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The end of a long term relationship between the price of crude oil and natural gas

A cointegration approach

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Abstract

In this master thesis we explore the relationship between the natural gas price and crude oil price in the U.S. We find that the prices have been cointegrated in the period from 1997-2006, and that the prices have decoupled in the period after this. We have discussed factors explaining the historical coupling of the prices, and factors explaining why the prices have decoupled. We argue that the main reason for decoupling is the shale gas production boom in the U.S. We find no single main reason for the historical cointegration relationship, but argue that this is a sum of many different factors. Many of these based on an energy arbitrage argument. We also discuss the future outlook for this price relationship, with special focus on expectations about the future developments in the natural gas market. Following this we have a discussion around the implications of the currently low natural gas price, and high crude oil price on the economics of gas to liquids technology in the U.S.

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Introduction

Natural gas and crude oil are both primary sources of energy. Production of both crude oil and gas use similar technology and are often discovered together in reservoirs. Natural gas and crude oil are close substitutes in several end use markets. This is however where the similarities stop. While the market for crude oil is a global market, with vast amounts of trade globally, natural gas is much more expensive to transport and store thus limiting global trade and creating many different regional markets. Despite the differences between the two markets, crude oil and natural gas prices have been moving together historically, and extensive research supports this through the use of cointegration tests.

We argue that the price of crude oil and the price of natural gas have shared a long-term relationship in the period 1997 – 2006, mainly because they are both primary carriers of energy. Next we argue that this relationship no longer exists after large quantities of cheap shale gas were put to market after 2006.

The advances in horizontal drilling and fracking technologies made vast amounts of onshore gas shales economical to develop in recent years, which have led to a drastic increase in production of natural gas in the U.S. While the increased demand for crude oil continuously has to be met from more expensive sources, the relatively stable natural gas demand in the U.S. is met by cheap and plentiful shale gas. This fundamental difference is likely to prevail in the foreseeable future, as we believe the supply of natural gas in the U.S. will stay at high levels even if prices for natural gas are at low levels. This is due to limited export capacity, dry gas production from oil fields and wet gas fields that will be developed regardless of the natural gas prices, and continued production from already developed shale gas fields. All these factors flood the market with natural gas, resulting in low natural gas prices.

The decoupling of the natural gas and crude oil market has created new possibilities for energy intensive energy industry and industry that uses natural gas as a feedstock. The cheap natural gas in the U.S. has lead SASOL, a South African energy company, to evaluate building a large scale gas to liquid facility in Louisiana. Gas to liquids is a process of converting natural gas into products that traditionally are refined from crude oil, such as diesel and kerosene. The spread between natural gas and crude oil is of great importance to a gas to liquids producer, because the price of natural gas determines the costs, while the price of crude oil determines the price of the end products. The possible development of gas to liquids in the U.S. is interesting because it contradicts with the historical record of developing gas to liquids in areas where there is no natural gas demand, but substantial natural gas resources. It is also very interesting from an energy policy viewpoint, but that is out of the scope of this paper.

We analyze the link between the price of natural gas in the U.S. and crude oil, with the use of cointegration tests and empirical investigation of the supply and demand factors that have traditionally linked the two energy sources. We combine the results from the empirical investigation with the cointegration tests to explain the link and decoupling observed in the data. Finally we discuss the implications of the decoupling, the future outlooks for the dry gas market and the possibilities this creates, with special focus on the opportunities for the gas to liquids industry in the U.S.

The market for crude oil and natural gas

The size and fundamental structure of the U.S. natural gas market is very different from the world market for crude oil. To fully appreciate the analysis of the demand and supply links between natural gas and oil it is important to have an idea of the fundamentals in the two markets. This part is not meant to explain any co-movement or why the two prices decoupled, but as a support for our further analysis of the link between the two commodities.

The world market for crude oil is about 6.7 times larger than the U.S natural gas market (BP , 2012). Crude oil is a product that can easily be shipped around the world and stored for long periods of time, due to cheap shipping and storage relative to the product value. Natural gas can be shipped through pipelines, and on liquid natural gas ships. Shipping of natural gas is quite expensive because the natural gas has to be liquefied before entering the ship, and then regasified once the ship has reached its harbor. Natural gas can be stored, but it is voluminous, so there is a lack of storage possibilities. Because of these fundamentals, the oil market and the U.S. natural gas market are quite different. The market for oil is the world's largest commodity market (Deutche Bank, 2010). There is no world market for natural gas, but regional markets that are interconnected by some liquefied natural gas trade. The US natural gas market is viewed as the most efficient and liquid market for natural gas in the world (Deutche Bank, 2010).

For our analysis of the co-movement and later decoupling between the oil and natural gas price, these fundamentals have some implications. The main one is the fact that the price of oil is set on the world market, while the price of natural gas is set in the U.S. Any changes in the U.S. consumption of energy will impact the price of natural gas much more than the price of oil. In our analysis we therefore assume that the natural gas market in the U.S. will have limited effect on the crude oil price, but that the crude oil price could affect natural gas market.

GTL – History and technology

The high spread between natural gas and crude oil has sparked the gas to liquids industry's interest in the U.S. Gas to liquids is a technology that converts natural gas to produce high quality, high value liquid fuels such as diesel, gasoline, jet fuel and naphtha. As these liquid fuels are traditionally refined from crude oil they are also closely linked to the price of crude oil. This makes the relationship between natural gas and crude oil interesting to examine, as this spread lays the foundation for whether or not gas to liquids is economic to develop. The current high spread between the two leads us to believe that the gas to liquids technology can be profitable. This is also based on our argument that the prices are no longer cointegrated, meaning that the prices are not likely to converge over the medium to long term. In addition, the gas to liquids industry could play a role in reducing the U.S.'s dependence on crude oil. Below we give a short introduction to the technology in order to provide a backdrop for the later discussion about the implications of the decoupling between the natural gas and crude oil prices on the gas to liquids technology.

The gas to liquids technology uses a process known as Fischer-Tropsch synthesis that was developed in Germany during the 1920´s. (Heng & Idrus, 2004) This technology was used at the time to convert coal to gas (often referred to as syngas) and then to liquids. At this time the technology was not economically competitive compared to standard oil refining, but was used to fulfill a petroleum supply shortage. The technology fueled Nazi Germany´s war machine during the second world war. The first commercial use of the Fischer-Tropsch was developed by SASOL in South Africa in the 1950s (Rahmim, 2003). The world´s first commercial scale gas to liquids plant was built by Petro SA in 1992 in Mossel Bay South Africa with a capacity to produce 36,000 barrels per day (White, 2012). One year later Royal Dutch Shell opened its first commercial facility in Bintulu Malaysia with a capacity of 14,700b/d. Shell and Quatar owned Pearl GTL is currently the worlds largest GTL facility and opened production in 2011 with a capacity of 140 000 barrels per day. Pearl GTL cost 18-19 billion $ to develop (Shell).

The Fischer-Tropsch is the most widely used technology in gas to liquids facilities. (Wood, Nwaoha, & Towler, 2012) It follows three steps. First Natural gas is mixed with oxygen and transformed into synthesis gas (syngas). Second syngas is processed in reactors to create synthetic crude or syncrude. The final step is the product refining, also called cracking. In this step syncrude is refined into diesel naphtha and lube oils through a conventional refining process. The different facilities around the world have developed different technologies to integrate these three steps and optimize efficiency, but the three step process is common to all facilities. (International Gas Union, 2007)

We will only briefly mention that there are different types of reactors, different catalysts, high temperature and low temperature processes, and also possibilities to adjust the process in order to get the desired product distribution and a range of product slates. Since our field of study is economics we decided not to look further into these differences. However for interested readers the book Fischer-Tropsch Refining by Arno de Klerk should give deeper insight into the more technological aspects of the gas to liquid process. This book also includes chapters about the different commercial scale technologies existing today.

Diesel is the main product from the gas to liquids process. In addition we get gasoline, kerosene for use in jet fuel, lubricants and naphtha as a primary feedstock for plastics production. The common denominator for all these products is that they all have superior quality and lower emissions compared to the same products refined from crude oil (Sasol, 2011). This should in theory make these products obtain a price premium compared to the crude oil refined products, however as we think this premium would be limited and the uncertainties of the prices to be high, we have decided to disregard this in the later discussion. This premium could however prove a significant factor under a U.S. emission tax.

Price developments

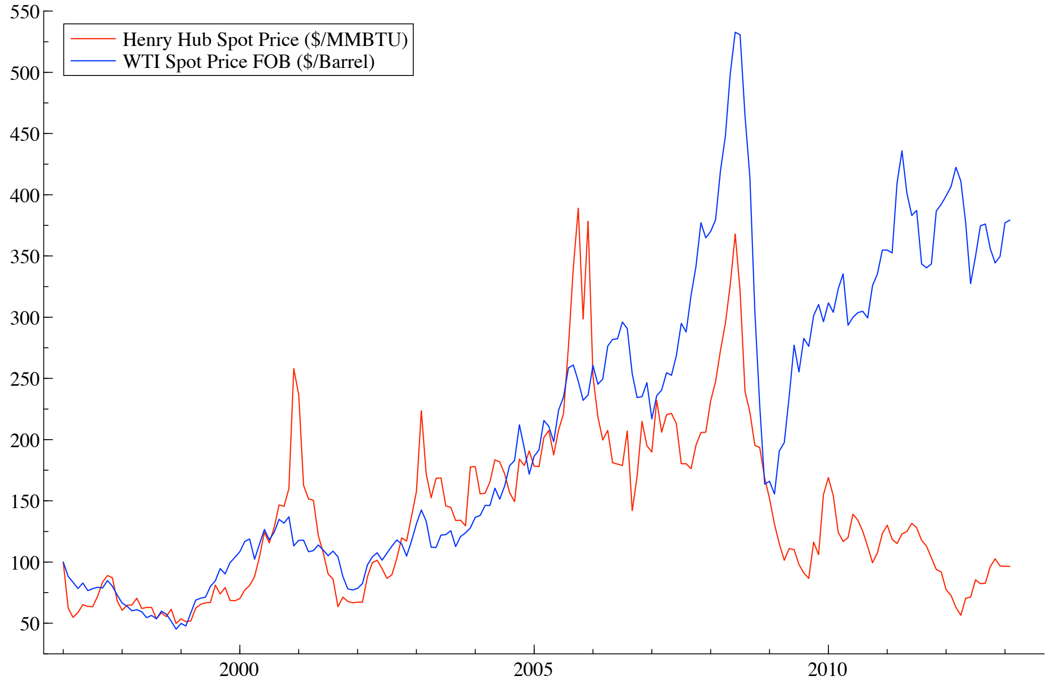

Figure 1: Indexed natural gas and crude oil prices. Source: EIA

In the figure 1 above we have plotted the indexed monthly prices of crude oil and natural gas from 1997 up until today. If we look at the price developments it is clear that in the period up until 2006 the developments in the price of crude oil and the price of natural gas is following each other closely. This is due to the fact that the two prices are linked by many factors both on the supply side, and on the demand side. We can notice that the price of natural gas is more volatile than the price of crude oil, with some distinct spikes in the period up until 2006. This can be explained by the fact that the regional natural gas market is much smaller than the global oil market, and that demand or supply shocks in the natural gas market, with limited opportunities for trade and storage, more directly impact the price. We would also argue that the prices of natural gas and crude oil are not connected in the short term, partly because there are limited possibilities of short-term substitution between the two. We can also see this in the graph by noting that the prices have spikes and dips in different months. However the long-term development as mentioned before is clear in the period up until 2006.

In 2006 a rapid increase in shale gas production started in the US, and shale gas production has continued to increase up until today. Since US proven natural gas reserves has increased significantly in the period after 2004, and natural gas production increases significantly after 2006. This has led to a large increase in supply of natural gas, which can explain the price developments we observe in the graph above. The large increase in the proved natural gas reserves from cheap shale plays will provide a continued high supply of low cost natural gas. This leads us to believe that the price of natural gas will remain low for many years to come.

We argue that the price of natural gas and crude oil have decoupled after 2006. We can observe that from 2006 the indexed price of natural gas falls below that of crude oil and stays below up until today. In addition we can note that after 2009 the price of crude oil starts to recover from the dramatic fall during the financial crisis. In this same period the price of natural gas continues to decline, and is currently at a level similar to that in 1997, and less half of what the price was in 2006. The price of crude oil has quadrupled since 1997, and nearly doubled since 2006.

Price Spread

Historically a much used rule of thumb for the price relationship between crude oil and natural gas has been that the crude oil price should be 6 times higher than the price of natural gas. This is probably because 1 barrel of crude oil is equivalent to 5,8 million British thermal units (MMBTU) (U.S. Energy Information Administration, 2013). In the figure 2 below we look at the spread between the price of WTI crude oil and the Henry Hub price of natural gas. The WTI price has been converted from $/barrel to $/MMBTU using the aforementioned 5,8 MMBTU/barrel. As

British thermal unit is a measure of energy we now have a spread directly comparing the cost of energy from natural gas and from crude oil.

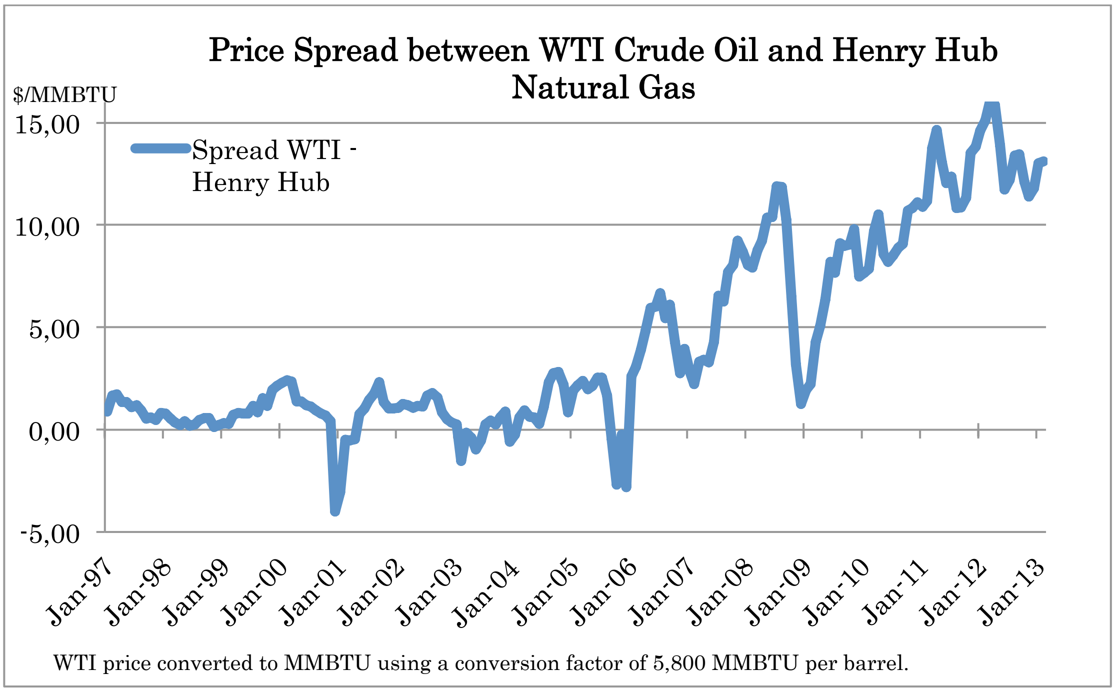

Figure 2: Price Spread Crude oil – Natural gas in $/MMBTU. Source: EIA

In the period before 2006 we would argue that the spread should be fairly stable, since the prices tend to follow each other. The long-term trend is fairly stable, however with some shorter periods of spikes and dips supporting our argument that the prices move together in the long term, but not in short term. We expected the spread to be positive due to the fact that crude oil is less bulky and cheaper to transport suggesting a price premium with regards to energy content. From 1997-2006 the spread is trending just below 1$/MMBTU with an average of 0,79 over this period. After 2006 we see the spread trending upwards for the same reasons mentioned in the price developments section. In addition the spread does not appear very stable even in the last couple of years. This supports our argument that the prices have been permanently decoupled, and not recoupled on a higher spread.

Returns, volatilities and correlations

To further investigate the price series developments and the relationship between the price of crude oil and natural gas, we calculated average returns, volatilities and the correlations of both sub periods and the time period as a whole. We use logarithmic returns throughout this section, and the numbers presented are annualized. The results are presented in the table 1 below

Annualized monthly returns and volatilities of Natural Gas and Crude oil				
	Henry Hub		WTI	
	Avg Return	Volatility	Avg Return	Volatility
1997-2013	-0,096 %	0,21	3,60 %	0,13
1997-2006	6,48 %	0,22	4,19 %	0,12
2006-2013	-6,76 %	0,20	2,86 %	0,14

Table 1: Returns and volatilities of crude oil and natural gas

Now if we look at the Henry Hub natural gas price, we see that the average annualized return throughout the whole period is close to 0, in the first half of the period the annual average price growth is 6,5% and after the shale gas started to come to the market the average annual decline in prices have been -6,8%. These observations are simply the same as we saw in the graph of the indexed prices in the previous section. For the crude oil price we see positive average growth rates in both sub periods, resulting in an overall average annual price growth of 3,6%. These numbers show that in the period from 1997-2006 both prices trend upwards at fairly similar growth rates. This clearly changes after 2006, with the price of crude oil continuing upwards, while the gas price shows a significant decline.

From examining the volatilities we can confirm our observation from the price graph that the price of natural gas is more volatile than the price of crude oil. The volatilities of both price series do not appear to have changed significantly. The volatility of crude oil can appear to increase after 2006, however these numbers are biased by the very high volatility during the financial crisis. By calculating the volatility from 2009 up until today we find the volatility of crude oil to be 0,11, a seemingly un-significant change. Before doing the same procedure with the price of natural gas we already observe that the volatility has decreased slightly. The volatility of natural gas after 2009 is 0,18. These developments lead us to believe that the reason for the decoupling of the two prices is in fact coming from the changes in the gas market. In other words, we believe that the gas price has decoupled from the price of crude oil and not the other way around.

Next we computed the correlations between the crude oil returns and the natural gas returns. As correlations is a measure of the short-term co-movements of the returns, with a maximum of 1(perfectly correlated) and a minimum of -1 (perfect negative correlation). A correlation of 0 means that the returns do not co-move together at all. We decided to include the correlations of the weekly returns in order to examine the correlations in an even shorter term. The results are found in the table 2 below.

Correlation between Natural Gas and Crude oil Returns		
	Monthly	Weekly
1997-2013	0,24	0,194
1997-2006	0,33	0,190
2006-2013	0,14	0,192

Table 2: Correlations between crude oil and natural gas

We can see that overall the correlation between the returns are quite low, meaning that there is not a close relationship in the short term. We can see that the weekly return correlations are relatively stable throughout the time periods. We note however that the weekly return correlations are lower than the monthly return correlations in the period from 1997 – 2006. We interpret this as an indication that the longer term (monthly) relationship is closer than the short-term (weekly) relationship. In the monthly correlations we see a clear decrease from the first sub period to the next. This is in support of our argument that the prices have decoupled and that they do not share a relationship anymore. Why this is not apparent in the weekly returns, we are not quite certain of, but a possible explanation is that there is much more noise in these returns and that they do not reflect the actual relationship very well. In conclusion we can say that the correlations support our argument that the two prices are not closely linked in the short term, and that the small link that exist has become even smaller in the period 2006-2013.

As correlations are limited only to explain short-term co-movements we will explore the long-term cointegration relationship. Cointegration is often used to describe economically meaningful equilibrium relationships such as commodity market arbitrage and purchasing power parity. These theories states that in the short run prices of similar products in different markets might differ, however arbitrageurs will limit how far the prices might mover apart (Enders, 2010). As crude oil and natural gas are both carriers of energy, cointegration may be explained by energy arbitrage .

Presentation and review of previous research

There is a substantial amount of papers describing the cointegration relationship between the price of natural gas and the price of crude oil. The standard procedure is to use either Engle & Granger or Johansens test for cointegration, and then produce an error correction model based on this. We are only interested in finding evidence that the prices of natural gas and oil have decoupled, so an error correction model is not of interest for our paper. We use the Engle and Granger two-step procedure for cointegration tests.

All the research suggests that the relationship between natural gas and crude oil changed or ended in the latter part of the last decade. Ramberg and Parsons (2012) argue that the oil and natural gas price are cointegrated in the period 1997-2010, but that the relationship is changing over time and is weak. They test for breaks in the cointegration relationship, and find a break in the start of 2009 and in 2006. Brigida

(2012) rejects cointegration in the period 1997-2012 when he uses a standard one-state cointegration test. However, when he employs a Markov-switching cointegration analysis, with two-states, he can confirm cointegration for the same period. Brigida (2012) is the only one that uses a cointegration test with a regime shift. To what degree the authors have confirmed if the price relationship decoupled depends on the time of writing – and hence the availability of data, and chosen time period for the cointegration tests among other things. Erdős (2012) find that the natural gas decoupled from the oil price in the period after 2008.

Time series analysis section

We will now do formal testing on the relationship between the price of natural gas and the price of crude oil. We want to get a formal empirical confirmation that the two prices are in fact cointegrated in the years up until the shale gas developments. We also want to see if our visual observation and argument that the prices have in fact decoupled after 2006 is supported by formal testing. As potential GTL investments are long-term investments we will examine the long run relationship between the oil price and the gas price. A paper on this exact topic states that a shock to the price of WTI crude oil has an effect on the price of natural gas, but the effect of a shock to the natural gas price on the price of WTI crude is negligible (Villar & Joutz, 2006). We decided to use this in our discussion as this seems reasonable due to the relative size of the two markets.

Data

We collected monthly prices for Henry Hub natural gas and WTI Crude oil from the period January 1997 – December 2012 in order to follow the relationship a while back. The reason for collecting monthly data instead of weekly or daily data is because we are exploring long-term relationships between the price series. Using weekly or daily data would tell us more about short-term effects, but would cause a lot of noise in the long-term time series. We have also noticed that it is quite common to use logarithmic price series, however we decided to do our main analysis of the price series. In addition we do all computation and statistical analysis also on the logarithmic prices and on the weekly prices, as a sort of robustness check of our results.

Exploring Time Series Properties

In order to explore the long-term relationship between two variables X & Y, here price of crude oil and price of natural gas, we use Engle-Granger two-step procedure (Engle & Granger, 1987). First we need to examine whether or not the price series of natural gas and crude oil are first order integrated I (1). This means that the price time series is non-stationary, but the first difference or the price change time series are stationary. Stationary time series are stochastic processes with a finite mean and variance. In a simplified sense, it means that the mean and variance are approximately constant across time. If both the oil price series and the gas price series were to be stationary, one could model a relationship through a regression. By inspection neither of the two price series appear stationary. By looking at the WTI crude oil price series it is obvious that this does not have a constant mean, this also seems clear for the natural gas price series. To formally test this we use the augmented Dickey Fuller unit root test to find out if the price series are non-stationary, and to see if the price change series are stationary. If the augmented Dickey Fuller test rejects the null hypothesis of non-stationary time series, we conclude that the series is stationary. For a further description of the Dickey Fuller test see Appendix I.

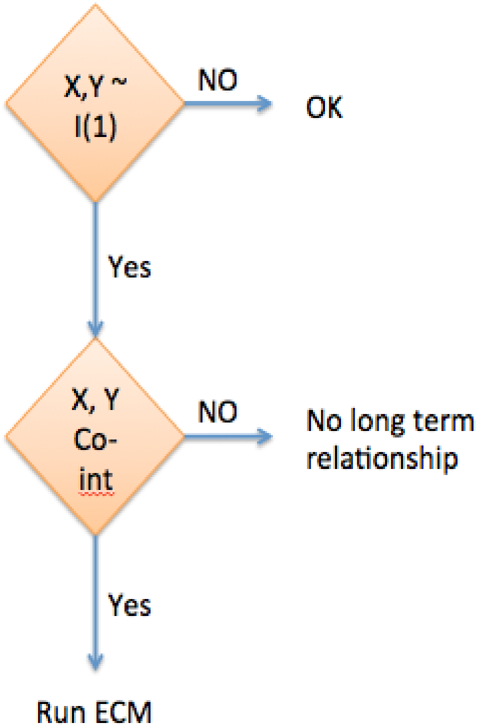

Figure 3 Engle & Granger two-step

We explored the properties of the prices of natural gas and crude oil, both with weekly and monthly frequencies. We also explored the properties of the logarithm of the monthly prices. We tested for unit roots as explained above and determined the order of integration. The results of the monthly price series are presented in table 3 below. The weekly and log monthly properties can be found in appendix II.

Augmented Dickey Fuller unit root test of prices and returns						
	Monthly					
	1997 -2013		1997-2006		2006-2013	
	Henry Hub	WTI	Henry Hub	WTI	Henry Hub	WTI
Prices						
Optimal lag length	0	6	2	5	10	2
T value ADF	-2,516	-1,187	0,8317	0,3143	-1,814	-3,396*
First differences (Returns)						
Optimal lag length	0	5	0	4	9	0
T value ADF **	-14,09	-7,107	-9,853	-3,61	-5,596	-5,661
Order of integration	I(1)	I(1)	I(1)	I(1)	I(1)	I(0)
Critical t-value 5% confidence	-2,88	-2,88	-2,87	-2,87	-2,9	-2,9
Critical t-value 1% confidence	-3,47	-3,47	-3,45	-3,45	-3,51	-3,51
* H0: Non stationary series rejected at 5% level of confidence						
** All first difference series reject non-stationarity on 1% level of confidence						
Critical Values from output in PC Give						

Table 3: Unit root test of monthly prices and returns

Table 3 shows the results for the two sub-periods and the period as a whole. The optimal number of lags for each test, selected using Akaikes information criteria, is presented. We also present the t-values of the augmented Dickey Fuller tests. We can see that all returns series reject the null hypothesis of non-stationarity. For the prices all of the series contain unit roots, and we cannot reject the null hypothesis of non stationarity. The exception here is WTI crude oil in the period from 2006-2013 where non-stationarity is rejected at a 5% level of confidence. This means that a test for cointegration is not meaningful in the period from 2006-2013. These results are confirmed by the log monthly prices. For the weekly prices both the natural gas and crude oil price series are stationary in the period 2006-2013, meaning that we could try to model a linear relationship between the two. We expected the weekly prices to contain more noise than the monthly prices. If this variance was higher, but constant within some months this would dominate the variance between the months. This could be an explanation to why we got different results using weekly data. We did not find any significant difference in the variance using weekly than monthly data in the period from 2006-2013.

However we do find sub periods within this period where the variance in the weekly data is clearly higher than in the monthly. As this is not an essential part of our thesis, we did not investigate this further, but it highlights the importance of selecting proper data intervals.

Testing for cointegration

Now that we have found evidence that both the natural gas price and the crude oil price are non-stationary and the first differences are stationary for the periods 1997-2013 and 1997-2006 the next step is to examine whether these prices are cointegrated. If two price series are cointegrated a linear combination of the non-stationary time series will provide stationary residuals. This means that they share a long-term relationship that can be described through an error correction model. Further explanation of the cointegration testing framework can be found in appendix III.

We defined the cointegration vector as $P_t^{Gas} = \alpha + \beta P_t^{Oil} + \varepsilon_t$ and ran an ordinary least squares regression of this relationship. The residuals were stored in a separate time series. The residuals were then tested for stationarity using the same procedure as we did for the prices and returns series. However this time we did the unit root test without a constant, as this in most cases improves the estimate (Sjö, 2008). As before we did the same analysis for log monthly and weekly prices as robustness checks. The results from the cointegration tests are presented in table 4 below. In addition a more extensive table from the test can be found in appendix IV, where we also included the constant in the unit root test of the residuals as a robustness test.

t-values from Augmented Dickey Fuller test on residuals from Cointegration regression			
	1997-2013	1997-2006	2006-2013
Monthly	-2,57	-3,35*	-1,78
Log Monthly	-2,14	-3,27*	-1,62
Weekly	-2,88	-4,20**	-2,33
* Rejected on 10% level of significance			
** Rejected on 1% level of significance			

Table 4: Cointegration test results

We can see that the unit root test on the residuals in the period 1997-2006 rejects the null hypothesis of non-stationarity on a 10% level of significance. This is not a very high significance level, but we can conclude that the oil price and the price of natural gas is cointegrated, and share a long term relationship in the period 1997-2006, with fairly high confidence. Furthermore we see that for the period 2006-2013, the null hypothesis of no cointegration cannot be rejected. We have already concluded this since WTI crude oil price series was stationary for this period, testing for a cointegrating relationship was not meaningful. We chose to do it anyhow, because of the high lag dependence of this result, and as we see the conclusion remains the same. Through these tests we have first of confirmed our argument that the price of crude oil and natural gas has been sharing a long-term relationship up until 2006. Second we have confirmed that the prices no longer share a long-term relationship and have decoupled after 2006. We should also note that in the overall time period from 1997-2013 there is no cointegration for the obvious reason that the cointegration ended around 2006.

The results from testing the log monthly series support the conclusions presented above. There are only small differences in t-values from the tests, but the conclusions are exactly the same. For the weekly prices we however find that cointegration is found on a 1% level of significance in the period 1997-2006, meaning that we can be certain that the weekly prices are cointegrated in this period. Whether or not we include a constant in the unit root test of the residuals does not affect our results or the conclusion.

Sensitivity of the results

Some of our results are highly dependent on the number of lags we select in the unit root test. We have included more extensive tables where we explore the stability of the results for different number of lags. These can be found in appendix V. We also explored the additional time periods from 1997-2009 and 2009-2013 as this is a more commonly used point of decoupling. We wish to show evidence that the prices have decoupled, but it is not the aim of this thesis to state an exact breaking point. Exploring the additional time period will give insight into the time dependence of the results.

When we explore the lag dependence of the results on the monthly price series, we find that for the whole period and the first sub period the prices are non-stationary for all lags. However in the final period from 2006-2013, 5 out of 11 lag selections for the Henry hub price reject the null hypothesis of non-stationarity. For the WTI crude oil price series 4 out of 11 reject the null of non-stationarity. We are therefore not very confident of the results we find here. We could have used additional lag selection criteria to increase our confidence in the result, however this is not essential for our overall analysis.

For the return series we only find lag dependence for the returns in the period 1997-2006. The returns show slight lag dependence, with 4 of 11 and 2 of 11 lags for Natural gas and crude oil being non-stationary. This is only for a few lags and the rejection of non-stationarity is at 1% for many of the lags. We are therefore fairly confident when we conclude that the returns are stationary.

When we test the residuals of the cointegrating equation we find that the results of both the overall period, and the period from 2006-2013 are not dependent on the number of lags in the unit root test. In the period from 1997-2006 we find that 7 out of 11 lags suggest cointegration. The remaining lags all give fairly high t-values, which leaves us confident that the series are cointegrated in this period.

The results from the period 1997-2009 and 2009-2013 leads us to the same conclusions, however for this period we can say with certainty that both the crude oil price and the natural gas price series are I(1), since non of the tests show lag dependence. The cointegration test does not reject the null hypothesis of no-cointegration in the period 2006-2013, a result that is not lag dependent. In the period 1997-2013 the results of the cointegration test show that 9 out of 11 lags rejects the null of no-cointegration. This fact leads us to conclude with confidence that there is a cointegrating relationship in the beginning of the period, and that this relationship ceases to exist in the period between 2006 and 2009, much likely as a result of the growing importance of shale gas production.

Implications of the results

Now that we have found evidence for our argument that the price of crude oil and the price of natural gas in the US have shared a long-term relationship up until 2006, and that the prices have decoupled in the years after this. We will now comment on the implications of these results. In the period up until 2006 there was information to be found in the price of one commodity upon the price of the other. The relationship could in the period be modeled using an error correction model, in such a way that shocks to the price of crude oil could would be absorbed into the price of natural gas over a period of time. We have not explored the causality of the relationship, but the paper “the relationship between crude oil and natural gas” (Villar & Joutz, 2006) states that oil price changes affects the gas price but the gas price cannot affect the oil price, a reasonable assumption due to the size difference of these markets. When the prices now have decoupled, shocks to the oil price no longer affects the price of natural gas. This can be explained by a number of factors on both the supply side of the natural gas market, but also on the demand side. We argue that the main factor is though the fact that the market after 2006 have seen significant increases in the production of shale gas. A more extensive analysis of the different factors that speak for a relationship and then a decoupling of the two prices can be found in the section on oil and gas market links.

After 2006 when the prices no longer share a co-integrating relationship this has the important implication that even though the price of crude oil has doubled after this, the decupled gas price has not followed this increase. Previously we would have expected the gas price to follow in the longer-term. This could affect investment decisions both on the supply and demand side of the gas market. Where investors previously could use information from the crude oil market together with the supply demand situation in the gas market, one should now look at the natural gas market in a more isolated manner.

For companies considering investment in the gas to liquids industry, this has an impact, as they will be competing against refineries using crude oil as feedstock. The competitiveness of a gas to liquids producer is essentially dependent on the spread between the natural gas and crude oil price. Under a cointegrating relationship this spread would stay fairly stable in the long term. Now that the prices have decoupled we will expect the spread to be more random and affected by both the volatility in the oil market and the volatility in the gas market, which can pull in different directions. An important note to make though is that the spread has become a lot more beneficial for a potential gas to liquids producer. Whether or not this will last is beyond the scope of this thesis, but we will give a brief discussion of this in the section about gas to liquids.

Supply Factors: Natural gas and Crude oil

There are various mechanisms on the supply side that link the natural gas production to crude oil production. Oil and gas are often found together in reservoirs, the drilling technology and costs are the same, and the natural gas price in other regions of the world have been and still is linked to the oil price through long term contracts. In addition there are several factors that drive the prices in opposite directions, such as natural gas production from associated gas and wet gas fields. We also want to see if there are any indications of changes within some of these factors. Especially we want to address what effect these factors has had on the price co-movements historically, how it has been in the recent years when the prices seems to have decoupled, and what we can expect about the future developments from these factors.

Natural Gas Supply

When natural gas is discussed one usually refers to methane as the primary chemical component. However natural gas resources often contain some smaller proportions of ethane, propane and butane, which are usually extracted and sold separately. These heavier gases are usually referred to as natural gas liquids (NGL). The terms “wet gas” and “dry gas” are widely used when considering natural gas. Wet gas then refers to unprocessed gas, while dry gas is processed gas where heavier components have been extracted.

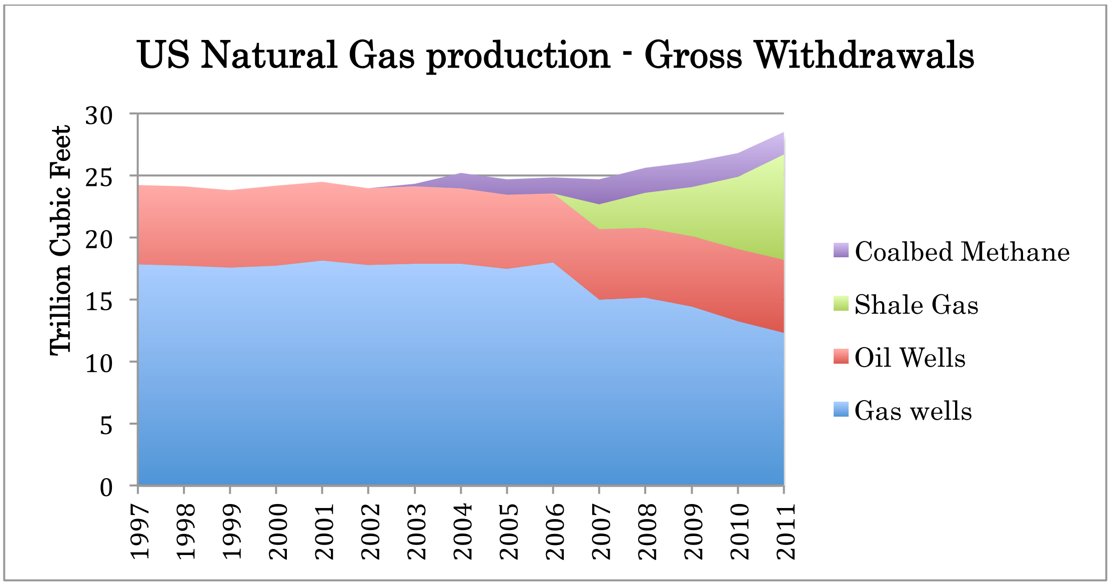

Figure 4: Natural gas production. Source EIA

Figure 4 above shows total gross withdrawals of natural gas from different sources in the US. We can clearly see that the main source of gas stems from gas wells, however after 2006 this production source starts to decline. Natural gas from oil wells, associated gas, is also a significant source of natural gas production. Over the period this source of production has declined slightly, but seems a fairly stable source. What should however be mentioned is that natural gas is often pumped back into oil reservoirs in order to increase pressure and thereby oil production. Assuming that gas used for re-pressuring comes from oil wells, the amount of gas used for re-pressuring is on average close to 60% of gross natural gas withdrawals from oil wells. Meaning that only about 40% of the gas is marketed. In figure 4 we can see that since 2006 the amount of shale gas being developed has increased significantly. In 2007 shale gas accounted for 8% of total gross withdrawals of natural gas, for 2011 the corresponding share is 30%.

An interesting observation to make from figure 4 is that in the period after shale gas production started total production of gas increased, but the production from gas wells decrease significantly. It appears that shale gas has replaced the conventional gas wells to some extent. A possible explanation discussed further in a later section is that the drilling capacity is switched from drilling gas wells, to drilling oil wells or shale plays since the conventional gas wells are less economical to develop at the current low gas price. It could also be that conventional gas wells are in the decline phase of production.

The shale gas boom

Shale gas is natural gas trapped in shale formations – a type of sedimentary rocks (EIA, 2012). Shale gas is produced by hydraulic fracturing, or "fracking", and using horizontal drilling techniques. Improvements in these technologies have drastically increased the economic viability of shale gas production in recent years. If we look at figure 4 in the previous section we can see the massive increase in production from shale gas in the years after 2006. In 1997, which is the starting point of our analysis, shale gas accounted for 1.27 % of the total gas production in the U.S. In 2011, 34 percent of all natural gas produced in the U.S. was from shale plays. The real production boom started around 2006, and from that year it has increased rapidly every year, becoming a dominant source of natural gas in the U.S. The fact that the production took off around 2006 supports our initial assumption that the prices have decoupled in the period after 2006. This increased production from shale gas, is very likely the most important driver behind the decoupling we have seen between the oil and natural gas price.

Proven reserves

The U.S. proven reserves has increased along with increased production of natural gas. This paradox has its explanation in the definition of proven reserves: *"Proved reserves are the estimated quantities which (…) with reasonable certainty to be recoverable in future years from known reservoirs under existing economic and operating condition (EIA, 2013)."* So, when technological improvement made shale gas economically viable, it drastically increased the proven reserves in the U.S. When shale gas became economical, it also increases the search effort which leads to more findings and increased gas reserves.

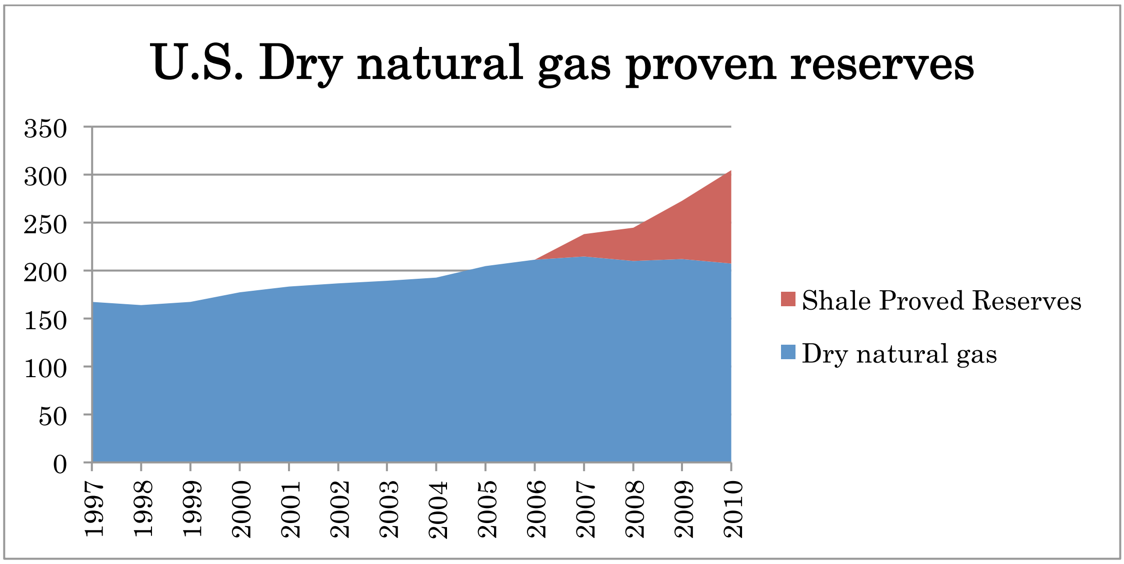

Figure 5 Proven natural gas reserves. Source EIA

Increased reserves tell us that the current high production of natural gas can be sustained for many years. As long as shale gas production in the U.S. is profitable, there will be exploration for more and this will prolong the gas production in the U.S. It is safe to say that the increased proven reserves will secure the U.S. with natural gas in the years to come.

Associated Gas

Natural gas production can either come from reservoirs that contain no oil or from reservoirs where natural gas is released as the oil is extracted. When natural gas is extracted together with oil, this is called associated gas. In reservoirs with associated gas, oil is the main product and natural gas is considered a byproduct of the production, whereas in non-associated gas reservoirs natural gas is the main product. Even though associated gas is an important source of natural gas production, 89% of the natural gas produced in the US is non-associated. Associated gas is then linked to oil, meaning that this can provide a possible explanation of why oil and gas prices move together. If we consider a gas reservoir that provides an investment opportunity for a company, the economics of drilling the well will be very different for non-associated gas than for associated gas. A non-associated gas reservoir will only be developed if the current and future expected gas prices are so that the project will provide positive net present value of the investment. The same is true for an associated gas field, however the oil price will be the main factor deciding whether or not the field will be developed. This means that if there is an abundance of oil in the market resulting in a low oil price, the field will probably not be developed. If the oil price is such that the field is developed, this will produce both oil and gas for delivery to the market. Now assuming well functioning markets, when supply increases prices will go down. This is a factor that connects the oil price and the gas price. However we need to make it clear that providing oil from one oil field to the global oil market will probably not have any significant effect on the oil price. On the other hand increasing supply of gas can provide significant decreases in the regional gas markets, as these markets are considerably smaller than the oil market.

Associated gas can have a role in explaining the increase in the gap between oil and gas prices over the last years. As oil prices increase, more and more oil fields will become economical to develop. If these fields have considerable amounts of natural gas as a byproduct, this can cause an overflow of natural gas to the market. The associated gas fields do not depend on the supply and demand situation in the gas market but the market situation in the oil market. We note that this connection between the oil and gas market is in fact relatively weak as most of the gas in the US market comes from non-associated gas fields. Also worth mentioning is that close to 60% is re-injected into the oil fields to increase pressure, and then oil production. This is most economical when gas prices are low and oil prices are high. In theory this could have the effect of reducing the price gap between oil and gas, however as these amounts are fairly small we do not expect this to have any considerable effect on either market prices.

Drilling costs

Drilling costs and capacity is another factor that can explain co-movements of the oil and gas price. As the technology used to drill an oil well and a gas well is the same, the costs of drilling and the drilling capacity available should be approximately the same.

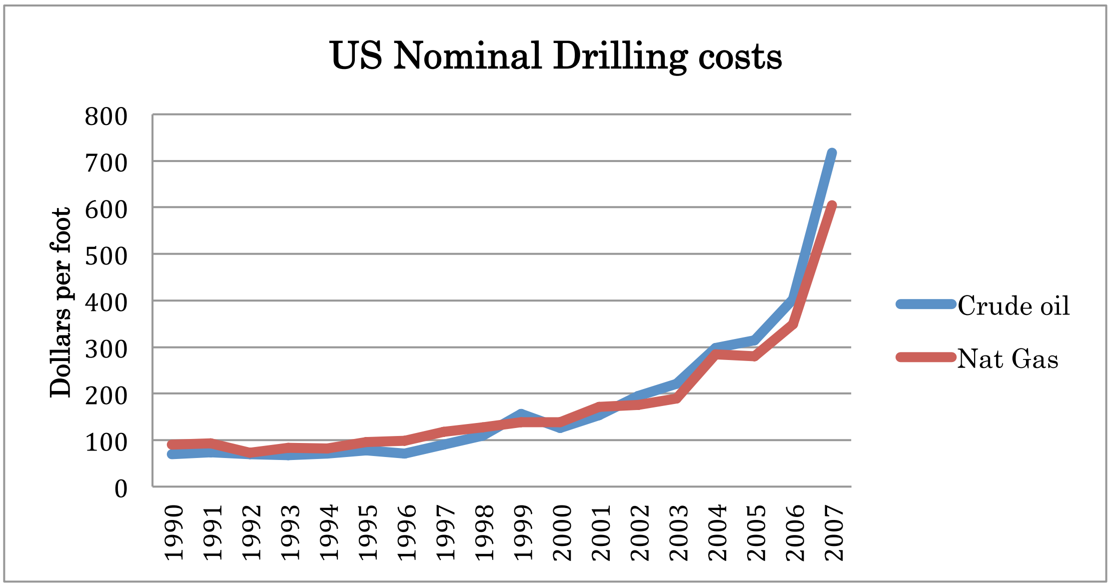

Figure 6: Drilling Costs. Source: EIA

In figure 6 above, we can see that drilling costs per foot follow each other fairly close throughout the period, with the cost of drilling natural gas wells slightly above that of oil wells in the first half. Towards the end crude oil drilling costs start to outgrow the costs of drilling for natural gas. A reason for this is that this is the beginning of shale gas production, which is mainly done onshore. Onshore drilling is less costly than drilling offshore, so the drilling costs for natural gas decreases relative to the costs of crude oil.

If drilling capacity is constrained we assume the cost of drilling new wells increase, which from a pure economic perspective should be reflected in higher prices in the future. If there is low activity and a lot of spare drilling capacity we would expect the prices to go down. The impact of the drilling costs is hard to measure, as there are so many other factors influencing the prices. However since the same technology is used to drill oil and gas wells this could be part of an explanation to why oil and gas prices share a long-run equilibrium. From a perspective of an oil and gas producer, if the price of oil increases relative to gas then it will be more economical to drill oil wells than gas wells. This will provide more oil supply that will put downward pressure on the oil price, and reduce supply of gas, which will put upwards pressure on the gas price.

The fact that onshore shale gas has become such a large source of supply in the US since 2006 suggests that the developing of new natural gas resources has become cheaper. We believe this to be the main explanation of the decoupling between the price of crude oil and the price of natural gas.

Technology improvement in drilling will affect both the economics of oil fields, as well as the economics of gas fields. As improved technology will decrease costs this will put downward pressure on the prices of both oil and gas, through lower costs and increased supply. Horizontal drilling technology is the most recent example. This greatly reduced the costs of developing both shale gas and shale oil. Drilling costs is only one part of the picture, as the profitability outlook is important for what kind of wells one decides to drill. In figure 7 below we have plotted US drilling activity by resource in the period.

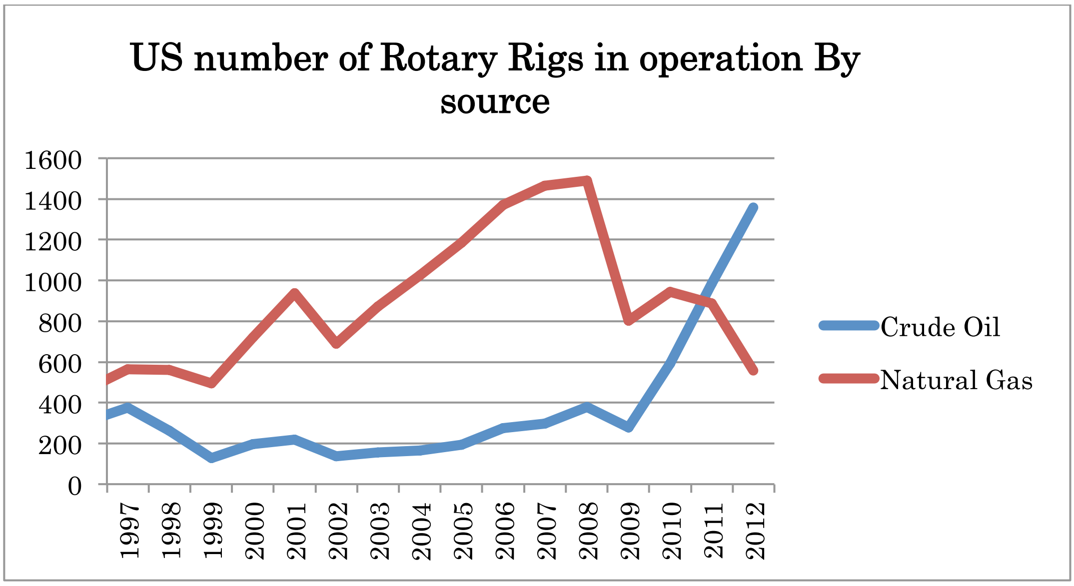

Figure 7: Drilling Activity. Source: EIA

If we look at drilling activity in the US over the period it becomes apparent that drilling activity is influenced by the prices. We can see that in the early part of the period the drilling activity for natural gas is growing steadily, while the activity in the crude oil industry is fairly stable. At the end of the period we see that this changes. After 2008 drilling activity in natural gas declines significantly, while the activity in crude oil skyrockets. This is most likely a response to the growing crude oil prices and the low and declining natural gas prices in the period in addition to the development of shale oil. Explaining the developments up to 2008 is not straight forward, as we do not see any clear price signals that indicate that natural gas will be more valuable than crude oil. In 1997 the slickwater fracturing technique was developed, making shale gas economical, the increase in natural gas drilling activity can be because this technology was gradually adopted. Comparing the increase in natural gas drilling activity with the natural gas consumption in the same period leads us to believe that significant overcapacity was developed, a possible explanation of the price drop of natural gas seen after 2006.

Drilling activity is also a potential explanation of why the prices shared a long term relationship. If the price of crude oil were to increase relative to the price of natural gas, the drilling capacity would be allocated to this resource. This cannot be done instantly, so there is no short-term link here, however a long-term link is apparent. On the other hand high drilling activity in natural gas over time can have caused oversupply of natural gas, which might explain why the prices now have decoupled. Also worth mentioning here is that lasting changes in natural gas drilling activity will most likely have an effect on the price of natural gas, however for crude oil drilling activity in the US is unlikely to have any effect on the global crude oil price. If the drilling activity in natural gas continues to decline we can expect the price of natural gas to increase in the future. It is also possible that market actors might anticipate higher future gas prices from the low drilling activity and decide to drill even though the current natural gas price is low.

Gas imports – Oil index linked gas prices in the LNG market

Another factor that could link the oil price and the gas price in the US is the trade of liquefied natural gas from Europe. Natural gas in Europe has been linked to the oil price through long-term oil indexed contracts. In 2005 as much as 80% of the gas sold in Europe was through these oil indexed contracts. In more recent years however this share has declined to about half of that in 2012 (The Economist, 2012). Imports of liquefied natural gas from Europe and Asia will then be affected by the oil linked contract prices in these regions. This means that an oil price increase will lead to a gas price increase, and increase the cost of imports. This is a factor that can explain co-movement of the oil and gas price also in the US. However looking at the total consumption in the US imports account for only a small part of this consumption (less than 17% on average over the period).

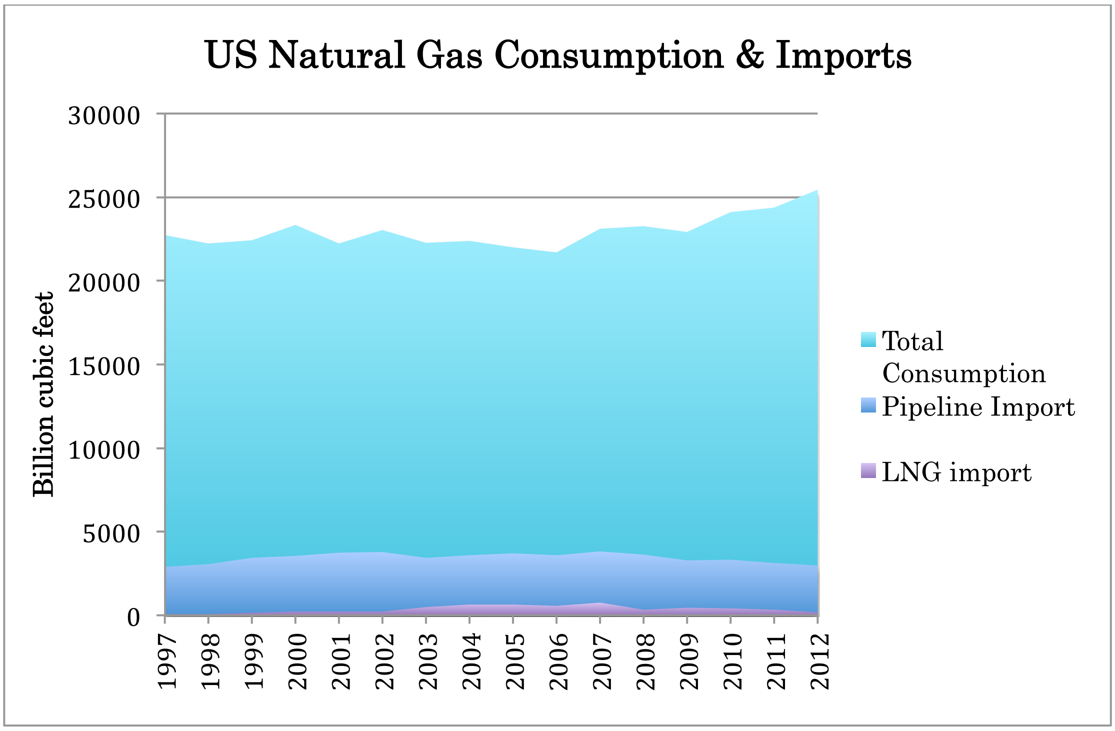

Figure 8: Imports and natural gas consumption. Source: EIA

In addition most of the US gas imports (about 90% on average) have historically been transported by pipeline mainly from Canada. Liquefied natural gas only accounts for about 10% of total imports into the US and only 1,6% of total consumption over this time period. This means that the market for liquefied natural gas, that is influenced by the oil linked contracts in Europe, Middle East & Africa and Asia, most certainly plays a minor role in the relation between the oil and gas price in the US.

In recent years imports of liquefied natural gas as a share of total imports have declined from a peak of 17% in 2007 to only 6% in 2012. In the same period total gas imports as a share of consumption has decreased from 17% to 12%. This reflects the decreasing prices from about 7,5 $/MMBTU in 2007 to about 2,5$/MMBTU in 2012.

From 2000 up until today the capacity of regasification plants in North America has increased from 2,3 billion cubic feet per day to 22,7 Bcf/day (35% of daily consumption), as a result of policy measures to ensure future supply of natural gas (MIT interdiciplinary study group, 2011). In this same period the increased supply from shale gas has radically changed the natural gas market, reducing the price and leaving most of this capacity unused. It is clear that the US would be better off with having built export capacity instead of import capacity. This illustrates how hard it is to anticipate the future developments in these markets, but also that putting all your eggs in one basket leaves you vulnerable for changes in the market. The current high domestic supply and corresponding low price does not provide economic foundation of importing LNG to the market. How this will develop in the coming years is hard to say, however significant free LNG import capacity is in place meaning that if the prices in the US should increase the there is LNG import capacity in place to supply the market and limit the price increases. Assuming that the LNG prices are still affected by the oil index linked contracts, the natural gas price will then be more closely connected with the price of crude oil.

Wet Gas & Natural Gas Liquids

Some natural gas reservoirs contain significant amounts of wet gas. Wet gas is gas that contains heavier gases such as ethane, propane, butane etc. A process is undertaken to separate these heavier gases from the dry gas (methane). The common term for the heavier gases is Natural Gas Liquids (NGL). Natural Gas liquids are considered high value products that can generate higher income from natural gas fields. On the supply side this is interesting when making investment decisions about new field developments. Natural gas fields that contain high amounts of natural gas liquids can be economical to develop even if the price of natural gas (dry gas) is low. As an illustration of this we wish to show the breakeven natural gas price for a mean performing well in the Marcellus shale play with varying condensate ratios, as presented in the MITEI study (MIT interdiciplinary study group, 2011).

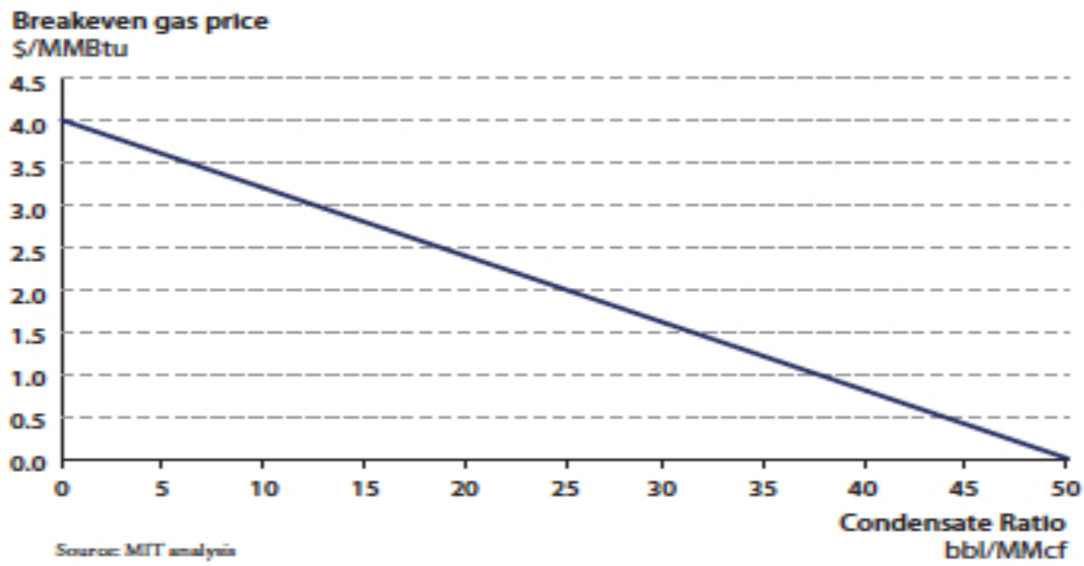

Figure 9: Breakeven gas price analysis. Source: MITEI

In the study they assume a liquids price of 80$/bbl, which as we see from the figure makes the natural gas price insignificant in the investment decision for high condensate ratios. In certain areas of the Marcellus and Eagle ford shale plays the condensate ratios are above 100bbl/MMcf, so dry gas supply from these areas will be developed and sold even at prices close to zero. This clearly puts downward pressure on the natural gas price, and provides a good explanation of why gas production persists even at the current low price level.

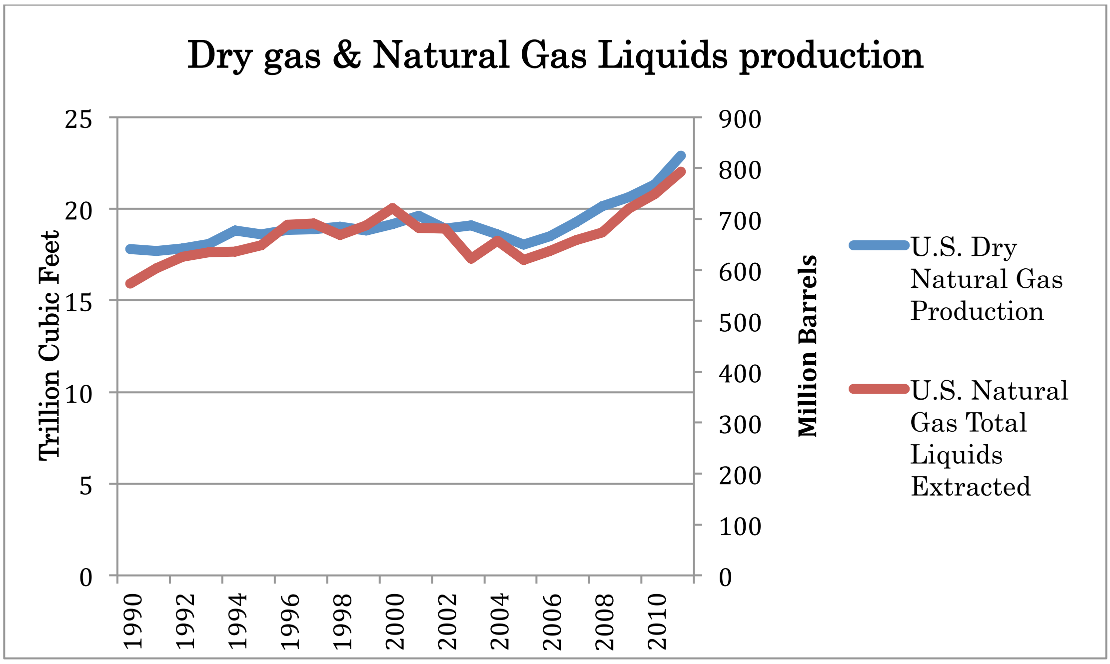

Figure 10: Dry gas and NGL production. Source: EIA

Figure 10 shows the development of dry gas production and the production of natural gas liquids in the US from 1990 up until today. We see that the development of the two data series follow each other fairly closely a clear indication that increased production of dry gas will also increase production of natural gas liquids and vice versa. High prices of natural gas liquids can cause increased production of dry gas, putting downwards pressure on the dry natural gas price. This does not support the argument that the oil and gas price have been coupled, but it can be part of an explanation current low natural gas price and the decoupling.

Demand Factors: Natural gas and Crude oil

Oil and gas are both carriers of energy and therefore they are substitutes, so their prices should be linked in the long term (Asche, 2012). The consumer will shift between energy sources depending on the relative prices between different carriers of energy. This behavior will then tilt demand in the direction of the energy source with the lowest price, until the price difference has disappeared. This energy arbitrage argument supports a tight link between oil prices and prices for natural gas, since they are both energy carriers. Figure 11 illustrates this: we have divided the price of oil on the price of natural gas, both are in $ per MMBtu. They are priced equally when the graph is at 1. Since oil is easier to transport and store, we can expect it to be cheaper than natural gas, and the graph should therefore be above 1. From 1997 until 2006, the relative price is between 1 and 2, from 2006 it starts to trend around 2. After 2009, the relative price band that has been observable since 1997 is gone, and oil is priced considerably higher than natural gas. The graph shows that the theoretical argument of energy arbitrage is not so straight-forward in practice. Shifts in energy source often require a complete change or significant remodeling of existing equipment, and storage possibilities and availability of the resource itself may hinder the switch.

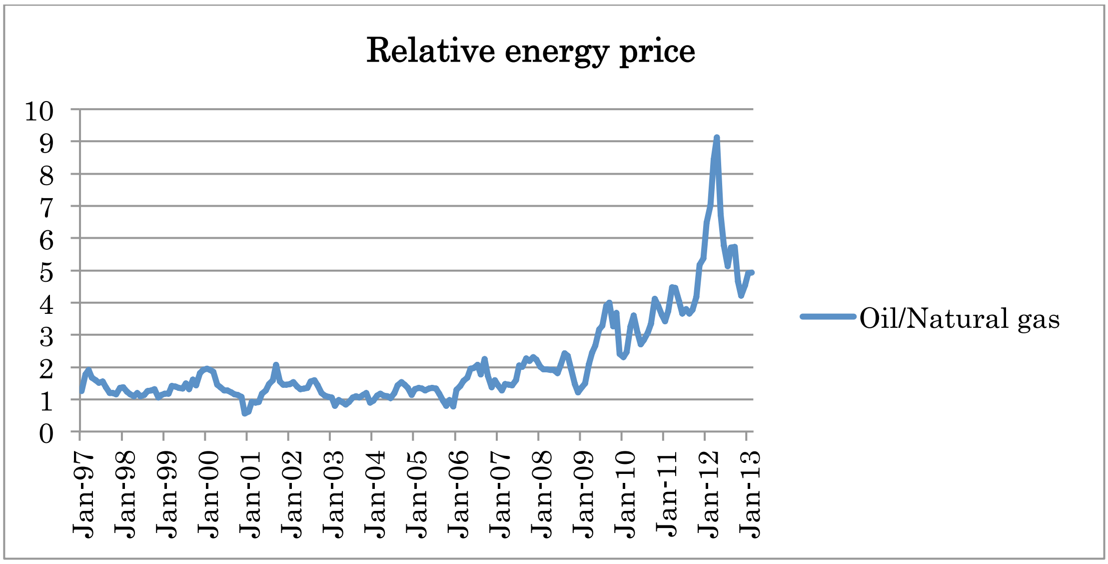

Figure 11: Relative energy price.

All of the limiting factors above involve significant capital investment to overcome, and it is of non-reversible nature. Some consumers have equipment that can run on both petroleum and natural gas. This behavior will create links between the price of oil and natural gas in the short term, as consumers shift demand in response to prices. The following section will describe the demand link between oil and natural gas, and analyze any factors that may have contributed to the recent decoupling of oil and natural gas in the U.S.

Natural gas demand

The main end use markets for natural gas is the residential and commercial sector with 35 percent, the industrial sector with 32 percent and electric power generation with 34 percent. The relative size of these end markets change over time depending on technological development and prices of other energy sources, figure 12 shows the development in the period 1997 to 2011.

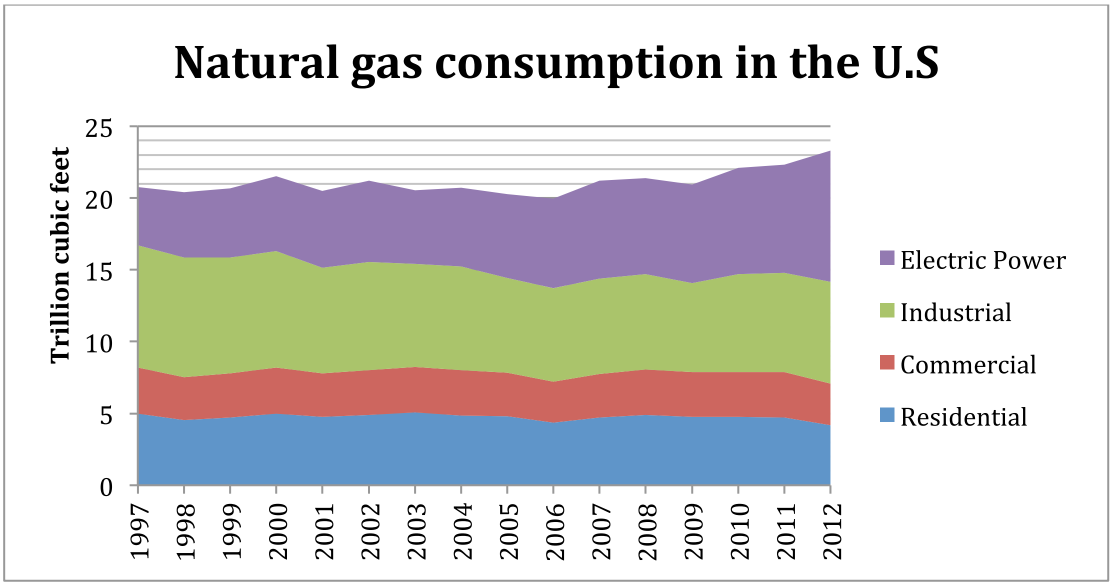

Figure 12: Consumption by sector. Source:

Total consumption decreased somewhat towards 2006, when it reached bottom and increased steadily towards 2012. Throughout the overall period from 1997-2012 U.S. natural gas consumption has increased. The increased consumption after 2006 is probably a response to the falling natural gas prices in this time period. The most significant change in the period we are looking at is the increased use of natural gas in electricity production. If we exclude natural gas used for electricity generation from the graph, all the other end use markets have reduced their combined consumption of natural gas by almost 18 % throughout the period.

Power generation

The electricity sector has traditionally been the industry with the clearest link between oil and natural gas, since both historically have been peak load producers and some generators can run on both oil and gas. This creates a short-term link between natural gas and oil through daily competition between oil and natural gas. Electricity generation also provides a long-term link because a power producer decision to invest in new generation assets will depend on the relative price between oil and natural gas. A high oil price relative to the price of natural gas will favor investments in natural gas generation assets, and vice versa. This will increase the demand for the relatively cheaper energy source and should increase the price, while it will reduce demand for the more expensive commodity and should put a downward pressure on prices. We will now go through the development in the electricity sector in the U.S. and look at the possibilities for short-term price connections through competition for peak load production and the long-term connection created by investments influenced by relative prices.

In 2012 the U.S. electricity was mainly generated from coal (37 %), natural gas (30%) and nuclear (18%). Electricity generated from petroleum generation accounted for only 0.5 %. Over the last two decades natural gas has continuously increased its output, while generation from petroleum has declined.

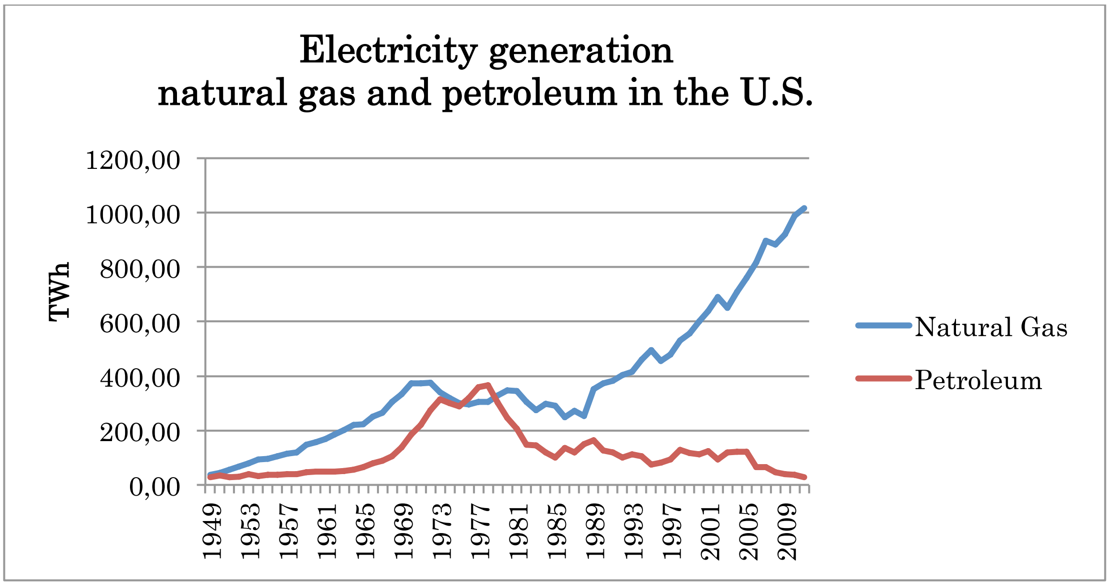

Figure 13: Electricity generation from natural gas and petroleum. Source:

Generation from petroleum has declined since the late seventies, when petroleum generation in the U.S. reached its peak. Fuel for petroleum power generation is either liquid petroleum products or petroleum coke, which is a waste product from refining and can be compared to coal. Liquid petroleum power generation is only used as peak production, because the cost of operating a generation unit requires high electricity prices. From 1982 and until 2005 generation from petroleum was relatively stable. In 2006 U.S. generation from petroleum decreased by 48 percent, by 2012 it had decreased by 77 percent from 2005 levels. The petroleum generation assets are aging in the U.S as eighty percent of the U.S. petroleum fired power generators where built before 1980 (EIA, 2011). The drastic reduction of petroleum generation reflects our assumption of a decoupling between the oil and gas price where we see higher relative pries of petroleum compared to natural gas. This relative price difference has a large impact on the production of electricity from petroleum. This does not mean that the reduction in petroleum generation created the decoupling situation; it is merely a reflection of the price signals in the two markets.

Natural gas accounted for 30 percent of U.S. power production in 2012, and 41 percent of the capacity. Production of electricity from natural gas has risen steadily for a long period, due to advances in generation technology and lately reduced prices of natural gas. Natural gas is also a significantly less CO2 intensive source of energy than coal and petroleum. Historically in the U.S. natural gas has been used during peak hours or periods with high demand (EIA, 2012). However, the reduction of the relative natural gas price since 2009 has increased competition between natural gas and coal as base power producers. Recent analysis preformed by the EIA shows that natural gas and coal now overlap in the merit order in the Southeast (EIA, 2012), due to the reduction in the relative price between natural gas and coal.

Short-term link through electricity market

The competition between natural gas and oil power generation should in theory create a link between the two prices through the electricity price. However, the effect on prices will depend on the amount of oil and gas that actually competes relative to their respective market sizes. The market for crude oil is large compared to the amount consumed by the U.S. electricity sector, and oil generation is a very small part of U.S. power generation. Natural gas on the other hand generated 30 percent of U.S. electricity, and consumption from natural gas is the largest end user in the U.S. natural gas market (39 %). So, the electricity market is a major consumer of natural gas relative to the natural gas market, and a minor consumer of petroleum relative to the oil market. It is reasonable to assume that oil prices will have low direct impact on electricity prices, and vice versa. We therefore believe the short term-link between the natural gas and oil through the electricity price to be weak throughout the whole period, and almost negligible towards 2012.

Long-term link trough electricity market

As already mentioned power generated from both petroleum and natural gas are usually used as peak load power generators, because of the high fuel cost and the fact that they can be shut on and off quickly. Investments in gas generation versus petroleum generation will to a degree be influenced by the expected price of the two fuels. Therefore, natural gas and oil are substitutes in the long term. Natural gas has been the favored energy source for U.S. peak power generation in the last two decades, while petroleum has lost a lot of market share. As discussed above, without the increased generation of electricity, the demand for natural gas would have decreased during the period 1997 until 2012. The increase in natural gas demand from the electricity industry is due to a large surge in capacity additions in the early 2000's that we can see illustrated in figure 13 below.

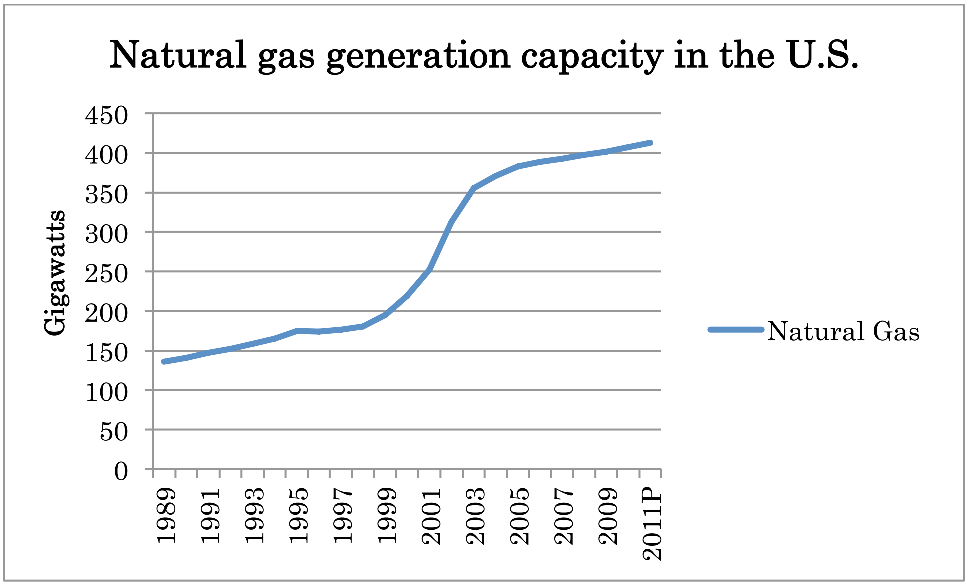

Figure 14: Natural gas electricity generation capacity. Source:

If we look closer at the time period that we are investigating, 1997 until today, we can observe that the capacity of natural gas generation has increased from 175 gigawatts to 413 gigawatts in 2011. This increase has been reflected in the demand for natural gas from the electricity sector, which has increased by 86 percent in the period 1997 – 2011 and by 125 percent in the period 1997-2012. This increase in generation capacity that has created a steady increase in natural gas demand has to some degree happened at the expense of petroleum generation. It has created higher demand in the gas market, and could very well be a large part of the reason why we saw rising gas prices in the first part of our sample period. This increased capacity creates a long-term link between the two energy carriers, and explains some of the co-integration we observe between the oil and natural gas price.

Residential and commercial consumption - Heating

Residential and commercial consumers account for 30 percent of demand for natural gas and use it mainly for heating purposes, but also for cooking and other household equipment (EIA, 2012). Natural gas and heating oil, a product refined from crude oil, are both used as fuels for residential and commercial heating. Heating is an area where natural gas and oil are substitutes and therefore a possible factor in the link between the oil and gas market and the resent decoupling of the prices. There is no ability for rapid fuel switching among different fuels. Consumers usually only have equipment that can handle one type of fuel, and a change of fuel source require substantial investments (Cardwell, 2012).

Natural gas competes with heating oil and electricity as a fuel source for heating. Heating oil has lost a lot of ground towards natural gas (and electricity) in the last decade. Heating oil is primarily used in the North East region, which in 2010 represented 85 percent of the heating oil demand. In total roughly eight million American homes use heating oil (Cardwell, 2012). Heating oil is a much more expensive fuel source than natural gas, but lack of sufficient infrastructure is the limiting factor for fuel switching in the North East region (Cardwell, 2012).

In figure 15 below (EIA, 2011) we can see the number of consumers that switched in or out of natural gas and heating oil from winter to winter. There is a clear trend of switching away from heating oil and into natural gas. The number of consumers that switch away from heating oil is higher than the amount of new natural gas consumers, indicating that electricity is also taking substantial market shares from natural gas.

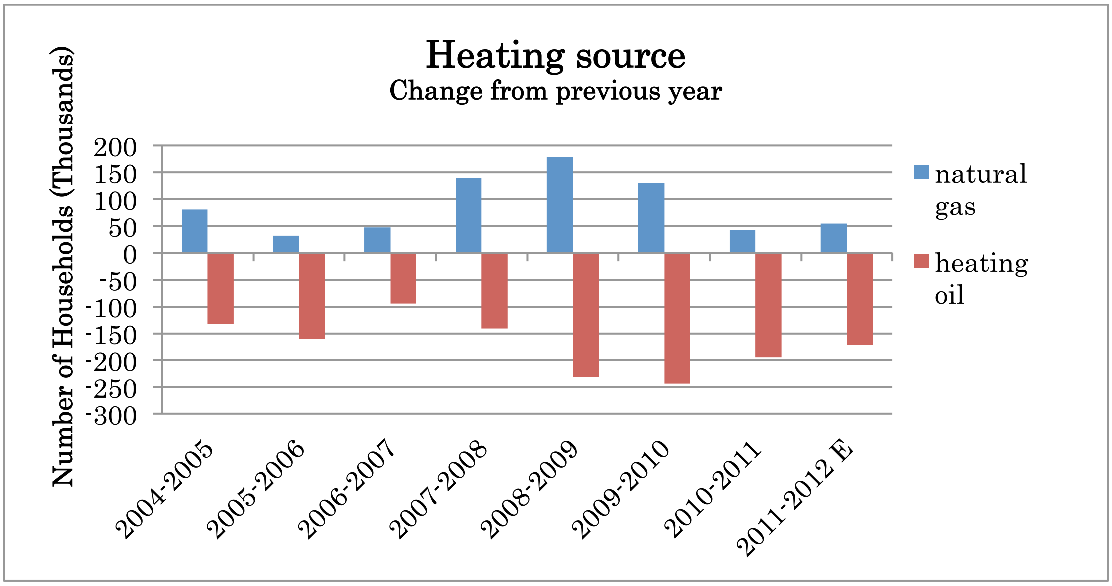

Figure 15: Change in number of consumers using natural gas and heating oil. Source: EIA

What we have seen in the U.S. is that the relative price between heating oil and natural gas has favored natural gas over time and consumers have shifted to the cheapest energy source. In theory, this should create a higher demand for natural gas and drive prices up, while at the same time the price of heating oil should be reduced as a result of reduced demand. This would then create a link between the two prices as the wide spread between the cheap natural gas and expensive heating oil narrows as a result of shifting demand. This has not been the case, firstly because the consumption of heating oil represents a minor part of the U.S. petroleum market, and an even smaller part of the world oil market. Secondly, the increased amount of natural gas consumers have not resulted in increased demand for natural gas. If we examine figure 16 below we can see a plot that shows the number of residential and commercial consumers that are connected to the natural gas grid, and the natural gas consumption of these two groups. Number of consumers are plotted on the left side and indicated by the blue line, while consumption is plotted on the right side and indicated by the red line.

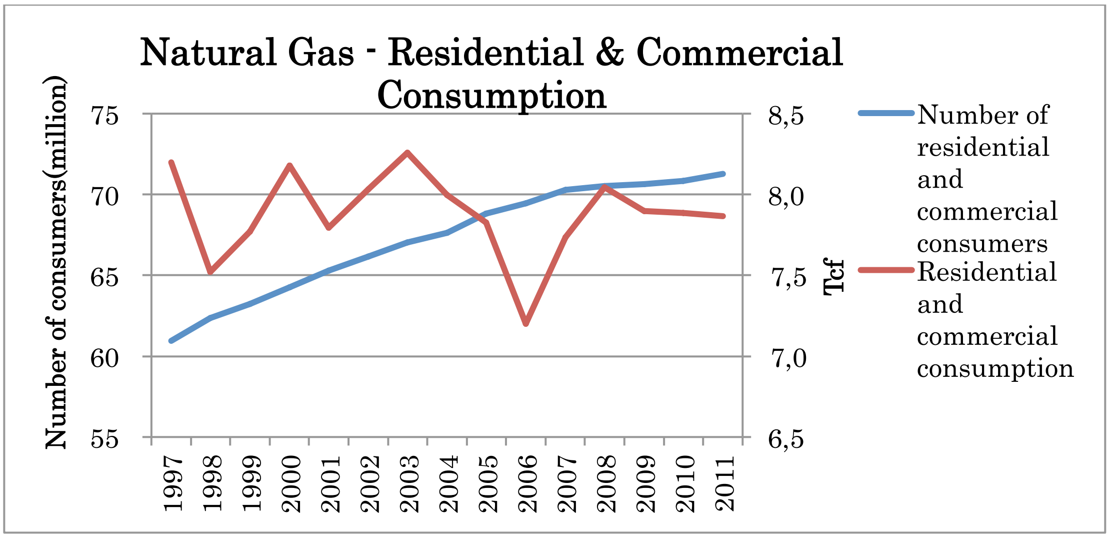

Figure 16: Number of residential and commercial consumers an consumption. Source:

The figure gives a good indication of improved efficiency in the U.S. heating and household equipment market. The number of consumers has steadily increased from about 61 million in 1997 to about 71 million in 2012, and the consumption has fallen during the same time period. Thus there has been no pressure on natural gas prices from the residential and commercial industry.

There are still eight million homes in the U.S that uses heating oil as a fuel source, during the next decade they could switch to natural gas or electricity. If all of them switched to natural gas, that would represent an increase in the consumer base of a little over ten percent. What would happen to natural gas demand as a result of this hypothetical fuel switch is uncertain, and depends on future efficiency improvements. But if the trend from the last decade continues it will not create a significant demand pressure in the U.S. natural gas market. It is also likely that a large portion of the heating oil consumers will switch to electricity as their source of heat, because of infrastructural challenges with natural gas grids in the north-east.

Our argument that there are no short-term co-movements between the crude oil price and the natural gas price is supported by the fact that consumers cannot change fuel source quickly back and forth as a response to price changes of natural gas and crude oil. We have seen that many consumers have switched from heating oil to natural gas in the period, a development that could support a long-term co movement of the two prices. However in figure 16 we observed that the increased number of natural gas consumers has not led to increased natural gas demand, and thereby have not created the upwards pressure on the natural gas price that we would have expected. The reduction of heating oil consumption in the U.S. is too small to affect the price of oil in the world market. The development we have seen in the market for heating should in theory, all else equal, have increased the price for natural gas and reduced the price for heating oil. As we know, the opposite has happened.

Industrial consumption

About 30 percent of the natural gas demand in the U.S. stems from the industry and is used for a wide range of purposes. In order to analyze the relationship between natural gas and oil in the industrial sector we take a closer look at the main end-use activities. The principal uses are: boilers and process heat which uses natural gas as fuel, and ammonia and hydrogen production where natural gas is used as feedstock. The industrial use of natural gas accounts for 30 percent of the market, and 91 percent of that is used as fuel according to the EIA. Since over 90 percent of the natural gas consumed by the industry is used as fuel, we will focus on the switching abilities when natural gas and oil is used as fuel. If natural gas can be substituted by oil or vice versa in any of these activities then there will be a link between the oil and gas markets through these industrial processes.

As with electricity generation, there is a long term link and a short term link through industry consumption. The industry's ability to switch fuel source quickly is of interest to our analysis, because this behavior creates a short term link between the oil and gas price. The industry's investment in new technology and long term consumption patterns are of interest because it creates a long term link between the two energy carriers.

Short-term link

If the users of natural gas have the ability to switch fuel in response to prices, this could create short-term co-movements between the oil and natural gas price. The main question however is how much influence does the oil market have on the natural gas market through this industrial fuel switching behavior?

The Energy Information Agency releases a survey called Manufacturing Energy Consumption Survey (MECS) every fourth year where they collect data from manufacturing industry. In this survey, they collect data about fuel switching capability in the manufacturing industry. They do not collect data on whether or not they actually switch, but if they have the ability to do so. The most recent data on fuel switching is from 2006. Manufacturing industry that uses natural gas as a fuel can switch 21 percent of their gas usage to other fuels within 30 days. Eleven percent of the natural gas can be switched to oil. For the manufacturing industry that uses oil, a much larger portion is switchable, and 26 percent of the oil consumption could be switched to natural gas.

If all the industrial users who list natural gas as their primary fuel switch to oil, it would result in a three percent reduction in the natural gas demand. This means that three percent of the natural gas market is in short-term competition with the oil market. The possibility to switch from petroleum to natural gas will also create short-term co-movements. The amount of natural gas that could be consumed by a potential switch from petroleum products to natural gas would be equal to 0.3 percent of the total U.S. natural gas market according to MECS. The industry's capacity to switch fuel in the short term represents 3.3% of the total U.S. natural gas market. This is a relatively small overlap, and it is difficult to believe that this can create any significant short-term co-movement. This supports our argument that there are little short-term co-movements between the two prices.

Long-term link

As we have seen in the last section, the industry has an ability to switch between natural gas and oil as their energy source in the short term. The price of energy determines what energy source the companies use in the short term decision making. The expectation of future energy prices will determine what type of energy source the companies in the industrial sector choose when they make investment decisions. If natural gas has been cheaper than oil for a period of time, and is expected to stay cheaper, we can expect that the industry will favor gas over oil when they make new investments. This behavior creates increased demand for natural gas, which leads to higher prices. At the same time, demand for oil is reduced and prices drop. This creates a long term connection between the two energy sources. Figure 17 shows the consumption of natural gas and petroleum in the period 1997 to 2011, consumption of both have been reduced in the period, but so has total energy consumption by U.S. industry.

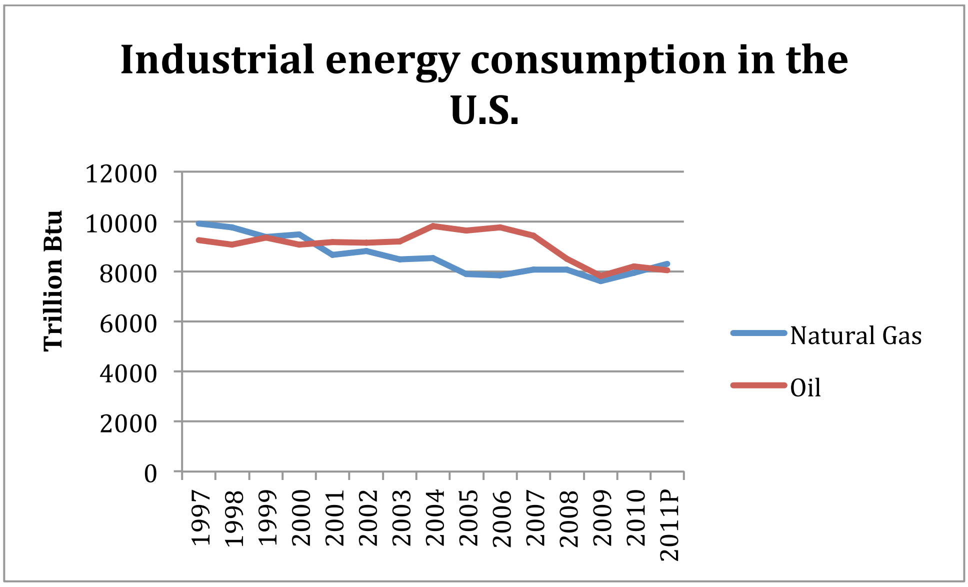

Figure 17 Industrial consumption of Oil and Gas Source: EIA

This figure does not indicate any substantial flight from natural gas to oil or vice versa. The consumption of energy by the industrial sector has been reduced, and that is reflected in the demand for natural gas and oil. The consumption of oil has been higher than natural gas from 2001 until 2010, with consumption declining rapidly from 2007 until 2009. Natural gas has had a downward sloping trend from 1997 until 2009, when consumption started to grow. This reflects the relative price developments, the two energy sources where priced equally on an energy basis, but oil started to drift away from natural gas after 2006. There are no signs of any trends in the industry of a change towards more use of natural gas or oil. However if the natural gas price remains low relative to crude oil in the future we will expect some change towards more use of natural gas.

Gas to liquids - expectations about the future.

After we now have confirmed that the two prices have decoupled, we will discuss what future expectations we have for the two markets with special focus on the implications and effects on gas to liquids. With the current high spread between crude oil and natural gas, gas to liquids is more likely to be economical in the U.S. market.

As mentioned before gas to liquids have previously been developed in areas with large amounts of natural gas reserves, but with limited access to the market for natural gas. This gas therefore represents a feedstock cost very close to the marginal production costs of the natural gas field. Currently the henry hub price of natural gas lies below the break-even costs of producing shale gas. The break-even price has been referred to as being somewhere between 4-6 $/MMBTU, however this is subject to uncertainty about the production profile and ultimate recovery from the shales. Due to this, many projections about the future gas price uses this as a lower level of the future natural gas price. We will avoid making forecasts about the future price of natural gas, however we will mention some of the factors influencing the future price development of natural gas.

Breakeven costs of natural gas production it is argued will act as a lower limit of future natural gas prices. We agree with this view, as it is unlikely that gas fields with breakeven costs higher than the expectation of the future gas price will be developed. This should mean that the current low price of natural gas will discourage investments in new resources, and future supply will be scarcer and prices will increase. There are however a few points of discussion that needs to be taken into consideration. First of all there are currently developed shale plays that have break-even prices that still makes them marginally profitable, this is an argument that the current price is not below a gas price floor. Second the development of shale gas resources is still in its early stages, so we would argue that learning curve effects will bring down the break-even prices of many of these fields. This can in part come from lower costs, but more importantly increase in ultimate recovery from the plays. Based on the cost factors we expect the price of natural gas to increase slightly in the coming as an adjustment of the current costs being below the average break-even price. However we believe the learning curve effects to limit the price increase.

Increasing future demand is a possible factor that could underline price growth in the price of natural gas in coming year. As presented earlier the electricity generation sector has been the main growth engine of the increase in gas demand. At the current low prices natural gas plants can displace coal fired power plants. We expect that future growth in natural gas demand will mainly be seen in the electricity generation industry, both as displacing older gas fired power plants, but also as balancing power for intermittent power sources. From an environmental perspective, the use of natural gas in electricity production is a much greener source than coal, and we believe that this will play an important role in the demand growth. We expect the power industry to cause substantial growth in demand of natural gas in the future, and thereby cause price growth in the natural gas industry.

Environmental policies will also play a role in the future development of natural gas demand. Already mentioned in the electricity industry, but also in transportation where policies for emission reductions of heavy duty vehicles could provide a significant increase in demand for natural gas. Already policies covering emission reductions of ferries and ships all along the coast of North America have been made, which could possibly be met by using natural gas as fuel. As CO2 and sulfur emissions from natural gas is significantly lower than for fuel oils we expect this to become an important part of the global and local environmental policy agenda. This will create a significant increase in demand for natural gas, and would put upwards pressure on the natural gas prices in the future. However it will take many years to build ships and vehicles and sufficient fuel infrastructure in such a scale that it will have a significant impact on the prices of natural gas.

Liquefied natural gas export is an alternative for natural gas producers that face the currently low prices in the US. This requires building liquefaction facilities, as most currently built LNG facilities are import facilities. This takes time and significant investments and there is significant risk connected to this, as the prices in other regions of the world needs to be sufficiently higher to cover the extra transportation costs. Since fracking exploration is now only beginning in other regions of the world, we may very well se lower prices for natural gas in both Europe and Asia. This could very well have an effect on local U.S. prices. At the moment LNG exports seems to be the most likely reaction to the currently low prices of natural gas. The future impact of LNG exports on the price of natural gas, will off course depend on how much capacity is built and the price developments in other regions of the world. We share the belief that over time significant LNG export capacity will be built. This will lead to a price increase in the US, however we also believe that competing supply of LNG from other parts of the world will dampen the effect on the price of natural gas in the us market.

In our opinion it is interesting to view gas to liquids as a technology that can compete with LNG, however gas to liquids provides some interesting advantages. First off one would not need to replace ships, heavy transportation vehicles and fuel infrastructure in order to reduce emissions from the transportation sector. One could use the cleaner diesel refined from a gas to liquids process. Second it turns the currently low value natural gas, into high value refined petroleum products. These products are easily transported and provide more income from the natural gas production. We also view this as a possibility for a gas producer to diversify the production into different markets, especially now that the prices have decoupled. With a drop in gas prices it becomes less economical to sell the gas directly, however the feedstock costs and thereby marginal cost of the gas to liquids facility goes down. After the decoupling we do not expect there to be a relationship with crude oil, so there may very well be a low gas price and a high oil price at the same time, as we have seen in recent years. The high crude oil price, we argue, will impact the prices of the refined petroleum products causing these prices to be high. In this case a gas to liquids producer faces lower feedstock costs, and higher end product prices. If the opposite was true and the price of natural gas was high and the price of crude oil and refined petroleum products low then the gas producer could sell gas directly to the market. This illustrates the diversification benefits of gas to liquids, and that it can be viewed almost as a real option. However the very high capital costs, suggests that this may be an expensive real option and that the capacity must be utilized fully to support the capital costs. This does not take away the important argument of diversification for a gas producer.

The decoupling of the natural gas and the crude oil price has also led the gas to liquids technology to differ further from the conventional crude oil refining industry. For the refining industry the spread between crude oil and the refined petroleum products is the most important profitability factor. In the light of the fact that the price of crude oil and the prices of the refined petroleum products tends to follow each other closely this spread will then be fairly stable. In the light of the fact that the refining industry has been struggling with profitability for years this spread is not high enough. The most important spread for a gas to liquids producer is the spread between natural gas and refined petroleum products, which is closely related to crude oil. As the price of natural gas and crude oil is no longer related, this means that the spread is not stable. This could mean that the spread and thereby profits are more volatile, but it also means that there are room for periods of substantial profits. By taking the option view we had previously we could say that the increased risk from the more volatile spread will be limited by the possibility of selling the gas directly.

The biofuels and emerging technologies team of the U.S. energy information association have performed a gas to liquids technology assessment for the annual energy outlook 2013 (EIA Biofuels and Emerging Technologies Team , 2013), where they perform a break even analysis of a mid sized gas to liquids facility. A mid sized facility here has the capacity of 34 000 barrels per day, and capital costs of 90 000$ per barrel. Based on assumptions about lifetime, cost of capital and financing they find that the cost composition for the production of a barrel of liquids is 49 % to capital costs, 37% feedstock and 14% operations and maintenance. It becomes clear that the capital costs play a very important role, however so does the feedstock costs. We will not discuss this study further, however we will encourage interested readers to have a look at it. What we wish to address is the breakeven analysis presented in this study. Given the assumed relationship between the crude oil price and the price of gasoline and diesel they find that at a natural gas price of

4$/MMBTU the breakeven price of crude oil is 80$/bbl. Increasing the natural gas price by 1$ per MMBTU causes the breakeven price of crude oil to increase by 9-10$/bbl. If natural gas prices were to double and reach a level of 8$/MMBTU the crude oil price would have to be just below 120$/bbl to break even. This illustrates that the economics of gas to liquids is very sensitive to increases in the price of natural gas to break even. However as we have argued previously, we do not expect the natural gas price to double anytime soon, meaning that we believe gas to liquids to be economical given that we do not see a lasting drop in the crude oil price. As a pure business case the spread might not support the risk of investing in a gas to liquids facility. However we would argue that for a gas producer the diversification element can make investment in a gas to liquids facility interesting.

Summary and main conclusions

We observed in the period 1997-2006 that the developments in the natural gas price and the price of crude oil were following each other. These long-term co-movements are best explained using a energy arbitrage argument, with no main factor standing out as the sole cause. From an energy arbitrage perspective the price spread have been stable up to 2006, meaning that no massive shift from crude oil to natural gas or vice versa have been beneficial, nor has this happened. We also found that our that there were low short-term co-movements between the two prices, even though there are fuel switching possibilities in both the industrial consumption and in the power generation industry. These fuel switching capabilities are so small that they cannot influence the short-term price relationship in any way.

We observed that the two prices decoupled after 2006, we attribute this to the large quantities of shale gas produced at lower costs and from large reserves. In a period up until 2007 we have seen a steady increase in natural gas drilling activity, which we think is the main factor of the increasing supply. At the same time the demand has increased slightly, however not enough to maintain a higher natural gas price. The shale gas supply fundamentally changed the natural gas market, through supplying vast amounts of cheap shale gas in the market. In addition we have seen that the links between natural gas and crude oil have become weaker in the electricity sector, and in the residential and commercial heating sector. Furthermore the high value of wet gas and natural gas liquids caused by the high crude oil price has made it economical to develop gas reservoirs even at low dry gas prices. Thereby increasing the supply and the spread.

Our main conclusion is that the energy arbitrage has been the main reason for the prices being coupled, and that vast amounts of shale gas has fundamentally changed the supply situation in the gas market causing the prices to decouple. Even though the energy arbitrage argument still holds the supply situation in the natural gas market now differ so much from the supply situation in the crude oil market that we do not think the prices will recouple.

We confirmed our observations of the coupling and decoupling by testing the long-term cointegration relationship where we found the price to be coupled in the years from 1997-2006 and to have in fact decoupled in the period after 2006. Telling us that the markets are no longer integrated, and that information about the oil price could no longer be used to say something about the natural gas price. Furthermore this decoupling means that the high crude oil price will not increase the price of natural gas in the future. This is important for gas to liquids, as there is now not the same limit to the spread and to the possibilities for profit. Gas to liquids can become a profitable investment for a gas producer if the gas prices do remain low relative to the price of crude oil. There are numerous factors that can cause the gas price to increase, however we argue that because of the large amount of proven reserves the prices will not increase too much in the future. Because the prices are no longer cointegrated the crude oil – natural gas spread has become more risky, however there is also a larger potential for a profitable spread. In addition we suggest viewing gas to liquids as a diversification method mitigating risks of low natural gas prices for a gas producer.

Appendix

Appendix I - Unit root testing

To explore whether or not we have unit roots in the time series we will use Augmented Dickey Fuller-test (ADF-test). If a time series have unit root, it is non-stationary. However if we differentiate once the time series may become stationary. This is the definition of a first order integrated time series I (1). The ADF-test equation is the following:

$$\Delta y_t = \alpha + \beta t + \gamma y_{t-1} + \sum_{i=1}^{p} \delta_i \Delta y_{t-i} + \varepsilon_t$$

Where y_t is the time series, α is a constant, β is the constant explaining the trend term. Υy_{t-1} is the first lag of the time series, which is 0 under the null hypothesis of non-stationarity. $\delta_i \Delta y_{t-i}$ is the lags of the first difference. The p number of lags is decided using Akaikes information criterion. Finally ε_t is the error terms.

The null hypothesis H0 is that the time series is non-stationary. If H0 is true then there is no additional information about the change in y_t in the lagged levels y_{t-1}, the only information lies in the lagged levels of the change in Δy. Hence H0: $\gamma=0$.

The optimal number of lags p is determined by minimizing Akaikes information criteria AIC. We want to balance having a model with a good fit without adding too many variables, this means selecting the number of lags that gives the model the lowest value of AIC. The t-value of γ is then provided by the ADF-test, as well as the critical value. The critical t-value is not the same as for a student t-test, and is provided in the test output by the software PC Give. We then compare these numbers, and if the t-value of γ is outside the critical value we reject the null hypothesis, and say that the time series is stationary.

Appendix II - Unit Root Test Results

Below we present the tables of results from the unit root test of the monthly, log monthly and weekly price series and first differences. The tables present summarized results from the output of PC Give. The tests are performed following the procedure presented in Appendix I.

Augmented Dickey Fuller unit root test of prices and returns						
	Monthly					
	1997 -2013		1997-2006		2006-2013	
	Henry Hub	WTI	Henry Hub	WTI	Henry Hub	WTI
Prices						
Optimal lag length	0	6	2	5	10	2
T value ADF	-2,516	-1,187	0,8317	0,3143	-1,814	-3,396*
First differences (Returns)						
Optimal lag length	0	5	0	4	9	0
T value ADF **	-14,09	-7,107	-9,853	-3,61	-5,596	-5,661
Order of integration	I(1)	I(1)	I(1)	I(1)	I(1)	I(0)
Critical t-value 5% confidence	-2,88	-2,88	-2,87	-2,87	-2,9	-2,9
Critical t-value 1% confidence	-3,47	-3,47	-3,45	-3,45	-3,51	-3,51
* H0: Non stationary series rejected at 5% level of confidence						
** All first difference series reject non-stationarity on 1% level of confidence						
Critical Values from output in PC Give						

Augmented Dickey Fuller unit root test of prices and returns						
	Monthly Logarithm					
	1997 -2013		1997-2006		2006-2013	
	Henry Hub	WTI	Henry Hub	WTI	Henry Hub	WTI
Prices						
Optimal lag length	0	1	0	0	10	2
T value ADF	-1,979	-1,289	-0,4816	-0,3524	-0,9673	-3,47*
First differences (Returns)						
Optimal lag length	8	0	0	0	9	5
T value ADF **	-6,066	-10,48	-9,414	-8,839	-5,534	-5,334
Order of integration	I(1)	I(1)	I(1)	I(1)	I(1)	I(0)
Critical t-value 5% confidence	-2,88	-2,88	-2,89	-2,89	-2,89	-2,89
Critical t-value 1% confidence	-3,47	-3,47	-3,5	-3,5	-3,5	-3,5
* H0: Non stationary series rejected at 5% level of confidence						
** All first difference series reject non-stationarity on 1% level of confidence						
Critical Values from output in PC Give						

The Monthly and log monthly series share the same properties. Cointegration testing can be performed on the overall period, and the first period. In the last period, cointegration testing cannot be performed, however the conclusion that WTI is stationary is highly uncertain, as the conclusion is very lag dependent.

Augmented Dickey Fuller unit root test of prices and returns						
	Weekly					
	1997 -2013		1997-2006		2006-2013	
	Henry Hub	WTI	Henry Hub	WTI	Henry Hub	WTI
Prices						
Optimal lag length	9	8	0	7	3	8
T value ADF	-2,562	-1,83	-1,043	0,3231	-3,085*	-3,211*
First differences (Returns)						
Optimal lag length	8	7	5	6	2	0
T value ADF **	-10,97	-7,737	-10,57	-9,706	-11,38	-16,05
Order of integration	I(1)	I(1)	I(1)	I(1)	I(0)	I(0)
Critical t-value 5% confidence	-2,87	-2,87	-2,87	-2,87	-2,87	-2,87
Critical t-value 1% confidence	-3,44	-3,44	-3,45	-3,45	-3,45	-3,45
* H0: Non stationary series rejected at 5% level of confidence						
** All first difference series reject non-stationarity on 1% level of confidence						
Critical Values from output in PC Give						

The time series properties of the weekly series allows for cointegration in the overall period and in the first period. Cointegration testing cannot be done for the last period from 2006-2013, possibly another relationship can be explored.

Augmented Dickey Fuller unit root test of prices and returns				
	Monthly			
	1997-2009		2009-2013	
	Henry Hub	WTI	Henry Hub	WTI
Prices				
Optimal lag length	0	2	1	0
T value ADF	-2,217	-2,548	-2,915	-2,417
First differences (Returns)				
Optimal lag length	0	5	0	0
T value ADF **	-12,46	-4,238	-5,689	-7,117
Order of integration	I(1)	I(1)	I(1)	I(1)
Critical t-value 5% confidence	-2,88	-2,88	-2,92	-2,92
Critical t-value 1% confidence	-3,48	-3,48	-3,57	-3,57
* H0: Non stationary series rejected at 5% level of confidence				
** All first difference series reject non-stationarity on 1% level of confidence				
Critical Values from output in PC Give				

The alternate time periods form 1997-2009 and 2009-2013 show no uncertainty about the time series properties, and cointegration test on these can be performed confidently.

Appendix III - Testing for cointegration

Cointegration is often used to describe economically meaningful equilibrium relationships such as commodity market arbitrage and purchasing power parity. These theories states that in the short run prices of similar products in different markets might differ, however arbitrageurs will limit how far the prices might mover apart (Enders, 2010). A much used cointegration example is a drunk man walking his dog, they will wander independently, but in the same general direction with the leash providing a limit of how far apart they might move. Cointegration is formally tested by formulating a linear relationship, called the cointegration vector, and test the residuals from this relationship for stationarity. If the hypothesis that the residuals are non-stationary is rejected, a long-term relationship exists. If the error terms are non-stationary no long-term relationship exists and we need to look somewhere else.

The definition states that if two variables that are I(1) can be combined linearly so that the combination is I(0) then the two variables are said to be cointegrated, meaning that they are joined together in a long run equilibrium. The linear combination of the two variables is called the cointegration vector. The cointegrating vector can either be defined based on a theory about the relationship, often referred to as restricted cointegration vector. The unrestricted method estimates a linear relationship, the cointegration regression, using ordinary least squares regression. In order to test the relationship between crude oil and gas we use the unrestricted method where the relationship is set up as following in equation 1.1

$$P_t^{Gas} = \alpha + \beta P_t^{Oil} + \varepsilon_t \qquad \text{Eq 1.1}$$

With the Henry Hub natural gas price as dependant variable and the price of WTI crude oil as explanatory variable. A constant is included to provide a measure of the level of difference. We have already found that the both the time series are integrated at order one. We expect to find that the error terms from the regression are stationary in the period up to 2006, but non-stationary in the period after 2006.

$\widehat{\varepsilon_t} = P_t^{Gas} - \alpha - \beta P_t^{Oil}$ Eq 1.2

The equilibrium relationship between the variables is then represented by equation 1.2. If we find the time series to be cointegrated in the first period, the estimated parameters will be correct estimates of the long-run equilibrium parameters. Furthermore in an error correction model the residual lagged once can be used as an error correction term. (Sjö, 2008)

The next step is to test for stationarity in the residuals process from the cointegrating regression Eq 1.1. The augmented Dickey Fuller is set up, however this time excluding the constant, as this in most cases improves the estimate (Sjö, 2008).

$$\Delta\hat{\varepsilon}_t = \gamma\hat{\varepsilon}_{t-1} + \sum_{i=1}^{p}\delta_i\Delta\hat{\varepsilon}_{t-i} + v_t$$

Because we obtained the residuals from a regression, the t-distribution is not the same as in the previous augmented Dickey Fuller test. The critical t-value, found in a paper by Engle & Yoo (Engle & Yoo, 1987), is presented in table 5.

Critical values for the cointegration test with two variables			
Sample Size	Significance level 1 %	5 %	10 %
50	4,32	3,67	3,28
100	4,07	3,37	3,03
200	4,00	3,37	3,02
Engle & Yoo (1987)			

Table 5: Critial values for cointegration test

If we reject the null hypothesis of non-stationary residuals, the price series of oil and gas can are cointegrated, and share a long-term equilibrium relationship represented by equation 1.2.

Appendix IV – Cointegration test results

Below we present the tables of results from the unit root test of the residuals from monthly, log monthly and weekly price series. The tables present summarized results from the output of PC Give. Stationary residuals mean that the series are cointegrated. The test procedure is explained in Appendix III, where also the critical t-values are presented.

Augmented Dickey Fuller Test of Residuals			
	Monthly		
Time Period	1997-2013	1997-2006	2006-2013
Constant			
Optimal nr of lags	0	0	0
Residual t-value	-2,56	-3,32*	-1,77
Nr of observations	193	107	85
Cointegration?	NO	YES	NO
No Constant			
Optimal nr of lags	0	0	0
Residual t-value	-2,57	-3,35*	-1,78
Cointegration?	NO	YES	NO
* Rejected on 10% level of significance			
** Rejected on 1% level of significance			
Critical values from Engle & Yoo 1987			

Augmented Dickey Fuller Test of Residuals			
	Log Monthly		
Time Period	1997-2013	1997-2006	2006-2013
Constant			
Optimal nr of lags	0	0	0
Residual t-value	-2,13	-3,25*	-1,61
Nr of observations	193	107	85
Cointegration?	NO	YES	NO
No Constant			
Optimal nr of lags	0	0	0
Residual t-value	-2,14	-3,27*	-1,62
Cointegration?	NO	YES	NO
* Rejected on 10% level of significance			
** Rejected on 1% level of significance			
Critical values from Engle & Yoo 1987			

The monthly and log monthly series gives us nearly identical results, both confirming decoupling and also cointegration on a 10% level of significance.

Augmented Dickey Fuller Test of Residuals			
		Weekly	
Time Period	1997-2013	1997-2006	2006-2013
Constant			
Optimal nr of lags	6	0	0
Residual t-value	-2,53	-4,19**	-2,33
Nr of observations	838	467	375
Cointegration?	NO	YES	NO
No Constant			
Optimal nr of lags	4	0	1
Residual t-value	-2,88	-4,2**	-2,33
Cointegration?	NO	YES	NO
* Rejected on 10% level of significance			
** Rejected on 1% level of significance			
Critical values from Engle & Yoo 1987			

The weekly time series support our results, and concludes on a high level of significance.

	Monthly	
Time Period	1997-2009	2009-2013
No Constant		
Optimal nr of lags	0	0
Residual t-value	-3,74*	-2,28
Cointegration?	YES	NO
* Rejected on 5% level of significance		
Critical values from Engle & Yoo 1987		

The alternate time periods 1997-2009 and 2009-2013 support our findings of a cointegrating relationship in the first part of the period, and decoupling in the last part of the period. On a 5 percent level of significance and low uncertainty from lag dependence of the conclusion.

Appendix V – Lag selection and sensitivity of results

The tables below presents Akaikes Information Criterion (AIC) and t-values for the number of lags used in the augmented Dickey Fuller tests on the monthly data used in the analysis. The number of lags used in the initial test is set to 10. We then minimize the AIC value stepwise to find the optimal number of lags. This is done by running the test with 9 lags then 8 lags and so on until the AIC value of the selected number of lags is the lowest of the lags in the output from the test. For the series from 2006-2013 we do not need to do this stepwise as we have data preceding this period. The AIC minimizing number of lags is presented with the corresponding t-value.

Henry Hub Spot Price								
1997-2013			1997-2006			2006-2013		
Lags	AIC	t-adf	Lags	AIC	t-adf	Lags	AIC	t-adf
10	-0,27	-1,915	10	-0,1921	0,5516	**10**	**-0,4052**	**-1,827**
9	-0,2805	-1,904	9	-0,1985	0,824	9	-0,4026	-2,141
8	-0,2445	-2,389	8	-0,2016	0,568	8	-0,2789	-2,825
7	-0,2553	-2,407	7	-0,2003	0,2804	7	-0,2876	-2,667
6	-0,2637	-2,575	6	-0,2122	0,1132	6	-0,3108	-2,744
5	-0,2679	-2,422	5	-0,2065	0,4353	5	-0,3275	-2,661
4	-0,2603	-2,831	4	-0,2212	0,2746	4	-0,3069	-3.211*
3	-0,2629	-2,647	3	-0,2225	0,7027	3	-0,33	-3.329*
2	-0,2724	-2,604	2	-0,2426	0,8317	2	-0,353	-3.356*
1	-0,2786	-2,481	1	-0,2359	0,1507	1	-0,3425	-3.268*
0	**-0,2895**	**-2,517**	**0**	**-0,2528**	**-0,01016**	0	-0,3649	-3.281*
Stepwise AIC minimization			Stepwise AIC minimization			Stepwise minimization not needed		
Lags	AIC	t-adf	Lags	AIC	t-adf	Lags	AIC	t-adf
0	**-0,3267**	**-2,507**	**0**	**-0,3236**	**0,05067**	**10**	**-0,4052**	**-1,827**
* Reject non-stationarity at 5% level of significance								
** Reject non-stationarity at 1% level of significance								

We see that the Henry Hub Spot price is non-stationary in all periods, however the period from 2006-2013 shows lag dependence, leaving some uncertainty about the conclusion.

Henry Hub First Difference								
1997-2013			1997-2006			2006-2013		
Lags	AIC	t-adf	Lags	AIC	t-adf	Lags	AIC	t-adf
10	-0,2472	-5.088**	10	-0,1815	-2,293	10	-0,3657	-4.670**
9	-0,2577	-5.672**	9	-0,2023	-2,429	**9**	**-0,3843**	**-5.721****
8	**-0,2686**	**-6.244****	8	-0,2094	-3.178*	8	-0,3666	-5.423**
7	-0,2203	-5.283**	7	-0,2156	-2.972*	7	-0,2023	-3.940**
6	-0,2309	-5.654**	6	-0,2173	-2,67	6	-0,2225	-4.567**
5	-0,2351	-5.685**	5	-0,2305	-2,562	5	-0,2419	-4.803**
4	-0,2438	-6.702**	4	-0,2231	-3.800**	4	-0,2649	-5.522**
3	-0,2246	-6.235**	3	-0,2393	-3.988**	3	-0,2089	-4.745**
2	-0,2327	-7.585**	2	-0,2351	-5.702**	2	-0,225	-4.933**
1	-0,2437	-9.283**	1	-0,253	-7.917**	1	-0,2476	-5.690**
0	-0,2535	-13.83**	**0**	**-0,2538**	**-9.853****	0	-0,2447	-9.916**
Stepwise AIC minimization			Stepwise AIC minimization			Stepwise minimization not needed		
Lags	AIC	t-adf	Lags	AIC	t-adf	Lags	AIC	t-adf
8	**-0,2755**	**-6.280****	**1**	**-0,3367**	**-8.333****	**9**	**-0,3843**	**-5.721****
7	-0,2289	-5.338**	0	-0,3357	-10.26**			
6	-0,2393	-5.710**						
5	-0,2433	-5.735**						
4	-0,2518	-6.761**						
3	-0,2326	-6.298**						
2	-0,2408	-7.647**						
1	-0,2517	-9.334**						
0	-0,2614	-13.88**						
* Reject non-stationarity at 5% level of significance								
** Reject non-stationarity at 1% level of significance								

The first difference/return series of Henry Hub is stationary for all periods. We do however note the lag dependence in the period 1997-2006. We interpret this uncertainty as low due to the high t-values of the non-rejecting lags, and the fact that the non-stationarity is rejected at a 1% level of significance.

WTI Crude Oil Spot Price								
1997-2013			1997-2006			2006-2013		
Lags	AIC	t-adf	Lags	AIC	t-adf	Lags	AIC	t-adf
10	3,211	-1,004	10	1,905	0,05163	**10**	3,828	-2,341
9	3,2	-1,016	9	1,905	0,3685	9	3,805	-2,442
8	3,19	-1,087	8	1,884	0,3842	8	3,782	-2,505
7	3,182	-1,031	7	1,864	0,3386	7	3,773	-2,341
6	**3,173**	**-1,093**	6	1,847	0,2329	6	3,754	-2,277
5	3,196	-1,393	**5**	**1,827**	**0,3143**	5	3,747	-2,656
4	3,201	-1,635	4	1,913	1,359	4	3,742	-3.201*
3	3,191	-1,709	3	1,929	0,7508	3	3,724	-3.158*
2	3,184	-1,845	2	1,919	0,4502	**2**	**3,701**	**-3.337***
1	3,181	-1,698	1	1,919	0,08836	1	3,717	-2.902*
0	3,337	-1,056	**0**	1,9	0,1907	0	3,952	-1,839
Stepwise AIC minimization			Stepwise AIC minimization			Stepwise minimization not needed		
Lags	AIC	t-adf	Lags	AIC	t-adf	Lags	AIC	t-adf
6	**3,152**	**-1,05**	**5**	**1,774**	**0,3399**	**2**	**3,701**	**-3.337***
5	3,176	-1,363	4	1,862	1,453			
4	3,18	-1,609	3	1,881	0,8008			
3	3,17	-1,686	2	1,872	0,4899			
2	3,163	-1,822	1	1,872	0,1224			
1	3,161	-1,671	0	1,854	0,2183			
0	3,316	-1,037						
* Reject non-stationarity at 5% level of significance								
** Reject non-stationarity at 1% level of significance								

The WTI crude oil price is found non-stationary in the overall period and in the first period. It is found stationary in the period from 2006-2013, there is high uncertainty in this result as we see most lags do not reject non-stationarity.

WTI Crude Oil First Difference								
1997-2013			1997-2006			2006-2013		
Lags	AIC	t-adf	Lags	AIC	t-adf	Lags	AIC	t-adf
10	3,218	-4.940**	10	1,881	-1,926	10	3,886	-3.579**
9	3,21	-4.998**	9	1,893	-2,383	**9**	3,877	-3.450*
8	3,2	-5.358**	8	1,89	-2.903*	8	3,858	-3.488*
7	3,191	-5.549**	7	1,87	-3.091*	7	3,838	-3.583**
6	3,182	-6.518**	6	1,849	-3.216*	6	3,818	-4.252**
5	**3,174**	**-7.041****	5	1,831	-3.273*	5	3,795	-4.997**
4	3,202	-6.443**	**4**	**1,811**	**-3.610****	4	3,809	-4.674**
3	3,21	-6.195**	3	1,916	-6.140**	3	3,839	-4.102**
2	3,201	-6.620**	2	1,918	-6.419**	2	3,817	-4.418**
1	3,197	-6.898**	1	1,905	-7.623**	1	3,805	-4.445**
0	3,191	-8.995**	**0**	1,901	-9.318**	**0**	**3,79**	**-5.805****
Stepwise AIC minimization			Stepwise AIC minimization			Stepwise minimization not needed		
Lags	AIC	t-adf	Lags	AIC	t-adf	Lags	AIC	t-adf
5	**3,147**	**-7.125****	**4**	**1,756**	**-3.838****	**0**	**3,79**	**-5.805****
4	3,175	-6.520**	3	1,865	-6.326**			
3	3,184	-6.280**	2	1,868	-6.583**			
2	3,175	-6.704**	1	1,855	-7.831**			
1	3,171	-6.990**	0	1,853	-9.587**			
0	3,166	-9.114**						
* Reject non-stationarity at 5% level of significance								
** Reject non-stationarity at 1% level of significance								

In the first difference of the WTI crude oil price series we find stationarity in all periods. There is slight lag dependence in the higher lag combinations, however when we reduce the number of lags the results become very clear. We conclude that the series is stationary with a high level of certainty.

Residuals from Cointegrationregression tests								
1997-2013			1997-2006			2006-2013		
Lags	AIC	t-adf	Lags	AIC	t-adf	Lags	AIC	t-adf
10	-0,3204	-1,435	10	-0,3164	-3.551**	10	-0,7882	-1,004
9	-0,3312	-1,434	9	-0,2755	-2.905	9	-0,8134	-1,071
8	-0,2894	-2.013	8	-0,2859	-3.472**	8	-0,7698	-1,484
7	-0,3002	-2.028	7	-0,2912	-3.263*	7	-0,7959	-1,563
6	-0,3073	-2.232	6	-0,3105	-3.377**	6	-0,8163	-1,742
5	-0,3136	-2.100	5	-0,3127	-3.117*	5	-0,8043	-1,428
4	-0,3081	-2.508	4	-0,3317	-3.188*	4	-0,8309	-1,462
3	-0,3158	-2.408	3	-0,3318	-2.876	3	-0,8546	-1,597
2	-0,3267	-2.445	2	-0,3277	-2.487	2	-0,8757	-1,521
1	-0,3357	-2.382	1	-0,3465	-3.016	**1**	**-0,9002**	**-1,651**
0	**-0,346**	**-2.511**	**0**	**-0,3668**	**-3.195***	0	-0,8678	-1,287
Stepwise AIC minimization			Stepwise AIC minimization			Stepwise AIC minimization		
Lags	AIC	t-adf	Lags	AIC	t-adf	Lags	AIC	t-adf
0	**-0,3859**	**-2.567**	**0**	**-0,4516**	**-3.349***	**0**	**-0,7013**	**-1,782**
* Reject non-stationarity at 10% level of significance								
** Reject non-stationarity at 5% level of significance								

From the unit root test of the residuals from the cointegrating equation we find uncertainty in the results only for the period 1997-2006. These are lag dependent, however we are quite confident in our conclusion of stationarity, since most lags reject non-stationarity and the ones that don't, have relatively high t-values.

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