The Stability of Energy Prices in the New Decade: The Case of European and US Oil and Natural Gas Prices

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Abstract

This paper investigates changes in stability of energy prices, and the consequences of instability on hedging energy price risk exposure. A period of economic recession and expanding energy supply from the shale oil and natural gas revolution has transformed energy markets. We provide evidence that in the current regime, oil and natural gas prices in Europe and the US has become unstable. Short run volatility in price spreads is lower, but the persistence in deviations from mean spreads has increased. This is consistent with previous findings on increased energy market segmentation, especially between the US and rest of the world. We show that the reduced stability has important consequences for energy risk exposure and price hedging opportunities, with reduced ability to hedge long-run energy price risk within the energy markets.

Keywords: Price Risk, Energy, Price Stability, Market Integration

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1. Introduction

Before the financial crisis, energy demand growth outpaced new supply sources, and energy prices soared. The economic boom originating from Chinese growth contributed to high demand for commodities in general (Kilian, 2009; Killian and Murphy, 2014). Current energy markets face substantially different conditions, with weaker aggregate energy demand growth and expansion in supply of oil and natural gas due to the shale revolution. In the US, the combined use of hydraulic fracking and horizontal drilling allowed the recovery of shale petroleum resources at significantly reduced cost. Lack of sufficient export capacity and regulatory issues has depressed US natural gas and oil and created more fragmented energy markets. The segmentation has been reinforced by strong demand for natural gas in Japan following the Fukushima accident in 2011, and in Europe following policies to phase out nuclear power generation.

In this paper, we will investigate the consequence of these market changes on the stability of energy prices and the ability to hedge exposure to energy price risk. We will look at two important oil price indices (the West Texas Intermediate and Brent crude prices) and two natural gas prices (the UK NBP and the US Henry Hub prices). This allows us to compare stability in prices between two important markets, and two important energy carriers. Our results show that stability in energy prices (across products and markets) is weaker now than before the financial crisis. Short run volatility in price spreads is lower, but shocks to the spreads are substantially more persistent. Weaker stability between energy prices means the ability to hedge long run energy price risk within energy markets is more difficult. When two energy prices are stable, their long-run returns are proportional to each other, and it is possible to eliminate all long-run risk by a short exposure in one of the prices. Prior to 2010, any two energy price pairs we examine had the ability to achieve this. This is no longer the case. Segmentation has led to idiosyncratic risk factors in energy prices making price risk management more difficult, something we will highlight in a hedging example later in the paper.

Our analysis relates to a large existing literature on energy price relationships and price volatility. Our finding of reduced stability after 2009 is consistent with previous findings. Erdős (2012) and Oglend et al. (2015) document that the shale gas expansion in the US manifested as a divergence between the US Henry Hub natural gas price and the oil prices around 2009. Oglend et al. (2015) further show that this transmitted to reduced stability between oil prices and related liquefied petroleum gas products (propane and butane). Kilian (2016) document a fragmenting of US oil markets (specifically between low and high quality oil) from 2010, and a segmentation of the US market from the global oil market in from around 2011.

Oil and natural gas are both carriers of energy, and energy sources can be substituted in order to utilize the most cost-efficient alternative (Asche et al. 2002; Asche et al, 2006; Panagiotidis and Rutledge, 2007; Asche et al, 2016). Energy parity suggests that prices should form a stable long run relationship with one barrel of oil trading at approximately 5.8 times the price of one MMBtu of natural gas. Historically, due to existing usage and infrastructure, the oil-to-gas spread has traded at 10 MMBtu of gas to 1 barrel of oil, known as the 10-to-1 rule of thumb. Lack of parity can also emerge due to constraints in markets leading to segmentation. Oil export restrictions from the US has depressed US oil prices relative to the global benchmark (Brent), and lack of pipeline and LNG liquefaction capacity has led to divergence in US natural gas prices.

Prices of oil and gas can affect macroeconomic variables, although the size and direction of this relationship is not yet clear. In his seminal paper, Hamilton (1983) provides evidence that all, except one, US recession can be explained by a sudden shock to the oil price and increased oil price variability. In a later study, Hamilton (2011) finds more evidence for this relationship. Bernanke (1983), Pindyck (1991) and Elder and Serletis (2010) argue that increased uncertainty in oil price may lead to a lower economic activity, as the uncertainty adds incentives to postpone investment for both producers and consumers of petroleum energy. This is confirmed in a recent paper by Ringlund et al. (2008) showing how rig activities drops due to oil price shocks and by Kellogg (2014) who shows how Texas oil producers reduce investments in periods of high price volatility. Moreover, Pinno and Serletis (2013), find that oil price volatility has a substantially impact for a set of industries on an aggregated level. Finally, Papapetrou (2001) links oil price volatility to stock returns and Ferderer (1996) to interest rates.

When energy prices form a stable relationship, the markets work essentially as a single market for energy. For instance, exposure to European oil markets would face similar risk as an exposure to European natural gas markets, or US oil markets. Expected price returns and long-run risks are equivalent. We can then talk about a common energy price risk factor. Furthermore, this long run risk can be hedged against within the energy sector given one can gain short exposure to one of the energy commodities. This was largely the case prior to 2010 for US and European oil and natural gas. As we provide evidence for in this paper, these energy prices currently appear to contain substantial individual idiosyncratic risk, making hedging activities more difficult.

The rest of this paper is structured as follows. We start by providing some figures and descriptive statistics for our price data to highlight some of the changes in energy price characteristics. We then proceed to a formal analysis of the stability in energy prices, where we define and test stability within a market integration framework. We then proceed to show by a simple hedging example the consequences of our findings for exposure to energy price risk. Finally, we provide some concluding remarks.

2. Preliminary Data Description and Analysis

Energy markets are complex, consisting of a multitude of energy carriers and derived products (i.e. oil, natural gas, coal, heating oil, propane, butane etc.), trading in different markets with different characteristics. Natural gas in continental Europe, and liquefied natural gas (LNG) in Asia, is often traded on long-term contracts indexed to a mix of petroleum product prices, including crude oil. Asian contracts normally have a three to six month lag with the oil price, while the European contracts have a six to nine months lag with crude and fuel oil. In Japan in 2013, 73% of LNG trade took place under LTCs (Agerton, 2014). Oil indexation explains in part why natural gas prices in Europe and Asia are integrated with oil prices (Asche et al., 2001; Asche et al., 2002; Asche et al., 2006; Siliverstovs et al., 2005; Panagiotidis and Rutledge, 2007). In the US, gas-to-gas competition is stronger than in Asia and Europe, and the relationship between oil and natural gas prices is generally found to be weaker (Villar and Joutz, 2006; Parsons and Ramberg, 2012). These differences in the US and rest of the world energy markets has been accentuated by the shale oil and natural gas revolution, creating more segmented markets.

For our analysis, we will use Brent (North Sea) and WTI (US) oil price indices, and UK (National Balancing Point, NBP) and US (Henry Hub) natural gas prices. These prices reflect liquid energy markets, and contain important information on supply/demand conditions for energy. Our data set consists of daily observations of spot prices from 01.01.1997 to 31.12.2015, in total 4957 observations for each price series. We start by transforming prices to an energy equivalence basis ($/MMBtu), and compare the development of the price of energy over time. This is shown in Figure 1.

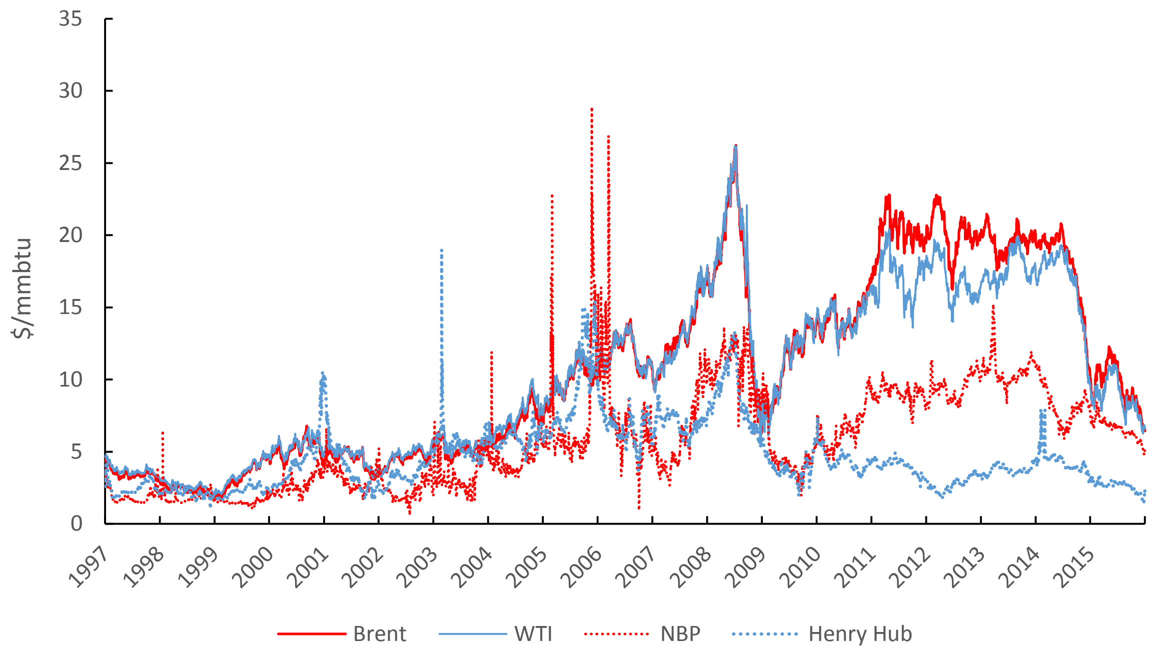

Figure 1. Price of Energy, Oil and Natural Gas in US and Europe

What is immediately clear from the figure is the substantial deviation in prices starting at around 2009/2010, and partly reversed following the recent large drop in the oil prices. We will be primarily concerned with the stability in these energy prices, and so figure 2 plots the log of relative prices (the log of price ratios) over the same period.

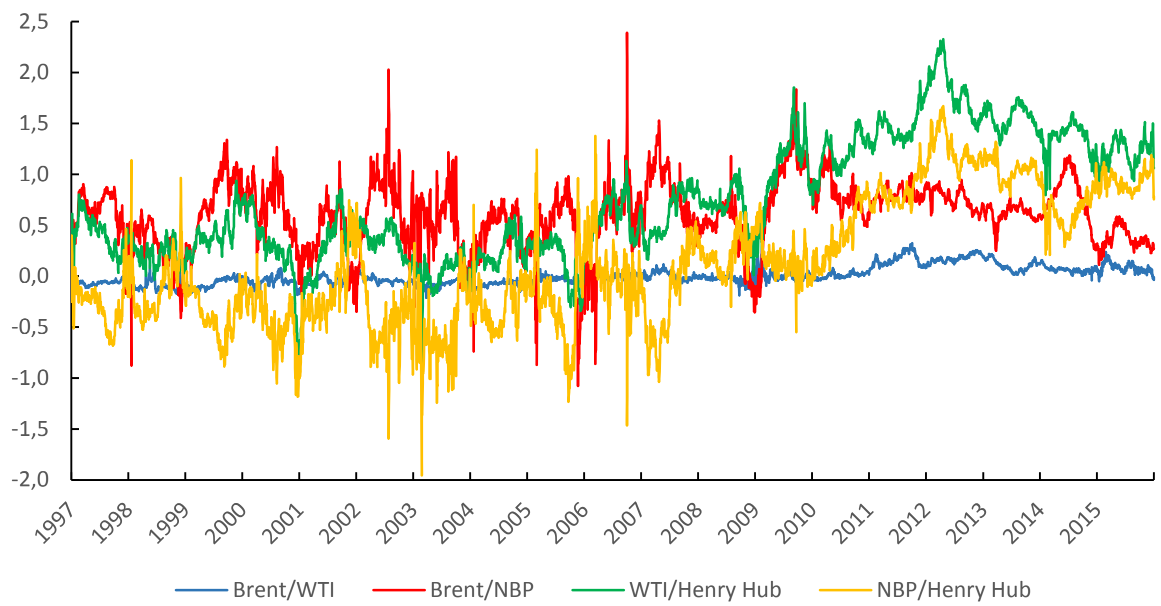

Figure 2. Log of relative energy prices, Oil and Natural Gas in US and Europe.

The figure gives a visual impression of the change in price stability. Prior to around 2010, there is substantial short-run volatility in price spreads, but with less persistent deviation in the prices of energy. The Brent/WTI spread is especially stable prior to 2010. After 2010, we see lower short run volatility but more persistent deviations. For natural gas, there is less pronounced price spiking after 2010. These spikes are primarily related to periods of strong demand (normally for heating during cold winter days) and limited short-run supply capability, leading to peak-load pricing. With greater abundance of natural gas in the market, such price spikes will occur less frequently (Oglend et al, 2016).

Table 1 provides some descriptive statistics of the data. We split the sample at the end of 2009 to compare characteristics over the two periods of interest.

Table 1. Descriptive Statistics

	1997-2009				2010-2015			
	Vol.	Pers.	ADF Level	ADF 1st Diff.	Vol.	Pers.	ADF Level	ADF 1st Diff.
Brent	0.0237	0.9968	-0.867	-59.04**	0.0161	0.9949	1.185	-37.15**
WTI	0.0261	0.9909	-0.856	-19.27**	0.0197	0.9732	0.2397	-11.91**
NBP	0.0999	0.9685	-2.218	-19.00**	0.0287	0.9770	-1.796	-16.36* *
HH.	0.0461	0.9861	-2.244	-15.46**	0.0348	0.9738	-2.056	-11.22**
Brent/WTI	0.0504	0.9136	-4.584**	-	0.0743	0.9591	-2.546	-
Brent/NBP	0.3643	0.9366	-4.590**	-	0.2119	0.9585	-2.065	-
WTI/HH.	0.3394	0.9602	-3.415*	-	0.2727	0.9655	-2.498	-
NBP/HH.	0.3728	0.9366	-4.855**	-	0.3214	0.9565	-3.115*	-

Note: Vol. measure the standard deviation in log daily returns. Pers. measures the unconditional probability of a given data series not crossing its mean in a given period. The ADF test is the Augmented Dickey Fuller test for a null of unit root. * indicates rejection at 1% critical value, ** at 5% critical value.

We will look at both the prices individually, and the log relative prices (the data shown in figures 1 and 2). The table reports short-run volatility (log of daily returns) and a persistence measure. Persistence is a measure of long run volatility, and the measure reported in the table refers to the unconditional probability of a given data series not crossing its mean in a given period (Marques, 2004). Specifically, the number reported for each series is $1 - \frac{n}{T}$, where T is the relevant sample length, and n is the number of times the series crosses its mean.

For the individual prices, we observe lower short-run volatility in the latter sample period. For persistence, the Brent price show almost no evidence of mean reversion over any of the sample periods. WTI is similar in the first period, but has somewhat stronger mean reversion in the second sample period. NBP natural gas show some evidence of weaker mean reversion, while the Henry Hub price display show increasing mean reversion in the latter sample prices. European prices have become more persistent, but all prices display low mean reversion in general. Related to this, the table also reports Augmented Dickey Fuller (ADF) unit-root test results. Not surprisingly, all individual prices appear to be integrated of order one, with a unit root in price levels. As such, some shocks in these markets appear to have permanent effects on price levels.

For log spreads, we also observe lower short run volatility after 2009. This has been followed by weaker mean reversion over all spreads. This is corroborated by the unit root test. This is our first test for stability in relative prices. If individual prices are integrated of order one, but the spread is stationary, then the two prices of the spread contain the same stochastic trend. This is also referred to as the Law of One Price holding between the price pairs. In the first sample period, the spreads appear largely stationary, meaning that any deviation in a spread is temporary. After 2009, the evidence for mean reversion is weaker. After 2009, energy prices appear to have stronger idiosyncratic risk factors, consistent with increased segmentation of the markets.

Table 2. Correlations in prices

	1997-2009					2010-2015			
	Brent	WTI	NBP	HH		Brent	WTI	NBP	HH
Brent	1.00	-	-	-	Brent	1.00	-	-	-
WTI	1.00	1.00	-	-	WTI	0.97	1.00	-	-
NBP	0.83	0.84	1.00	-	NBP	0.69	0.60	1.00	-
HH	0.81	0.82	0.81	1.00	HH	0.36	0.46	0.10	1.00

Table 2 reports price correlation in the two sample periods. In the first period, lowest correlation is towards the Henry Hub natural gas price. This is consistent with previous findings of stronger gas-to-gas competition in the US (less oil-influenced pricing). After 2009, correlations are substantially lower, reflecting the greater divergence in the spreads observed. In the next section, we provide a more rigorous analysis of the stability of the price and its consequences on risk exposure.

3. Stability

We start by defining a stable price relationship. The prices we analyze are non-stationary, so the proper methodological framework to define stability is cointegration. Consider two non-stationary prices $P_{1,t}$ and $P_{2,t}$. These prices form a stable relationship if it is possible to find a non-zero β such that

$$log(P_{1,t}) = \alpha + \beta log(P_{2,t}) + \varepsilon_t,$$

where ε_t is some mean zero weakly stationary (possibly heteroskedastic) random variable. Note that when $\beta = 1$, the two prices move proportionally in the long run, i.e. $E(P_{1,t}) = \mu E(P_{2,t})$ where μ is some constant and $E(.)$ the unconditional expectation. When this is the case, we say that the prices are perfectly stable, or that the Law of One Price holds between the two markets. When $\beta \neq 0$ and $\beta \neq 1$, the prices are partially stable, and when $\beta = 0$ they are unstable.

The above relationship between prices implies that the log-return of prices can be written as

$$\Delta log(P_{1,t}) = \beta \Delta log(P_{2,t}) - \varepsilon_{t-1} + \varepsilon_t,$$

Where Δ denotes the change in prices between period t and $t-1$. Stability implies that the expected return in $P_{1,t}$ is proportional (by β) to the expected return in price $P_{2,t}$. Outside short-run deviations, the risk exposure in $P_{1,t}$ is equal to the risk exposure in $P_{2,t}$. It is then possible to form a long/short portfolio of the two prices to eliminate all long run risk. This is because the two prices contain the same stochastic trend, or long-run risk factor. In terms of hedging daily returns, the minimum variance weights given to each product in this portfolio would be $\left(\frac{1}{\beta+1}, -\frac{\beta}{\beta+1}\right)$, where it is assumed we can gain short exposure to one of the products.

We proceed to test the degree of stability between the energy prices over the two sample periods. We start by testing for stability

$$H_0: \beta = 0.$$

We test this hypothesis for each price pair and sample period using the Johansen (1988) cointegration rank trace test. We first specify and estimate a VAR model for the bivariate system, and then test for the existence of one cointegration vector in this system. One cointegration vector in a system of two prices means that $\beta \neq 0$, given that the prices are integrated of order one. We specify a VAR model with an unrestricted constant, and choose lag length based on the Akaike Information Criteria.

If we reject H_0, we proceed to test for perfect stability:

$$H_{1|0}: \beta = 1 .$$

This is tested as a linear restriction in the estimated VAR model using a likelihood ratio test. We define the price spread as unstable if H_0 does not reject at <0.1 p-value, partially stable if both H_0 and $H_{1|0}$ reject at <0.1 p-value, and perfectly stable if H_0 rejects at <0.1 p-value but $H_{1|0}$ does not. Table 3 reports the p-values for the tests of the hypothesis' for all the price pairs over the two sample periods.

Table 3. Stability tests (p-values)

	1997-2009			2010-2015		
	$H_0: \beta = 0$	$H_{1\|0}: \beta = 1$		$H_0: \beta = 0$	$H_{1\|0}: \beta = 1$	
Brent/WTI	0.000	0.001	Part. stable	0.257	-	Unstable
Brent/NBP	0.001	0.520	Perf. stable	0.096	0.084	Part. stable
WTI/HH.	0.024	0.056	Part. stable	0.291	-	Unstable
NBP/HH.	0.000	0.122	Perf. stable	0.104	-	Unstable

The results show that all price spreads are stable for the 1997-2009 period, with the EU market being perfectly stable, and the natural gas (NBP/HH) being perfectly stable (although with less certainty). Energy prices in the current decade show very little evidence of any stability. In this period, the EU market (Brent/NBP) display strongest evidence for stability.

The evidence on stability can be corroborated by testing for cointegration in a VAR model containing all four prices. A full system approach. The results above suggests that in the first sample period all energy prices contain the same stochastic trend. This implies that there should be three cointegration vectors (rank 3 of long-run impact matrix of VAR model) in the system of four prices. In the latter sample, we should find only one cointegration vector in the full system (rank 1). Results for the cointegration trace test in the full system over the two periods is show in table 4.

Table 4. Cointegration Results, Full System

	1997-2009			2010-2015	
	Trace test	p-value		Trace test	p-value
Rank<=0	95.28**	0.000	Rank<=0	45.527*	0.080
Rank<=1	49.26**	0.000	Rank<=1	23.704	0.220
Rank<=2	16.23*	0.037	Rank<=2	9.4437	0.332
Rank<=3	0.98	0.321	Rank<=3	1.0658	0.302

Note: ** indicates rejection of the given null hypothesis at <5% critical vaue, * at <10% critical value.

The results in table 4 indicates one common stochastic trend in the first sample, and three stochastic trends in the latter sample. In the first sample period, the three (unrestricted) cointegration relationships can be represented as (standard errors of estimates in parenthesis, log-prices):

$$z_{1,1}:\ p_{t,brent} = 1.04(0.009)p_{t,wti},$$

$$z_{1,2}:\ p_{t,brent} = 1.08(0.103)p_{t,nbp},$$

$$z_{1,3}:\ p_{t,wti} = 1.34(0.169)p_{t,hh}.$$

$z_{1,1}$ refers to the stable oil relationship, $z_{1,2}$ the EU oil/natural gas relationship, and $z_{1,3}$ the US oil/natural gas relationship. For the second sample there is only one stable relationship containing. This relationship can be represented as

$$z_2:\ p_{t,brent} = 0.83(0.093)p_{t,wti} + 0.52(0.10)p_{t,nbp} + 0.08(0.079)p_{t,hh}$$

In the first sample period, exposure to any one of the prices requires only one of the other prices to eliminate the long-run price risk exposure (assuming short exposure is possible). In the second sample, one would need exposure to all other prices to eliminate the long-run risk.

Given the stable relationships, it is possible to examine which of the individual energy prices adjust to reclaim the stability once a deviation in spreads occur. Table 5 shows the significant (<0.05 p-value) adjustment coefficients to deviations from the stable relationships. These coefficients can be read as elasticities. A coefficient of 0.1 means a 1 % deviation in the spread from its long run equilibrium leads to a 0.1% change in the relevant price over one day. The first thing to notice from table 5 is that Brent is weakly exogenous. It does not adjust to any of the deviations from stability. The Brent oil price represents the long run risk factor in the energy markets in the first sample. The US oil price adjusted to deviations from the oil equilibrium ($z_{1,1}$). NBP natural gas seems the most flexible, adjusting to deviations in all the stable relationships. The US natural gas price only adjusts weakly to deviations from the US oil price in the first sample period. For the latter period, it is the natural gas prices that have adjusted to correct any instability. Both the oil prices have remained weakly exogenous. This is consistent with segmentation of the WTI from global oil markets.

Table 5. Adjustments (columns) to deviations in stable relationships (rows)

	1997-2009					2010-2015			
	Brent	WTI	NBP	HH.		Brent	WTI	NBP	HH.
$z_{1,1}$	-	0.042	-0.105	-	z_2	-	-	0.033	-0.022
$z_{1,2}$	-	-	0.031	-					
$z_{1,3}$	-	-	-0.011	0.008					

Note: Table reports only adjustments that are significant with a p-value <0.05.

We have documented that energy prices have become more unstable. As a final investigation, we explore the consequences of this in terms of hedging the exposure to energy price risk. We assume an energy investor is exposed to any of the four energy prices, and seeks to go short in another energy product to hedge price risk. We focus on the hedge that minimizes the portfolio variance. Specifically, we consider exposure to WTI oil and hedge in Brent oil, exposure to US natural gas and hedge in European natural gas, exposure to European natural gas and hedge in European oil, and exposure to US natural gas and hedge in US oil. As stated above, we assume it is possible to go short in the hedging instrument.

We consider hedging of short run price volatility (weekly returns) and long run price volatility (annual returns). The optimal hedge ratio β is found by estimating the regression

$$\Delta p_{1,t|t+j} = \alpha + \beta \Delta p_{2,t|t+j} + \varepsilon_t,$$

where $\Delta p_{1,t|t+j}$ is the j period log-return of the price the investor is exposed to, and $\Delta p_{2,t|t+j}$ is the j period log-return of the price of the hedging instrument ($j = 5$ for weekly returns, and $j =$

250 for annual returns). Table 6 shows the hedge ratio β and the mean percentage reduction in variance (compared to no hedging at all).

Table 6. Hedging Ratios and Variance Reduction in Energy Exposure

Hedging short-run risk (weekly returns)

		1997-2009		2010-2015	
Exposure	Hedge	H.R.	Variance Reduction	H.R.	Variance Reduction
WTI	Brent	0.87	73.5%	0.91	78.6%
HH	NBP	0.01	~0.0%	0.06	6.9%
NBP	Brent	0.13	42.3%	0.21	29.4%
HH	WTI	0.27	21.1%	0.17	24.5%

Hedging long-run risk (annual returns)

		1997-2009		2010-2015	
Exposure	Hedge	H.R.	Variance Reduction	H.R.	Variance Reduction
WTI	Brent	0.97	98.7%	0.89	78.3%
HH	NBP	0.55	64.9%	0.35	38.7%
NBP	Brent	0.70	70.9%	0.53	41.2%
HH	WTI	0.88	81.1%	0.57	52.8%

For the weekly returns, the ability to hedge does not change substantially between the two periods. There is lower variance reduction for WTI/Brent, HH/NBP and HH/WTI hedge, but improved reduction for the EU market (Brent/NBP). As we have seen above, the Brent/NBP relationship has remained the most stable over the two periods.

For the long run risk (annual returns), the results are different. We observe a substantial drop in the ability to reduce price risk by hedging in a single alternative energy market. This is consistent over all hedges considered. The increased instability across energy markets has created an environment where any of the energy prices considered no longer represents the other prices very well. Increased segmentation between US and EU, as well as US natural gas and oil price, has created substantial idiosyncratic risk factor within each specific market.

4. Conclusion

Energy markets are now substantially different from what we observed in the period leading up to the financial crisis. This period saw increasing commodity prices fueled by the economic boom originating from Chinese growth. Energy prices shared the same stochastic trends that resulted from the strong demand for commodities. As a result, energy prices were stable. Exposure to WTI oil implied exposure to the same long-run risk factors, outside short run variations, as exposure to Brent oil, for instance. This risk factor was the aggregate demand for energy.

The recession and the surge in available oil and natural gas in the wake of the US shale revolution has led to more segmented energy markets. Using daily prices of two oil indices (Brent and WTI) and two natural gas prices (NBP in the UK, and Henry Hub in the US), we investigate the stability between energy prices in the current decade, contrasting these to the historic degree of stability.

Our analysis provides evidence that energy prices are less stable now than before the financial crisis. This is consistent with previous analysis showing decoupling of US natural gas from oil in around 2009 (Erdős, 2012; Oglend et al., 2015), and increased segmentation between US and global oil prices (Kilian, 2016). We find that prior to 2010, all the four energy prices share a common stochastic trend, representing a common long-run energy price risk factor. After 2009, segmentation has led to different stochastic trends across the energy markets. The emergence of idiosyncratic long-run risk components in the energy markets has then led to unstable relative prices.

The finding of increased instability has consequences for dealing with exposure to energy price risk. Before 2010, exposure to any of the energy prices required hedging in one of the other prices in order to hedge the long run risk. In essence, there was one market for energy. Following 2009, more segmented energy markets means this is no longer the case.

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