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Inflation- and Energy-Adjusted Historical Prices Reflect Disruptive Events to Global Energy Systems

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ABSTRACT

The historical prices of oil, coal, and natural gas in the United States after adjusting for energy content and inflation are computed and provided in a comparative context from 1984 to the present (August 2022). The price history reflects impacts by disruptive local or global events. Although current oil and gas prices are high, when adjusted for inflation, they are still not as high as prices experienced during the early 1980s and late 2000s. However, high global inflation rates compound other factors that are increasing energy prices now, leading to record high prices in absolute terms, and sticker shock to consumers worldwide. The recent impacts of the pandemic, Texas Freeze, and Russian invasion of mainland Ukraine are evident. Although oil and gas generally trend up or down together, they remain decoupled on an energy basis as they have been since 2006.

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INTRODUCTION

Everyday consumers are usually most directly connected to global energy systems through fuel and energy purchases, particularly electricity, heating, and transportation fuels. The actual prices paid by consumers can have major impacts on public policy, economic activity, and simply daily life. Memories are short, and it is easy to believe that things are the worst they have ever been (especially just before US midterm elections). Therefore, it is useful to look at price history to understand if the changes we have been experiencing are common or unique.

Prices reflect reality, and therefore they are useful measurements that give hints as to what is going on with the larger global energy system. By looking at prices on an inflation-adjusted and energy-adjusted basis, one can understand how changes in technology and disruptive world events impact our relationship with energy and the interactions between its different forms. One can also ascertain the relative health of our energy system from this information, and perhaps heed the warnings it might provide. Therefore, I present inflation-adjusted and energy-adjusted historical prices since 1984 are with an analysis in the context of world events and the resiliency of the larger global energy system.

METHODOLOGY

Natural Gas

Data for natural gas uses the average US Natural Gas Price at the city gate expressed in USD per thousand cubic feet published by the US Energy Information Administration in various Monthly Energy Review reports, using the most recent data set available [1]. Residential customers have typically paid about 100% to 300% more than the city gate price in the past three years, which includes delivery charges to the home and other factors. The variability in residential prices compared to city gate prices is presently the highest it has been in the past 40 years. Although wellhead prices are no longer tracked in the dataset, the city gate price historically was typically anywhere between 20 to 200% higher than the price of gas at the wellhead.

The city gate price is chosen as the representative price because it avoids the additional complications associated with contracts, transportation, and delivery to the customer, as noted by its lower volatility compared to the other two metrics. After removing the data points related to the February 2021 Texas Freeze incident, the average absolute value of the percent change in price from month to month of all data available since 1976 is only 5.7% per month for the city gate, compared to 6.3% for the wellhead and 6.8% for the residential customer after delivery. Similarly, the interquartile range (the difference between the third quartile and first quartile) of absolute percentage monthly price change for the city gate is the lowest as well at 6.0%, compared to 7.7% for the residential price.

The price per standard cubic feet was converted to price per GJ by assuming an average energy content of 1037 BTU per cubic foot of natural gas on a higher heating value (HHV) basis. The energy content can vary from this depending on the specific blend of gases that comprise it from day to day. The value chosen was approximately the average value in the US from 2015-2021 with very little variation, noting that it is slightly higher (1%) than the previous twelve years [2] due to small changes in composition.

Coal

The coal price data was sourced from the US Energy Information Administration, which was listed in USD per short ton (1 short ton = 2000 lbs ≈ 907.18 kg) for four different types of coal, including both thermal and metallurgical coals [4, 5]. Quarterly data for steam coal exports was available from 2016 and annual data for domestic coal prior to it. The price used for "coal" in this study is a weighted "basket" of steam coal prices (a.k.a. thermal coal, used for energy purposes) consisting of 75 wt% bituminous coal, 8% lignite, and 17% anthracite coals. The heating values of bituminous, lignite, and anthracite coals were assumed to be 35, 17, and 35 GJ_{HHV}/tonne (1 tonne = 1000 kg) respectively (which uses a medium-rank bituminous heating value) [6-8]. Note that heating values will vary wildly from coal to coal but variations in the numbers do not alter the interpretation of the resulting plots much.

Oil

Oil prices used in this analysis are the composite prices for the refiner's acquisition cost of crude, provided on a monthly basis in USD per barrel [1]. The composite prices reflect both domestic and imported crudes. This is appropriate because it reflects the price of the oil purchased either domestically ("first purchase price") or internationally ("free on board cost") plus transportation and other costs associated with getting the oil to the refinery. The refinery acquisition composite cost is the most appropriate for comparison to the natural gas city gate and thermal coal export prices in this context. There is no distinction in oil quality (composition, API gravity, sweetness, etc.), and so an average heating value of 6.12 GJ_{HHV} per barrel of oil equivalent is used to determine the price on an energy content basis.

Inflation

Inflation adjustments were made using the appropriate consumer price index (CPI) value for that month [3]. For reference, January 1914 had an index of 10 and the years 1982 to 1984 collectively have a CPI of 100 by definition. All US Dollar prices were adjusted to August 2022, which has an index of 296.171. The overall CPI metric is used, not energy, specifically so that the changes in energy prices compared to the rest of the economy can be easily seen. For example, the CPI for August 2022 was 8.4%, but the CPI for the Energy Commodities is a whopping 27.1% [3].

RESULTS

The resulting inflation adjusted US energy prices are shown in Figure 1, on a $USD_{August2022}$ per GJ_{HHV} basis.

Gas and Oil Remain Decoupled

Table 1: Selected inflation and energy adjusted oil and gas price relationships. R is the correlation between oil and gas prices. O–G is the average relative price premium of oil over gas. Trend Match is the percentage of months when oil and gas both moved in the same direction (+/-) compared to the previous month.

Period	R	O–G	Trend Match
1984-2005	0.786	17%	49%
1992-2005	0.828	14%	32%
2008-Aug 2022	0.583	152%	58%

As discussed in a 2015 work [9], oil and gas prices were fully coupled from 1984 (and in fact much before it) until 2006, when hurricane Katrina significantly disrupted oil networks and its price. Essentially, prior to 2006, visual inspection shows that oil and gas were very similar in price per energy content at any time. Exceptions are seen in a few places, such as from impacts on oil (and not gas) of the Persian Gulf War in August 1990, but the correlation from 1984 to 2005

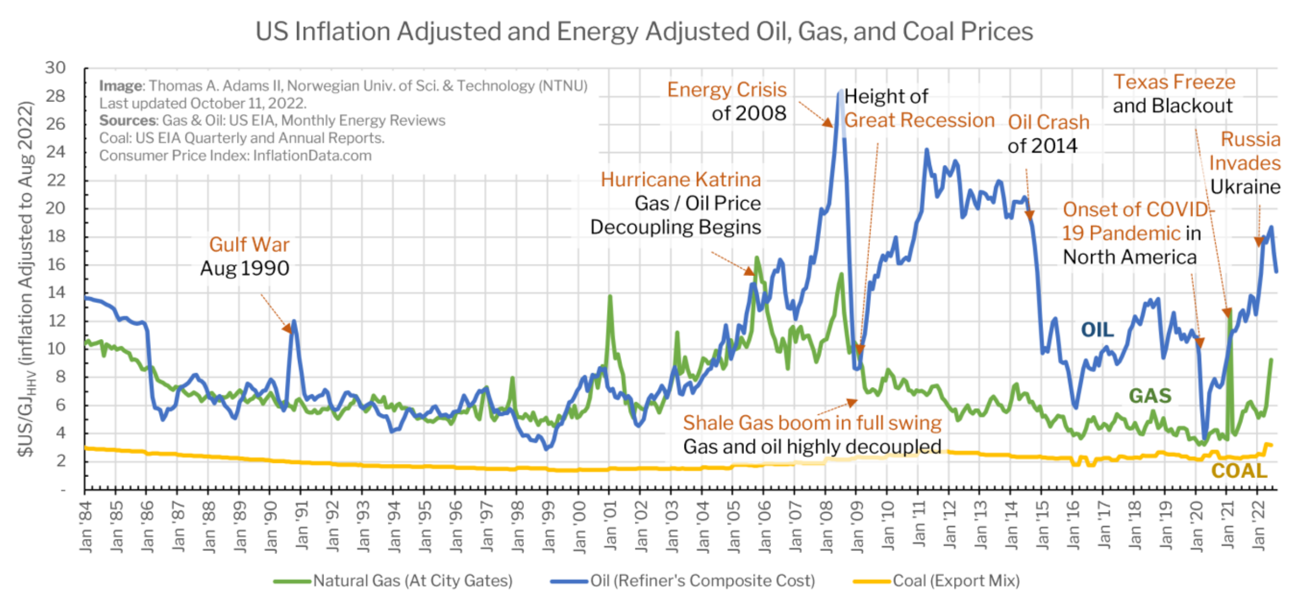

Figure 1. Comparative inflation adjusted prices of natural gas, oil, and coal in the United States. Selected disruptive events are noted. See text for methdology.

(inclusive) is a remarkable $R = 0.786$, as shown in Table 1. It was particularly highly correlated after the Persian Gulf War impacts resided (1992 to 2005 inclusive). However, after the shale gas boom takes full swing in 2008, the correlation drops precipitously—only $R = 0.583$ from 2008 to the present.

The relative price of oil to gas ("O-G") shown in Table 1 is computed as follows:

$$"O - G" = \frac{P_{oil} - P_{gas}}{P_{gas}} \quad (1)$$

where P_{oil} and P_{gas} are the inflation and energy adjusted prices of oil and gas in $USD_{Aug2002}$ per GJ_{HHV}. Prior to 2005, the oil price on an energy adjusted basis was on average roughly 17% higher than the price of gas (using the particular prices chosen), but after 2008 the oil been on average 152% higher per GJ_{HHV} than gas. Thus, the decoupling has been consistent and persistent since the shale gas boom, signaling a permanent change in global energy systems.

The "Trend Match" statistic shows the percentage of months in which oil and gas both trended in the same direction as compared to the previous month. This is interesting because when taken into comparison with R, short term and long term trends can be separated. For the highly correlated period after the Gulf War but before the shale boom (1992-2005), the trend match is low at only 32%. This can be interpreted that this period shows that generally speaking the oil and gas prices were strongly correlated at the macro or long term level, but at the micro level, they were not. Essentially, there is some market noise and other factors here which only has small impacts when comparing the two fuels. In fact, the price direction changes are likely anti-correlated, since the trend match should be 50% for completely random walks.

Contrast this with the post-shale boom period (2008-present), which has the least correlated prices, but the highest trend match at 58%. This means that although certain events might drastically change one price (but not the other) at the macro level (and then sustain it), oil and gas prices are much more correlated in the short term. In other words, they now tend more to rise and fall together in the short term, indicating that and noise or technical difference impacts on price are somewhat overcome by other day-to-day factors that impact energy more generally.

Coal's Historically Stability and Relative Cost Unchanged

Coal remains remarkably stable compared to the other two fuels, even when considering that the data are only available on annual or quarterly amounts and so short term noise cannot be seen. Coal continues to be consistently lower in cost than oil or gas on an energy and inflation adjusted basis and relatively impervious to major world events until very recently.

It is no surprise then that CO_2 emissions from coal power reached an all time global high in 2021 [10] due in large part to its availability, low price, and stability. This record high CO_2 emissions from coal is even despite efforts in North America and Europe to drastically reduce coal use, improve efficiency, and even capture CO_2 emissions in some cases. Canada for example has reduced coal power generation from 2000 to 2021 by 66%, and Europe likewise by 41% [11]. These cuts have been more than offset by growth primarily in China and India, together which are responsible for almost two thirds of the world's coal power generation. They have increased coal power production by 404% and 226% over the same period [11].

Impacts from the Pandemic

Three recent world events stand out strongly in the plot. The first is the impact of the pandemic on oil prices in North America. Billions of people across the world were either encouraged or forced to work from home or avoid travel, drastically reducing the demand for transportation fuels. The immediate plunge in oil price is evident, and it took all of 2020 to rebound to pre-pandemic levels. Headlines were made when West Texas Intermediate Futures contracts dropped below *negative* 40 USD per barrel on April 20, 2020 [12]. The demand became so low that there was insufficient storage available for upstream oil being produced, and companies had to pay to have it taken off their hands.

Gas prices in the pandemic actually increased somewhat over its February 2020 level, partly because it is not a major transportation fuel, and perhaps partly because it was needed for atypical peaking power generation uses due to drastic shifts in daily power demand cycles arising from massive changes in personal habits and behaviours.

Impacts from the Texas Freeze

The Texas Freeze impacted gas prices severely in the United States, but did not affect the other two fuels significantly. In February 14-15, 2021, an extreme cold weather event occurred (extreme for Texas that is) in which parts of urban Texas were well below freezing for days at a time, the Dallas-Fort-Worth area reaching down to −2°F (−19°C). The energy infrastructure Texas is not built for that unusual amount of cold, and nearly 49% of Texas' electricity generation capacity was knocked out at the same time at its worst moments. Controlled outages were required, and some areas were more impacted than others because of difficulties in implementing rolling outages. By 1:20 AM on the 15th emergency operations reached their highest level.

The impact on the grid was massive. Electricity prices in Texas from Feb 14-19 2021 averaged at roughly $6600 USD per MWh (the price was typically about $21 per MWh the previous winter!) and returned to normal by the Feb 20 [13]. Despite the relatively brief outage in just one US State, the country's average gas price for the whole month went up 258%. It is the biggest single month impact on gas price in both absolute and relative terms for the entire data range.

Impacts from Russia's Invasion of Ukraine

The 2022 invasion of Ukraine sparked more massive price fluctuations. Oil grew quickly over its already relatively high pre-invasion price, and gas had its third highest single month and two month percentage increases. Our Coal metric price reached an all time high (noting the annual and quarterly inflation adjusted prices used) in April 2022, shortly after the invasion. The coal price jump is significant because it reflects Europe's reliance on Russian oil and gas; prior to the invasion, the EU imported about 35% of its natural gas and about 25% of its oil from Russia [11].

Reductions in consumption of Russian imports (largely-self imposed by Europe for both punitive and other measures) caused increased demand for coal for power purposes. The subsequent impact on electricity prices is huge; electricity prices in Europe more than doubled since the invasion and are now about ten times as high as pre-pandemic prices.

CONCLUSIONS

A review of energy price history using energy adjusted and inflation-adjusted metrics is instructive because it provides important insights into the health and interconnectedness of global energy systems. Although consumers may be faced with sticker-shock at the pump, the impacts of inflation are huge at present, and so in relative historical terms the oil price is not presently the "worst" it has ever been.

What is more telling is how recent disruptive world events seem to have more of an impact on our energy systems than in the past. The three major examples of the past two years each point to individual problems with the resiliency of our global energy infrastructure. The first resulted in the historical absurdity of massively negative oil futures prices, the second resulted in the single biggest price disruption in natural gas, and the third produced highest price of coal (all since 1984 and in inflation adjusted terms).

This is a canary in the coal mine. It should be a warning that our global energy systems are quite vulnerable to disruption and are already stretched with what is a regionally limited European war. Although the way the world responded to the pandemic was a unique event, a cold weather event in a single US state and a geographically restricted war are not unique in history. They are quite likely to happen again in even more serious fashion. We need better preparedness, or we will face far worse consequences in the near future.

The solutions need to be multi-faceted, and include improved foreign energy policy, energy security, energy supply chain robustness, energy independence, and the incorporation of alternative forms of energy for transportation and use. Diversification improves resiliency, and these approaches can all be done while pursuing greenhouse gas reduction goals. These are the most urgent challenges of the energy systems engineer.

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