal Reserve Board: http://www.federalreserve.gov/releases/g17/caputl.htm
Industrial Capacity Utilization	1967-2003	Capacity rate (%), spliced series between pre-1986 and post-1985 data sets.	Federal Reserve Board: http://www.federalreserve.gov/releases/g17/caputl.htm
Heating	1949-2003	Heating Degree Days	AER Table 1.9.
Cooling	1949-2003	Cooling Degree Days	AER Table 1.10.
FPC Price Controls	1949-2003	Texas industrial gas price divided by US wellhead gas price, if ratio > 1.5.	Texas price is derived from http://www.eia.doe.gov/emeu/states/sep_prices/total/csv/pr_tx.csv. U.S. price reported in AER, Table 6.7.
Natural Gas Price	1967-2003	Producer Price Index (WPU0531), calibrated to 2000 price in AER Table 3.4.	US Bureau of Labor Statistics: http://www.bls.gov/ppi/home.htm
	1950-1966	Natural Gas Price for Industrial Customers.	American Gas Association, Table 72.
Fuel and Power Price	1949-2003	Producer Price Index (WPU05), calibrated to 2000 price in AER Table 3.4.	US Bureau of Labor Statistics: http://www.bls.gov/ppi/home.htm

Table 1: Data Explanation and Sources (Continued)

Variable	Dates	Description	Source
Distillate Fuel Price	1949-2003	Producer Price Index (WPU0574), calibrated to 2000 price in AER Table 5.22.	US Bureau of Labor Statistics: http://www.bls.gov/ppi/home.htm
Residual Fuel Price	1949-2003	Producer Price Index (WPU0573), calibrated to 2000 price in AER Table 5.22.	US Bureau of Labor Statistics: http://www.bls.gov/ppi/home.htm
Petroleum Product Price	1949-2003	Producer Price Index (WPU057), calibrated to 2000 price in AER Table 3.4.	US Bureau of Labor Statistics: http://www.bls.gov/ppi/home.htm
Coal Price	1949-2003	Producer Price Index (WPU051), calibrated to 2000 price in AER Table 3.4.	US Bureau of Labor Statistics: http://www.bls.gov/ppi/home.htm
GDP Price Deflator	1949-2003	Implicit, chain-weighted price deflator based in 2000.	AER Table D.1

Note: AER refers to U.S. Energy Information Administration, Annual Energy Review.

Table 2: Augmented Dickey-Fuller Tests for Non-Stationary Variables

Variable	Lags	DF Test	P-value	Trend	Constant Shift
Natural Gas Use	0	-4.01 **	0.014		
Fossil Fuel Use	0	-3.01	0.142		
Heating	0	-4.99 **	0.001		
Cooling	2	-2.62	0.280		
Structural Output (SIC)	0	-4.59 **	0.003	x	
GDP Output (SIC)	0	-3.39 *	0.064	x	
Structural Output	0	-4.73 **	0.002	x	
GDP Output	0	-3.59 **	0.040	x	
Capacity (Man)	0	-4.42 **	0.005	x	
Capacity (Ind)	1	-4.18 **	0.011		
Real Prices					
Natural Gas	3	-3.71 **	0.026		x
Fuel & Power	3	-3.97 **	0.013	x	x
Petroleum	3	-3.76 **	0.023	x	x
Distillate Oil	3	-3.94 **	0.014	x	x
Residual Oil	3	-3.57 **	0.037	x	x
Coal #	3	-2.80	0.198	x	

Notes:

Coefficients marked by ** (*) are significant 5% (10%) level.

Coal-price test excludes constant but includes squared-trend term.

Optimal lags are determined by t- and F-tests with maximum lag = 3 years.

Table 3. Tests for Length of Lags

	Degrees of Freedom	F-Test	P-value
Change, lagged two years	F(5,23)	1.52	0.22
Change, lagged one year	F(5,29)	0.23	0.95
Change	F(5,35)	9.73 **	0.00

** F-test rejects that the set of coefficients jointly equal zero at the 1% level.

Table 4. Coefficients for Explaining Change in Natural Gas Demand, 1958-2003

	(1)	(2)	(3)	(4)	(5)	(6)
Intercept	-2.953 *	-3.018 *	-1.004	-2.129	-2.961 *	-0.843
	(1.300)	(1.306)	(1.303)	(1.458)	(1.380)	(1.213)
Change in:						
Natural Gas Price	-0.244 **	-0.243 **	-0.293 **	-0.148 *	-0.224 **	-0.179 **
	(0.057)	(0.057)	(0.069)	(0.063)	(0.057)	(0.048)
Oil Price (Distillate)	0.121 **	0.128 **	0.144 **	0.067 *	0.132 **	0.086 *
	(0.034)	(0.035)	(0.039)	(0.029)	(0.040)	(0.038)
Structural Output	0.386 **	0.357 **	0.171	0.306 *	0.387 **	0.263 **
	(0.131)	(0.136)	(0.269)	(0.149)	(0.133)	(0.055)
Capacity Utilization	0.273	0.316	0.546	0.205	0.248	0.308 *
	(0.220)	(0.226)	(0.363)	(0.224)	(0.227)	(0.146)
Heating	0.239 *	0.246 *	0.238 *	0.237 *	0.227 *	0.249 *
	(0.107)	(0.107)	(0.119)	(0.114)	(0.109)	(0.126)
One-Year Lag (Level) in:						
Natural Gas Demand	-0.315 **	-0.293 **	-0.255 **	-0.242 **	-0.298 **	-0.323 **
	(0.059)	(0.064)	(0.060)	(0.080)	(0.060)	(0.052)
Natural Gas Price	-0.210 **	-0.206 **	-0.191 **	-0.085	-0.180 **	--
	(0.062)	(0.062)	(0.073)	(0.060)	(0.061)	
Oil Price (Distillate)	0.102 *	0.104 *	0.098	-0.006	0.090	--
	(0.051)	(0.052)	(0.062)	(0.042)	(0.060)	
Structural Output	0.289 **	0.273 **	0.193 **	0.174	0.280 **	--
	(0.067)	(0.070)	(0.061)	(0.088)	(0.078)	
Heating	0.473 **	0.465 **	0.456 **	0.433 **	0.450 **	--
	(0.138)	(0.138)	(0.158)	(0.157)	(0.140)	
1970s Shortage		-0.0137				
		(0.015)				
Adjusted R-squared	0.746	0.745	0.685	0.721	0.735	0.645
F (zero slopes)	14.231 **	12.930 **	10.806 **	12.613 **	13.472 **	14.613 **
Jarque-Bera test	2.490	1.839	2.142	1.963	2.180	2.892
Breusch-Godfrey test	0.090	0.096	0.124	0.022	0.027	0.070

Standard errors are reported in parentheses.

Coefficients or tests are significant at 5% if marked by * and at 1% if marked by **.

Sector's GNP replaces structural output in eq. 3.

Oil price is for residual (eq. 4) and for all refined products (eq. 5).

Table 5. Summary of Elasticities

	(1)	(2)	(3)	(4)	(5)	(6)
Short-Run Elasticities:						
Natural Gas Price	-0.244	-0.243	-0.293	-0.148	-0.224	-0.179
Oil Price (Distillate)	0.121	0.128	0.144	0.067	0.132	0.086
Structural Output	0.386	0.357	(0.171)	0.306	0.387	0.263
Long-Run Elasticities:						
Natural Gas Price	-0.668	-0.703	-0.748	-0.349	-0.606	-0.553
Oil Price (Distillate)	0.325	0.356	0.384	-0.024	0.303	0.267
Structural Output	0.916	0.929	0.759	0.717	0.942	0.814

Elasticities are based upon coefficients shown in Table 4.
Elasticity in parenthesis is based upon a coefficient that is not significant at 5% level.
Sector's GNP replaces structural output in eq. 3.
Oil price is for residual (eq. 4) and for all refined products (eq. 5).

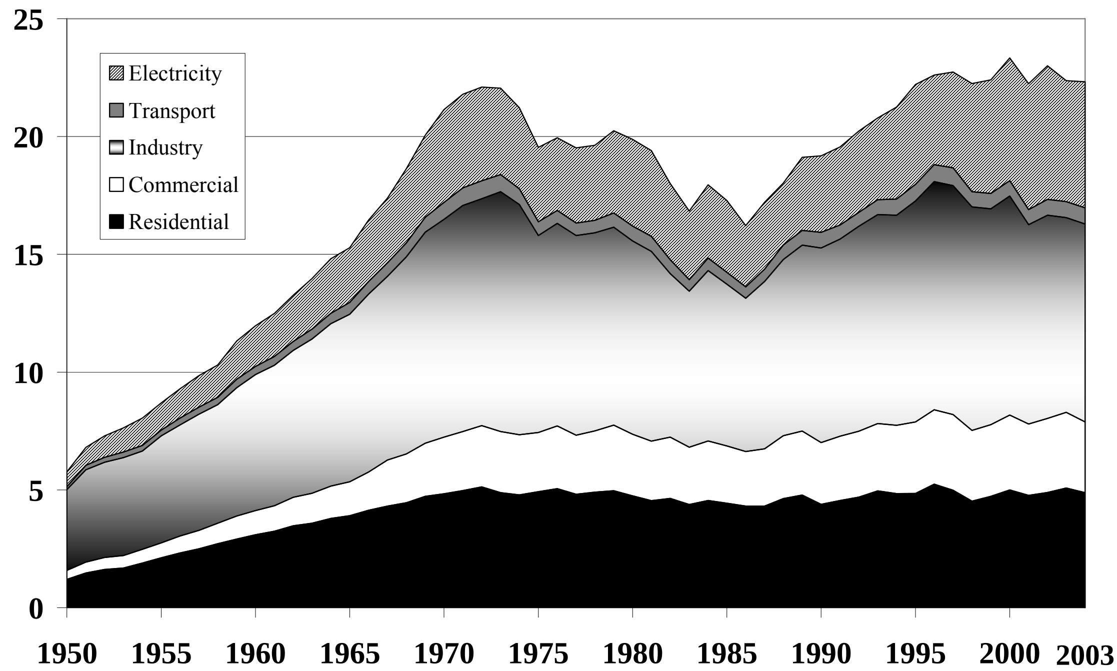

Fig. 1. U.S. Natural Gas Use (Tcf/yr) by Sector

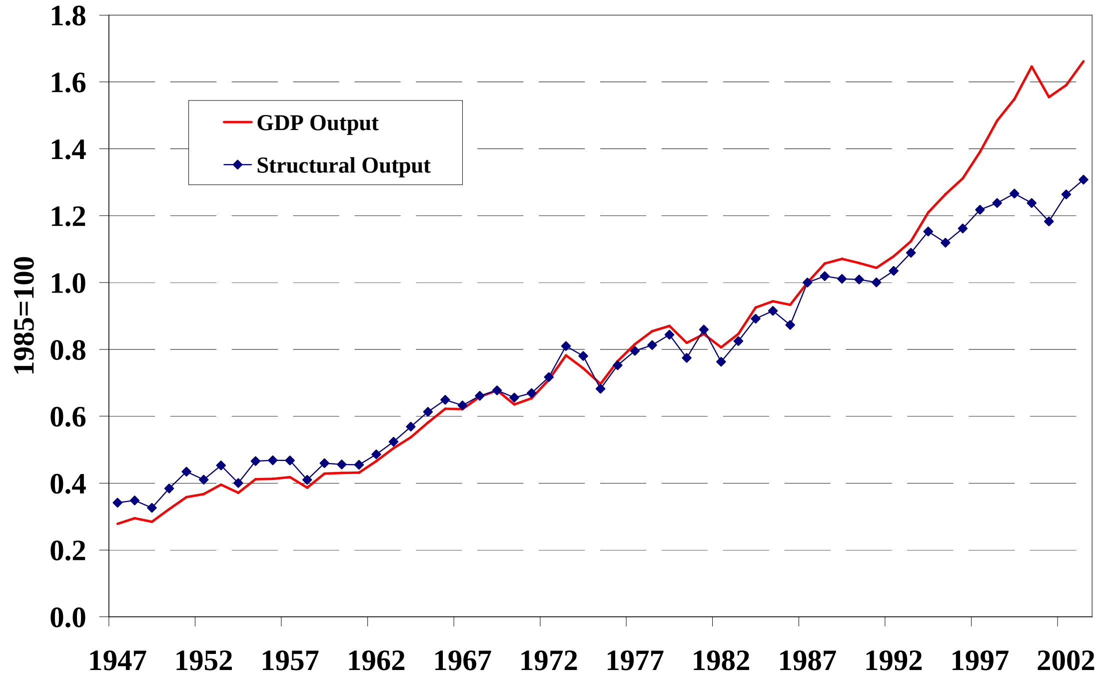

Fig. 2. Structural Output vs GDP Output, 1948-2003

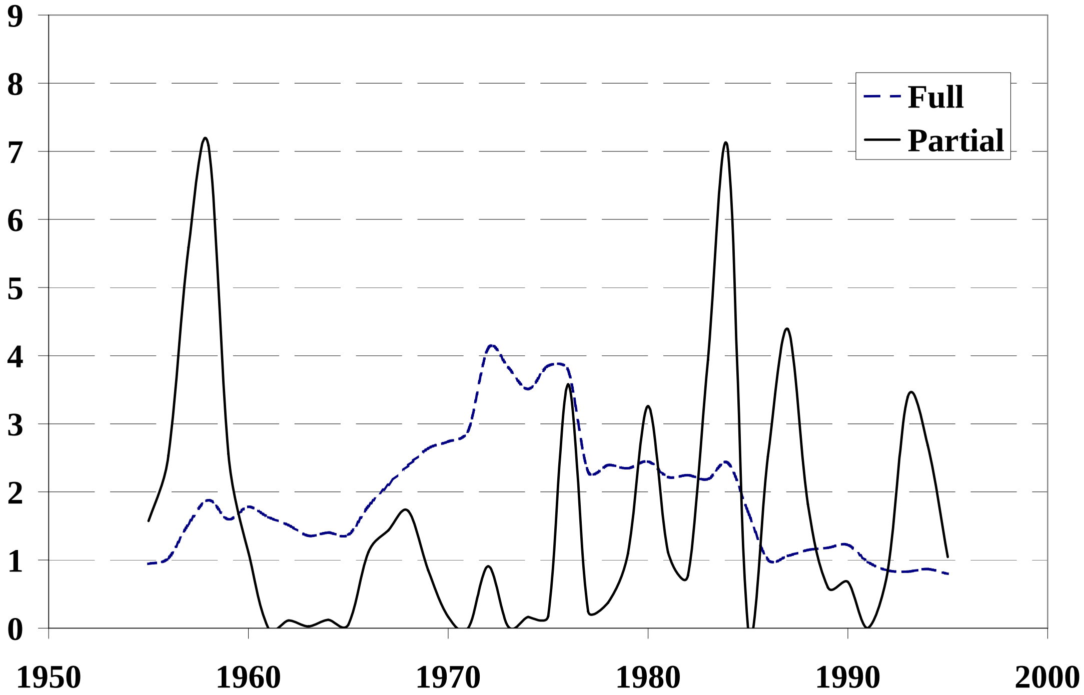

Fig. 3. F-Test by Break Year

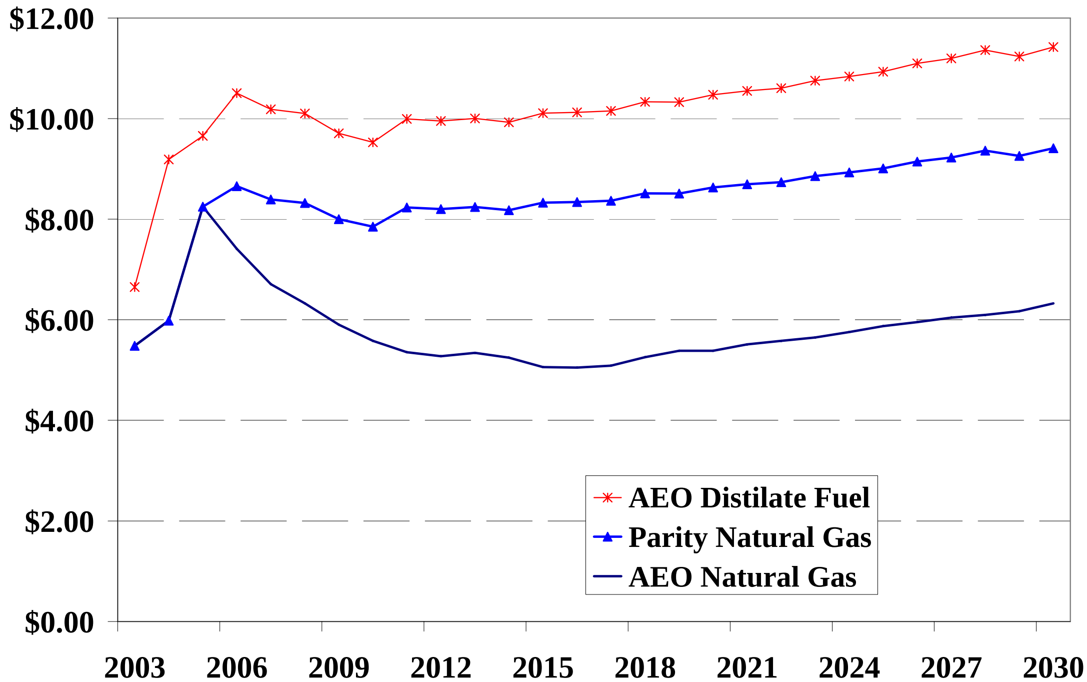

Fig. 4. Fuel Prices (2000$/mmbtu)

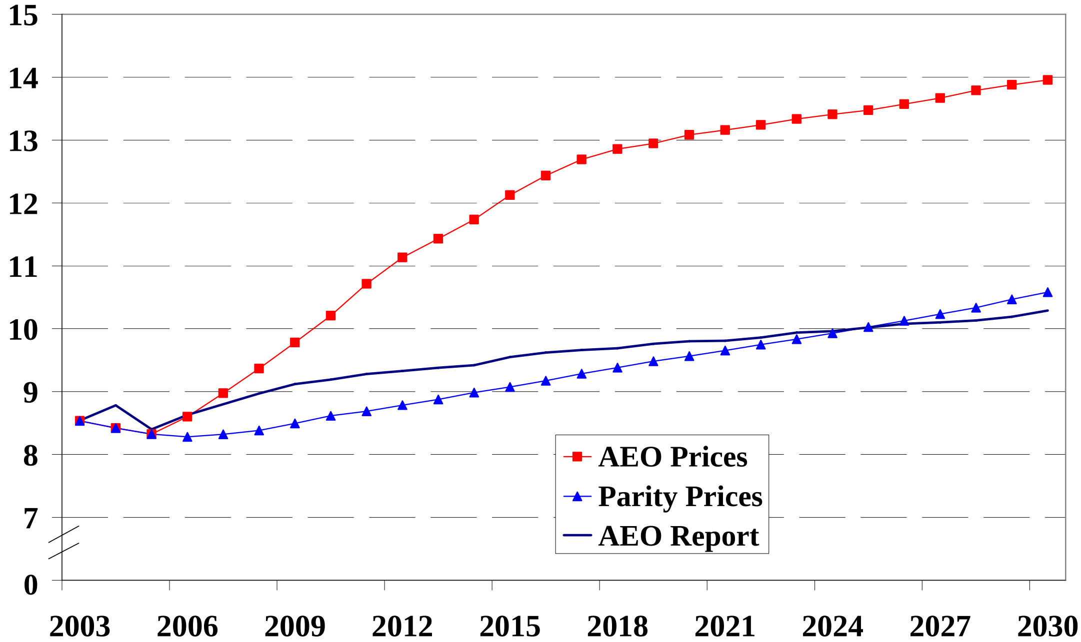

Fig. 5. Effect of Fuel Prices on Industrial Natural Gas Consumption (Tcf/yr)

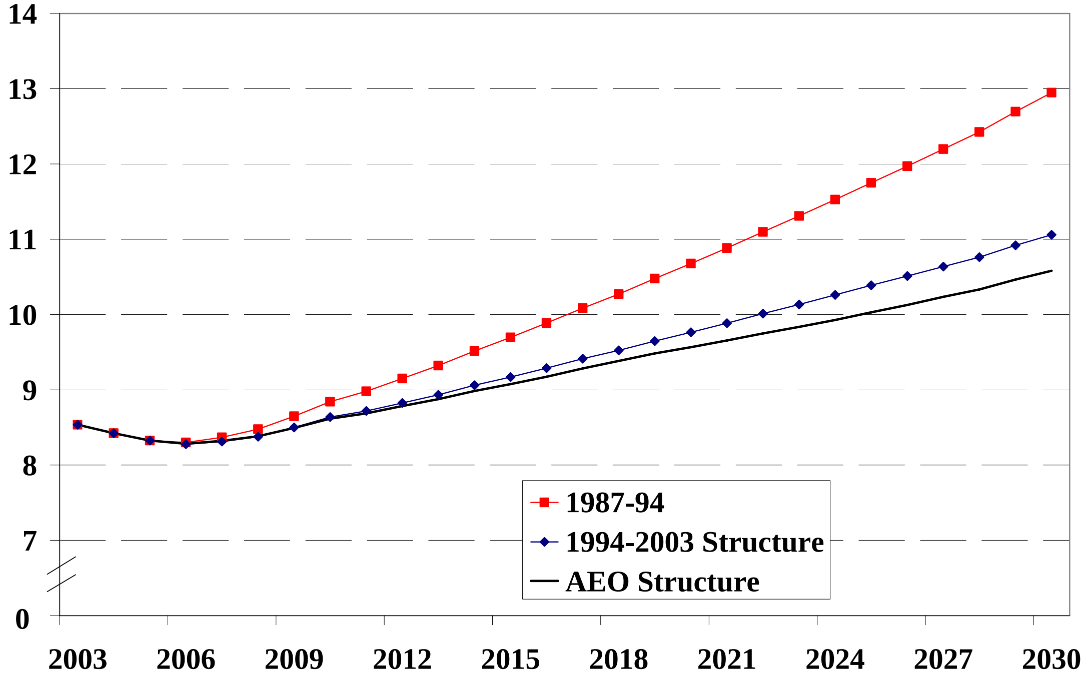

Fig. 6. Economic Growth and Industrial Natural Gas Consumption (Tcf/yr)

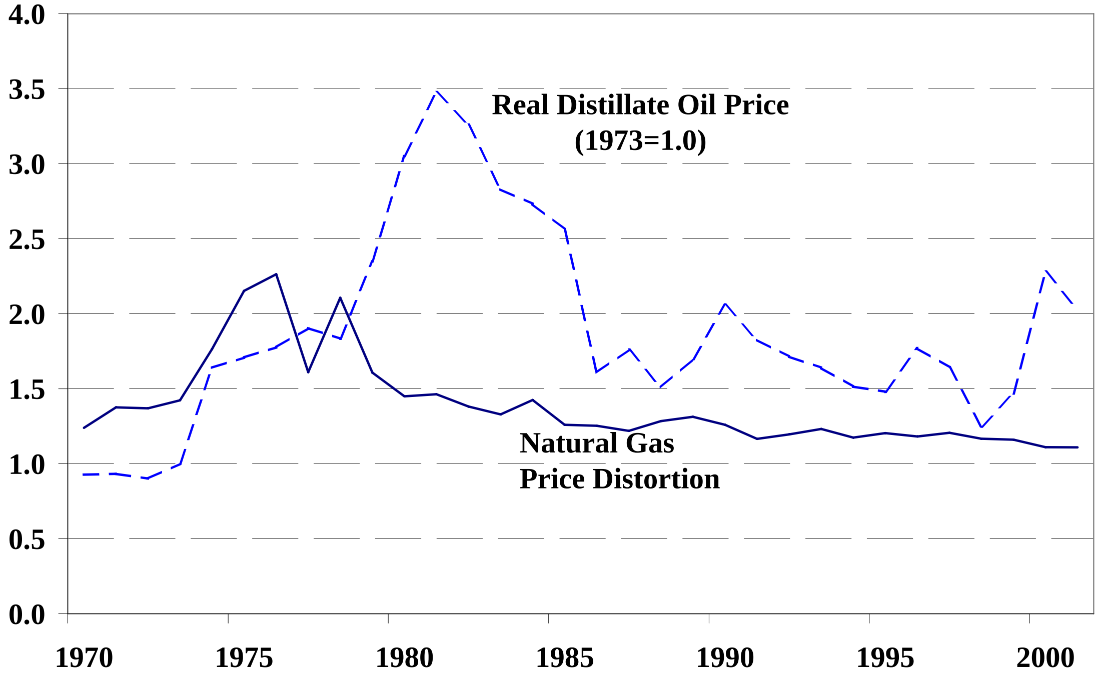

Fig. A.1. Price Distortion Between Texas and US Markets