International Journal of Quantitative and Qualitative Research Method

Vol.1, No.1, pp.11-40, September 2013

Published by European Centre for Research Training and Development UK (www.ea-journals.org)

IS THERE ANY CRUCIAL RELATIONSHIP AMONGST ENERGY COMMODITY PRICES AND PRICE VOLATILITIES IN THE U.S.?

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ABSTRACT: *The objective of the paper is to empirically examine the static and dynamic short-run and long-run interaction between the prices (and their volatility) of natural gas, crude oil, propane and heating oil in the US economy, using the Toda and Yamamoto (1995) procedure of Granger's Causality. Long-run equilibrium relationship is examined using Johansen's maximum likelihood procedure. The price volatility spill over is also examined between the energy markets using ARCH model. The relationship between prices of energy products may have several implications for the pricing of their derivative products and risk management. This study also examines the efficiency of these markets using the Lo-Mackinlay and Chow-Denning's (1993) multiple variance ratio tests. The study uses daily timeseries data from 7th January 1997 to 4th April 2012. To avoid non-stationarity in the variables, all prices are converted into returns form. Based on this data, we found that the return on Henry Hub Natural gas is , well explained by the explanatory variables such as the return of WTI crude oil, Heating oil, propane and the past values (two days lags) of its own return. The study found that there is bidirectional causality between Henry Hub Natural Gas return and Heating Oil return. Unidirectional causality is found between three pairs of energy products and the causality runs from Propane return to Crude Oil return, Crude Oil return to Heating Oil return and Heating Oil return to Propane return. Surprisingly, we did not find any causal relationship between Henry Hub Natural Gas return and WTI crude oil return. .There exists a long run equilibrium relationship between the each pair of commodities except between Henry Hub Natural gas and WTI crude oil price. Bidirectional volatility spillover is found between Henry Hub natural gas return and heating oil return, Henry Hub natural gas return and Propane return, WTI crude oil return and Heating Oil return, WTI crude oil return and Propane return. The result from efficient market hypothesis reveals that the energy market in the U.S. does not seem to follow the weak form of efficiency during the study period.*

KEYWORDS: Natural Gas, Heating oil, crude oil, volatility spike, volatility clustering, GARCH, EGARCH, Toda and Yamamoto causality, Vector Auto Regression

JEL Classifications: G17, C32, Q42

INTRODUCTION

In the globalization era, the energy market is the most prominent market in each country of the world. This is because of the production and distribution of energy, often in the form of natural gas and power leads industrialization which is the ultimate path for the economic growth and development. Natural gas is considered as one of the cleanest, safest, and most useful fossil fuels, producing less carbon dioxide per joule delivered either by coal or oil and far fewer pollutants than other hydrocarbon fuels among all energy sources at the global level. It has also emerged as the most preferred fuel due to its inherent environmentally benign nature, greater efficiency and cost effectiveness. Its global consumption increased from 2,245 billion cubic meters in 1997 to 2,921 billion cubic meters in 2007, which represented nearly 25 percent of world's total primary energy consumption in 2007. During the past decade, the increase in consumption of natural gas has been accompanied by changes in the market structure and regulatory framework guiding the natural gas markets, especially in the major demand regions of the world. The aim of market deregulation has been to improve competition and energy security. Moreover, technological advancements that make exploration and transportation more cost effective are likely to play an important role in determining the market dynamics in the future. Due to limited storage capacity and relatively regional nature of the natural gas market, price volatility witnessed in the natural gas markets is generally higher than that of other fuels, besides electricity which cannot be stored. Another feature which increases volatility is that consumption of natural gas occurs as a direct flow from the transmission and distribution network. As a result, market supplies have to adjust accordingly to maintain system integrity in the face of changing consumption and production.

The US is one of the major producers of natural gas in the world accounting for more than 18 percent of the total world production in 2007. It produced 570.8 bcm of natural gas in 2007 which accounted for 94.8 percent of the domestic consumption. The production remained stagnant between 1997 and 2006. This was followed by a 4 percent growth in 2007 and 9 percent growth in first half of 2008 on year on year basis. Recent increase in production is mainly due to improvement in gas drilling technology which has made extracting natural gas from unconventional sources, such as shales, economical. The US has the largest natural gas storage capacity in the world which is about 40 percent of the annual production in the US. As per EIA, the storage capacity of the US stood at 235.1 bcm in 2006 and has increased by approximately 0.2 percent from 1996 to 2006. Working gas storage is seasonal in nature with peak occurring prior to the onset of winter season and troughs at the end of the winter season. In the periods of low storage, the storage and volatility are found to be positively correlated. This correlation is much weaker in periods of high storage. The US is the largest consumer of natural gas in the world accounting for more than 22 percent of the total world consumption in 2007. The domestic consumption has remained relatively stable between 1997 and 2007 growing at a CAGR of 0.2 percent to 601.5 bcm in 2007. Historically, industrial sector was the largest consumer of the natural gas accounting for about one-third of the total consumption. In 2007, the demand for natural gas by the industrial sector was surpassed by demand for natural gas by the power sector. The demand in residential and commercial sector, which constitutes 36 to 40 percent of the total demand, is seasonal in nature, while the demand remains stable in the industrial sector. Traditionally, pipeline imports from Canada catered to the market demand. But, recently LNG imports are becoming popular as they allow diversification of sources. LNG imports constituted about 17 percent of the total imports in 2007 with Trinidad and Tobago as the largest supplier of LNG to the US, while Algeria and Egypt are second largest exporters. LNG is poised to play a promising role in the US market, given the large investments in increasing the LNG infrastructure. Demand of natural gas varies due to unexpected weather conditions which can cause an increase in price volatility of natural gas. Any increase in demand due to unexpected weather conditions is met by withdrawals from storage as production is not seasonal. The price response to variations in weather changes is asymmetric, i.e. the percentage change in price during colder than normal winter is seen to be more than percentage change in price during warmer than normal winter.

Natural gas price volatility impacts investment decisions, value of contingent claims demand for storage and convenience yield. The various demand and supply drivers for price volatility of natural gas includes weather changes, import dependency, speculation, storage capacity, consumption and elasticity demand, price of crude oil, geopolitical factors, and environmental concerns. Both weather and storage are universally considered as factors impacting short term price fluctuations in the natural gas market. Some studies have accessed the long term relationship between oil and gas prices and price volatilities and have concluded contrary results. For the US market Borenstein et.al. (1997) found that natural gas prices adjust faster when oil prices increase than when they decrease. Radhchenko (2005) finds that the degree of asymmetry is negatively related to oil price volatility. Bachmeier and Griffin (2006) get a weak relationship between prices of oil and natural gas. Natural gas prices were found to be higher than its historic relationship with oil prices in 2000, 2002, 2003 and late 2005, while it was below the historic relationship in early 2005 and 2006. Brown and Yucel (2007) find a long term relationship between the prices, though natural gas prices adjust to oil prices with a lag ranging from 12 – 27 weeks depending on their model specification. Lee and Zyren (2007) find that for sample data from January 1992 to June 2007, there was no volatility spillover or contagion between the oil and natural gas markets.

Against this back drop, this paper put an earnest effort to examine the short term and long term dynamic relationship between the natural gas and crude oil at both price and volatility level. The study also explores the dynamic interrelationship between the price volatility of natural gas, crude oil, heating oil, and propane in the context of US. The major motivation of the study is to better inform the policy makers and industry participants and traders of the interrelationship between crude oil, propane, heating oil and natural gas pricing in North America. In the section II, we are presented the theoretical underpinnings behind the interrelationship between the energy products. Section III presents the selective empirical literature. In the Section IV and V, we have presented the sources of data and empirical methodology. Section VI interprets the empirical results followed by the conclusion.

THEORETICAL UNDERPINNINGS:

There might be a potential question occurs that why at all one should bother about the relationship between the crude oil and natural gas. This is because, both the energy commodities have widely different uses and they operate in separate markets. The answer to this question is twofold from the perspective of traditional economic theories and from industry participants and policy maker’s point of view. As per the Micro economic theory, the natural gas market and the oil market are linked due to substitution and competition between the two products. Many power plants have direct fuel switching capabilities and are sensitive to relative price change of oil and

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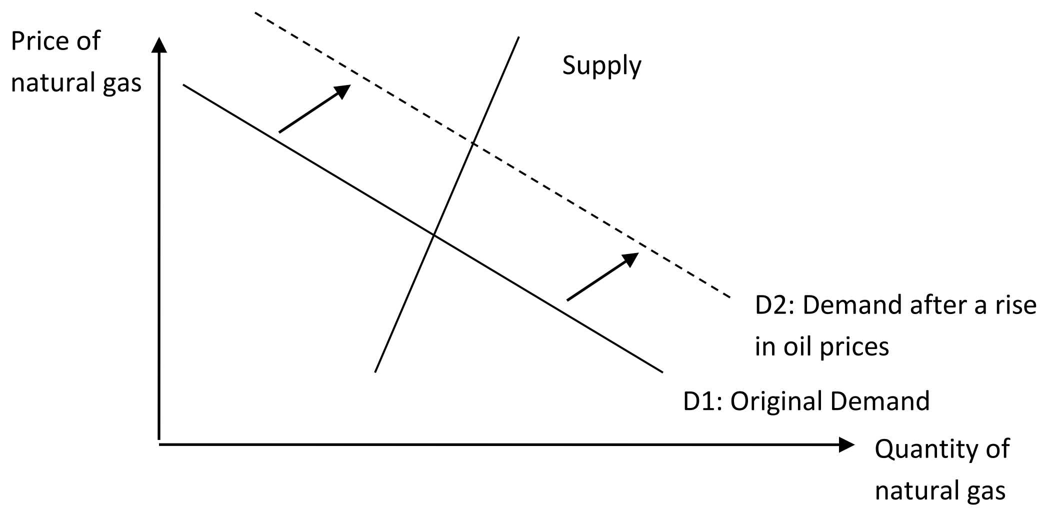
natural gas. Besides direct fuel switching, power companies also have the choice to operate different plants. An increase in the price of crude oil will increase the demand for natural gas and hence increasing its price and vice versa. This is further surmised as an increase in price of oil will increase the demand for natural gas, placing an upward pressure on natural gas prices. The magnitude of price increase depends on the shape of the supply curve. The impact is likely to be larger in the short term compared to the long term due to short-term supply constraints, resulting in inelastic short term supply curve. This is represented in the following diagrammatic representation.



Source: Author's analysis

As higher oil prices shift the demand away from oil, oil prices face a downward pressure. The final price and quantity equilibrium in the two markets depends on the supply constraints in each market, and the degree of substitutability between oil and natural gas. In general, theory dictates that the possibility of substitution between natural gas and residual fuel oil anchors the natural gas prices to that of crude oil.

Furthermore the oil and natural gas markets are linked via competition in petrochemical markets; while the US petrochemicals industry uses natural gas as feedstock; other regions around the world predominantly use crude oil derived products. Additionally, the direct price link comes from the fact that while price of natural gas is determined by marginal trade in the US and the UK, the price of natural gas and the value of LNG contracts are based on oil prices in the rest of the world.

The demand factors linking crude oil and natural gas is due to the competition between natural gas and petroleum products occurs principally in the industrial and electric generation sectors. On the other hand, the supply factors linking both the markets are due to as follows. An increase in crude oil prices may increase natural gas produced as a co product of oil, tending to decrease in natural gas prices. Secondly, an increase in crude oil prices may spur more exploration and development as cash flow expands, which could put downward pressure on natural gas prices.

Thirdly, an increase in crude oil prices may lead to increased costs of natural gas production as natural gas and crude oil operators compete for similar economic resources.

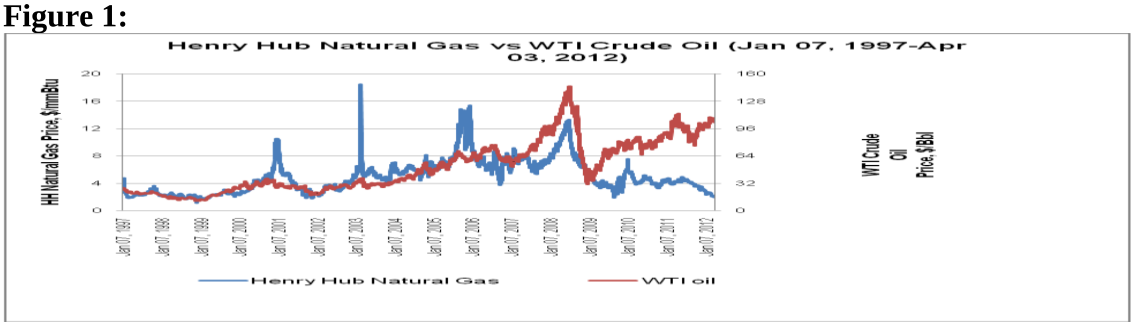
There are numerous reasons why industry participants and policy makers might find an understanding of the crude oil and natural gas price relationship useful. The major players in both these markets are international energy majors, independent power producers and utilities and energy marketers and traders. International energy majors operate both in crude oil and natural gas exploration and marketing. Project lifetimes are measured in decades and investment levels are measured in billions of dollars. Thus and understanding of both the markets will help to predict the price behavior of one commodity by observing the price behavior of other commodity over the long run, facilitate project planning and profit maximization and identifying the potential hedging strategies.

Market participants in the natural gas and crude oil trading market can be broadly classified into hedgers, arbitrageurs and speculators. Hedgers engage in standardized futures contracts to minimize their risks. They engage in transactions which are relatively large in volume, thereby increasing liquidity. However, hedgers do not trade frequently and thus they do not have a major impact on price volatility. The second category of market players, namely arbitrageurs capitalize on the price difference of the same underlying asset, in two markets and make profit. This tends to smoothen out the price differential between different markets. Therefore, arbitrageurs increase the liquidity in the market but do not have significant impact on price volatility. On the other hand, speculators participate with a motive to make a quick profit due to price difference of the underlying asset trading on two different markets. They react to news and other information flowing into the market, thereby increasing liquidity and volatility in the market.

Examining the relationship between the oil and natural gas market is also useful to the policy makers in the sense that policy makers are generally tasked with decision making that affects broad swaths of the economy. This will help policy makers to predict how policies affect the oil-gas relationship would allow for a more realistic analysis of the likely impact of such policies.

Petroleum and natural gas producers, marketers and traders operate in the market on the assumption that crude oil prices and natural gas prices exhibit a more or less stable historical relationship. This linkage spans both supply and demand side connections between the two commodities. Before examining this price relationship profoundly, it is useful to examine the actual price series of the two commodities.

Figure 1:



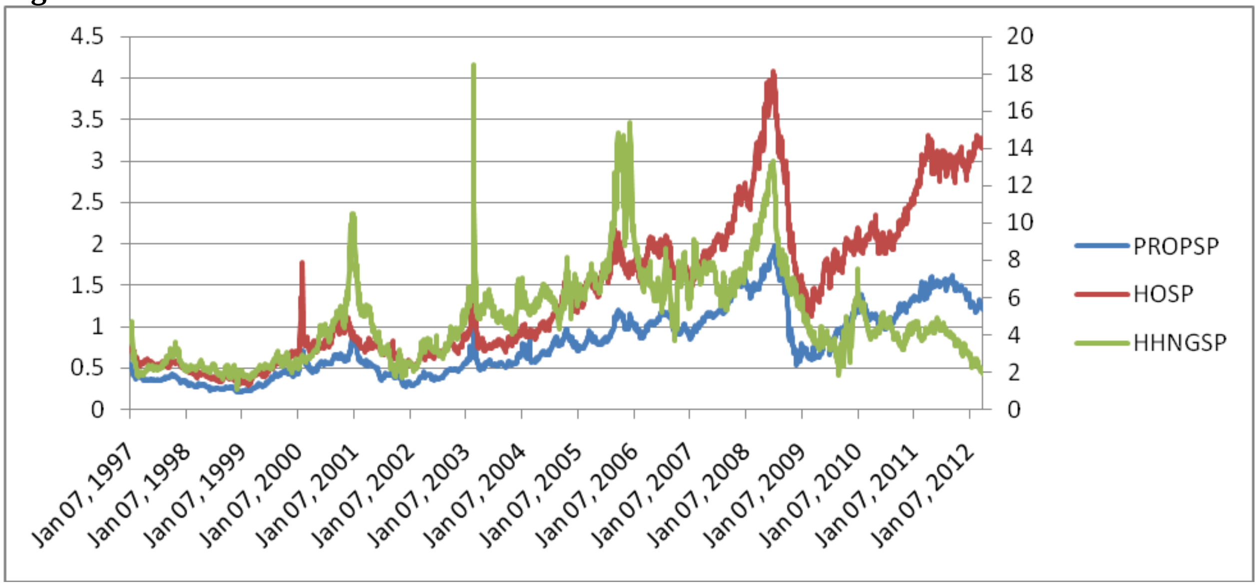
Source: EIA

The time series plot of daily Henry Hub Gulf Coast Natural Gas spot price and Cushing, OK West Texas Intermediate (WTI) crude oil spot price in the U.S. from 07th Jan 1997 to 04th Apr 2012 is presented in the Figure 1. The daily spot price data of natural gas at Henry Hub in Louisiana and the daily spot price of WTI crude oil at Cushing in Oklahoma are sourced from U.S. Energy Information Administration website. WTI crude is a high quality, high volume light sweet crude oil stream. It is important to note here that the pricing hub of WTI at Cushing, Oklahoma is very close to the pricing hub of Natural gas at Henry Hub. Therefore their proximity eliminates the need for a transportation differential to be considered.

From the above Figure 1, it is surmised that both of these price series seem to share the same general trend. Another important observation from the figure by observing the trend pattern of both the series is that the natural gas price series is much more volatile than the crude oil price series. During 2008, the price run-up in crude oil and natural gas prices shows as if they are highly correlated with each other. From this figure, there is a obvious question arises is that what causes the volatility in Natural gas and why gas prices seems to return to some sort of relationship with crude oil prices.

With this research set and our theory of relationship between prices, our study investigates if and how the two markets are related in terms of volatility as well. Before going to examine the relationship between natural gas and WTI crude empirically, it is also important to examine the relationship between natural gas with heating oil and propane. This will provide us a picture on the energy and cost relationship between the natural gas and propane. While natural gas occurs in nature as a mixture of methane and other gases, propane is actually a byproduct of both petroleum refining and natural gas processing. Natural gas must be cleaned before being used, and byproducts of this process include hydrocarbons like propane in addition to butane, ethane, and pentane. The difference between propane and natural gas in domestic use comes down to their energy efficiency, cost, compression, storage, and risk factors. Propane provides more energy per unit of volume than does natural gas. While propane is usually measured in gallons (or liters), natural gas is found in cubic feet (or cubic meters). Heat is measured in British Thermal Units (BTUs), which is the amount of heat needed to increase the temperature of 1 pound (0.5 kg) of water by 1°F (0.56°C). Natural gas provides just over 1,000 BTUs per cubic foot (0.0283 cubic meters); the same volume of propane provides about 2,500 BTUs. This means that propane contains about 2.5 times more usable energy content. So, less propane is needed to produce the same amount of energy as natural gas. Heating oil, also known in the United States as No. 2 heating oil, is used to fuel building furnaces or boilers. Heating oil is widely used in parts of the United States and Canada where natural gas or propane is frequently not available. The time series plot of spot price of natural gas, heating oil and propane is presented in the Figure 2. The daily spot price of Mont Belvieu, TX Propane spot price FOB, measured US$ per gallon and New York Harbor No. 2 Heating oil spot price FOB measured US$ per gallon is collected from the EIA website. In this graph Henry Hub natural gas spot price is measured in the right side Y-axis and both the spot prices of propane and heating oil is measured in the left side Y-axis.

Figure 2:



In the above figure, it can be seen that all the spot price series have almost moved together. Looking at this graph, it is also expected that there is an existence of long run equilibrium relationship among the price series. We explore this relationship by employing the co-integration technique in the latter section. It is also seen from the graph that there are a lot of price spikes during the year 2003, 2006 and 2008. From the event analysis, it is found that the factors such as weather, low storage level, low level of production, less imports, and severe pipeline restrictions through major parts of the country especially in the Mid-Atlantic and New England regions, where temperatures have consistently fallen below normal in the week starting February 24, 2003 played crucial roles in the relatively high gas prices and volatility during this heating season. With the strong influences of moderate weather, high storage levels, and a lack of hurricane activity still in place, spot prices fell through September 2006. Spot prices increased since Wednesday, September 27, 2006. Several market factors likely contributed to the price increases. Some natural gas producers voluntarily shut production, reducing the available supply of natural gas in the market. Meanwhile, some coal and nuclear power plants were down for maintenance, which likely contributed to increased demand for natural gas for electric generation. Working gas in storage totalled 1,014.069 Bcm as of Friday, September 29, which was about 12 percent above the 5-year average inventory level for the reported week. This matched the highest level that weekly working natural gas stocks had reached in the 12-year history.

Previous Research:

Post to the U.S. Federal Energy Regulatory Commission (FERC) granted natural gas customer's access to pipelines in 1985, the number of open access pipelines and spot markets grew rapidly (De Vany and Walls, 1994). By 1989 almost all the major pipelines had open access and by 1991 more than 65% of the regional markets had become co-integrated (De Vany and Walls, 1993). Doane and Spulber (1994) also find, using spot market data from 1984-1991, that the geographical scope of the market for natural gas broadened considerably after 1985 and conclude that open access has led to the development of a national competitive natural gas market. The strong integration on the field level, as the above studies reflect, was however not mirrored on the city gate level, as shown in Walls (1994) using data from July 1990 to June 1991; natural gas prices were much less integrated between the field and city markets. Serletis, A., and Herbert, J. (1999) attempted to examine that how similar is the price behavior of North American natural gas price at Henery Hub and Transco Zone 6 natural gas prices, fuel oil prices for New York Harbor, and Pennsylvania, New Jersey, Maryland (PJM) power market for electricity prices by employing the Error Correction Mecanism (ECM), Vector Auto Regression and Granger‗s causality on the daily price data spanning from 25 October 1996 to 21 November 1997. The Studyrevealed that there are shared trends among the Henry Hub and Transco Zone 6 natural gas prices and the fuel oil price. This means that there are empirically effective arbitraging mechanisms for these prices across these markets. The estimation of error-correcting causality models for the integrated price series also revealed causality and a feedback relationship between any two price pairs.

Serletis, A and Ruiz, R. R. (2002) explored the strength of shared trends and shared cycles between North American natural gas and crude oil markets using daily data from January 1991 to April 2001 on spot U.S. Henry Hub natural gas and WTI crude oil prices. The results show that has been `de-coupling' of the prices of these two sources of energy as a result of oil and gas deregulation in the United States. They also investigated the inter-connectedness of North American natural gas markets and find that North American natural gas prices are largely defined by the U.S. Henry Hub price trends. Villar, A. J. and Joutz, L. F. (2006) examined the time series econometric relationship between the Henery Hub natural gas price and the West Texas Intermediate (WTI) crude oil price. They have considered the monthly data from 1989 to 2005 and used the co-integration technique and Vector Auto Regression (VAR) model to explore the long run and dynamic relationship between the natural gas price and crude oil. The study found co-integrating relationship between Henry Hub prices and WTI. The study also reported that the dynamics of the relationship suggest a 1-month temporary shock to the WTI of 20 percent has a 5-percent contemporaneous impact on natural gas prices, but is dissipated to 2 percent in 2 months. A permanent shock of 20 percent in the WTI leads to a 16 percent increase in the Henry Hub price 1 year out all else equal. Hunt and Given (2007) attribute unreasonably high gas prices at Henry Hub to persistent high crude prices, increased world tension, a ―risk premium‖ or ―security premium‖ built into petroleum prices, strong demand growth of hydrocarbon fuels (crude oil products, LNG, coal) in several large developing countries (especially China and India) and ―scarcity premium‖ due to depleting conventional gas fields. Moreover, absence of immediate alternative sources of supply, rising gas exploration and development costs across North America, the partial decline in drilling in the Gulf of Mexico despite record high prices, and pre-determined rising electric power fuel demand due to the current generator overbuild also influence the gas prices. In addition, the study identifies uncertainty around weather and LNG supply, political unrest, cartel formation, uncertainty around other potential new supplies in North America as some of the drivers of price volatility.Stoppard and Srinivasan (2007) study convergence between North American and

European gas prices concludes that Europe will continue to have a dual price environment of long-term contracts and spot prices, with the two potentially far apart for a long period. Oil indexation is likely to remain the predominant price-setting mechanism for the bulk of long-term contracts, representing the majority of supply in Continental Europe based on the preferred choices of both sellers and buyers. The study further concludes that the European spot prices will become increasingly influenced by North American prices. The growth of LNG infrastructure in all parts of the chain—liquefaction, regasification, and shipping—will drive increasing arbitrage opportunities between the two markets. However, at certain times of the year, the markets may disconnect when regasification hits a constraint point and seasonal factors become dominant. Mjelde and Bessler (2009) using a multivariate time series framework and prices from two diverse markets: PJM and Mid-Columbia (Mid-C), and four major fuel sources: natural gas, crude oil, coal, and uranium find that the eight price series are cointegrated. However, they are not able to detect one single source of randomness (one common trend) but find that fuel source prices move electricity prices. Gay, Simkins and Turac (2009) investigated whether investors learned about analyst accuracy using gas inventory announcements and gas futures prices from 1997 through 2005. Focusing only on futures return and disregarding price volatility, they concluded that the oil futures return reacted to analyst forecasts. Gay, Simkins and Turac (2009) investigated whether investors learned about analyst accuracy using gas inventory announcements and gas futures prices from 1997 through 2005. Focusing only on futures return and disregarding price volatility, they concluded that the oil futures return reacted to analyst forecasts. Mohammadi (2009) found that the three fossil fuels (coal, natural gas and crude oil) do not affect electricity prices significantly. Significant long-run relationships are found only between electricity and coal prices. Bjursell, Gentle and Wang (2009) considered, among other things, the effect of oil inventory announcements on oil intraday volatility and the effect of gas inventory announcements on gas intraday volatility. Instead of subtracting the market expectations from the actual values to arrive at the unexpected component, they estimated the \surprise" based on historical inventory levels. They concluded that this "surprise" increased volatility in gas and heating oil prices.

Bencivenga, C. and Sargenti (2010) investigated the short and long run relationship between crude oil, natural gas and electricity prices in US and in European commodity markets. Using daily price data over the period 2001-2009, they performed a correlation analysis to study the short run relationship, while the long run relationship is analyzed using a co-integration framework. The study reported that the results show an erratic relationship in the short run while in the long run an equilibrium may be identified having different features for the European and the US markets. Halova, W. M (2012) studied the relationship between oil and gas in two different ways in compare to previous studies by using high-frequency, intraday oil and gas futures prices and by analyzing the effect of specific news announcements from the weekly oil and gas inventory reports. The results dispel the notion of one-way causality and provide support for the theory. The reaction of the futures volatility and returns is asymmetric, although this asymmetry does not follow the ―good news" vs. ―bad news" pattern from stock and bond markets; the response depends on whether the shock is driven by oil or gas inventory gluts or shortages. The two-way causality holds not only for the nearby futures contract but also for contracts of longer maturities. These findings underscore the importance of analyzing financial markets in a multi-market context.

Against the back drop of the above review of literature, it can be surmised that the relationship between natural gas and crude oil has been largely investigated predominantly by employing the Time series models and co movement analysis. However, the conclusion derived from all this study is mixed and inconclusive. In this context, the current paper made an pioneer attempt to examine this crucial relationship between natural gas and crude oil along with propane and heating oil at both price and volatility level. In compare to the previous research paper, we have applied the advanced time varying volatility school of models such as Threshold GARCH and EGARCH model to assess the transmission of volatility spillovers between the energy market products in the U.S, which is not attempted earlier. Secondly, none of the study attempted to examine the efficiency of the energy markets in the US, which is attempted here in this paper.

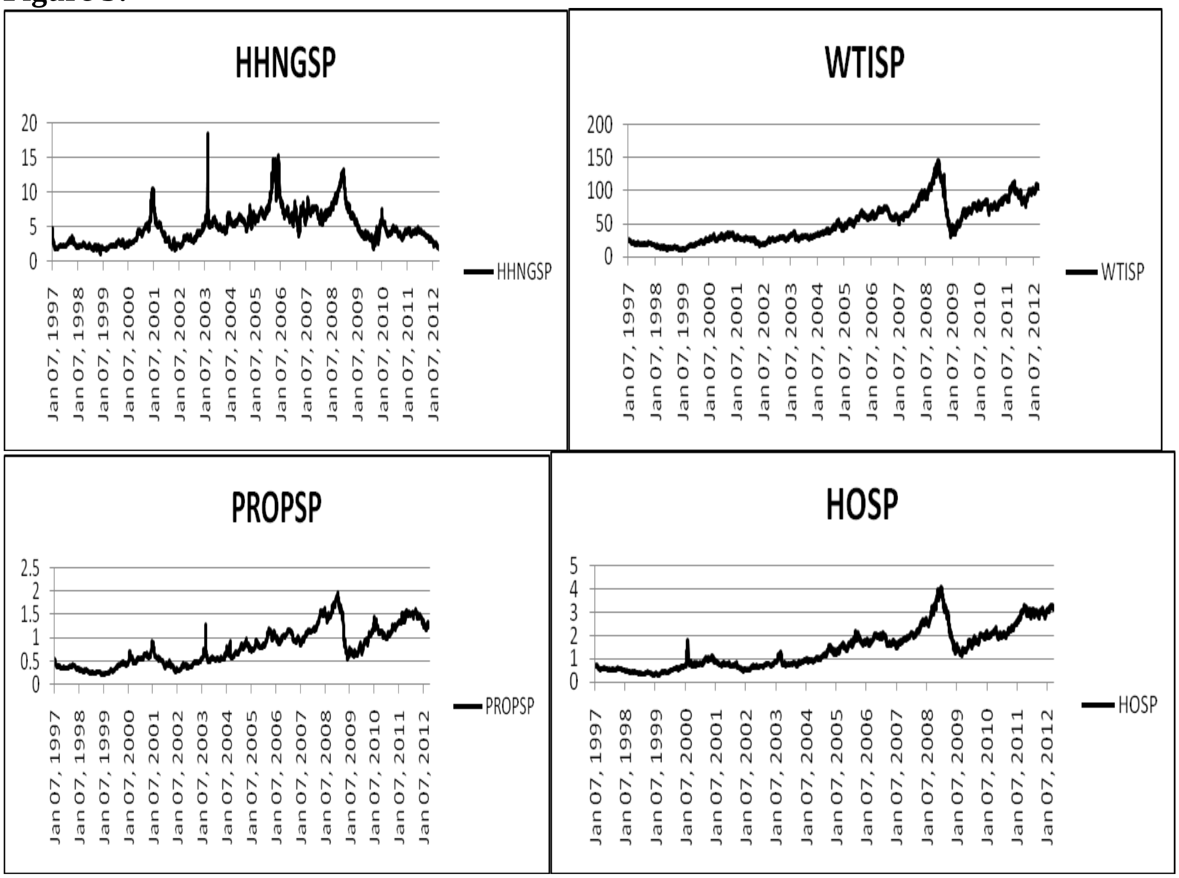
Data:

To capture the dynamic relationship between the natural gas, WTI crude oil, propane and heating oil at their respective price and volatility level, the study considered Henry Hub Gulf coast natural gas spot price (US$/MMBTU), Cushing, OK WTI Spot Price FOB (US$/ per Barrel), Mont Belvieu, TX Propane Spot Price FOB (US$/ per Gallon), New York Harbor No. 2 Heating Oil Spot Price FOB (US$/ per Gallon). Henry Hub is one of the key hubs in the US, given the large volumes of natural gas traded at this hub. Further, NYMEX uses Henry Hub prices as the basis for pricing its natural gas futures contract. The hub is also well connected with other interstate and intrastate pipelines. West Texas Intermediate (WTI), also known as Texas light sweet, is a grade of crude oil used as a benchmark in oil pricing. This grade is described as light because of its relatively low density, and sweet because of its low sulfur content. It is the underlying commodity of Chicago Mercantile Exchange's oil futures contracts. It is listed as WTI, Cushing, Oklahoma. Propane is produced as a by-product of two other processes, natural gas processing and petroleum refining. The processing of natural gas involves removal of butane, propane, and large amounts of ethane from the raw gas, in order to prevent condensation of these volatiles in natural gas pipelines. Additionally, oil refineries produce some propane as a by-product of cracking petroleum into gasoline or heating oil. Propane is traded at Mont Belvieu. Heating oil is known in the United States as No. 2 heating oil. New York Harbor No. 2 Heating Oil is a liquid petroleum distillate used as fuel for burning in furnaces and boilers in buildings. It accounts for 25% the yield of a barrel of crude oil, the second largest cut after gasoline. It must conform to American Society for Testing and Materials (ASTM) standard D396. New York Harbor No. 2 Heating Oil contracts trade at the NYMEX. Contract size is 42,000 gallons (1,000 barrels) quoted in US dollars and cents per gallon. Heating oil is widely used in parts of the United States and Canada where natural gas is not available and propane is priced higher.

The daily data of the spot prices of Henry Hub Natural Gas (HHNGSP), WTI Crude Oil (WTISP), Propane (PROPSP) and Heating Oil (HOSP) are collected from EIA website. The study period of daily spot price data spans over the period from 7th January 1997 to 4th April 2012, forming around 3827 observations. As the data are time series in nature, we have converted the daily price series data to daily continuous compounding return in order to satisfy the inherent properties of time series analysis such as 'Unit Root'. The continuously compounded rate of return (R_t) is computed by taking the first difference of natural logarithmic prices i.e. $R_t = 100 * \ln(P_t / \ln P_{t-1})$.

The time series plot of the daily spot price of Henry Hub Natural Gas, WTI crude oil, Propane and Heating oil is presented in the Figure 3.

Figure 3:



Source: EIA

METHODOLOGY:

At the outset, a time series regression model built up in order to measure the degree and direction of the relationship between the energy variables by assuming the Henry Hub Natural Gas price as the dependent variable. Before performing the regression model, the Unit Root test was employed to examine the stationarity properties of the time series variable. This has been tested through Augmented Dickey Fuller and Phillips Peron test. Then in order to examine the short run dynamics between the energy products Toda and Yamamoto (1995) procedure of Granger's Causality test in the Vector Auto Regression Block Exogenity form. This model is employed to avoid the inherent limitation of conventional Granger's causality test such as biased towards lag augmentation criterion and stationary data. In order to examine the long run equilibrium relationship between the energy products Johansen's Maximum Likelihood procedure is employed. Here we are not attempting to explain all these time series techniques because these are much celebrated methods and are available in any standard text books of Time Series Econometrics.

To analyze the possibility that the transmission of volatility or volatility spillover effect can exist between the natural gas, crude oil, propane and heating oil, both Generalised Autoregressive conditionally Heteroscedastic model (GARCH) and Exponential Generalised Autoregressive conditionally Heteroscedastic model (EGARCH) have been taken into consideration. This is in fact the major methodological contribution of the paper. To model the volatility spillover between energy products both ARMA (1, 1)-GARCH (1, 1) model and the ARMA (1, 1)-EGARCH (1, 1) model have been used. To examine the volatility spillover, the same is carried over in two ways. First, the volatility series generated from the specific model entertained are extracted for all the energy products. Then, in order to ascertain the possible existence of co-movement among them, we apply Johansen Maximum Likelihood Cointegration (1988) test. Secondly, the residuals are generated from a specific model and for a particular product. These residuals are used as shocks emanating in one product and are made to enter to the volatility equation of the other product. If the coefficient of the same is significant, this confirms the presence of volatility spillover.
The AR (1) equation as well as both GARCH (1, 1) and EGARCH (1, 1) spillover equation may be specified as follows:

AR (1): $y = c + \tau\ y_{t-1} + \varepsilon_t$ …..(1)

Where, y_t is the return of each of the energy products at time period t, c is the intercept, y_{t-1} is the previous period return at the time period t-1 and ε_t is the white noise error term. Here, return on daily spot prices of the energy products are a function of previous period returns plus an error term.

GARCH (1, 1) Spillover Equation

$$h_{t(NaturalGas)} = \omega_0 + \beta_1 \varepsilon_{t-1}^2 + \alpha_1 h_{t-1} + \psi(sqresid_{crudeoil}) \ldots. (2)$$

$$h_{t(crudeoil)} = \omega_0 + \beta_1 \varepsilon_{t-1}^2 + \alpha_1 h_{t-1} + \psi(sqresid_{naturalGas}) \ldots. (3)$$

Where $\omega_0 > 0$, $\beta_1 \geq 0$, $\alpha_1 \geq 0$. In both equation (2) and (3), h_t is the conditional variance of both Natural Gas and Crude oil, which is a function of mean ω_0, news about volatility from the previous period measured as the lag of the squared residual from the mean equation (ε_{t-1}^2), last period's forecast variance (h_{t-1}) and the squared residual of crude oil and natural gas respectively in both the above equations.
In the GARCH (1,1) spillover equation, we use the squared residual of another market (ψ) instead of residual on their level, which is used, as a proxy for shock in other market because in case of GARCH, we make sure that volatility is positive.
EGARCH (1, 1) Spillover Equation

$$\log h_{t(NaturalGas)} = \omega_0 + \beta_1 h_{t-1} + \alpha_1 \left| \frac{\varepsilon_{t-1}}{\sqrt{h_{t-1}}} \right| + \phi \frac{\varepsilon_{t-1}}{\sqrt{h_{t-1}}} + \psi(resid_{CrudeOil}) \ldots\ldots (4)$$

$$\log h_{t(CrudeOil)} = \omega_0 + \beta_1 h_{t-1} + \alpha_1 \left| \frac{\varepsilon_{t-1}}{\sqrt{h_{t-1}}} \right| + \phi \frac{\varepsilon_{t-1}}{\sqrt{h_{t-1}}} + \psi(resid_{NaturalGas}) \text{ .... } (5)$$

The above represents the EGARCH (1, 1) model. The asymmetric behavior of log volatility with respect to past changes in innovations is captured by the term multiplying α_1 and ϕ_1. The logarithmic specification ensures the positivity of the estimated conditional variance and non-negativity constraints on the parameters are relaxed.

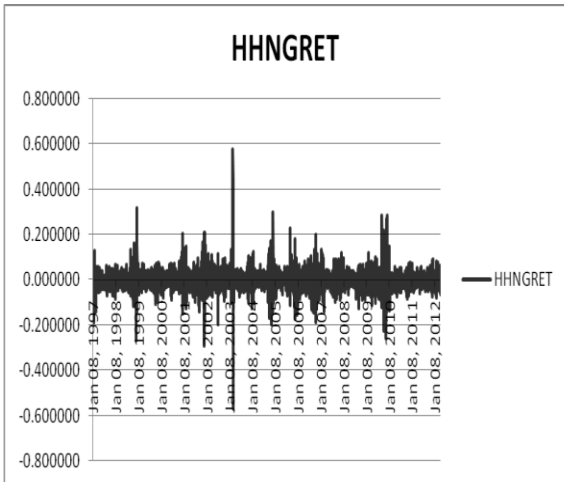
In the above EGARCH (1, 1) model, only residuals of other market have been taken into consideration instead of squared residual, since EGARCH, by definition ensures that volatility is positive.

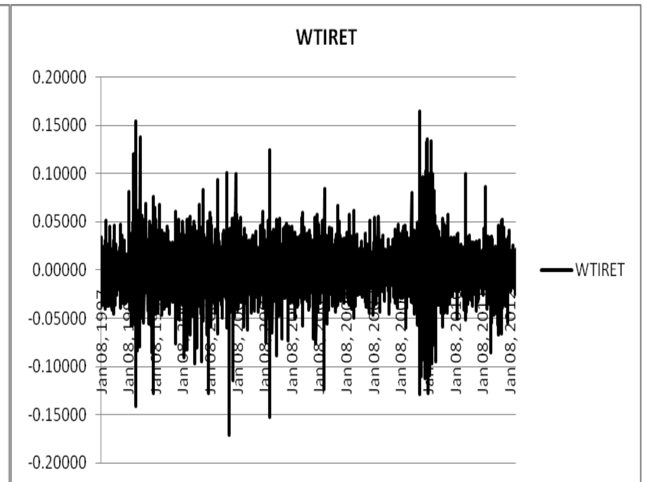
The efficient market hypothesis (EMH) states that the security price fully reflects all available information. The market is regarded as weak-form efficient if the current price of a security fully reflects all its information contained in its past prices, which means that studying the behaviors of historical prices cannot earn abnormal returns. Although there are an abundance of empirical studies concerning testing the RWH (Liu and He (1991), Huang (1995), Poshakwale (1996), Islam and Khaled (2005), etc.), the interest in the market efficiency still remains in academicians and practitioners. Lo and MacKinlay (1988) initiate the conventional variance ratio test. Later, Chow and Denning (1993) modify Lo-MacKinlay's test to form a simple multiple variance ratio test and Wright (2000) proposes a non-parametric ranks and signs based variance ratio tests to address the potential limitation of Lo-MacKinlay's conventional variance ratio test. We have employed the Chow and Denning multiple variance ratio test to examine the Random Walk Hypothesis of the U.S. energy markets.

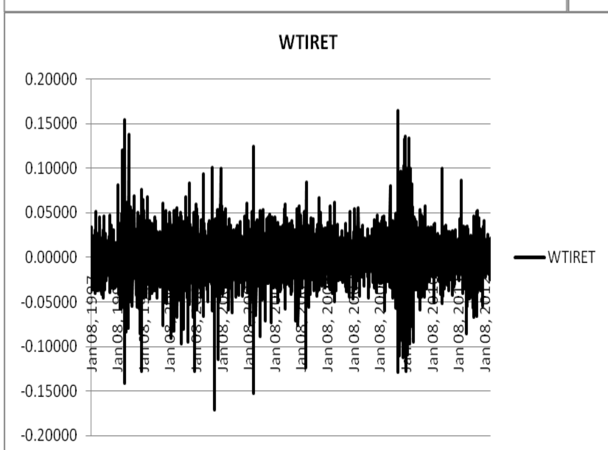
EMPIRICAL FINDINGS:

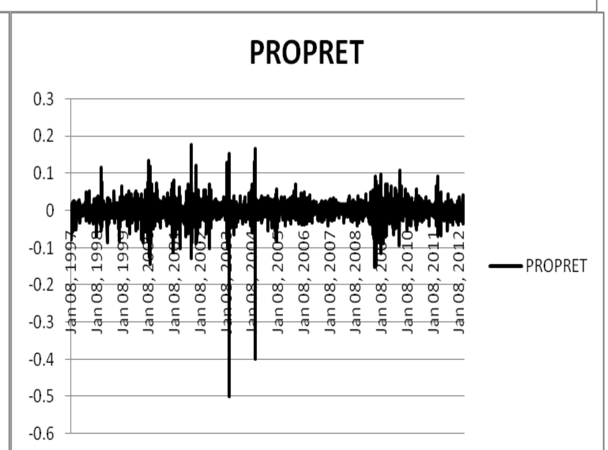
Before undertaking any time series econometric analysis of the data, it would be useful to see the broad trends and behavior of the variables, which may help in interpreting the model results latter. For this purpose, time series plots are drawn for all the variables. Figure 3 plots the time series of the daily movement of the spot prices of Henry Hub Natural Gas, WTI crude oil, Propane and Heating Oil and their rate of return is plotted in the Figure 4. It is quite clear from these figures that the returns exhibit pronounced clustering- a fact that consistent with the observed empirical regularities regarding the financial asset returns.

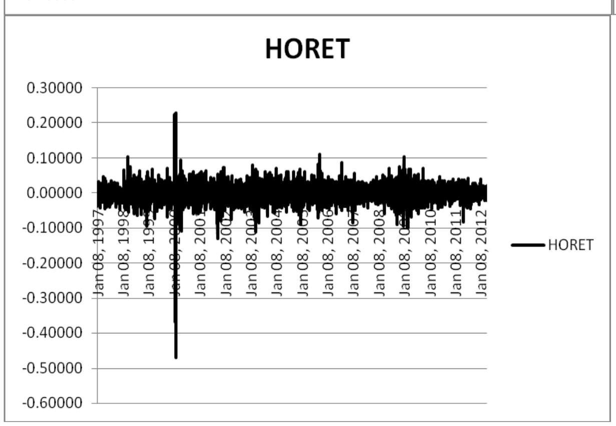
Figure 4: Time Series Plot of the Return series of Energy Commodities











The summary statistics of the concerned variables and their respective returns are presented in the Table 1 and Table 2 respectively.

Table 1: Summary Statistics of Daily Spot Prices of Natural Gas, Heating oil, Propane and WTI crude Oil

	HHNGSP	HOSP	PROPSP	WTISP
Mean	4.87	1.41	0.79	50.36
Median	4.39	1.189	0.71	41.01
Maximum	18.48	4.083	1.98	145.31
Minimum	1.05	0.284	0.204	10.82
Std. Dev.	2.47	0.88	0.41	29.76
Skewness	1.18	0.75	0.53	0.68
Kurtosis	4.78	2.61	2.25	2.51
Jarque-Bera	1394.75	381.56	266.77	331.18
Probability	0.00	0.00	0.00	0.00
Sum	18629.99	5411.71	3040.15	192719
Sum Sq. Dev.	23268.31	2930.823	655.0179	3388834
Observations	3827	3827	3827	3827

Table 2: Summary Statistics of Daily Returns of Natural Gas, Heating oil, Propane and WTI crude Oil

	HHNGRET	HORET	WTIRET	PROPRET
Mean	-0.00016	0.000383	0.000354	0.000207
Median	0.000	0.000	0.000904	0.000
Maximum	0.576663	0.229538	0.164137	0.176737
Minimum	-0.56818	-0.47012	-0.17092	-0.49913
Std. Dev.	0.04583	0.026963	0.025815	0.025119
Skewness	0.491736	-1.54732	-0.16915	-2.99364
Kurtosis	22.81215	41.18424	7.548835	64.99763
Jarque-Bera	62728.61	233961.9	3316.879	618465.6
Probability	0.00	0.00	0.00	0.00
Sum	-0.61754	1.46697	1.352688	0.791645
Sum Sq. Dev.	8.033881	2.780791	2.549049	2.41337
Observations	3826	3826	3826	3826

The spot prices and the rate of return of WTI Crude oil, Propane, and Heating Oil have very small positive rate of return except Henry Hub Natural gas. The kurtosis coefficient, a measure of thickness of the tail of the distribution, which is quite high at the respective return level of the concerned variables. A Gaussian (normal) distribution has kurtosis equal to three, and hence, this implies that the assumption of Gauuianity cannot be made for the distribution at their respective return levels. This finding is further strengthened by Jarque-Bera test for normality which in our case yields very high values –much greater than for a normal distribution, and, this rejects the null hypothesis of normality of spot prices as well as their respective rate of return distributions at any conventional confidence level.

In order to find out the pair wise degree of association between the energy variables, the correlation matrix is constructed and presented in the Table no. 3 and 4 respectively.

Table 3: Correlation Coefficient Matrix of Daily Spot Prices

	HHNGSP	**HOSP**	**PROPSP**	**WTISP**
HHNGSP	1			
HOSP	0.502317	1		
PROPSP	0.589599	0.971205	1	
WTISP	0.51151	0.989561	0.970504	1

Table 4: Correlation Coefficient Matrix of Daily Returns

	HHNGRET	**HORET**	**PROPRET**	**WTIRET**
HHNGRET	1			
HORET	0.113203	1		
PROPRET	0.222111	0.396875	1	
WTIRET	0.069045	0.647557	0.413332	1

From the Table 3, it can be seen that there is a high positive correlation between the spot prices of propane and Heating oil, WTI crude oil and propane and Heating oil and WTI crude oil. However, there is a very low correlation exists between Henry Hub natural gas spot price and WTI crude oil. From the Table 4, it is found that there is a positive low correlation between WTI crude oil return and return on heating oil and WTI crude oil return and return on natural gas.

Table 5: Unit Root Test

Unit Root Test		
	ADF	**PP**
Variables	***With Trend and Intercept***	
HHNGSPOT	-3.02(4)	-3.27(8)
WTISPOT	-3.16(4)	-3.07(8)
HOSPOT	-2.73(4)	-2.85(8)
PROPSPOT	-3.24(4)	-3.19(8)
HHNGRET	-28.07(4)	-60.31(8)
WTIRET	-28.60(4)	-62.56(8)
HORET	-28.43(4)	-62.25(8)
PROPRET	-27.66(4)	-62.01(8)

Note: The figures in the parentheses shows the number of lags and the Mackinnon critical values for ADF and PP test at both 1 % and 5% level of significance are -3.99 and -3.41 respectively.

Then before presenting in any time series model, the unit root test is conducted at the level of energy price variables. This is because, when the data have unit roots characteristics, such analysis may lead to spurious results and misleading conclusions. Hence, the time series result is presented in the Table no. 5. From the Augmented Dickey Fuller (ADF) test and Phillips Peron (PP) test, it is concluded that all the energy price variables are non-stationary at their level and their respective return series are stationary at their level at both 1percent and 5 percent level of significance. This is also clear from the time series plot of all the energy variables at their return level presented in the figure 4. The time series plot of all these variables at their return level shows that there is absolutely no stochastic or deterministic trend at the return level.

In the beginning of the analysis, we have run the multiple time series regression model by assuming the Henry Hub Natural gas return as the dependent variable. The regression result is presented as follows.

HHNGRET = - 0.000248 - 0.119517 WTIRET+0.116216 HORET +0.406508 PROPRET

(0.000722)	(0.037633)	(0.035744)	(0.406508)
[-0.34]	[-3.17]*	[3.25]*	[12.66]*

Adj. R^2 = 0.052, F-Stat = 70.70263, Prob (F-Statistic) =0.0000, DW = 1.9871, DF = 3822

*- significance at 1 % level

From the above estimated equation we find that the coefficient of all the explanatory variables preserve expected sign. The estimated Henry Hub Natural Gas return function have very low R^2 and Adjusted R^2 and 'F' values indicating that the chosen determinants could explain the variation in the dependent variable quite well. Likewise a 10% increase in the rate of return of WTI crude oil will lead to 1.1% decline in the Henry Hub Natural Gas return level. Similarly, 10% increase in the rate of return of Heating Oil (HORET) will lead to a rate of 1.1% increase in the rate of return of Henry Hub Natural Gas. A 10 % increase in the Propane return increases the rate of return of Henry Hub Natural Gas by 4%. This shows that WTI crude oil return has the indirect relationship with the return of natural gas, where as Heating Oil return and Propane return has the direct relationship with the return of hennery hub natural gas.

But unfortunately the estimated Durbin-Watson statistics in this estimated equation is lower than the critical upper limit either at 1% or 5% level of significance, implying the presence of autocorrelation in the estimated residuals. The Durbin Watson'd' test shows that the estimated DW statistics lie in the zone of indecision at 1% level of significance and using the modified 'd' test we found the presence of positive autocorrelation in the above equation. As a result, the t-ratios of the coefficients and the F-values are likely to be over estimated. To correct the autocorrelation problem in the above equation, we have re-estimated this price equation by using Cochran-Orcutt procedure. The AR (2) regression as the alternative to this previous regression provides better result. This estimated return equation is reported below.

HHNGRET = -0.000239- 0.116296 WTIRET+0.104782 HORET +0.404328 PROPRET-0.185962AR (2)

(0.000598)	(0.036722)	(0.034418)	(0.030753)	(0.015908)
[-0.39]	[-3.16]*	[3.04]*	[13.14]*	[-11.68]*

Adj. R^2 = 0.084, F-Stat = 88.86485, Prob (F-Statistic) =0.0000, DW = 1.99, DF = 3819

*- significance at 1 % level

In this equation, the Adjusted R^2 is improved, that is 0.084. Based on't' ratios, we notice that return on WTI crude oil, Heating Oil and Propane are the most important determinant of return of Henry Hub Natural Gas price. In this equation, autocorrelation is removed and all the coefficient of the variables is at 99% level of significance. The AR (2) coefficient in this equation turned to be also significant at 99%. This surmised that the return on Henry Hub Natural gas is well explained by the explanatory variables such as the return of WTI crude oil, Heating oil, propane and the lagged past values of it's own i.e. Hennery Hub natural gas return.

In the next step to avoid the limitation of assuming the HHNGRET as the dependent variable and in order to find out the causal relationship between the variables, we have employed the Toda and Yamamoto (1995) procedure to test for Granger causality in the Vector Auto Regression (VAR) block exogeneity form. To determine the appropriate maximum lag length for the variables in the VAR, we have employed different lag augmentation criterion such as sequential modified Likelihood Ratio test statistic, Final Prediction Error, Akaike Information Criterion, Schwarz Information Criterion, and Hannan Quinn Information criterion. The result of this optimum lag based on the above mentioned criterion is reported in the Table 6.

Table 6: Lag Length Criterion for Granger's Causality Test

Lag	LogL	LR	FPE	AIC	SC	HQ
0	3.35E+04	NA	2.82E-13	-17.54463	-17.53808	-17.5423
1	3.36E+04	218.5135	2.69E-13	-17.59356	-17.56083	-17.58193
2	3.37E+04	187.2548	2.58E-13	-17.63434	-17.57543*	-17.6134
3	33748.36	96.49905	2.54E-13	-17.65132	-17.56623	-17.62108
4	33816.89	136.4569	2.47E-13	-17.67883	-17.56756	-17.63930*
5	33834.84	35.69176	2.47E-13	-17.67985	-17.5424	-17.63101
6	33862.19	54.3352	2.45E-13	-17.6858	-17.52216	-17.62766
7	33883.29	41.88935	2.44E-13	-17.68847	-17.49866	-17.62103
8	33900.94	34.98755*	2.44e-13*	-17.68933*	-17.47334	-17.61259

* indicates lag order selected by the criterion

LR: sequential modified LR test statistic (each test at 5% level)

FPE: Final prediction error

AIC: Akaike information criterion

SC: Schwarz information criterion

HQ: Hannan-Quinn information criterion

From this table, it can be seen that majority of lag length criterion unanimously reported 8days as the optimum lag length. By considering the eight days as the optimum lag lengths we have examined the causality test among the energy variables in the form of VAR block exogeneity test. The result is reported in the Table 7.

Table 7: VAR Block Erogeneity Test (Causality Analysis)

Dependent Variable	Excluded	Chi-sq	df	Prob.
HHNGRET	WTIRET	3.94742	8	0.8618
	HORET	31.2536	8	0.0001
	PROPRET	10.8923	8	0.2079
	All	93.0999	24	0.0000
WTIRET	HHNGRET	5.83867	8	0.6653
	HORET	11.0467	8	0.1991
	PROPRET	23.7359	8	0.0025
	All	42.1024	24	0.0126
HORET	HHNGRET	14.6873	8	0.0655
	WTIRET	62.2971	8	0.0000
	PROPRET	10.6915	8	0.2198
	All	92.7824	24	0.0000
PROPRET	HHNGRET	58.6522	8	0.0000
	WTIRET	5.18047	8	0.7381
	HORET	78.4721	8	0.0000
	All	199.639	24	0.0000

From this table, the chi-square result revealed that there is bidirectional causality between Henry Hub Natural Gas return and Heating Oil return. There exists a unidirectional relationship between three pairs and the causality runs from Propane return to Crude Oil return, Crude Oil return to Heating Oil return and Heating Oil return to Propane return. Surprisingly, we did not find any causal relationship between Henry Hub Natural Gas return and WTI crude oil return.

The causality test motivates us to examine the possible long run equilibrium relationship among the energy variables. In order to ascertain the possible existence of co-movement among the variables, we employ Johansen Maximum Likelihood cointegration (1988) test.

Table 9: Co-integration Test among Energy Commodities (Lag 1 to 5)

Null Hypothesis	**Alternative Hypothesis**		**Critical Values**	
□ Trace Test	**□ Trace Test**	**□ Trace Value**	**5%**	**1%**
r = 0	r > 0	77.27	47.21	54.46
r ≤ 1	r > 1	41.48	29.68	35.65
□ Max Test	**□ Max Test**	**□ Max Values**	**5%**	**1%**
r =0	r = 1	35.79	27.07	32.24
r = 1	r = 2	32.28	20.97	25.52

Table 9 summarizes the cointegration result of the energy variables at their level. The test of trace statistics shows that the null hypothesis of variables is not co- integrated (r = 0) against the alternative hypothesis of one or more co integrating vectors (r > 0). Since 77.27 exceed the 5% and 1% critical value of λ_{trace} statistic (in the first panel of table), it is possible to reject the null hypothesis of no cointegrating vectors and accept the alternative of one or more cointegrating vectors. Next, we can use the λ_{trace} (1) statistic to test the null of r ≤ 1 against the alternative of two cointegrating vectors. Since the λ_{trace} (1) statistic of 41.48 is greater than the 5% and 1% critical value, we conclude that there are two cointegrating vectors.If we use the λ_{max} statistic, the null hypothesis of no cointegrating vectors (r =0) against the specific alternative r = 1 is already rejected. The calculated value λ_{max} (0, 1) = 35.79 exceed the 5% and 1% critical values. Hence, the null hypothesis is rejected. To test r = 1 against the alternative hypothesis of r = 2, the calculated value of λ_{max} (1, 2) is 32.28 which exceeds the critical values at the 5% and 1% significance levels are 20.97% and 25.52% respectively. Thus, it is concluded that there are two cointegrating vectors. To further analyze the possible co- integrating relationship among the each pair of energy commodities, we replay the cointegration test among each of the possible pair. These results are reported from the Table 9.1 to 9.6 with their respective lags selected through various lag augmentation criterion.

Table 9.1 Co-integration Test between HHNGSP and WTISP (Lag 1 to 7)

Null Hypothesis	**Alternative Hypothesis**		**Critical Values**	
** Trace Test**	** Trace Test**	** Trace Value**	**5%**	**1%**
r = 0	r > 0	9.66	15.41	20.04
r ≤ 1	r > 1	0.69	3.76	6.65
** Max Test**	** Max Test**	** Max Values**	**5%**	**1%**
r =0	r = 1	8.96	14.07	18.63
r = 1	r = 2	0.69	3.76	6.65

Table 9.2 Co-integration Test between HHNGSP and HOSP (Lag 1 to 5)

Null Hypothesis	**Alternative Hypothesis**		**Critical Values**	
** Trace Test**	** Trace Test**	** Trace Value**	**5%**	**1%**
r = 0	r > 0	10.01	15.41	20.04
r ≤ 1	r > 1	0.18	3.76	6.65
** Max Test**	** Max Test**	** Max Values**	**5%**	**1%**
r =0	r = 1	9.83	14.07	18.63
r = 1	r = 2	0.18	3.76	6.65

Table 9.3 Co-integration Test between HHNGSP and PROPSP (Lag 1 to 7)

Null Hypothesis	Alternative Hypothesis		Critical Values	
□ Trace Test	**□ Trace Test**	**□ Trace Value**	**5%**	**1%**
r = 0	r > 0	11.00	15.41	20.04
r ≤ 1	r > 1	1.85	3.76	6.65
□ Max Test	**□ Max Test**	**□ Max Values**	**5%**	**1%**
r =0	r = 1	9.15	14.07	18.63
r = 1	r = 2	1.85	3.76	6.65

Table 9.4 Co-integration Test between WTISP and HOSP (Lag 1 to 8)

Null Hypothesis	Alternative Hypothesis		Critical Values	
□ Trace Test	**□ Trace Test**	**□ Trace Value**	**5%**	**1%**
r = 0	r > 0	26.36	15.41	20.04
r ≤ 1	r > 1	0.55	3.76	6.65
□ Max Test	**□ Max Test**	**□ Max Values**	**5%**	**1%**
r =0	r = 1	25.80	14.07	18.63
r = 1	r = 2	0.55	3.76	6.65

Table 9.5 Co-integration Test between WTISP and PROPSP (Lag 1 to 6)

Null Hypothesis	Alternative Hypothesis		Critical Values	
□ Trace Test	**□ Trace Test**	**□ Trace Value**	**5%**	**1%**
r = 0	r > 0	28.90	15.41	20.04
r ≤ 1	r > 1	1.02	3.76	6.65
□ Max Test	**□ Max Test**	**□ Max Values**	**5%**	**1%**
r =0	r = 1	27.87	14.07	18.63
r = 1	r = 2	1.02	3.76	6.65

Table 9.6 Co-integration Test between HOSP and PROPSP (Lag 1 to 6)

Null Hypothesis	**Alternative Hypothesis**		**Critical Values**	
□ **Trace Test**	□ **Trace Test**	□**Trace Value**	**5%**	**1%**
r = 0	r > 0	21.31	15.41	20.04
r ≤ 1	r > 1	0.69	3.76	6.65
□ **Max Test**	□ **Max Test**	□ **Max Values**	**5%**	**1%**
r =0	r = 1	20.61	14.07	18.63
r = 1	r = 2	0.69	3.76	6.65

The result from the above table shows a long run relationship between the each pair of energy commodities except between Henry Hub Natural gas and WTI crude oil price.

In order to analyze the volatility spillovers between the USA energy variables, we have employed two widely accepted models in this sphere, *viz,* Generalized Autoregressive Conditionally Heteroscedastic (GARCH) and Exponential Generalized Autoregressive Conditionally Heteroscedastic (EGARCH) model. The logic as to why these models are used to explore volatility spillover has been clearly discussed in the previous section. To start with, the study fits an Auto Regressive Moving Average (ARMA) model of order one. This is carried out primarily to eliminate the first degree auto correlation among the returns, which makes the data amenable for further analysis. This also vindicates the fact that residuals from a fitted model of energy variables exhibit no autocorrelation whereas squared residuals are associated with significant correlation among themselves over time. Infact, this makes the case for applying the ARCH class of models, which are based on this notion. In tune with this, we have presented the results due to fitted ARMA (1, 1) model to respective return series in Table 10, which shows that the ARMA (1, 1) coefficients for HHNGRET, WTIRET, HORET, and PROPRET are highly significant. After fitting the ARMA (1, 1) model we have tested for the presence of autocorrelation among the residuals as well as squared residuals from the fitted model. The results from Ljung Box Q statistics, which are used to test the null hypothesis of 'No Autocorrelation' against the alternative of existence of autocorrelation, are reported in table 10.

Table 10: ARMA Model Fitted to the Data

Variable	**Constant**	**AR(1)**	**MA(1)**	**Q(8)**[5]	**Q^2(8)**[6]	**LM**[7]
HHNGRET	-0.0001 (0.83)	-0.609 (0.00)	0.70 (0.00)	112.85 (0.00)	1525.9 (0.00)	1019.47 (0.00)
WTIRET	0.0003 (0.28)	0.842 (0.00)	-0.865 (0.00)	25.524 (0.00)	726.28 (0.00)	341.40 (0.00)
HORET*	0.0003 (0.39)	-0.617 (0.00)	0.654 (0.00)	40.419 (0.00)	1481.0 (0.00)	310.36 (0.00)
PROPRET	0.0003 (0.46)	0.935 (0.00)	-0.932 (0.00)	35.864 (0.20)	128.42 (0.00)	99.88 (0.00)

- [5] represent L-Jung Box Q statistics for the residuals from ARMA (1, 1) model at lag 8.
- [6] represent L-Jung Box Q statistics for the squared residuals from ARMA (1, 1) model at lag 8.
- [7] represent LaGrange Multiplier statistics to test for the presence of ARCH effect in the residuals from AR (1) model.
- * indicates in case of HORET, ARMA (2, 2) order found to be the best fit.

From the results, it is inferred that the null hypothesis is not rejected in case of residuals whereas it is strongly rejected in case of squared residuals. Prima facie, this creates the case to apply GARCH models. In order to confirm the presence of ARCH effect in the data we go for a LaGrange Multiplier (LM) Test and the result shows that the null hypothesis of 'No ARCH Effect' is strongly rejected in case of all the concerned variables.

Table 11: Volatility Spillover: HHNGRET &WTIRET

Coefficients[1]	**ARMA(1,1) – GARCH (1,1)**		**ARMA(1,1) – EGARCH (1,1)**	
	HHNGRET → WTIRET	**WTIRET→ HHNGRET**	**HHNGRET→ WTIRET**	**WTIRET→ HHNGRET**
c	-0.00012 (0.65)	0.0007 (0.02)	-0.0003 (0.47)	0.0002 (0.31)
τ	0.994 (0.00)	-0.539 (0.40)	-0.869 (0.00)	0.862 (0.00)
τ_1	-0.997 (0.00)	0.529 (0.42)	0.902 (0.00)	-0.889 (0.00)
ω_0	0.00002 (0.00)	0.00001 (0.00)	-0.283 (0.00)	-0.250 (0.00)
β_1	0.130 (0.00)	0.057 (0.00)	0.981 (0.00)	0.979 (0.00)
α_1	0.866 (0.00)	0.921 (0.00)	0.215 (0.00)	0.126 (0.00)
ϕ	-	-	-0.018 (0.00)	-0.052 (0.00)
ψ	0.004 (0.26)	0.0006 (0.02)	-0.870 (0.00)	0.250 (0.13)
LM[2]	1.59 (0.20)	5.04 (0.02)	7.16 (0.00)	6.37 (0.01)

Note:

[1]For description of coefficients the Equations 2 to 5 respectively may be referred in the Methodology Section

[2] represent LaGrange Multiplier statistics to test for the presence of additional ARCH effect in the residuals from ARMA (1, 1) - GARCH (1, 1) and ARMA (1, 1) - EGARCH (1, 1) models.

Table 12: Co-integration of GARCH VARIANCE (HHNG and WTI)

Null Hypothesis	**Alternative Hypothesis**		**Critical Values**	
□ Trace Test	**□ Trace Test**	**□ Trace Value**	**5%**	**1%**
r = 0	r > 0	228.29	15.41	20.04
r ≤ 1	r > 1	76.53	3.76	6.65
□ Max Test	**□ Max Test**	**□ Max Values**	**5%**	**1%**
r =0	r = 1	151.75	14.07	18.63
r = 1	r = 2	76.53	3.76	6.65

Table 13: Cointegration of EGARCH VARIANCE (HHNG and WTI)

Null Hypothesis	**Alternative Hypothesis**		**Critical Values**	
□ Trace Test	**□ Trace Test**	**□ Trace Value**	**5%**	**1%**
r = 0	r > 0	174.40	15.41	20.04
r ≤ 1	r > 1	24.33	3.76	6.65
□ Max Test	**□ Max Test**	**□ Max Values**	**5%**	**1%**
r =0	r = 1	150.06	14.07	18.63
r = 1	r = 2	24.33	3.76	6.65

At the outset in table 11, we present the estimation results of ARMA (1, 1)-GARCH (1, 1) as well as that of ARMA (1, 1)-EGARCH (1, 1) model. It may be pointed out that the study uses the GARCH and EGARCH models of order (1,1) because this order has been found to provide the most parsimonious representation of ARCH class of models and at the same time empirically the acceptability of the order has been strongly proved. Apart from this, we have already discussed the basis on which we have selected EGARCH model as it incorporates the sign of the residuals in the volatility equation and thus distinguishes between bad news and good news. The results presented in table 11 shows that all the coefficients of GARCH equation for HHNGRET to WTIRET obey the restrictions inherent in the model in terms of their signs as well as magnitude. The first panel shows the spillover explained through the use of GARCH models where the residuals have been extracted after estimating the GARCH for each of the markets and the same has been used as the shock (as a proxy for volatility) spilling over to other market. With reference to equation 2 to 5, the coefficient ψ represents the volatility spillover parameter. It may be pointed out here that incase of GARCH model, squared residuals have been used instead of residuals on their level in order to ensure positivity in variance or volatility. This is, however, not the case for EGARCH model as the definition of the model ensures variance turning to be positive. The results in table 11 show that volatility spillover parameter is significant in case of WTIRET to HHNGRET in the GARCH specification and it is exactly opposite in case of EGARCH specification, i.e. the volatility spillover is spilling from HHNGRET to WTIRET. Test for autocorrelation as well as ARCH effect in the residuals and squared residuals also validates the estimation of the models.

The second approach that we adopt to test for volatility spillover is through cointegration analysis. The results of the same are presented in table 12 and 13 respectively. Here first we have extracted the volatility series from each of the models for each market. Then the attempt has been made to explore cointegration relationship, if any, between volatility series from Henry Hub natural gas and WTI Crude oil through GARCH and EGARCH. To examine the cointegration relationship we have used Johansen Maximum Likelihood (1988) procedure.

In table 12, the cointegration result of the volatility series of return of HHNG and WTI is presented. The test of trace statistics shows that the null hypothesis of variables are not cointegrated ($r = 0$) against the alternative hypothesis of one or more cointegrating vectors ($r > 0$). Since 228.29 exceed the 5% and 1% critical value of λ_{trace} statistic (in the first panel of table), it is possible to reject the null hypothesis of no cointegrating vectors and accept the alternative of one or more cointegrating vectors. Next, we can use the λ_{trace} (1) statistic to test the null of $r \leq 1$ against the alternative of two cointegrating vectors. Since the λ_{trace} (1) statistic of 76.53 is greater than the 5% and 1% critical value, we conclude that there are two co integrating vectors.If we use the λ_{max} statistic, the null hypothesis of no cointegrating vectors ($r =0$) against the specific alternative $r = 1$ is already rejected. The calculated value λ_{max} (0, 1) = 151.75 exceed the 5% and 1% critical values. Hence, the null hypothesis is rejected. To test $r = 1$ against the alternative hypothesis of $r = 2$, the calculated value of λ_{max} (1, 2) is 76.53 which exceeds the critical values at the 5% and 1% significance levels respectively. Thus, it is concluded that there are two co integrating vectors. The same result is also concluded from Cointegration of EGARCH variance between HHNG and WTI.

In the similar way, the results of volatility spillovers between HHNGRET and HORET, HHNGRET and PROPRET, WTIRET and HORET, WTIRET and PROPRET, and HORET and PROPRET are generated and we are not presenting these results here in the text because of the space constraint. From these results, it can be surmised that there exists a bidirectional volatility spillover between Henry Hub natural gas return and heating oil return, Henry Hub natural gas return and propane return, WTI crude oil return and heating oil return, WTI crude oil return and propane return. However, there exists unidirectional volatility spillover between heating oil return and propane return in both the GARCH and EGARCH model and the volatility is spilling over from propane return to heating oil return.

Table 14: Random Walk Hypothesis Testing of Market Efficiency

Multiple Variance Ratio Test for Daily Data of the U.S. Energy Markets

Market	Instruments	Lags→	Lag 2	Lag 4	Lag 8	Lag 16	Chow-Denning
Energy	HHNGRET	VR(q)	0.606	0.243	0.122	0.065	
		Z(q)	(-24.31)*	(25.00)*	(18.35)*	(13.13)*	9.68*
		Z*(q)	(9.68)*	(9.05)*	(7.01)*	(5.86)*	
	WTIRET	VR(q)	0.521	0.244	0.127	0.059	
		Z(q)	(29.64)*	(24.99)*	(18.25)*	(13.22)*	
		Z*(q)	(15.93)*	(14.56)*	(11.66)*	(9.22)*	15.93*
	PROPRET	VR(q)	0.471	0.261	0.125	0.061	
		Z(q)	(32.70)*	(24.41)*	(18.27)*	(13.18)*	
		Z*(q)	(5.89)*	(5.25)*	(5.03)*	(4.72)*	5.893*
	HORET	VR(q)	0.488	0.271	0.120	0.062	
		Z(q)	(31.65)*	(24.10)*	(18.39)*	(13.17)*	
		Z*(q)	(7.80)*	(7.22)*	(5.75)*	(4.54)*	7.801*

The empirical results of Chow and Denning (1993) test are provided in Table 14. For a comparison purpose, the individual variance ratios (Lo and MackKinlay variance ratios) and corresponding homscadasticity and hetroscadasticity robust test statistics for various investment horizons like 2, 4, 8, and 16 are presented in the table. From this result, we have concluded that all the energy markets in U.S. reject the random walk hypothesis. This result has also confirmed that energy markets are not following the weak form of efficiency.

CONCLUSION

This paper analyses the U.S. daily spot price data for Henry Hub Gulf Coast Natural Gas, Cushing WTI Crude Oil, New York Harbor No. 2 Heating Oil, Mont Belview, TX Propane in order to understand the nature of the existing relationship both at price and their respective price volatility level among these commodities. Using the time series Ordinary Least Square approach, we found that the return on Henry Hub Natural gas is well explained by the explanatory variables such as the return of WTI crude oil, Heating oil, propane and the lagged past values of its own i.e. Hennery Hub natural gas return. The result of short run dynamic relationship through the Toda and Yamamoto (1995) procedure to test for Granger causality in the Vector Auto Regression (VAR) block erogeneity format revealed that there is a bidirectional causality between Henry Hub Natural Gas return and Heating Oil return. There exists a unidirectional relationship between three pairs and the causality runs from Propane return to Crude Oil return, Crude Oil return to Heating Oil return and Heating Oil return to Propane return. Surprisingly, we did not find any causal relationship between Henry Hub Natural Gas return and WTI crude oil return. The long run equilibrium relationship is investigated using a cointegration approach. By employing the Johansen Maximum Likelihood procedure, two co-integrating relationship found, implying one common trend among the four commodity price series. The common trend may be interpreted as one source of randomness affecting the dynamics of the three other commodities within each market.

To further analyze the possible co integrating relationship among the each pair of commodities, we rerun the cointegration among each pair. This witnesses a long run relationship between the each pair of commodities except between Henry Hub Natural gas and WTI crude oil price. Finally the price volatility spillovers among the Energy commodities are examined by using ARCH school of models such as GARCH (1, 1) and EGARCH (1, 1). We found that there is a unidirectional volatility spillover from HHNGRET to WTIRET as per GARCH specification and as per EGARCH specification, the unidirectional volatility spilling from WTIRET to HHNGRET. This result is quite contradictory to each other. However, there exists a bidirectional volatility spillover between Henry Hub natural gas return and heating oil return, Henry Hub natural gas return and propane return, WTI crude oil return and heating oil return, WTI crude oil return and propane return. There exists a unidirectional volatility spillover between heating oil return and propane return in both the GARCH and EGARCH model and the volatility is spilling over from propane return to heating oil return. In general, the results of significant bidirectional volatility spillover suggest that there is an information flow (transmission) between these markets and these markets are move in tandem and integrated with each other.

We found a surprising result that there is no short term and long run equilibrium relationship exists price, return, and volatility level of natural gas and crude oil. This result is contradicting the previous research despite of the fact that the study period considered in the present study in compare to previous research is not similar. This also contradicts the economic theory which suggests that the existence of the relationship between natural gas price and oil prices being competitive and substitutes and complements in the industrial production. This may be due to the gradual deregulation of natural gas market to move in some more independent way and the current oil price dynamic not exclusively linked to the market forces of supply and demand conditions, may cause this relation to fail. This finding suggests for further research on identifying the various demand and supply drivers for the price volatility of natural gas market in the U.S. Finally, we found that energy markets in the U.S. are not following the weak form of efficiency.

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