# Oil and other energy commodities

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**Abstract.** This chapter provides a survey of studies concerning the relationship between crude oil prices and other energy commodities such as coal and natural gas. Although such an assessment demands an interdisciplinary approach to provide readers with important background information, the approach taken here is based upon the economics of the energy market. The empirical studies summarized here can be categorized into three groups: time series studies analyzing market integration between oil and other energy commodities, studies that examine the predictive content of futures prices for energy, and the role of tail risk in explaining price volatilities of oil and other energy commodities. Several suggestions for future research are offered.

**Keywords:** Oil price, time series of energy prices, tail risk, predictive content of energy futures.

## 1. Introduction

Coal, oil, and gas have been the primary fuels of the modern industrial economy since the past 250 years. "If coal drove the industrial revolution, oil fueled the internal-combustion engine, aviation"[2] and every realm of modern life. Natural gas, due to its availability, affordability, and environmental acceptability is likely to be the most preferred fuel of the 21st century.

In recent years, prices of natural gas and coal are exhibiting similar volatility that is usually seen in crude oil prices. The main reasons behind the increased price volatility are market liberalization and greater international trade of these primary energy fuels. In that process, both natural gas and coal are increasingly exposed to the same common factors affecting crude oil prices. It's no wonder that the behavior of natural gas and coal prices are getting more like that of crude oil prices (Figures 1 and 2).

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[2] The Economist, "Special Report: Oil", November 26, 2016.

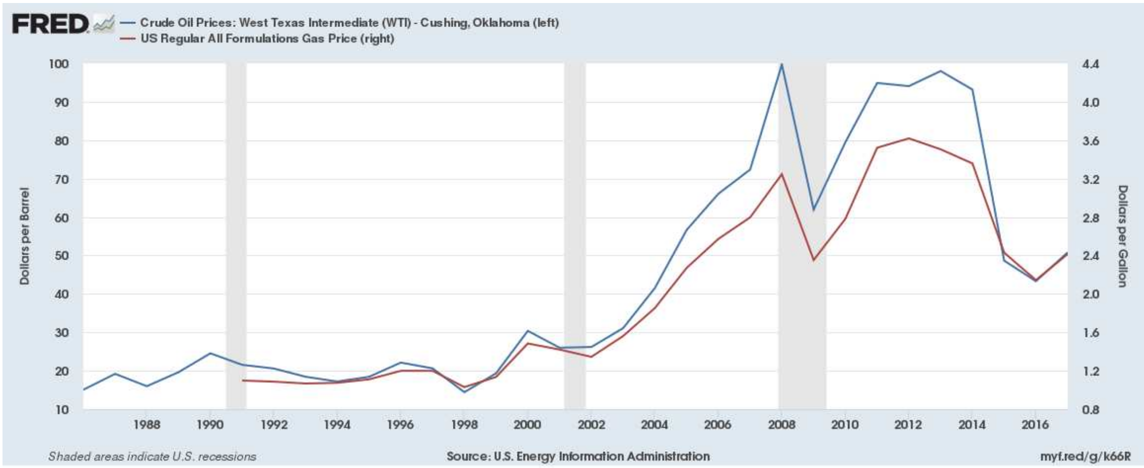



**Figure 1. Oil and gas prices**

Historically, a simple 10-to-1 and 6-to-1 rule of thumb have been used to relate natural gas prices to those for crude oil (Brown and Yücel 2008). According to this rule, a $50 WTI crude oil per barrel would mean a natural gas price of $5 per million Btu at Henry Hub. In practice, the relative price relationship is more complex is determined by a variety of demand- and supply-side factors.[3]

Despite being a highly polluting fuel (relative to natural gas), coal still accounts for roughly one-third of global energy and makes up 40% of electricity generation. The price of coal follows a cycle like oil even though their demand and supply are affected by different dynamics. Since 2010, both coal and oil prices have been falling roughly in tandem and the common factor behind this price decline is a massive production of the US shale gas.

[3] For instance, the price ratio of natural gas to crude oil fluctuated from almost 6 in December 2008 to 36 in September 2009 before falling to 21 by the end of 2010 (Ramberg and Parsons 2012).

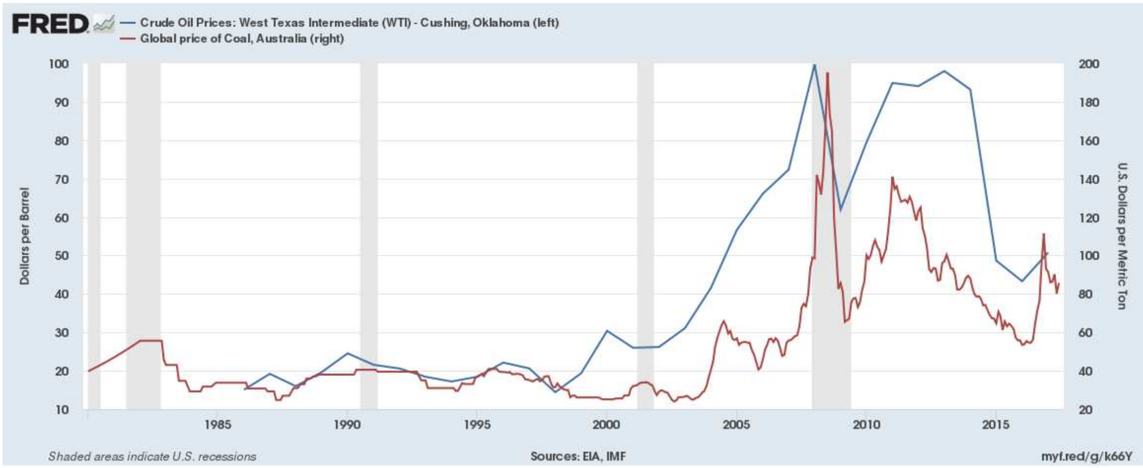
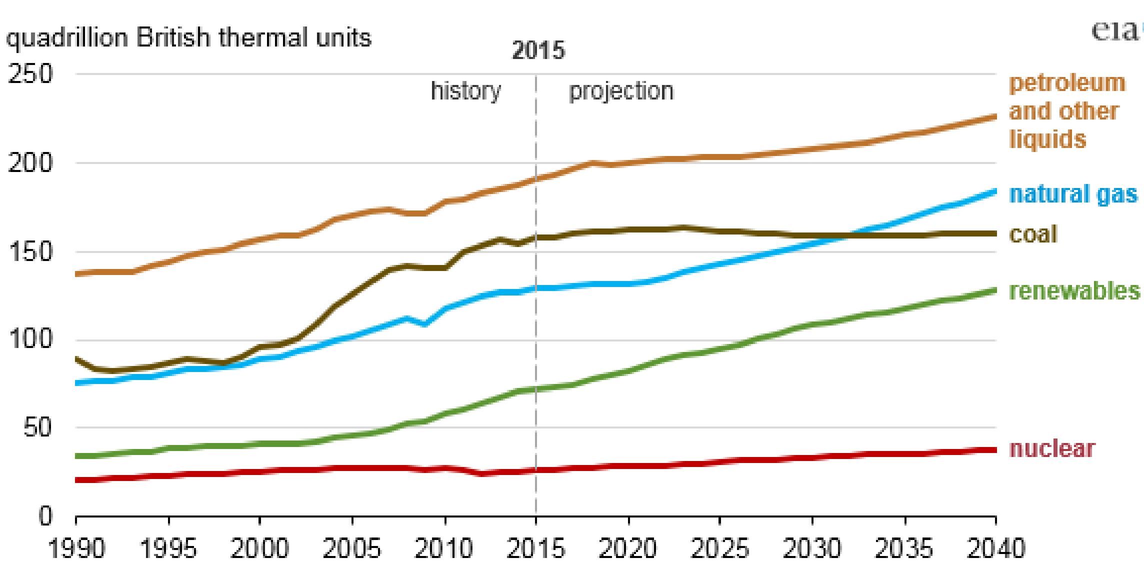



**Figure 2. Oil and coal prices**

Regardless of all the environmental concerns with using fossil fuels, the world has been consuming more fossil fuels and global energy appetite is projected to grow by 28% between 2015 and 2040 (Figure 3). Driven by strong economic growth, most of the demand for fossil fuel is expected to come from Asia, especially China and India.

While direct competition and substitution between these primary fuels are somewhat limited in the short-term, depending on their respective costs of conversion technologies, they may become a much closer economic substitute in the long-term (Bachmeier and Griffin 2006). Oil can always replace gas, depends if we accept a higher $CO_2$ emission factor. Both oil and coal are easy to transport and store, compared to gas which has the lowest energy density.



Source: U.S. Energy Information Administration, International Energy Outlook 2017

**Figure 3. World energy consumption by energy source**

Recognizing the crucial importance of the three fossil fuels to the economy, over the past decades a large number of papers have been written on oil prices and other energy commodities. The goal of this chapter is to summarize the recent empirical literature on the relationship between oil price and other energy commodities. These studies are categorized into three groups. The first group of studies examines market integration among fossil fuels, primarily in the context of the United States. The second group of studies examines the predictive content of futures energy prices in forecasting spot prices, while the final set of studies look at the role of tail risk in energy commodities.

## 2. The interaction between crude oil and other energy commodity prices

There is no better way to understand the complex interaction among crude oil, natural gas, and coal prices than to analyze the power generation industry, which simultaneously uses all three fuels to generate electricity. And nowhere the story gets more interesting than the United States where the forces of regulation, technology, market forces provide an intriguing narrative.

Unlike industrial use, consumers' relationship with these primary fossil fuels is rather inflexible. Consumers drive cars that run on petroleum and heat their houses with natural gas. No matter how volatile prices are, fuel switching between oil and gas is not a practical option for the consumer because of high adjustment costs. Whereas, direct use of coal as a fuel is limited to cooking and heating in some parts of the world.

During the late 1960s, there was a sign of growing concerns about emissions from coal-fired power plants in the United States. On November 25, 1966, the front page of the New York Times featured an image of the New York City engulfed in high levels of smoke and haze. In fact, the air was so filthy that one resident of New York City quipped: "I not only saw the pollution, I wiped it off my windowsills," (Dwyer, 2017). Meanwhile, increasing oil production along with low and stable crude oil prices during the 1960s was the catalyst for many to shift from coal- to petroleum-fired power plants. By the early 1970s, the share of oil in electric power generation culminated to around 20 percent, the highest share ever (Figure 4). However, the two great oil shocks in 1973-74 and 1979 have eliminated the cost advantage and oil was virtually banished from power production (Figure 4). Furthermore, the Powerplant and Industrial Fuel Use Act of 1978 (PIFUA) had simultaneously restricted the construction of new petroleum and gas power plants and encouraged the construction of new coal-based power plants. As a result, during the 1980s—when global crude oil prices were on a downhill especially in the second half of 1980s—coal's share in power generation expanded (Figure 4).

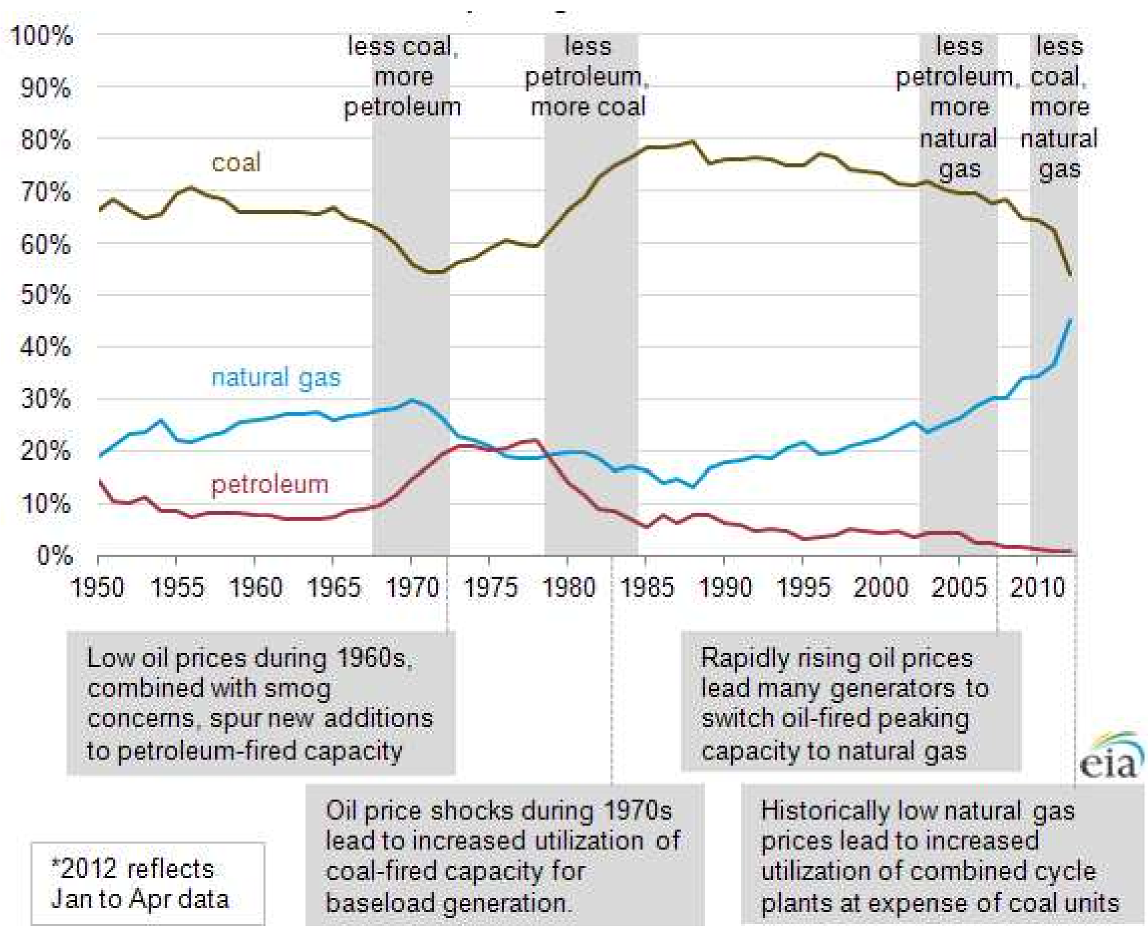



**Figure 4. Annual share of fossil-fired electric power generation**

A combination of factors has led to a sudden and welcome change in the power sector. First, the PIFUA was repealed in 1987 by President Ronald Regan to pave the way for America's energy independence and energy security. Second, by the early 1990s, the natural gas market in the United States (as well as the United Kingdom) was fully deregulated allowing fuel substitution between petroleum and natural gas as a fuel for peaking generation. Higher profit margin driven by the availability of tax credits, in conjunction with the increased use of efficient combined cycle technology for power production, was responsible for much of the growth of the natural gas produced in the United States during the 1990s. Fast forward to the 2000s, the rapid rise of domestic shale gas production has not only contributed to a relatively sustained period of low natural gas prices, but it has also further encouraged power plant operators to use more combined-cycle units by gradually displacing coal generation (Figure 4).

The basic mechanism underlying the interaction between oil and gas can be traced through both demand- and supply-side channels.[4] The demand side channel concerns to what extent (or how easily) energy consumers can switch to natural gas when, say, the price of oil increases. One way to examine this is by estimating the value of elasticity of substitution. For the United States, the EIA's (2012) estimate of oil-gas elasticity is 1.89, which reflects plant operators' flexibility to choose the most economic fuel and the fact that some combustion turbine and combined-cycle units are designed to run on either petroleum or natural gas. In contrast, the estimated oil-coal elasticity is -0.63, indicating that the two fuels are complements rather than substitutes. Based on a meta-analysis of 47 studies, Stern (2012) finds that compared to the United States the extent of interfuel substitution is higher in India, Korea, Italy, the Netherlands, and Germany. Particularly, for the industrial sector, the estimated elasticities for coal-oil, oil-gas, oil-electricity[5], and gas-electricity are significantly greater than unity, which Stern (2012) considers as good news for climate mitigation policies concerning replacing dirty fuels (e.g. coal) with relatively cleaner fuels (e.g. gas).

On the supply side, a higher price, say, encourages more drilling which in turn increases production of associated or dissolved gas, that comes along as a basically free byproduct when petroleum is produced. In fact, the production of associated gas has become so prominent in the United States in recent years that it triggered an inverse relationship between oil and natural gas prices (Clemente, 2018).[6] Furthermore, a higher oil price may lead to a competition for the resource in the sense that skilled labors and drilling equipment are redirected from gas to oil sector due to price differential and increased level of activity.

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[4] See Villar and Joutz (2006) for a discussion of demand and supply side factors linking crude oil and natural gas prices.

[5] Electricity is considered an alternative fuel and can be produced from a variety of energy sources including oil, coal, natural gas, nuclear energy, hydropower, wind energy, solar energy, and stored hydrogen.

[6] In addition, the increasing availability of liquified natural gas (LNG), in conjunction with growing spot gas trading, has contributed to the recent decoupling of gas price from oil price.

A better way to understand substitutability or complementariness among fuels is by looking at the sources and usage of fuels. Figure 5 shows the primary energy sources and their consuming sectors in 2017 in the United States. As can be seen, in both the transportation and residential sectors, the extent of fuel overlapping is marginal. Only in the industrial and electric power sectors, there is an opportunity for fuel substitutability.

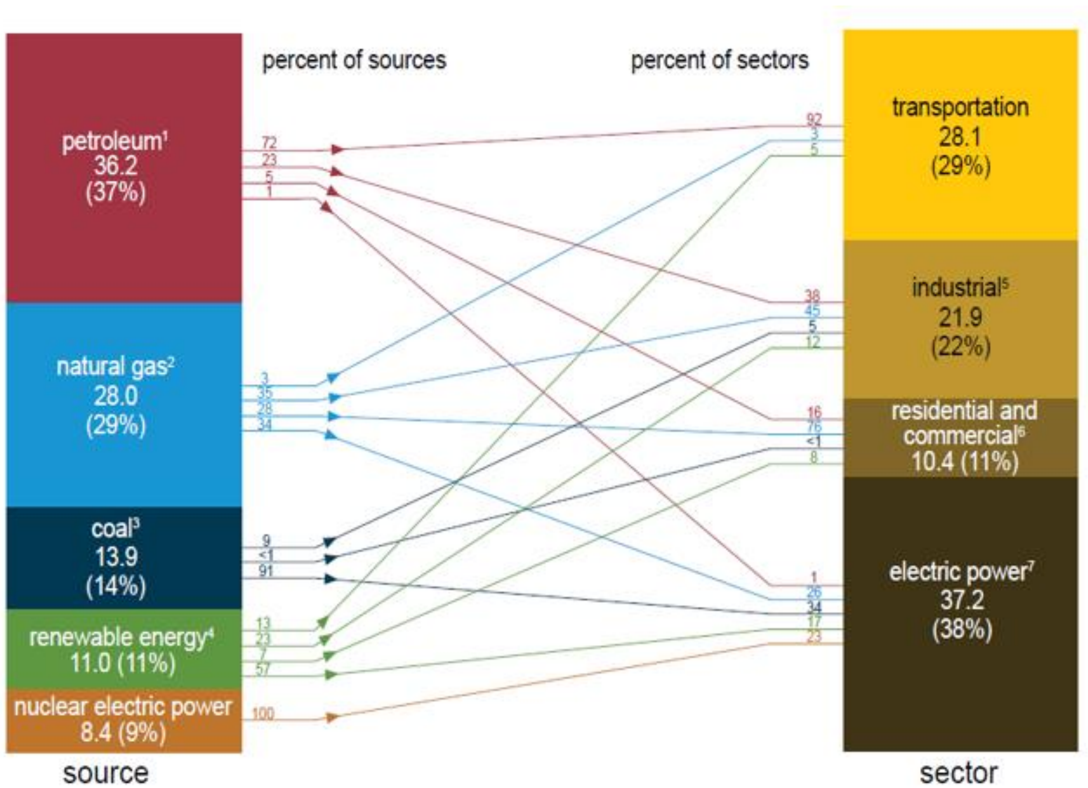


**Figure 5. U.S. primary energy consumption by source and sector, 2017**

Source: EIA. Total = 97.7 quadrillion British thermal unit (Btu)

## 3. Empirical evidence

### 3.1 Market integration

In empirical research, due to the nonstationarity of energy prices, the most common and preferred way to study the integration among oil, gas and coal markets is by means of time series methods. Thanks to the availability of energy prices at a higher frequency, several studies have used cointegration and error correction techniques to quantify the short- and long-run relationship among prices of fossil fuels. Particularly, cointegration is widely used as a method for testing market integration.

Bachmeier and Griffin (2006) apply error correction model to test market integration both within and between crude oil, coal and natural gas markets. The within market integration in crude oil and coal is quite strong, but market integration between the three primary energy fuels is rather weak. Villar and Joutz (2006) find that the WTI oil price and Henry Hub gas price are cointegrated around a time trend over the period 1989-2005. The statistical significance of the coefficient of time trend suggests that, following a shock, natural gas price grows faster to narrow the gap with crude oil prices. Baffes (2007) finds that out of 35 internationally traded primary commodities, the pass-through of crude oil prices to natural gas was highest with an estimated elasticity of 0.64.

Hartley et al. (2008) derive several interesting results from their empirical study. Unlike previous studies that document a direct relationship between crude oil and natural gas prices, Hartley et al. find that oil prices affect natural gas prices via an indirect route, the residual fuel oil (or heavy fuel oil). This is not surprising since for many years industries and electric power plants in the United States have treated natural gas and residual fuel oil as close substitutes, using whichever fuel was less expensive (Brown and Yücel 2008). Another way of interpreting this result is that both the U.S. natural gas and residual oil prices respond to the changes in international crude oil price, but not the other way around.

Brown and Yücel (2008) fill a gap in the literature by examining how the relationship between natural gas and crude oil change when external factors such as weather, inventories and disruptions to production are considered. Despite the strong relationship between crude oil and natural gas, both energy prices have considerable independent movement. They find that the prices of both natural gas and crude oil are cointegrated and the causality is running from oil to natural gas prices. The results of the error correction models reveal that when natural gas prices deviate from the long-run equilibrium relationship with crude oil, natural gas prices adjust by roughly 6 percent a week to close the gap between the two. The rate of adjustment is doubled (12 percent per week) when the external factors are included in the analysis. The short-term dynamics of natural gas prices are driven by a variety of transitory and other exogenous factors, while in the long-term the history of natural gas prices contributes to its motion.

However, Ramberg and Persons (2012) have shown that the cointegrating relationship between crude oil and natural gas prices has changed over time. Put another way, the historical relationship documented in earlier studies cannot be used as a reliable predictor of the natural gas prices, at least in the longer horizon. One possible explanation for the shifting long-run equilibrium relationships between crude oil and natural gas prices is the improvement of technology in horizontal drilling and hydraulic fracturing to makes it possible to extract shale gas at a relatively low cost.

In conventional time series methods such as cointegration, the frequency and time components of economic series are analyzed separately. Time-frequency techniques such as wavelet analysis study overcome this limitation by studying the frequency components of time series without losing the time information. Vacha and Barunik (2012) apply the wavelet method to analyze co-movement among four energy variables (crude oil, gasoline, heating oil, and natural gas). Their results suggest that while heating oil, gasoline, and crude oil strongly comove, natural gas is unrelated to the three commodities. From the investment perspective, this finding implies incorporating natural gas in a well-diversified commodity portfolio.

### 3.2 The predictive content of energy futures

Energy prices, especially oil price, have a historical relationship with macroeconomic fluctuations. Hamilton (2001) pointed out that 10 of the 11 postwar recessions in the United States have been preceded by a sharp increase in oil price. Recognizing this relationship, Chinn et al. (2005) examine whether futures prices are unbiased and/or accurate predictors of subsequent spot prices in the markets for crude oil, natural gas, gasoline, and heating oil. In so doing, Chinn et al. consider the following regression specification:

$$s_t - s_{t-1} = \alpha + \beta\left(f_{t,t-k} - s_{t-k}\right) + \varepsilon_t \qquad (1)$$

where the left-hand side of (1) is the change in the spot rate and the term in parentheses on the right-hand side is called the “basis” in the commodity futures literature. The composite null hypothesis is $\alpha = 0$ and $\beta = 1$, where a rejection implies the rejection of the joint hypothesis of market efficiency and unbiased expectations.

Chinn et al. find that only for natural gas, futures prices have some ability to predict future spot prices, especially at the longer horizon (12 months). This result seems a bit surprising given the very high comovement among the prices of different energy products. In a subsequent study, Chinn and Coibion (2013) use a regression like equation (1) and find that by exploiting information from heating oil and natural gas, one can anticipate a larger fraction of ex-post oil price changes. Their results suggest that oil futures prices do not only fail to predict its own ex-post price changes but also prices of other commodities. Moreover, since the mid-2000s the effectiveness of the predictive content of energy (and commodity) futures has sharply reduced.

In a recent paper, Jin (2016) proposed a future-based unobserved components forecasting model of crude oil price that utilizes the term structure of the future prices as additional regressors. Compared to Chinn and Coibion (2013), Jin's (2016) model provides better forecasts of oil price due to the latter's more granular assessment of the changing short-term component volatility or the changing market conditions.

### 3.3 Tail risk

Since the 2007-08 global financial crisis, 'tail risk' has become a buzzword among commodity traders and investors in energy markets. Tail risk is a low probability event that has an outsize impact on prices. Event such as the eurozone sovereign debt crisis, tsunami in Japan, the Federal Reserve's possible tapering of asset purchases and unrest in the Middle East caught many investors by surprise and the belated realization that safeguarding their portfolios against such events (both large and small) must become a more integral part of their investment strategy (The Economist 2012). Indeed, the survey of institutional investors shows that not only they routinely underestimate tail risk events, but the commonly used volatility-based risk management tools such as value-at-risk (VaR) also produce artificially depressed volatilities (The Economist 2012, Grepin et al. 2010).[7]

There is a growing body of empirical work[8] analyzing the impact of tail risk on asset market, but relatively few studies on the role of tail risk in explaining oil price volatility. The main reason for focusing on tail risk is to gauge the forecasting power of future asset returns that is not contained in traditional asset price predictors. Ellwanger (2017) finds that the tail risk measures

[7] Some estimates reckon that if Israel attacks Iran, a rather low probability event, it could push oil prices temporarily towards $250 a barrel (Blas, 2011). A crisis like that would not only affect oil prices, but also natural gas and coal prices, and even the cost of agriculture raw materials where oil is used as an input.
[8] See Kelly and Jiang (2014) and the references cited therein.

have strong predictability for crude oil futures and spot returns. Furthermore, the option-implied tail risk premia convey important information on price dynamics of crude oil than traditional macroeconomic and oil market uncertainty measures.

Ewing et al. (2002) find that volatility in the natural gas market is indirectly affected by events originating in the oil sector. However, their results also show that a change in volatility in natural gas returns affects the volatility in oil returns (with a lag), implying that options traders in oil market may benefit by keeping a close eye on events in the natural gas market. On the other hand, based on daily natural gas and crude oil futures price data, Pindyck (2004) found that crude oil volatility has significant predictive power with respect to natural gas volatility but not the other way around. Unlike Ewing et al. (2002), Pindyck found volatility persistent to be short-lived, implying that fluctuations in volatility are unlikely to impact the value of real options in oil- or gas-related investment.

Besides exerting a direct effect in the form of higher gasoline prices, unanticipated oil price shocks affect expectations about the future path of the price of oil which in turn feed into the calculations of the net present value of investment decision (Baumeister and Kilian 2016). A case in point is shale gas production in the US, which requires a crude oil price of $60 a barrel for shale gas to be economically viable. Hence, when oil price is rising, the shale gas sector attracts more investment than expected, whereas the momentum quickly turns reverse when oil price collapses.

The 2018 US-China trade war is yet another sign of how a dramatic shock in oil market could spillover into other energy commodities. Following the US's duties on Chinese imports, China is contemplating to impose a 25% tariff on crude oil and other energy commodities (Kumon 2018). However, China is not banning import of US LNG, which is seen vital to the country's shift away from coal as it fights deteriorating air pollution. At the same time, China is considering importing more gas from the Middle East is rising.

## 4. Discussion and conclusions

Oil shaped the 20th century through wars and prosperity. Against many predictions that the influence of crude oil would wane as new supplies and sources of energy become abundant, oil's dominance remains entrenched at least in the first half of the 21st century. A primary reason for this is the extremely slow process of changing the global fuel mix toward more cleaner energy sources. The most likely outcome for oil in the coming decades is a long plateau, rather than a sharp decline.

Despite the vast literature on the nexus between oil prices and other energy commodities, there is much room for future research. First, as the supply of natural gas becomes abundant and stable, will gas follow oil to become a liquid global market with growing disconnection from oil production and prices? Second, what if citizens of richer countries decide to stop buying oil from countries with highly repressive governments such as Saudi Arabia and Venezuela? What would be the potential impacts of such a low probability event on oil price and the resulting spillover into other energy commodities? Third, compared to about 40 years in the US, the average age of the coal plants in Asia in only 11 years.[9] Given a lifetime of 50 years, there is still plenty of coal to be burnt in Asia. As gas price is rising in response to increasing demand in Asia, how will China and India trade-off the use of coal and gas in their energy mix will be a very important topic of discussing in the decades ahead? Finally, it is still not clear why the predictive content of futures prices has become less important for subsequent price changes of energy products, and whether incorporating a richer dynamic specification of the spot and futures prices would yield superior forecasts.

As public policymakers and business professionals closely track the commodity prices, the erosion of the predictive content of future prices is a matter of serious concern across all policy areas. Furthermore, the weakening and changing equilibrium relationship between crude oil and natural gas prices, as documented by numerous time series studies, is potentially making the task of managing energy price volatility even more difficult.

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