WORKING PAPER SERIES

The Importance of Natural Gas in the Industrial Sector With a Focus on Energy-Intensive Industries

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Background

The expanding understanding of the breadth of U.S. energy resources from shale formations has brought new attention to the industrial sector. This sector, which is comprised of manufacturing, construction, agriculture, and mining industries, is one of the largest consumers of natural gas (NG), and increased energy production is known to result in more economic activity broadly. The industrial sector, consuming 8.3 quadrillion Btu of natural gas in 2011, approximately one-third of total U.S. dry natural gas consumption, may be an important beneficiary of an expansion in oil and gas resources [1]. Uncertainty regarding the ultimate outcome for the industrial sector lies in development of technology, the quantity and types of energy products ultimately produced, and legislative and regulatory changes. Investment and innovation are both known to drive and be driven by technological change. Both investment and technological change are also affected by resources and other economic activity. Though future production of oil from shale formations is uncertain, some estimates indicate a large quantity of domestic crude could also be produced (called tight oil), which is yet another source of uncertainty for large consumers in the industrial sector.

Recent statistical tests [2] show that some expected links between aggregate industrial production, energy, and economic indicators may not be as clear as once thought. The results indicate a need for further analysis of relationships between energy and economic factors and, in particular, NG supply and price connections to the industrial sector. Questions about NG have also arisen due to the "shale revolution" and the changing content of NG via Natural Gas Liquids (NGLs)[1]. It is believed that much of this change has also driven profound structural shifts in the industrial sector, which creates a further need for statistical testing to determine what relationships exist, did exist, and/or are changing. These issues are not new, however, as much the same questions have been raised only with regard to *rising* energy prices, not so long ago [3].

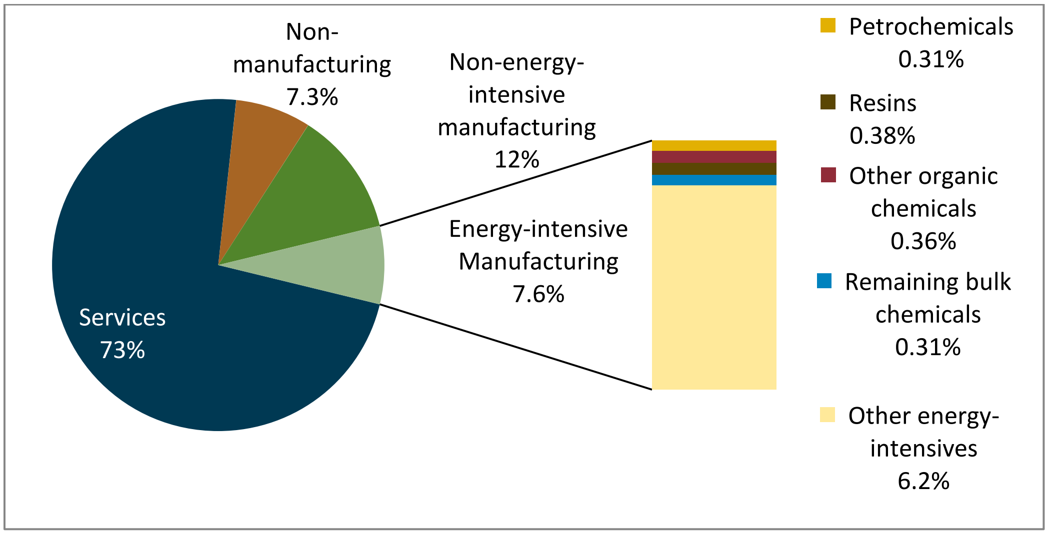
Further analysis was first attempted using EIA's NEMS as a tool in the *AEO2013* High Resource side case [4], which included estimates for a significant increase in oil and gas resources relative to the Reference case. The industrial sector portions of this model are heavily informed by past data and trends, which may be a poor indicator of future behavior if significant structural changes have taken place. The work presented here aims to build on previous work and answer questions not yet answered. The purpose of this paper is to determine if simple, long-term relationships between NG price and supply and industrial production exist and have ever changed or are currently changing to determine if past (even recent past) data can/should inform future trends.

The Industrial Sector

The industrial sector in this context, with 2007 North American Industrial Classification (NAICS) codes [5], specifically includes agriculture (11), construction (23), mining (21), and manufacturing industries (31-33). The size of the industrial sector in real dollar shipments, and more specifically energy-intensive industries, in the economy is relatively small. Figure 1 shows select energy-intensive industries and sub-sectors within total gross output of goods and services to provide a "big picture" view of how these parts fit the whole.

[1] Dry NG refers to methane, while NGLs refer to ethane, propane, butane, and pentanes plus.

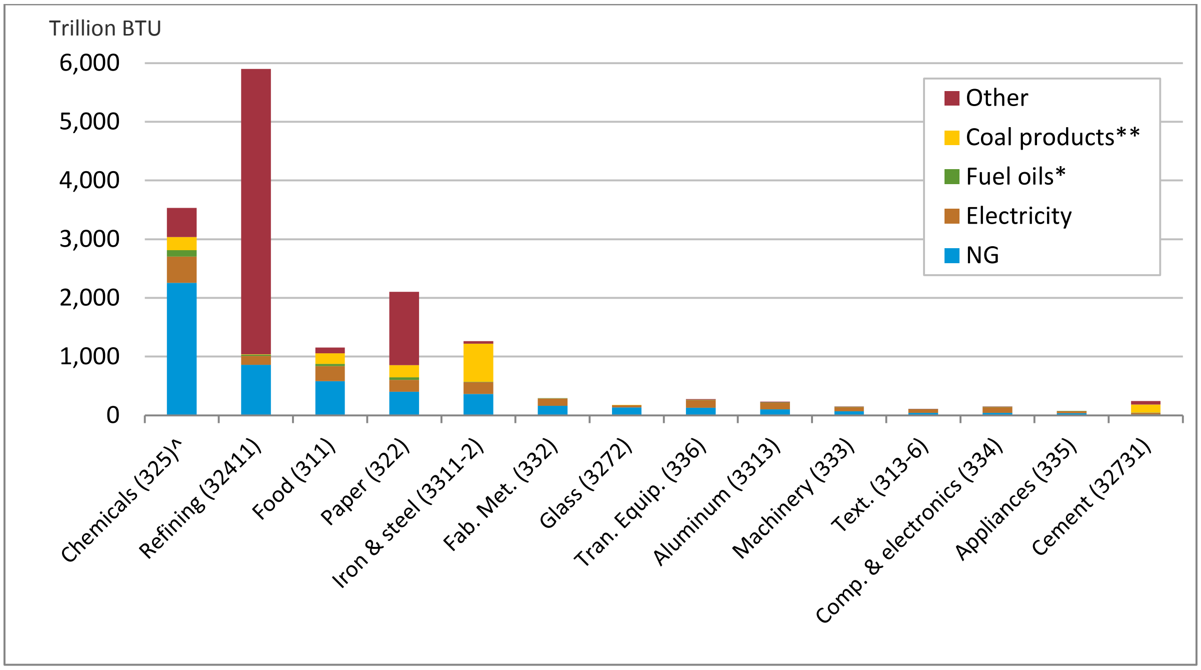
Figure 1. U.S. gross output of goods and services for 2010 [6]



Energy Intensity

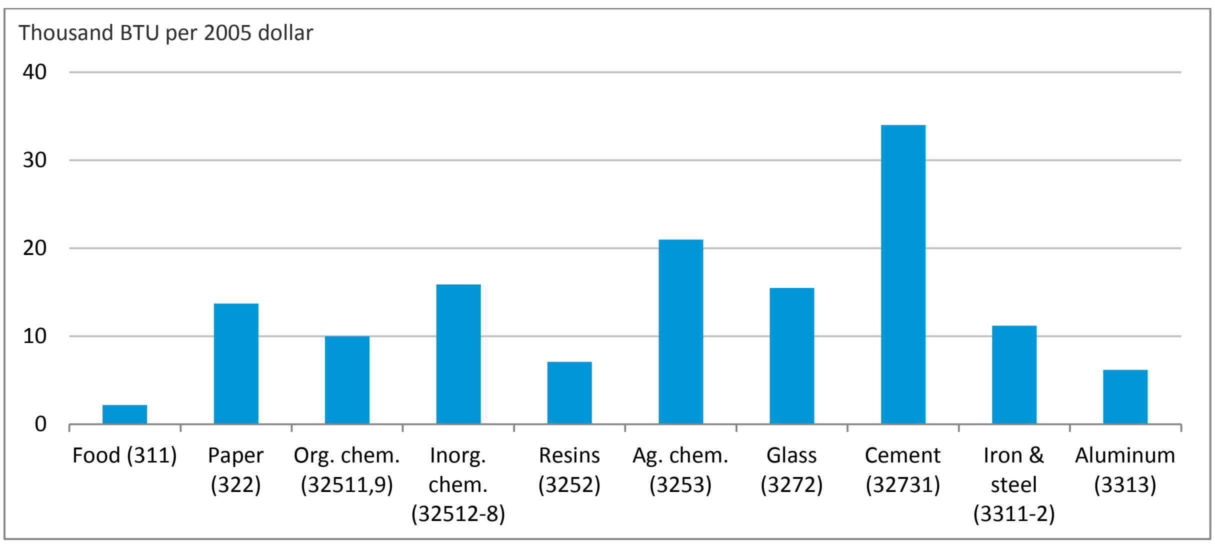
The importance of energy, particularly NG, to any industry is difficult to discern since each industry may measure the *value* of fuels, NG in particular, in different ways. Total quantity of consumption (levels) is often used, as is energy intensity (consumption of energy per unit of output), relative use of certain fuels, and finally one might consider the expenditure on energy (fuels and electricity) relative to all other expenditures. Figures 2 through 5 show some of the top industries for each of these measures.

Figure 2. Industries (NAICS code) by largest estimated dry NG quantity consumed[2] (trillion BTU) in 2010 [7]



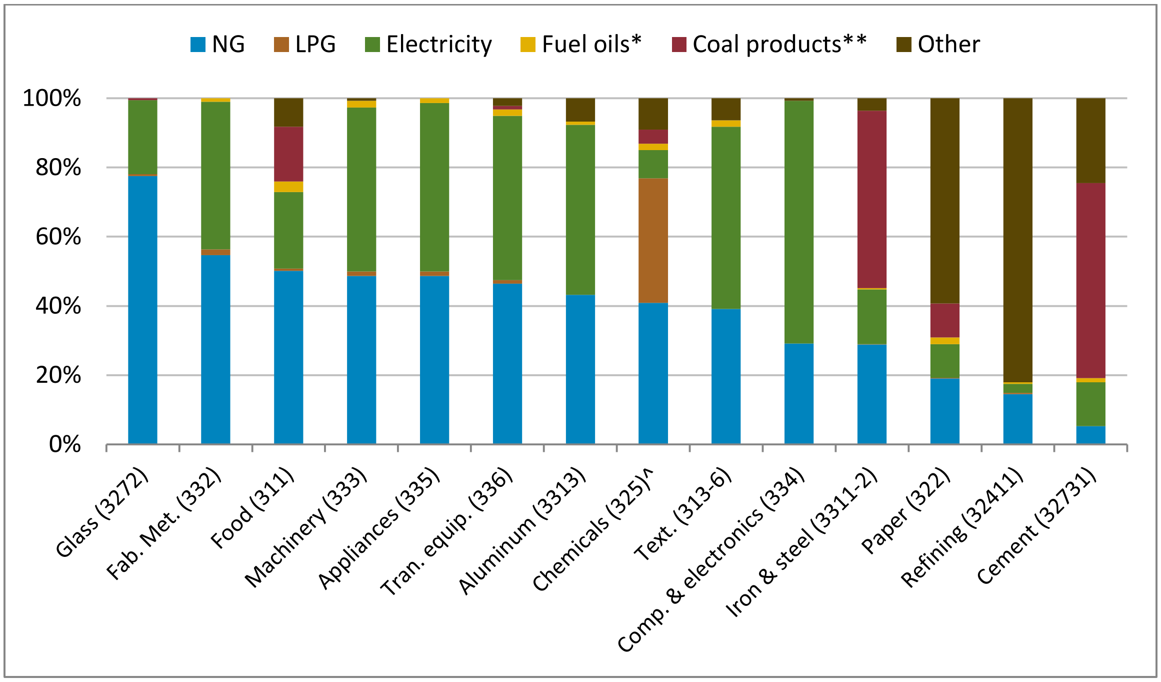
Estimates with near zero values or with exceedingly high error were set to 0; *residual and distillate fuel oil; **coal, coke, and breeze; ^many estimates for disaggregated chemical industries are withheld due to disclosure and are therefore not included.

Figure 3. Estimated total energy intensity (thousand BTU per 2005 dollar) of "energy-intensive" industries (NAICS code) included in the *AEO2013* [4, 8]



[2]Does not include "shipments of energy sources produced on site"; for more information see *MECS2010*.

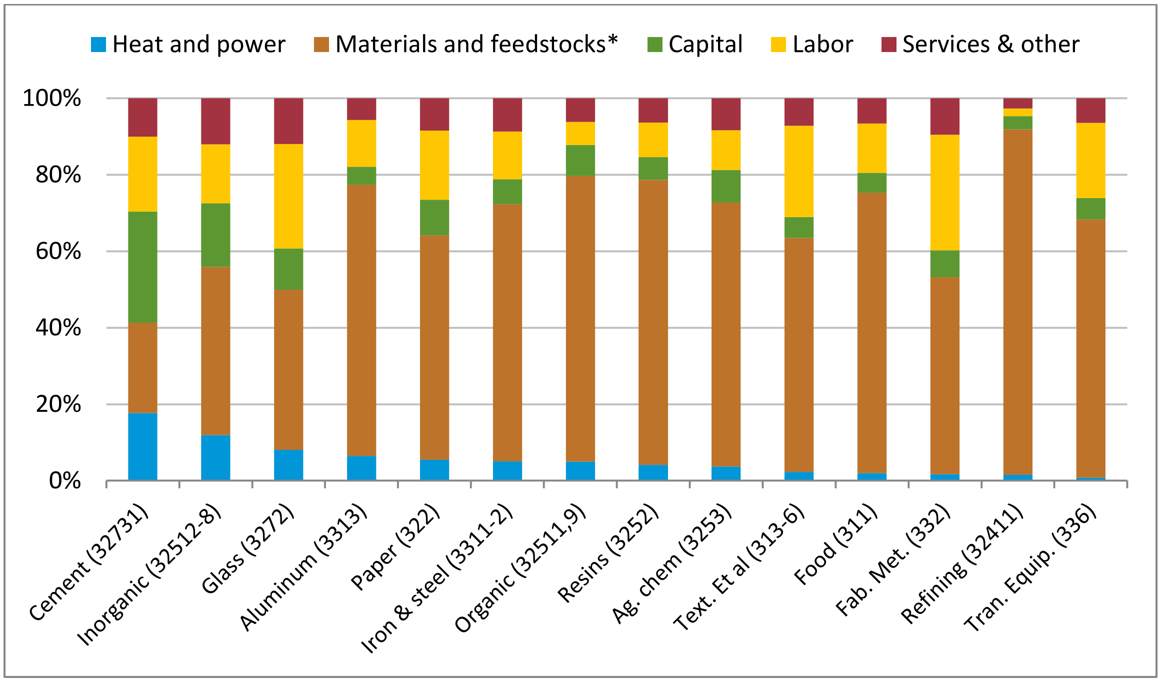
Figure 4. Industries (NAICS code) by largest dry NG fraction of fuel consumed[3] [7]



Estimates with near zero values or with exceedingly high error were set to 0; *residual and distillate fuel oil; **coal, coke, and breeze; ^many estimates for disaggregated chemical industries are withheld due to disclosure and are therefore not included.

[3] Ratios taken as BTU of a given fuel out of total BTU of all fuels consumed without subtracting "shipments of energy sources produced on site"; for more information see *MECS2010*.

Figure 5. Expenditure profile for key industries (NAICS code) by largest heat and power share [9]



*Feedstocks include energy products not used for heat and power.

These charts show that important NG users, especially bulk chemicals, have higher expenditure in materials, which includes feedstocks, and capital or labor, rather than heat and power. One can also see that the food industry has a relatively low measured intensity (2.2 thou. BTU/2005$), but because of the large quantity of consumption and importance of energy to the processes of this industry it is often included as a traditional energy-intensive manufacturing industry. For simplicity this work defines industries as "energy-intensive" using the definitions of the National Energy Modeling System (NEMS) used for the Annual Energy Outlook (AEO) [4], and includes one non-energy-intensive industry, apparel, because it was identified as potentially sensitive to energy variables in Arora et al. [[2]].

Characteristics of Energy in the Industrial Sector

To understand the industrial sector's relationship with NG several important characteristics were considered: the wellhead price of dry NG [[10]], marketed dry NG supply [[11]], total liquids supply[4] [[12]], and as applicable feedstock supplies [[12, 13]].

As a first analysis, each of the relevant NG characteristics was plotted against each of 12 key NG-intensive industries. Figures 6 through 9 show examples of scatter plots of energy-intensive outputs against dry NG price; remaining outputs and NG variables are plotted in the appendix.

[4] Data only available through 2010

Figure 6. Real dry NG price (2005$/tcf) plotted against organic chemical output (2005$)

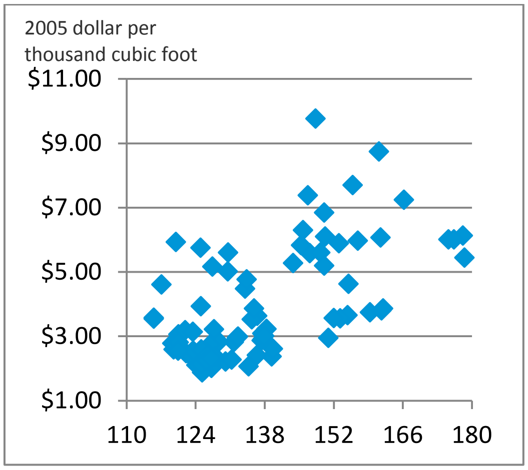


Figure 7. Real dry NG price (2005$/tcf) plotted against agricultural chemical output (2005$)

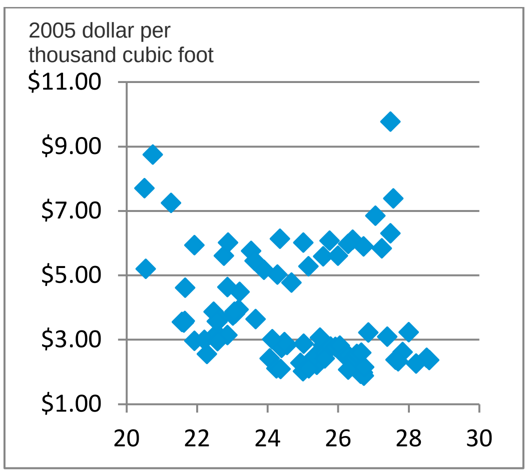


Figure 8. Real dry NG price (2005$/tcf) plotted against iron and steel output (2005$)

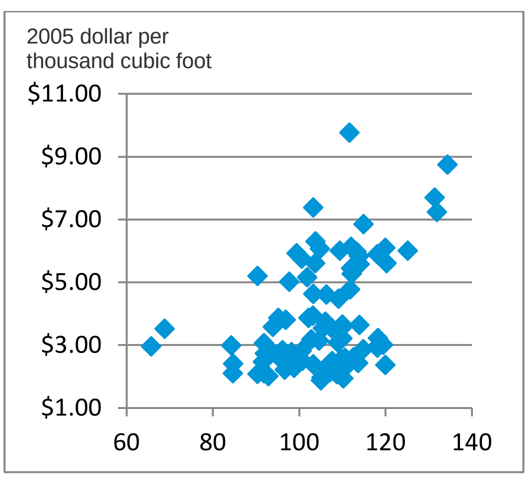
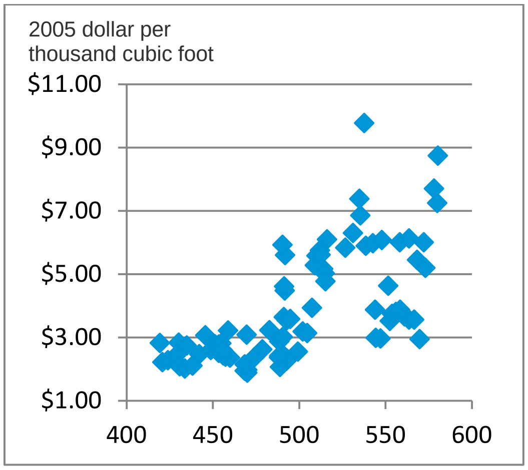


Figure 9. Real dry NG price (2005$/tcf) plotted against food products output (2005$)



Further Empirical Analysis

A simplified test to determine if there is any basic correlation between two variables is the Granger Causality[5] pair test [[14]]. For the work presented here, basic Granger pair testing was used with the lag length determined using the Akaike Information Criteria in Eviews [[15]]. Price lag length was deemed an exception and a shorter lag length of 2 quarters (6 months) was deemed appropriate. Each variable presented here is non-stationary and so each test was performed with the seasonally adjusted first difference of the natural log[6]. This test, while referred to as Granger *Causality*, is not truly a test of causal relationships, but instead simply indicates whether changes in one variable are in some way related to another, which is to say they may both be driven by a same "third variable" not being tested. This type of "prediction" is still an important test given that some results may help to support dynamics proposed by experts, and a result of "no relationship" is also very informative. Provided here are some key industrial output and energy variable pair results with proposed mechanisms or causality, but, again, no further testing was done to "prove" the direct relationship between any pair. Much of the benefit of these results lies in the ability to point the way for further research and testing.

A summary of the results for this approach can be found in Tables 1 through 6. The key finding is the need for further research and testing. One meaningful result would be the identification of the relationship between dry NG production and chemical output (organic, inorganic, and resins). Another would be the confirmation that resin output changes prior to changes in ethane supplies.

[5] Test is of the form $y_t = \sum_1^n \alpha_n \, y_{t-n} + \sum_1^n \beta_n \, x_{t-n} + \epsilon_t$ where the null hypothesis, x does not Granger Cause y, is determined by the sum of the coefficients being near 0.

[6] Eviews function *dlog(X,0,4)*; '4' selected due to quarterly data

Table 1. Granger pair test F statistics and p values (in parentheses) over 21 years of historical industrial sector data for changes occurring after or before changes in dry NG gas price. Bold p values indicate statistical significance at the 95% confidence level

Industry	NAICS code	After dry NG price	Before dry NG price
Food	311	0.67 (0.615)	0.11 (0.978)
Apparel	315	5.73 (**0.001**)	2.02 (0.101)
Paper	322	1.10 (0.365)	0.16 (0.956)
Organic	32511a9	0.42 (0.794)	1.13 (0.352)
Inorganic	32512t8	1.86 (0.127)	1.21 (0.313)
Resin & synthetics	3252	0.76 (0.552)	0.88 (0.483)
Ag. Chem	3253	1.30 (0.279)	1.60 (0.183)
Glass	3272	0.81 (0.525)	1.87 (0.126)
Cement	32731	5.68 (**0.001**)	3.48 (**0.012**)
Other SCG	327o	1.52 (0.206)	1.22 (0.308)
Iron and steel	3311-2	2.37 (0.061)	2.80 (**0.032**)
Aluminum	3313	1.13 (0.349)	0.66 (0.621)

Table 2. Granger pair test F statistics and p values (in parentheses) over 21 years of historical industrial sector data for changes occurring after or before changes in marketed dry NG production. Bold p values indicate statistical significance at the 95% confidence level

Industry	NAICS code	After marketed dry NG production	Before marketed dry NG production
Food	311	1.85 (**0.015**)	1.00 (0.461)
Apparel	315	2.16 (**0.033**)	1.15 (0.343)
Paper	322	1.55 (0.149)	0.63 (0.794)
Organic	32511a9	2.46 (**0.015**)	0.89 (0.555)
Inorganic	32512t8	2.89 (**0.005**)	0.99 (0.469)
Resin & synthetics	3252	2.28 (**0.026**)	0.78 (0.645)
Ag. Chem	3253	1.90 (0.062)	1.47 (0.173)
Glass	3272	3.04 (**0.004**)	1.45 (0.182)
Cement	32731	1.24 (0.301)	1.55 (0.185)
Other SCG	327o	2.67 (**0.008**)	1.05 (0.422)
Iron and steel	3311-2	2.59 (**0.010**)	1.21 (0.307)
Aluminum	3313	0.36 (0.698)	0.67 (0.514)

Table 3. Granger pair test F statistics and p values (in parentheses) over 21 years of historical industrial sector data for changes occurring after or before changes in NG liquids supplied. Bold p values indicate statistical significance at the 95% confidence level

Industry	NAICS code	After NG liquids supplied	Before NG liquids supplied
Food	311	1.07 (0.404)	2.67 (**0.011**)
Apparel	315	2.59 (**0.013**)	0.81 (0.624)
Paper	322	0.46 (0.905)	1.32 (0.253)
Organic	32511a9	1.52 (0.160)	3.64 (**0.001**)
Inorganic	32512t8	1.49 (0.171)	1.28 (0.265)
Resin & synthetics	3252	0.91 (0.528)	1.55 (0.150)
Ag. Chem	3253	0.40 (0.943)	6.11 (**0.000**)
Glass	3272	2.14 (**0.034**)	3.22 (**0.002**)
Cement	32731	0.76 (0.664)	1.36 (0.228)
Other SCG	327o	1.74 (0.099)	0.32 (0.973)
Iron and steel	3311-2	1.42 (0.198)	1.06 (0.413)
Aluminum	3313	0.56 (0.848)	0.81 (0.629)

Table 4. Granger pair test F statistics and p values (in parentheses) over 21 years of historical industrial sector data for changes occurring after or before changes in ethane supplied in applicable industries only. Bold p values indicate statistical significance at the 95% confidence level

Industry	NAICS code	After ethane supplied	Before ethane supplied
Organic	32511a9	2.16 (**0.044**)	3.03 (**0.007**)
Inorganic	32512t8	0.97 (0.489)	1.27 (0.284)
Resin & synthetics	3252	0.48 (0.894)	2.33 (**0.030**)

Table 5. Granger pair test F statistics and p values (in parentheses) over 21 years of historical industrial sector data for changes occurring after or before changes in petrochemical feedstock supplied in applicable industries only. Bold p values indicate statistical significance at the 95% confidence level

Industry	NAICS code	After petrochemical feedstock supplied	Before petrochemical feedstock supplied
Organic	32511a9	3.25 (**0.002**)	0.92 (0.531)
Inorganic	32512t8	2.48 (**0.013**)	2.94 (**0.004**)
Resin & synthetics	3252	2.90 (**0.005**)	1.46 (0.174)

After first review of the results above it was determined that a more nuanced approach to price testing might be necessary because the wellhead price is a wholesale price. The final conclusion was that an additional test should be done using an industrial sector specific NG price[7] [[16]].

[7] Estimates only available from 1995 to 2011

Table 6. Granger pair test F statistics and p values (in parentheses) over 21 years of historical industrial sector data for changes occurring after or before changes in industrial dry NG price. Bold p values indicate statistical significance at the 95% confidence level

Industry	NAICS code	After industrial dry NG price	Before industrial dry NG price
Food	311	1.91 (0.124)	0.84 (0.507)
Apparel	315	4.38 (**0.004**)	2.23 (0.079)
Paper	322	3.89 (**0.008**)	0.94 (0.450)
Organic	32511a9	2.55 (**0.050**)	2.17 (0.086)
Inorganic	32512t8	3.26 (**0.019**)	1.29 (0.286)
Resin & synthetics	3252	2.75 (**0.038**)	1.02 (0.407)
Ag. Chem	3253	1.14 (0.350)	1.83 (0.138)
Glass	3272	0.74 (0.572)	2.03 (0.104)
Cement	32731	3.73 (**0.010**)	2.34 (0.067)
Other SCG	327o	3.71 (**0.010**)	1.27 (0.293)
Iron and steel	3311-2	0.72 (0.584)	1.34 (0.267)
Aluminum	3313	3.11 (**0.023**)	1.71 (0.162)

Discussion of Results

Overall Industrial Sector and Dry Wellhead NG Price

Over the 21-year data sample Granger tests indicate a two-way relationship between total industrial sector output, sometimes referred to as Industrial Production (IP), and dry wellhead NG price, which, as a wholesale price, is a general NG price experienced broadly across the economy. A "two-way relationship" means industrial output changes both before and after NG price changes, which is actually a nonsensical logic trap. Fortunately, if the sector is disaggregated to manufacturing and non-manufacturing this relationship becomes clearer. Changes in the NG price occur before changes in total manufacturing sector output but after changes in total non-manufacturing sector output, indicating the mechanism underlying the industrial sector: mining, which includes NG extraction, a key non-manufacturing industry, most likely affects NG price through supply, and NG price then subsequently drives consumption in manufacturing industries broadly, and this continues in a "cyclic" fashion over time (the lag having been indicated by the Akaike Information Criteria). This is consistent with generally accepted or understood industrial behavior. Unfortunately, not all two-way relationship can be as easily untangled, which will be discussed in later sections.

Bulk Chemicals and Dry NG

The bulk chemicals sector is comprised of the energy-intensive, high-volume chemical industries: basic chemicals, which include both organic and inorganic, resins and synthetic fibers (shortened to "resins"), and agricultural chemicals, which includes fertilizers, pesticides, and herbicides. The results here show changes in the general wellhead NG price do not have a relationship with any of the bulk chemical industries.

Changes in bulk chemical output, except agricultural chemicals, precede changes in dry NG production, the metric representative of supply. These results indicate "response" to supply changes, which are the crux of the "shale revolution" or "game changer" hypothesis. It has been publicly speculated that NGLs are a key element of this change [[17], [18], [19]] and it is reasonable to expect supply may further affect the bulk chemical sector through liquid feedstock selection, which is discussed in greater detail in the next section.

Given links to supply, initial price results were suspect. Upon further contemplation it was determined that perhaps the proper test would be of an industrial specific dry NG price. All bulk chemical industries except agricultural chemicals showed changes in output following changes in dry industrial NG price, implying a direct response to price changes, which supports traditional price behavior theory.

The agricultural chemicals industry shows no relationship to dry NG supply or price, which does not support theories that suggest the off-shoring/re-shoring trend of the nitrogen-based fertilizer industry is simply driven by supply. The lack of a relationship between agricultural chemicals and dry NG supply or price may be explained by a variety of factors including, but not limited to, the unique position of this industry as a large-scale user of dry NG as a feedstock and its ability to pass costs on to its customers since the primary driver of fertilizer demand is the food system, which is most tightly tied to population growth.

Bulk Chemicals and Liquid Feedstocks (NGLs and Naphtha)

Using energy products as feedstock for chemical conversion, rather than for heat and power, is a unique facet of the bulk chemicals sector, and, although dry natural gas (methane) can be used as feedstock (mostly for nitrogen-based fertilizer and methanol; see previous section), for the purposes of this section only "liquid feedstocks" were tested. There are two types of liquid feedstocks: liquids derived from natural gas (NGLs), which include ethane, propane, butane, and pentane, and "petrochemical feedstock", which is primarily petroleum-based naphtha but includes a small amount of gas oil. In terms of recent developments related to NG, ethane is the most important NGL to changing the bulk chemical paradigm as its production has changed most significantly with the advent of shale formation extraction [20].

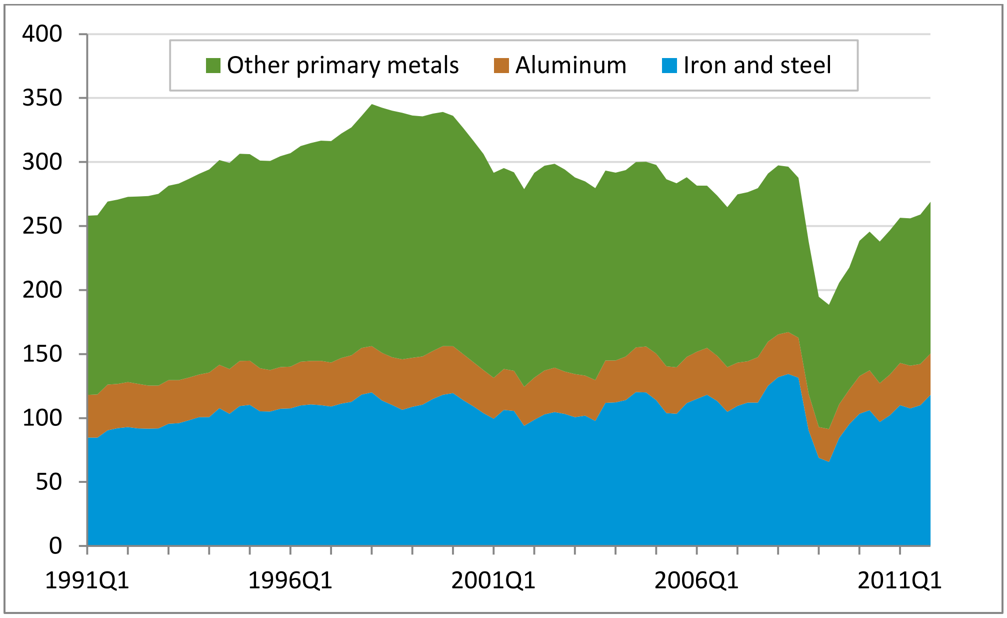
Granger tests show changes in ethane supply follow changes in resins output. This could be explained by the demand for plastics driving ethane demand, which in turn might encourage suppliers to produce "wetter" NG. The relationship between organic chemical output and ethane is two-way, which can only indicate complexity and nothing more, but is also possibly a result of lag length and could be argued to mirror the resins industry dynamic due to the direct link between ethane and ethylene derived plastics, which require organic chemical intermediates.

Changes in petrochemical feedstock supply precede changes in organic chemical and resins output, but have a two-way relationship with inorganic. One might reasonably expect the organic chemicals and resins industries behavior is driven by two factors: petrochemical supply is driven by other demands for crude oil because these feedstocks are produced as a secondary product; and the organic chemicals and resins industries are, to some degree, feedstock flexible. Inorganic is not a direct consumer of feedstock so the result was determined to be a result of the reliance of this industry on organic intermediates.

Primary metals

The primary metals sector includes industries that convert raw mined metals to ingots or products and industries that use these ingots to produce final consumer and intermediate metal goods, such as sheets or tubes. Because the iron and steel and aluminum industries are energy-intensive they are of special interest.

Figure 10. Components of output (billion 2005 dollar) for the primary metals industries [4]



Aluminum

Though it might be reasonable to expect that both dry NG price and supply would affect *all* energy-intensive industries, particularly the aluminum industry [[21]], aluminum output does not demonstrate a statistical relationship with dry NG production, only the industrial sector specific dry NG price. Aluminum output changes following price changes without a link to supply changes suggests that demand of NG is the driver of this relationship. Because the Granger result is limited to the industrial sector price specifically, it implies that the link is industrial sector demand for NG specifically. Changes in industrial sector demand for NG without broader economic demand for NG, which would affect the more general wellhead price, points to demand for manufactured goods outside the U.S. (i.e. exports). Dry NG price may also indirectly affect aluminum via electricity prices given the aluminum industry is also a large user of electricity; although some regions rely heavily on hydro-power.

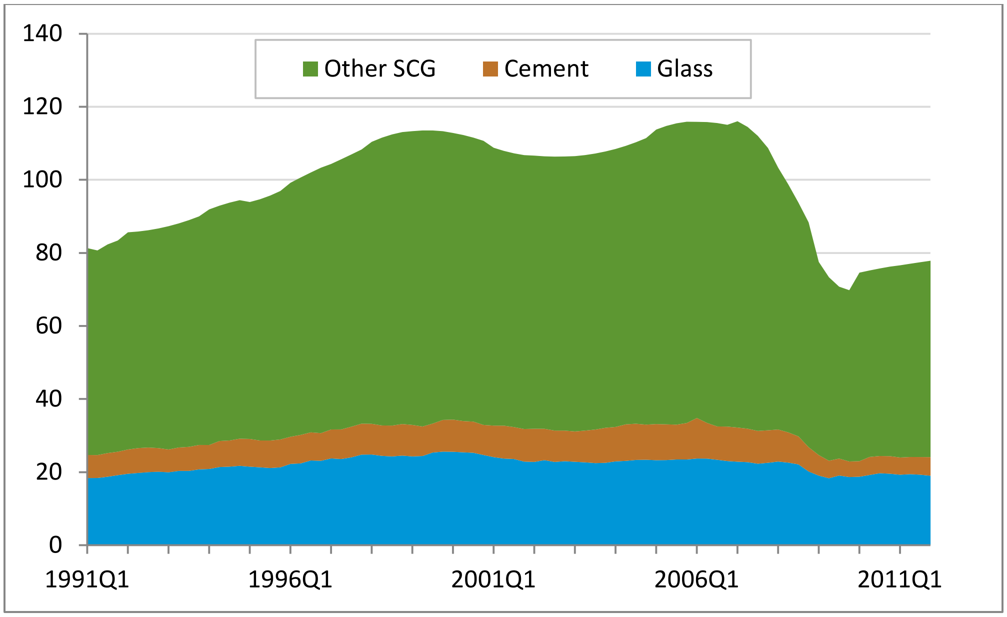
Iron and Steel

The iron and steel industry is an energy-intensive producer that uses the most diverse mix of fuels and might be expected to respond to various energy drivers. While changes in iron and steel output occur after changes in dry NG production, there are changes in wellhead dry NG price *after* changes in iron and steel output, and no other price links apparent. These dynamics are intriguing but also quite difficult to explain. One possible implication is this industry has higher expenditure for heat and power than many other manufacturing industries and is a high quantity consumer of both NG and electricity, which means they may simply pass costs onto consumers since it is so “core” to their product. Also, many iron and steel products are used in the oil and gas exploration, development, and production process, which could explain a link to supply, where the industry is otherwise “agnostic” to supply and price.

Non-metallic Minerals

The non-metallic minerals, or Stone, Clay, and Glass (SCG), sector comprises a very diverse set of industries that produce a number of basic commodities and final consumer goods in both energy-intensive and non-energy-intensive processes. Because the glass and cement industries are energy-intensive they are of special interest, and the remaining "other" SCG industries were tested due to prior results in the literature [2].

Figure 11. Components of output (billion 2005 dollar) for the non-metallic minerals industries, also known as the Stone, Clay, and Glass (SCG) sector [4]



Glass and Glass Products

Like the iron and steel industry, changes in glass output follow changes in supply without showing a response to price. This relationship is likely a reflection of both the energy-intensity of this industry and the link between demand for glass products and the broader economy. The glass industry has a relatively high expenditure on heat and power and relies almost exclusively on NG for fuel (with purchased electricity being its only other significant energy consumption). Again, because NG is so "core" to these products the cost may be passed onto the customer severing a link to price. The dynamic with supply of dry NG, and two-way relationship with liquid supply, are probably the result of an economic "third variable", which most likely operates through overall demand for goods.

Cement

The results show changes in cement output occur after changes in the industrial sector dry NG price but not dry NG supply, and there is also a two-way relationship with the "general" wellhead NG price. This dynamic mirrors the aluminum results, suggesting NG demand affects price, which then specifically affects this industry. The difference for the cement industry is the complex relationship with wellhead price. This result might be an indicator of the role of broader *domestic* NG demand as opposed to the implied isolated industrial demand in the aluminum result. Broader domestic drivers for cement industry behavior make sense since the use of cement in construction is primarily domestic demand, and changes in construction activity are often spurred by broader economic activity.

Other Non-metallic Minerals

This group includes diverse industries such as lime, cut stone, and mineral wool, which might explain the very straightforward Granger results. Changes in output of other non-metallic minerals occur after changes in both industrial dry NG price and dry NG supply, supporting a basic “supply affects price; price affects industrial output” behavior.

Pulp and Paper

The pulp and paper industry is comprised of the production of commoditize raw materials (pulp), commoditized products (reams and rolls), and end-user level products (boxes and package materials). Changes in this industry occur after changes in the dry industrial sector NG price, like aluminum. A price response with no supply behavior is probably an indicator of the effect of broader industrial NG demand due to demand for goods. Again, the lack of broader price impact may point to a non-domestic demand driver, such as exports. It is also interesting to note that aluminum, by way of hydro electricity, cement, by way of tire-derived and refuse-based fuels, and paper, by way of black liquor, are significant consumers of alternative fuels and also all exhibit similar price and supply Granger behavior. This is an issue left open for further investigation.

Food

The food industry, while a large consumer of energy, is also an aggregate of many small operators and tends to have different dynamics than the other energy-intensive industries. The food industry results are exactly the same as agricultural chemicals, with changes in food output preceding changes in liquids supply and no other links to NG. Food demand is driven by consumer demand and receives much of its input from the agriculture industry, to which the agricultural chemicals industry is also closely tied. These results combined point to a special dynamic in the broader food supply-chain that may drive industry behavior rather than factors that drive other manufacturing industries.

Apparel

The apparel industry was highlighted by results from Arora [[2]] and serves as a non-energy-intensive manufacturing example for comparison to the other results presented here. It is worth noting that the apparel industry effectively consumes only electricity and NG, with NG making up approximately a third of all energy consumption for the industry [7]. For each of the variables tested all show changes prior to apparel output. These results suggest the apparel industry is either extremely sensitive to the natural gas market (all prices and all supplies) or is an indicator of broader economic activity, the proverbial “canary in a coal mine”, with the latter seemingly more likely.

Can recent Data Help Inform The Future?

By performing the Granger tests across 21 years of data one can hope to determine trends or relationships in output and energy variables, but what if these trends have been changed in recent years? By plotting the variable pairs presented in the tests above over time one can begin to look for divergence or convergence.

To more readily analyze potential trend changes, each of the variables included in the tests here were indexed, to reduce the potential for absolute values overwhelming trends, subtracted from each other, and then plotted across time. Figures 12 through 15 are sample plots of the difference (delta) between the various indexes over time; the remaining plots for any Granger relationships can be found in the appendix.

Figure 12. Plot of dry marketed NG production (index 1995) minus output of three bulk chemicals (real, index 1995)

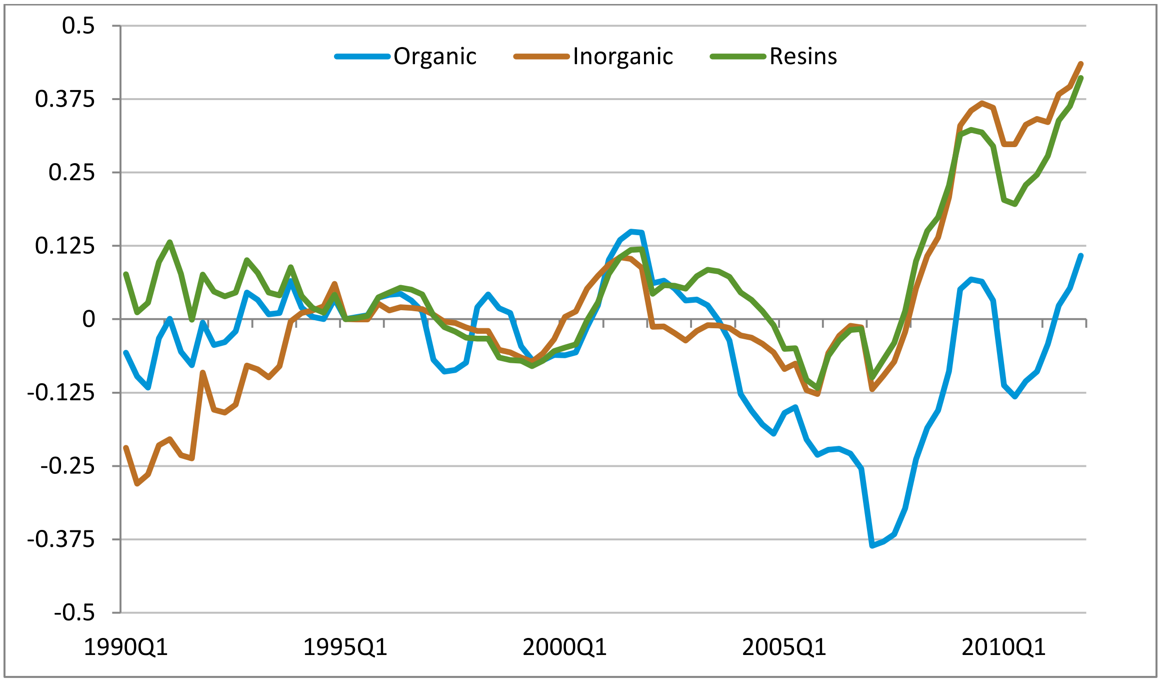


Figure 13. Plot of dry industrial sector NG price (real, index 1995) minus output of three bulk chemicals (real, index 1995)

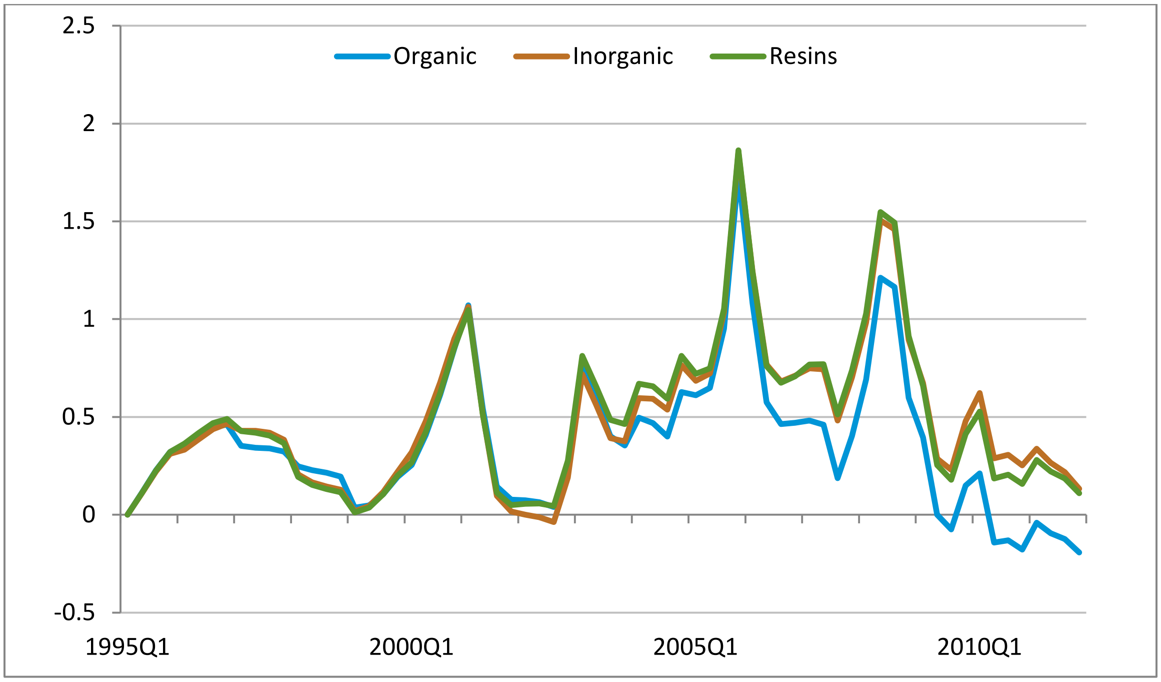


Figure 14. Plot of dry marketed NG production (index 1995) minus output of iron and steel (real, index 1995)

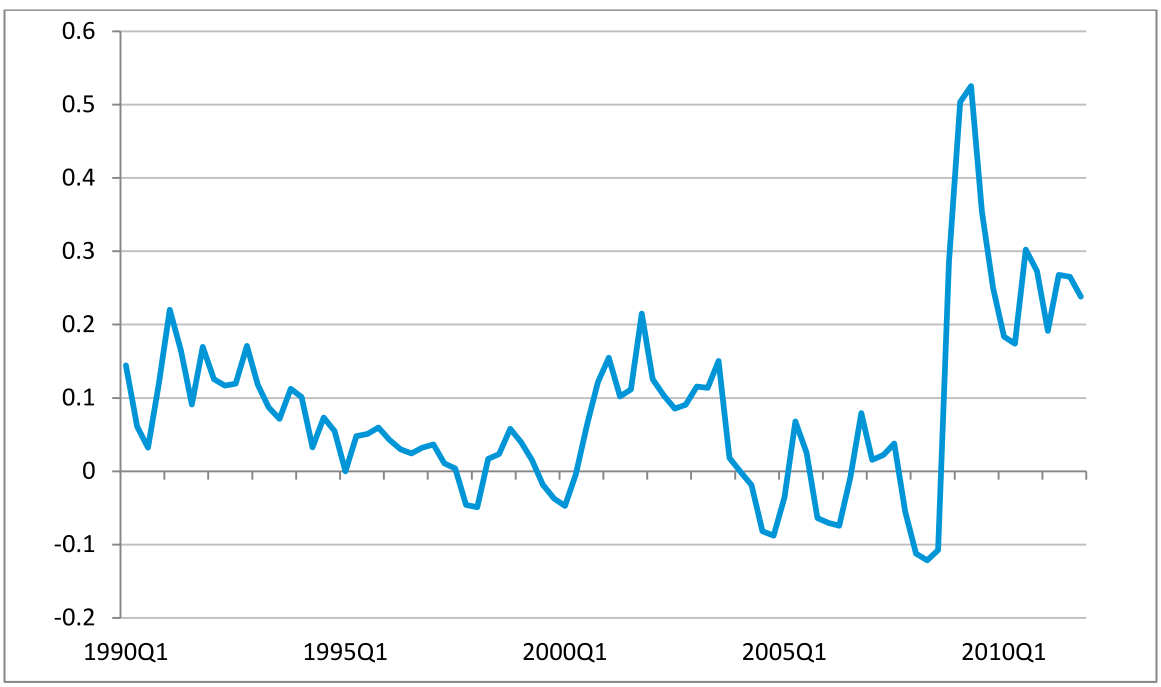
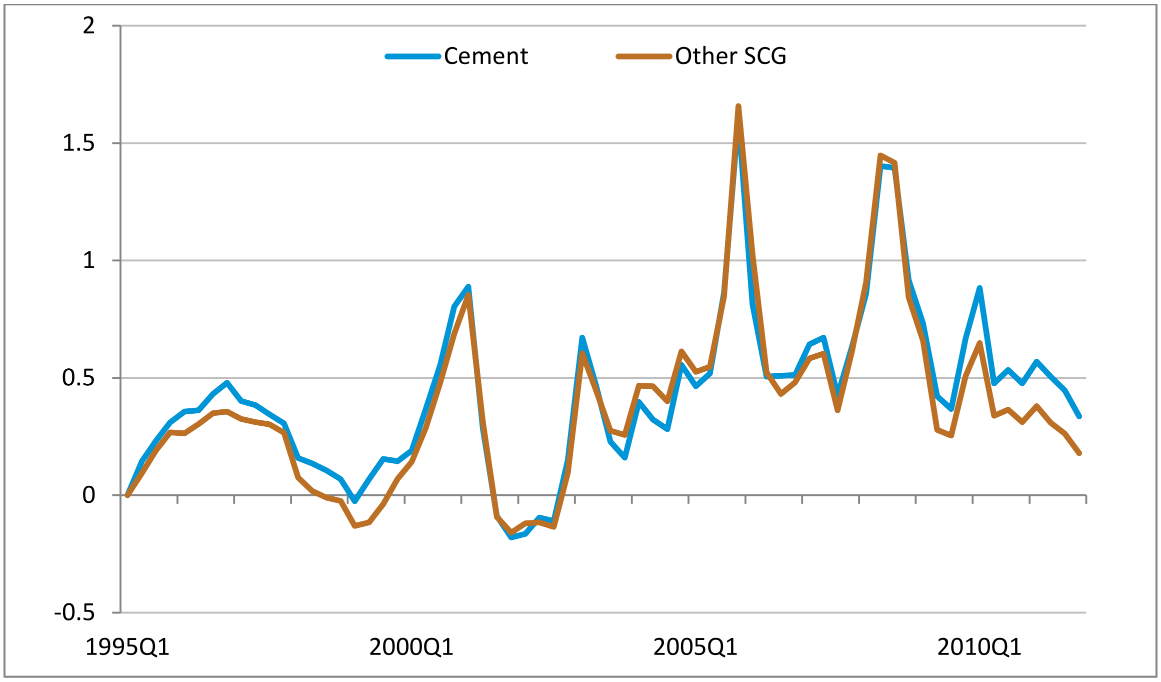


Figure 15. Plot of dry industrial sector NG price (real, index 1995) minus output of cement and other non-metallic minerals (real, index 1995)



Although the timing differs, at least one breakpoint is present for each of the energy variables tested with the various industries. The implication of these results is the energy variables or the industries tested here went through fundamental changes in approximately the last decade and exhibited new trends.

Risks and Future Tests

One known risk of the work performed here is misspecification. Granger tests grossly simplify the dynamic at work in the industrial sector, and it is not the intent of this work to fully control for all possible drivers or fully analyze industrial production trends. Future work to expand on these results might include the use of vector auto-regression (VAR) models to truly assess the proper influencing variables for each industries output. Of course, VARs based on this work will still risk omitted variable bias so a Granger-type exogeneity test on each can further test the validity of some of the mechanisms proposed in this paper.

With regard to recent structural breaks, the currently available data does not provide enough data points after the most hotly contested potential break (the 2007 shale gas “game-changer”) to determine what a “new norm” might look like, making this work inconclusive. Once new data, such as the Economic Census 2012 and the 2007 input-output tables, become available one might revisit these tests [[22,] 6].

Conclusion

As is often the case, the questions raised by this work outnumber the questions it answers. The results of the Granger tests and breakpoint analysis presented here point to the need for even more work in understanding the dynamics of the industrial sector and energy, specifically NG. The relationships and drivers of the industrials sector, as related to the energy sector, and the subsequent feedbacks are highly complex and are rarely limited to just two variables.

These tests do support things we already thought we knew, such as the dynamic between energy suppliers in the non-manufacturing sector and energy users in the manufacturing sector. The results that represent things we didn't know or that contradict things we thought we knew, such as the seeming insignificance of NG prices or supply to agricultural chemicals, are sometimes surprising and, in some cases, are only conjecture without further research. These findings are helpful, however, in framing the discussion about relevant characteristics of the industrial sector and pointing the way for future research on industrial sector and NG patterns.

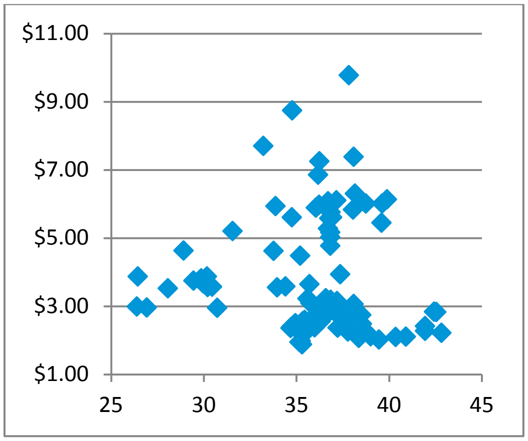
The most telling general results are those industries with little to no relationship with NG (agricultural chemicals and food), those results that seem to confirm the expected price-supply-production dynamic (non-agricultural bulk chemicals and other non-metallic minerals), and the possibly changing connection amongst all industries and their energy inputs. The importance of selecting the correct price was another important, and unexpected, outcome of the work here. Lastly, the expected relationship between bulk chemical industries and liquid feedstocks is supported by the results here. The implication of the chemical sector demand driving ethane supply and the importance of bulk chemicals industries' flexibility is suggestions of a "revolution" driven by new, wet NG supply via shale formations carry some weight with regard to this sub-sector if supply dynamics continue into the future. Of course, it is unclear if this relationship will be maintained if the competitive advantage of natural gas-sourced liquids is diminished by development of similar resources in other nations.

Appendix

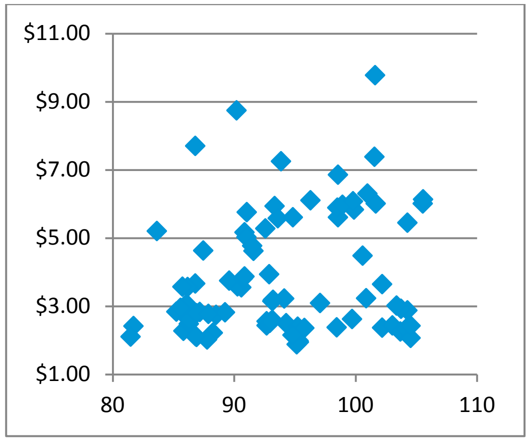
Additional scatter plots

Wellhead price

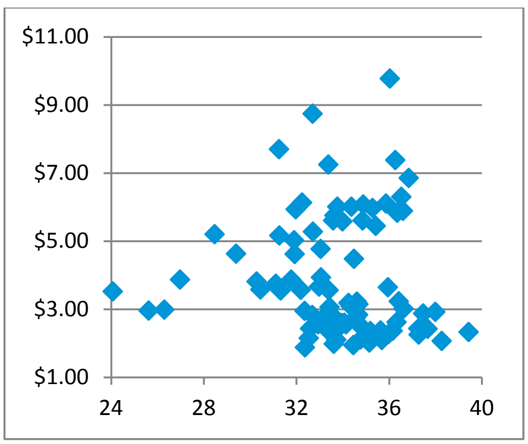
Real dry NG price (2005$/tcf) plotted against inorganic chemical output (2005$).



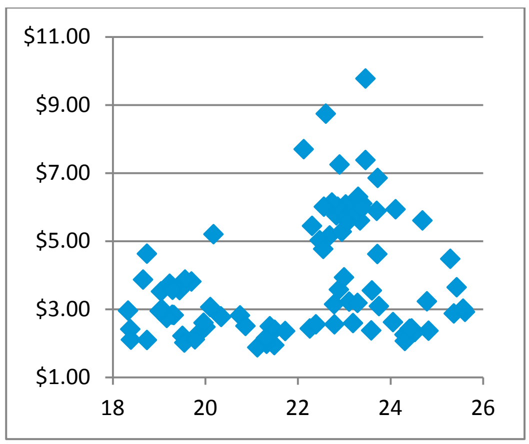
Real dry NG price (2005$/tcf) plotted against resins output (2005$).



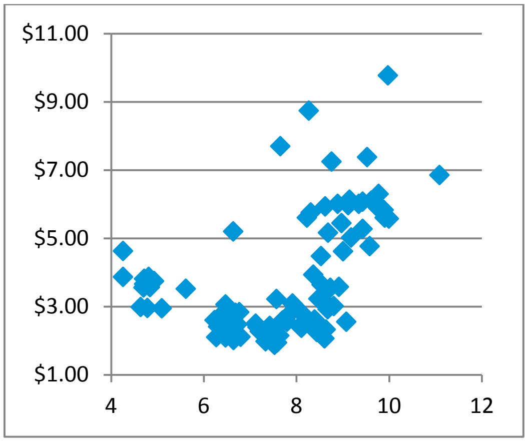
Real dry NG price (2005$/tcf) plotted against aluminum output (2005$).



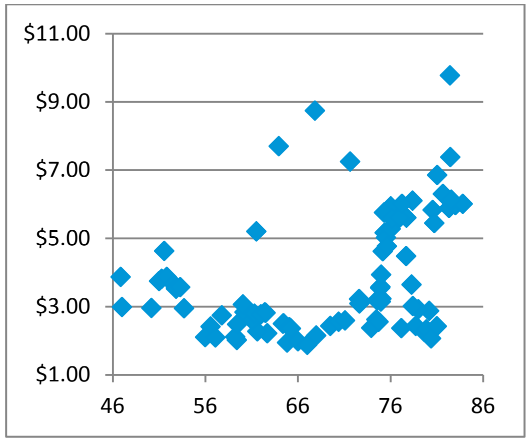
Real dry NG price (2005$/tcf) plotted against glass output (2005$).



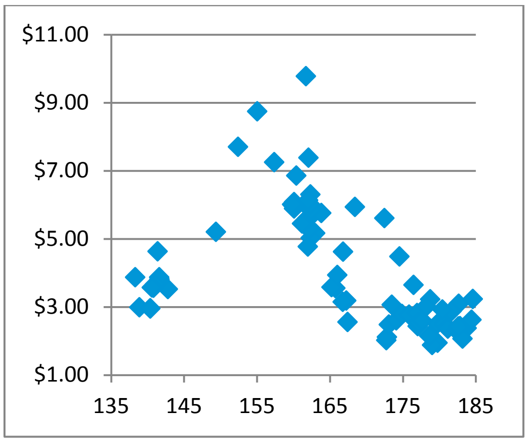
Real dry NG price (2005$/tcf) plotted against cement output (2005$).



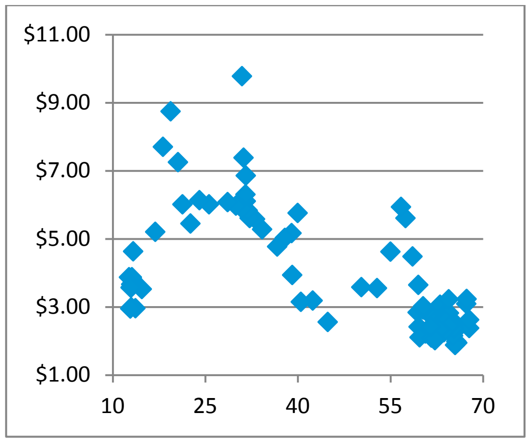
Real dry NG price (2005$/tcf) plotted against other non-metallic minerals output (2005$).



Real dry NG price (2005$/tcf) plotted against paper output (2005$).

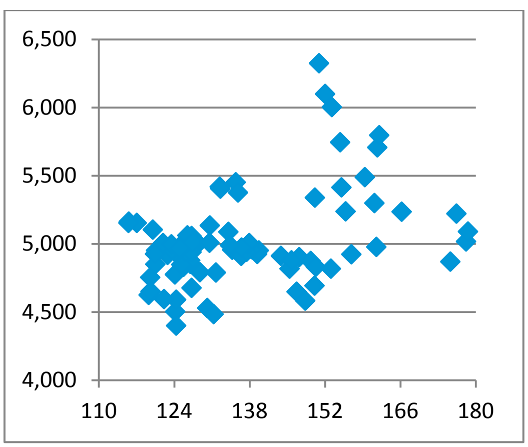


Real dry NG price (2005$/tcf) plotted against apparel output (2005$).

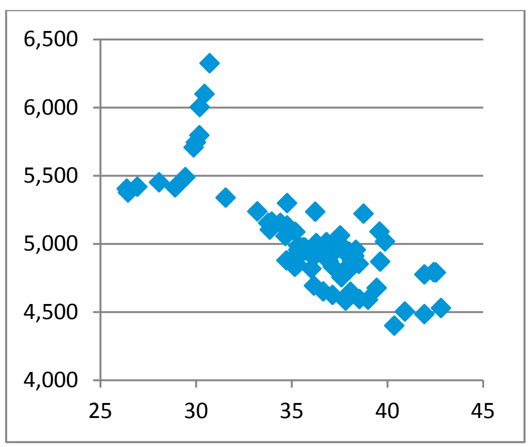


Dry supply

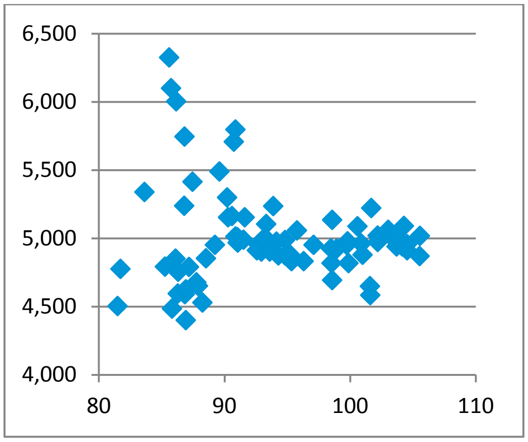
Dry marketed NG production (bcf) plotted against organic chemical output (2005$).



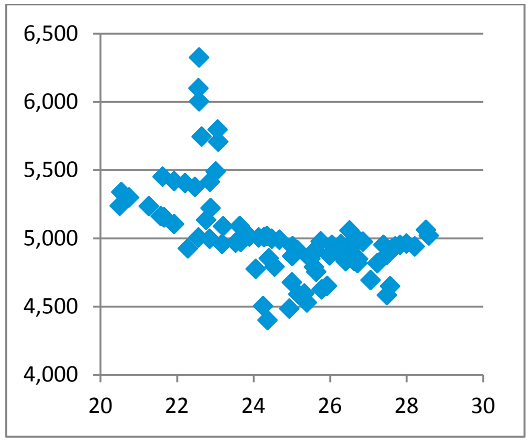
Dry marketed NG production (bcf) plotted against inorganic chemical output (2005$).



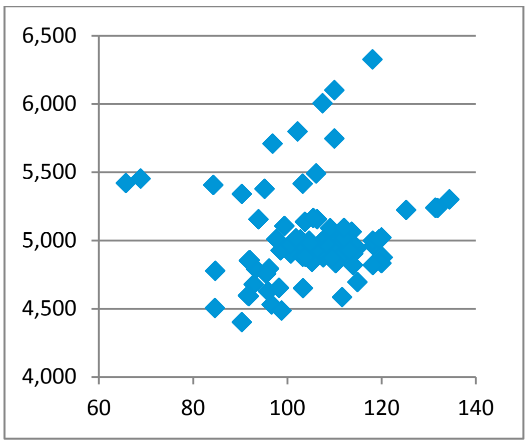
Dry marketed NG production (bcf) plotted against resins output (2005$).



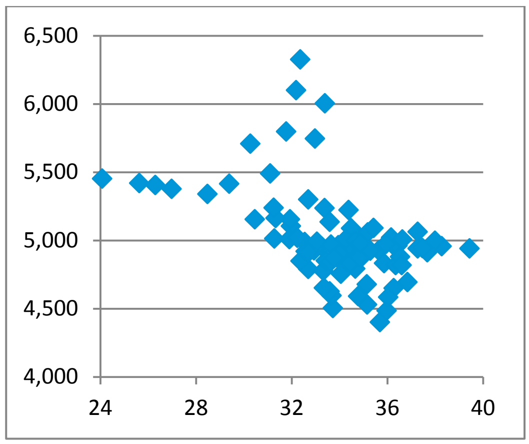
Dry marketed NG production (bcf) plotted against agricultural chemical output (2005$).



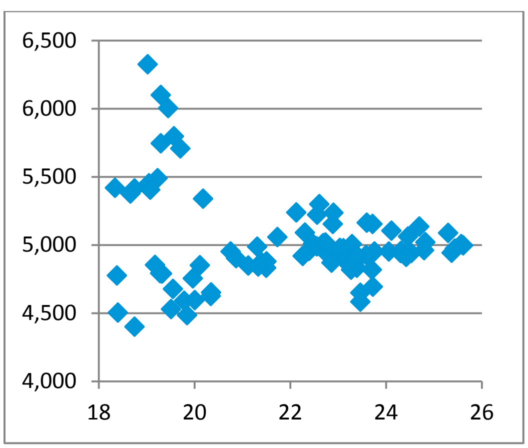
Dry marketed NG production (bcf) plotted against iron and steel output (2005$).



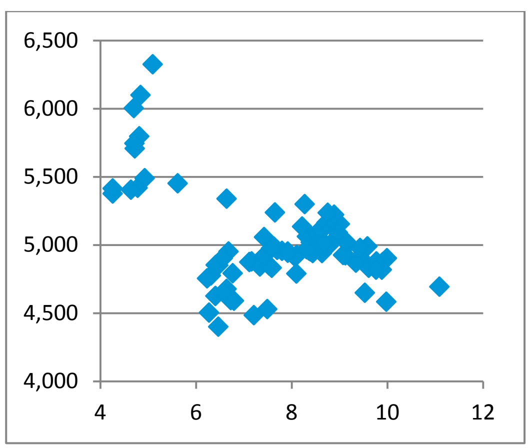
Dry marketed NG production (bcf) plotted against aluminum output (2005$).



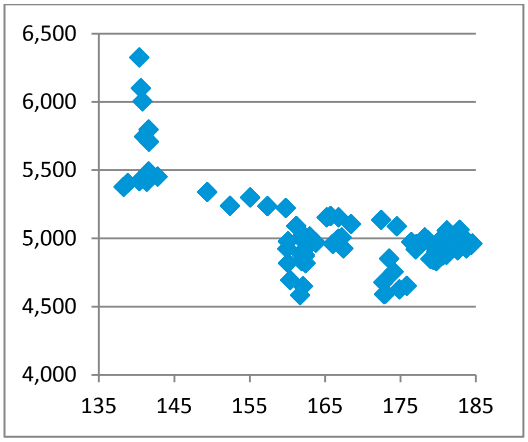
Dry marketed NG production (bcf) plotted against glass output (2005$).



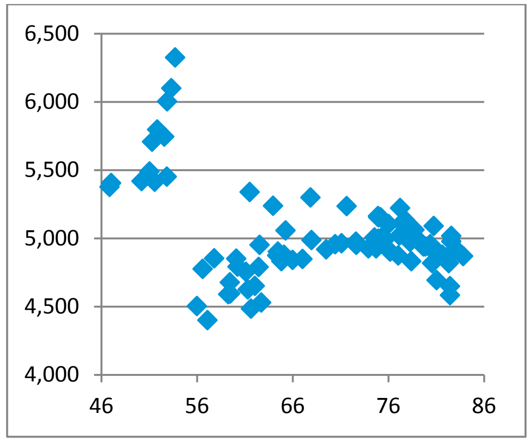
Dry marketed NG production (bcf) plotted against cement output (2005$).



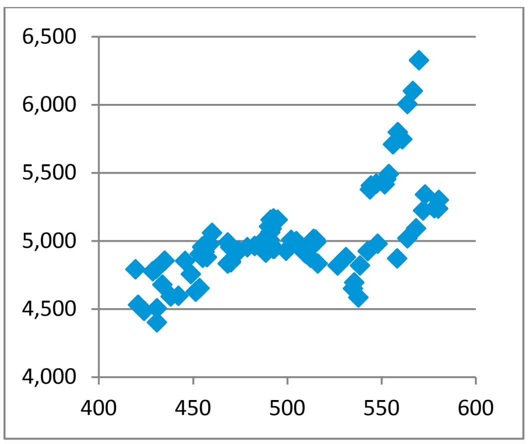
Dry marketed NG production (bcf) plotted against paper output (2005$).



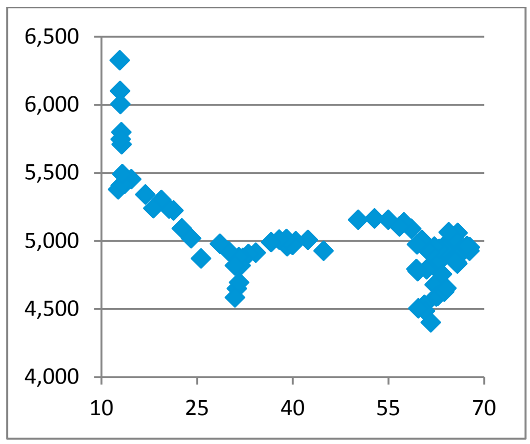
Dry marketed NG production (bcf) plotted against other non-metallic mineral output (2005$).



Dry marketed NG production (bcf) plotted against food products output (2005$).

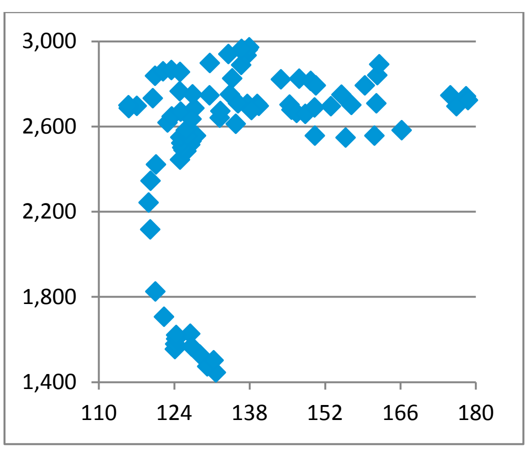


Dry marketed NG production (bcf) plotted against apparel output (2005$).

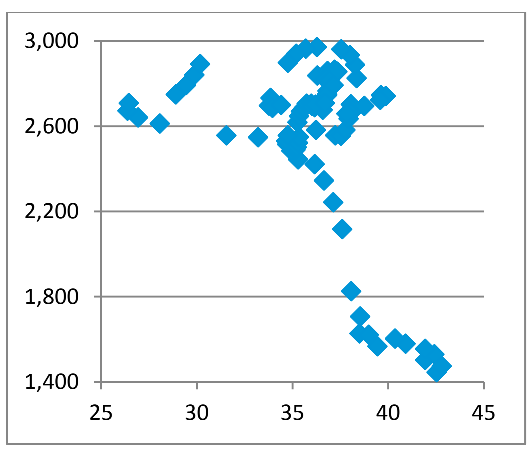


Liquids supply

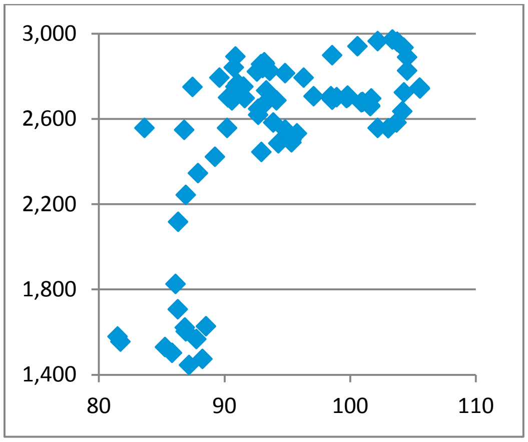
LPG supply (trillion BTU) plotted against organic chemical output (2005$).



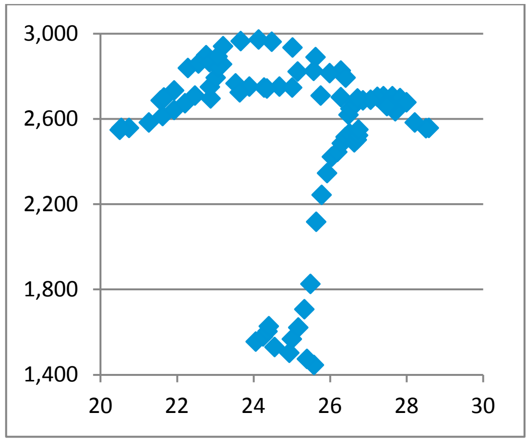
LPG supply (trillion BTU) plotted against inorganic chemical output (2005$).



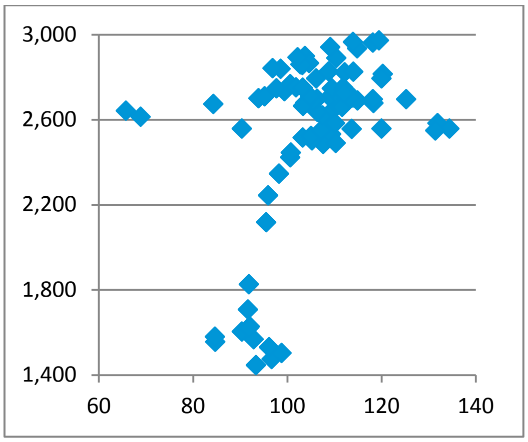
LPG supply (trillion BTU) plotted against resins output (2005$).



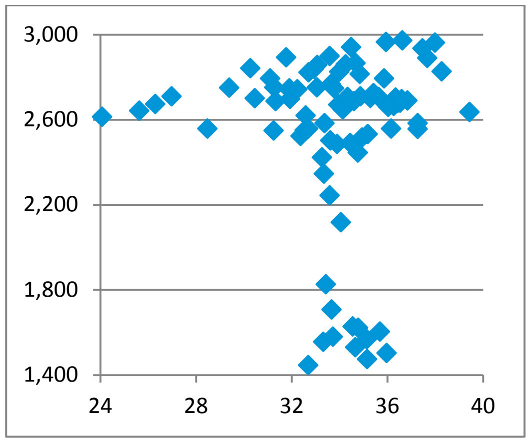
LPG supply (trillion BTU) plotted against agricultural chemical output (2005$).



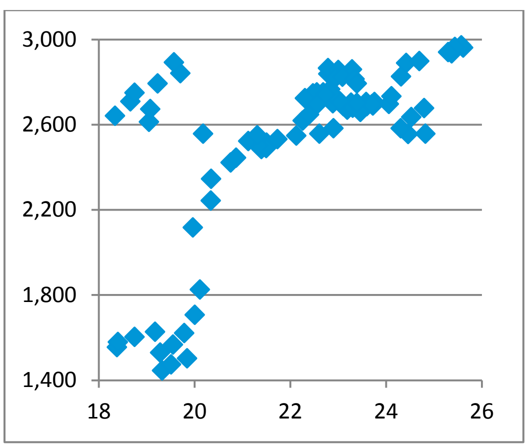
LPG supply (trillion BTU) plotted against iron and steel output (2005$).



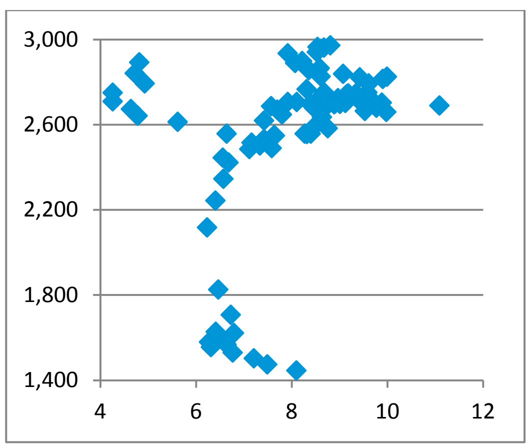
LPG supply (trillion BTU) plotted against aluminum output (2005$).



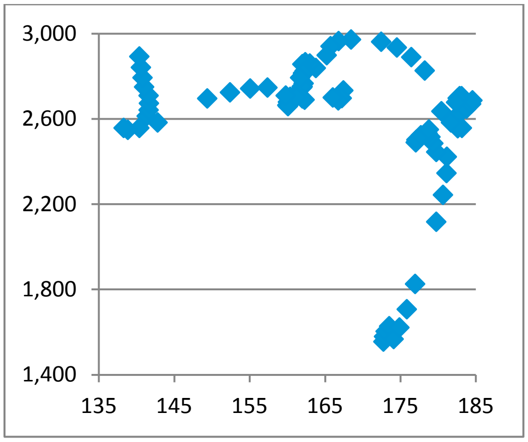
LPG supply (trillion BTU) plotted against glass output (2005$).

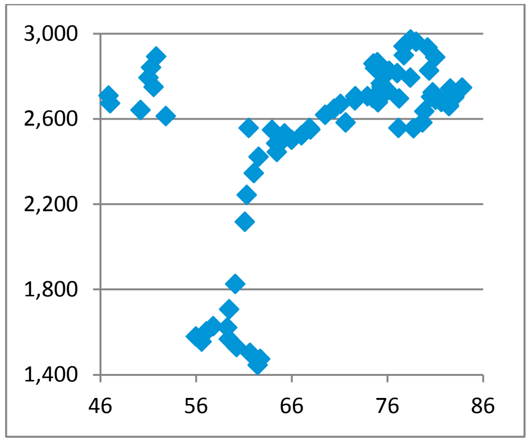


LPG supply (trillion BTU) plotted against cement output (2005$).

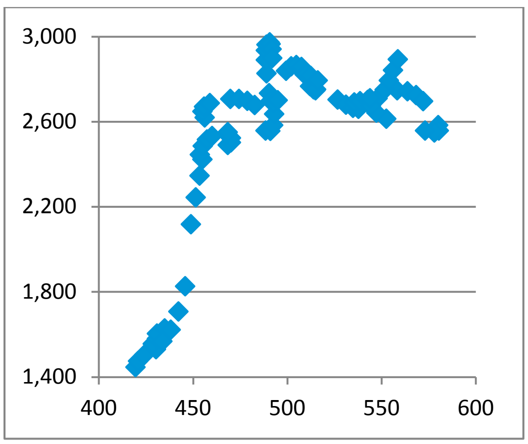


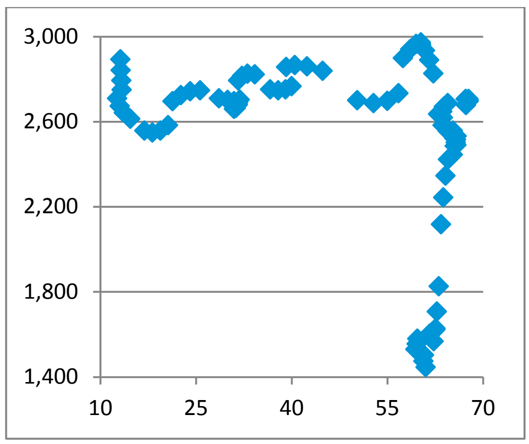
LPG supply (trillion BTU) plotted LPG supply (trillion BTU) plotted
against paper output (2005$). against other non-metallic mineral output (2005$).





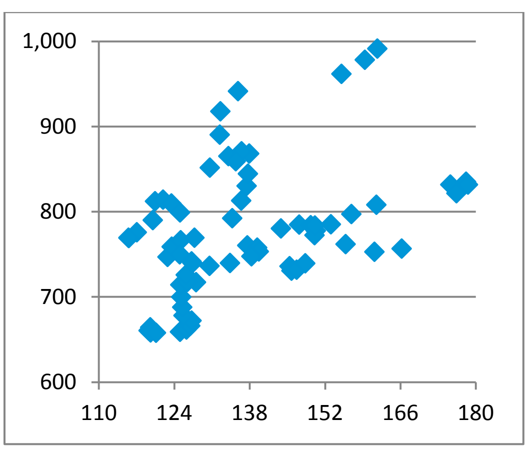
LPG supply (trillion BTU) plotted LPG supply (trillion BTU) plotted
against food products output (2005$). against apparel output (2005$).

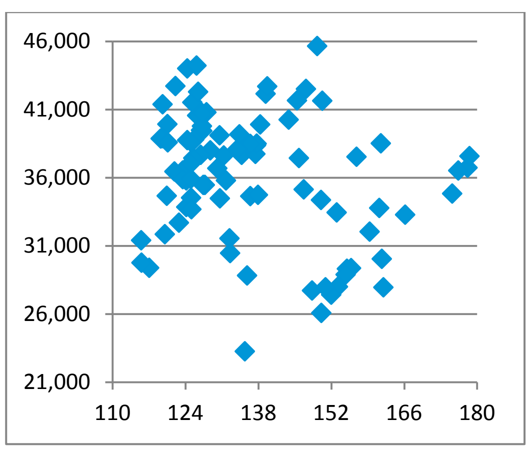




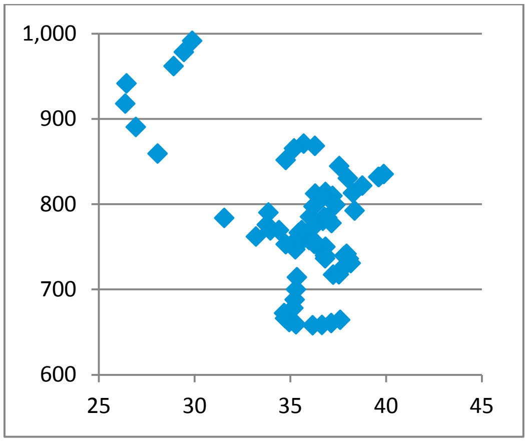
Feedstocks

Ethane supply (trillion BTU) plotted Petrochemical feedstock supply (thou. bbl) plotted
against organic chemical output (2005$). against organic chemical output (2005$).

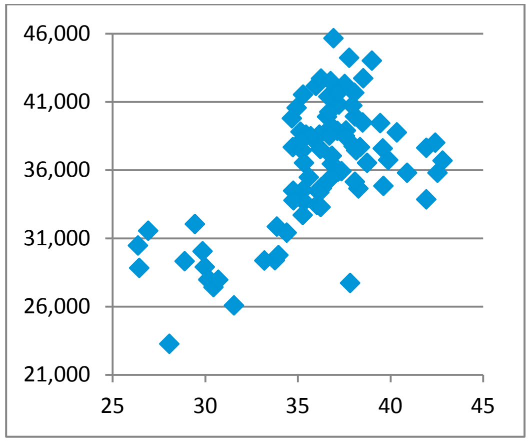




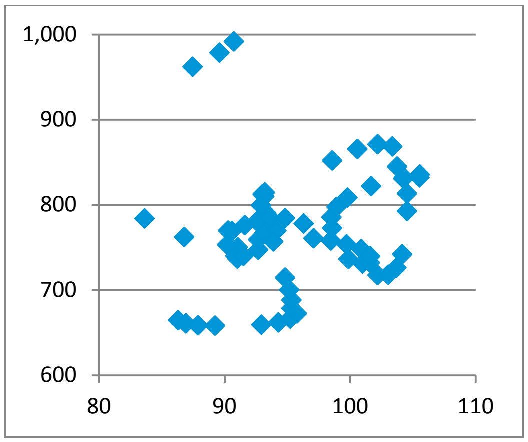
Ethane supply (trillion BTU) plotted against inorganic chemical output (2005$).



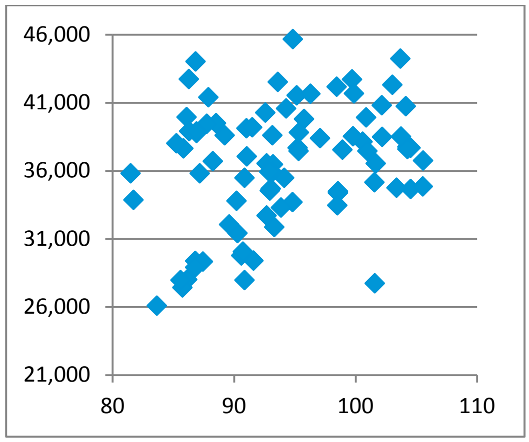
Petrochemical feedstock supply (thou. bbl) plotted against inorganic chemical output (2005$).



Ethane supply (trillion BTU) plotted against resins output (2005$).

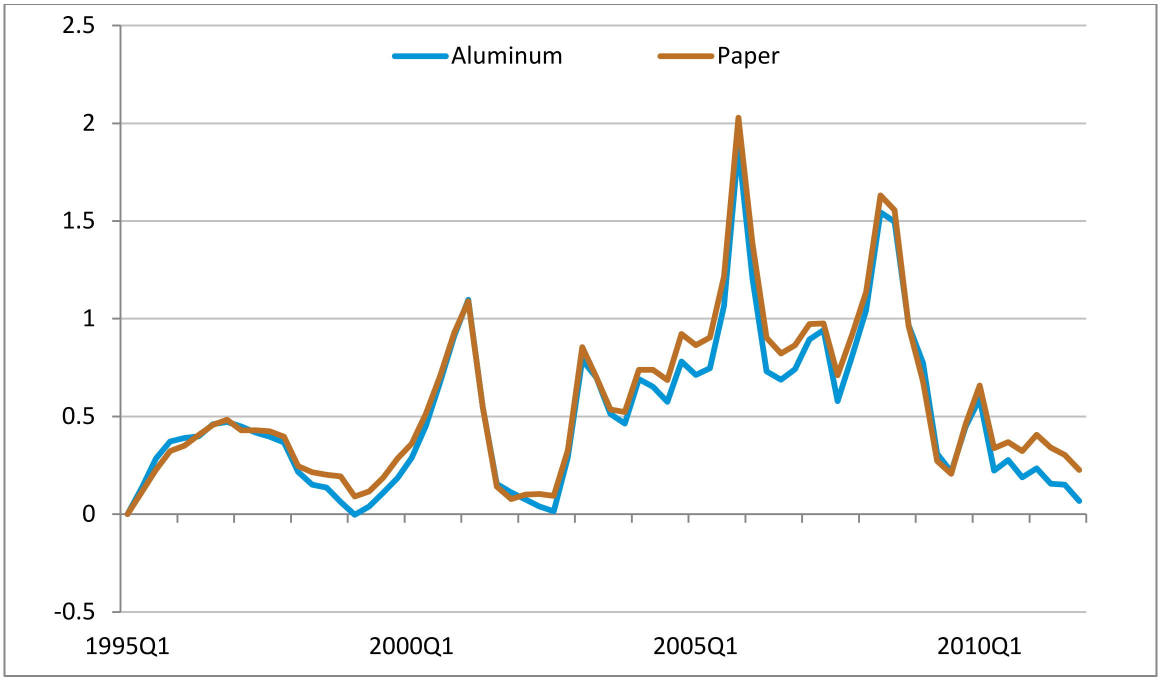


Petrochemical feedstock supply (thou. bbl) plotted against resins output (2005$).

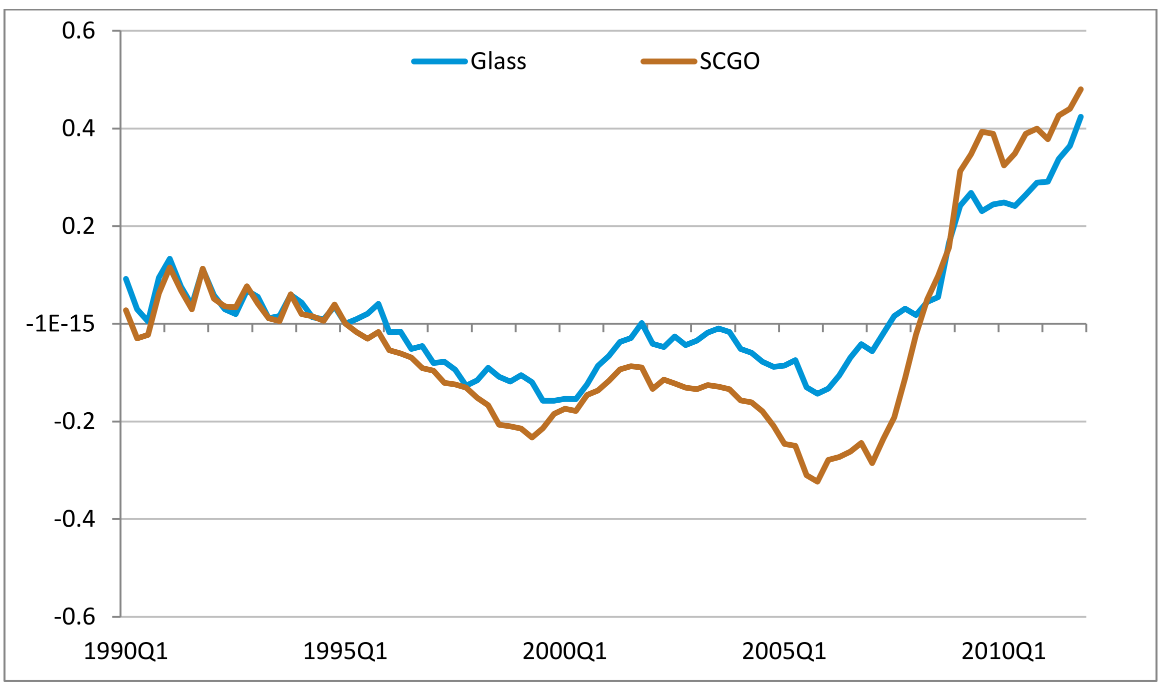


Additional delta plots (structural break plots)

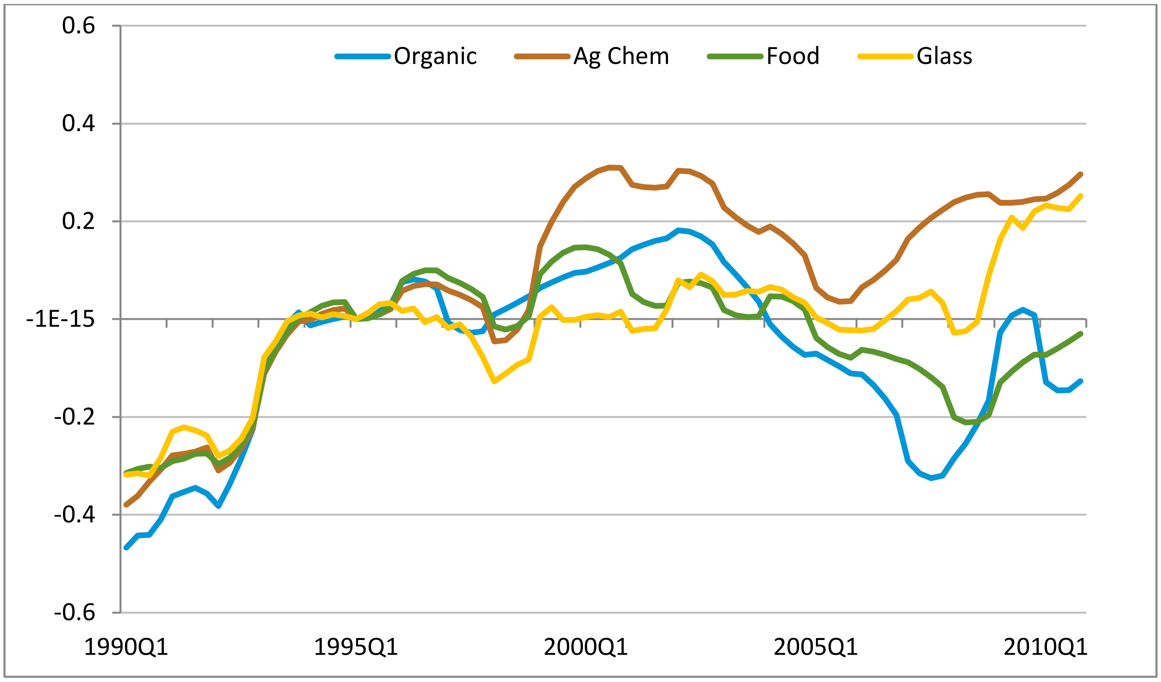
Plot of dry industrial sector NG price (real, index 1995) minus output of aluminum and paper (real, index 1995).



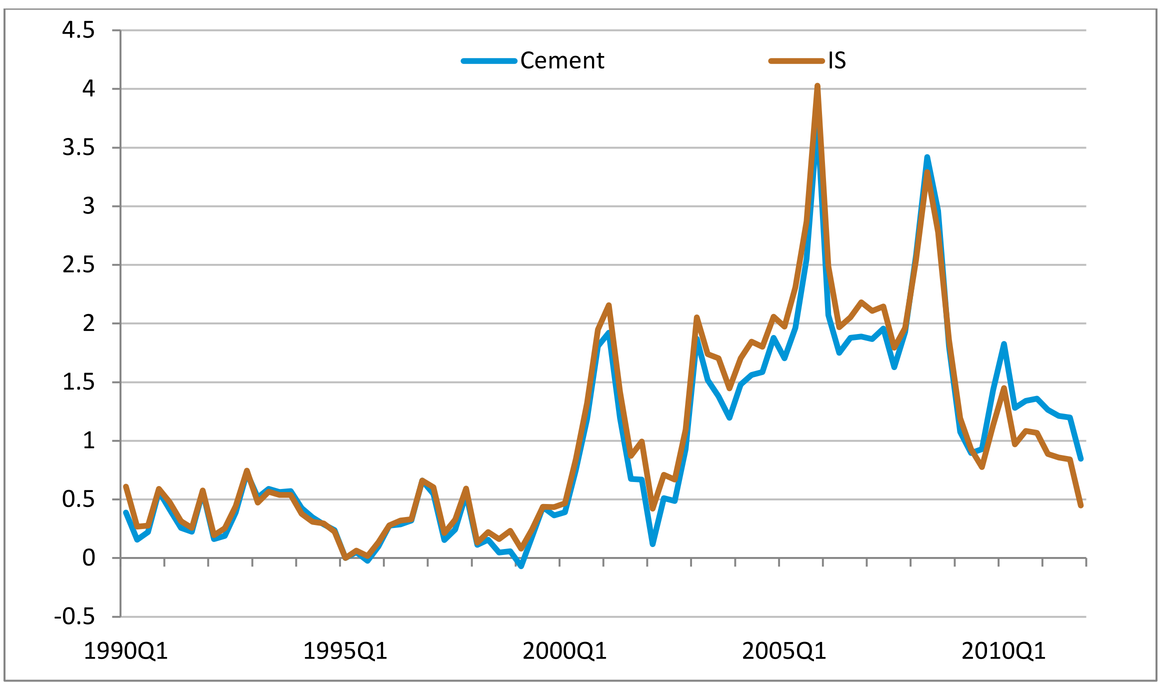
Plot of dry marketed NG production (index 1995) minus output of glass and other non-metallic minerals (real, index 1995).



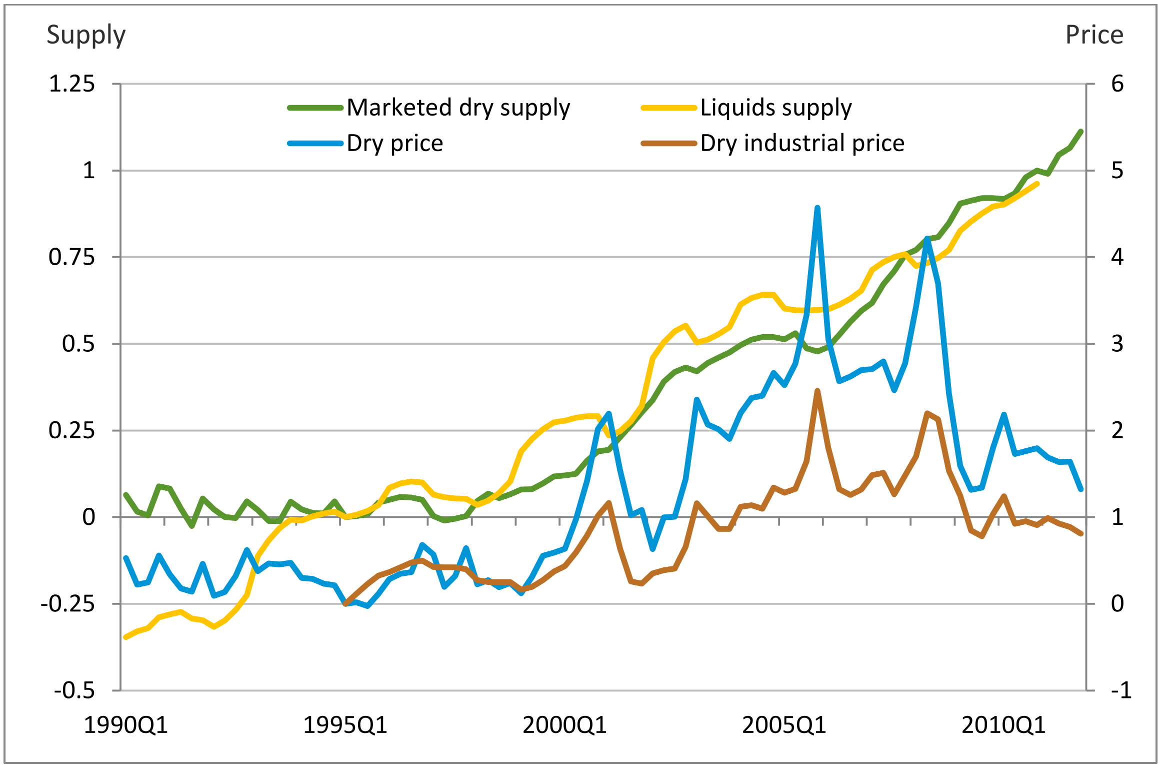
Plot of NGL and LPG supply (index 1995) minus output of organic and agricultural chemicals, food products, and glass (real, index 1995).



Plot of dry industrial sector NG price (real, index 1995) minus output of cement and iron and steel (real, index 1995).



Plot of several NG characteristics (index 1995) minus output of apparel (real, index 1995).



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