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Forward Curves, Scarcity and Price Volatility in Oil and Natural Gas Markets

Hélyette Geman,
Birkbeck, University of London and ESCP Europe

Steve Ohana,
Birkbeck, University of London

Abstract

The role of inventory in explaining the shape of the forward curve and spot price volatility in commodity markets is central in the theory of storage developed by Kaldor (1939) and Working (1949) and has since been documented in a vast body of financial literature, including the seminal paper by Fama and French (1987) on metals. The goal of this paper is twofold: i) validate in the case of oil and natural gas the use of the slope of the forward curve as a proxy for inventory; in contrast to Fama and French however, our slope is defined in order to filter out seasonality. ii) analyze directly for these two major commodities the relationship between inventory and price volatility. In agreement with the theory of storage, we find the negative correlation to be significant during those periods when the inventory is below the historical average (*scarcity*). Our results are illustrated by the analysis of a 20 year-database of US oil and natural gas prices and inventory.

I. Introduction

The high activity recently experienced in the crude oil and natural gas markets over the last few years with the arrival of hedge funds and other new players has led researchers and practitioners to focus on these crucial commodities. Our goal in this paper is to give a particular attention to two quantities which play a key role in economics and finance, namely the shape of the forward curve and the spot price volatility.

The theory of storage introduced in the founding papers by Kaldor (1939), Working (1948, 1949), Telser (1958), Brennan (1958), asserts that the holder of some inventory of a commodity earns a "convenience yield" because readily available stocks allow him to respond more efficiently to unexpected supply-and-demand shocks and avoid costly disruptions in the manufacturing process. In the financial literature, this convenience yield - usually denoted as y – is exhibited in the spot forward relationship derived from no arbitrage arguments, under the following form

$$f^T(t) = S(t)\left[1 + \left(r(t,T) + c(t,T) - y(t,T)\right)(T - t)\right]$$

where:

- $f^T(t)$ denotes the forward price of the commodity at date t for delivery at date T
- $c(t,T)$ is the (annual) cost of storage
- $r(t,T)$ is the (annual) interest rate over the period (t, T)
- $y(t,T)$ is the marginal convenience yield derived from an additional unit of inventory.

The quantity $s(t,T) = \frac{f^T(t) - S(t)\left[1 + r(t,T)\right]}{S(t)}$ represents the interest-adjusted spread of the forward curve relative to the spot price (or the first-near by). This adjusted spread reflects the storage cost and convenience yield over the period (t,T). It was analyzed by Brennan (1958) and Telser (1958) in the context of several agricultural commodities. Their findings were the following: when stocks decline, the adjusted spread becomes negative (and spot price volatility increases). Indeed, during low inventory periods, sudden shifts in demand cannot be easily absorbed by inventory and spot prices are likely to exceed Futures prices due to a high convenience yield. Conversely, when inventory levels are adequate, the change in demand can be addressed by resorting to storage; the convenience yield is then low and the Futures prices greater than spot prices due to the cost of storage. Hence, the adjusted spread is positive when inventories are high. Keynes (1930) was the first one to study the relationship between inventory and the shape of the forward curve, and exhibit positive correlation between backwardation (negative spread of the forward curve) and stockouts. Let us note that the spread, in contrast to inventories, has the merit of being an observable quantity for all commodities traded on an Exchange, which is the case for most of them today (CBOT, NYMEX, MCX). In a seminal paper, Fama and French (1987) take as a given the property of the spread being an adequate proxy for inventory. This allows them to analyze 21 commodities, metals in particular, for which good inventory data were often missing in their period of analysis. Other authors (see for instance Williams and Wright (1989)) proceed in the same manner. Ng and Pirrong (1994) examine four industrial and one precious metals over the period 1986-1992 and use the same proxy for inventory to conclude that fundamentals drive metal prices dynamics.

Besides the relationship between inventory and the shape of the forward curve, a number of authors have investigated another component of the theory of storage, namely the relationship between inventory and commodity price volatility. The volatility of a commodity tends to be inversely related to the level of global stocks. In the case of a stock outage, spot prices change dramatically in response to shocks in demand if inventories are not available to provide a buffering effect (electricity being the most extreme example as it is essentially non storable). Many authors, including Working (1948, 1949) and Williams (1986), analyze agricultural commodities and exhibit a negative relationship between the adjusted spread and variance of commodity spot prices. The statistical study performed by Fama and French (1987) on a variety of commodity Futures including metals, wood and live cattle shows that the variance of prices decreases with inventory levels; the adjusted spread is used as a proxy for inventory. Fama and French (1988) exhibit that in the case of metals, spot prices are more variable than Futures prices. Williams and Wright (1991) analyze a quarterly model involving a yearly production of an agricultural commodity and identify that price volatility regularly increases after harvest time until the next one. Ng and Pirrong (1994) also study metals, employ the same proxy for inventory and find that both spot and forward return variances increase with low inventory. Exploiting the dependence between the current commodity price and the expectation of future prices at a given inventory level, Deaton and Laroque (1992) find that the conditional variance of prices increases with current price and decreases with higher stocks. Geman and Nguyen (2005) reconstruct a database of soybean world inventory and exhibit a quasi-perfect affine relationship between spot price volatility and *scarcity*, defined as inverse inventory.

Our goal in this paper is to revisit some of the above mentioned issues in the particular context of oil and natural gas, two commodities which have been in the forefront of the actuality over the last few years. Firstly, we empirically document on a database of US Futures prices and inventory, the remarkable relationship between inventory and the adjusted spread; we define this adjusted spread in a way that filters out seasonality when it exists (natural gas). Secondly we focus our attention on volatility, a key quantity in all financial and commodity markets. We show that in the case of oil and natural gas, both storable energy commodities, inventory is negatively correlated to volatility in periods where stocks are below their historical average (scarcity), while, otherwise the correlation is low (for crude oil) or non-significant (for natural gas). Moreover, the negative correlation during times of scarcity is more pronounced in the case of natural gas. This suggests that for oil, other issues such as the availability of oil refineries, information release on depleting oil underground reserves worldwide[1], and geopolitical events are also key drivers of spot price volatility.

The remainder of the paper is organized as follows. Section 2 exhibits the remarkable relationship, in the case of oil and natural gas, between adjusted spread and inventory data; Section 3 examines for both commodities the comovements between inventory and price volatility. Section 4 contains some concluding comments.

[1] Let us note that the issue of reserves of oil and natural gas is a crucial subject in its own right; see Adelman and Watkins (2005) for the analysis of the unit value of in-ground proved oil reserves and natural gas reserves in the United States.

I. Adjusted spread and Inventory in oil and gas markets

In the first part of this section, we wish to analyze, in the context of US oil and natural gas, the joint evolution of inventory and adjusted spread over time periods of respectively 16 years and 13 years.

Description of the data

i) The price database comprises daily observations of NYMEX monthly Futures prices over the period January 1990 to August 2006 for oil and over the period January 1993 to August 2006 for gas; maturities range from 1 month to 13 months (see Figures 1 and 2). The daily forward curve slope or adjusted spread is defined as:

$$adjusted\ spread = \frac{Futures\ 13M - Futures\ 1M.(1 + rate\ 1Y)}{Futures\ 1M}$$

where Futures 1M and Futures 13M respectively denote the first-month and 13 month Futures prices and rate 1Y represents the one-year US interest rate[2].

The monthly average forward curve slope is computed as the average of daily forward curve slopes between two consecutive rolling dates. We choose an interval of 12 months between the short term and the long term contracts in order to filter out the seasonality of the natural gas forward curve in the calculation of the adjusted spread.

We observe that in the case of crude oil (see Fig. 4), the forward curve is mostly backwardated, a feature often identified in the literature (see for instance Gabillon (1991)).

[2] The daily US yield curve was obtained from the website of the US department of Treasury, i.e. www.treas.gov.

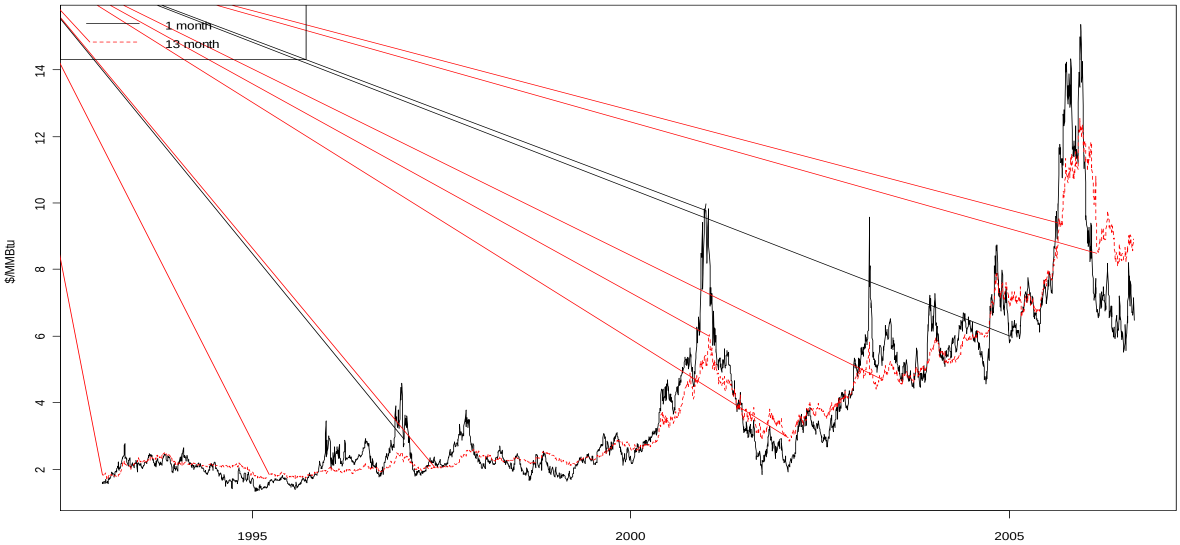

Fig 1: *Daily front-month and 13th month Natural Gas futures prices ($/MMBtu)*

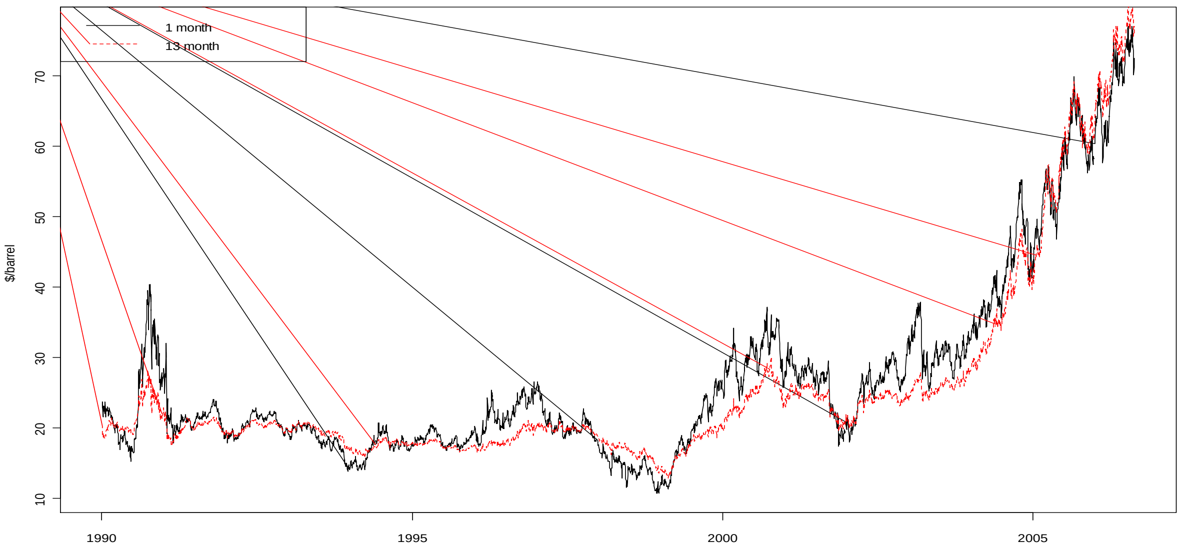

Fig 2: *Daily front-month and 13th month Crude Oil futures prices ($/Barrel)*

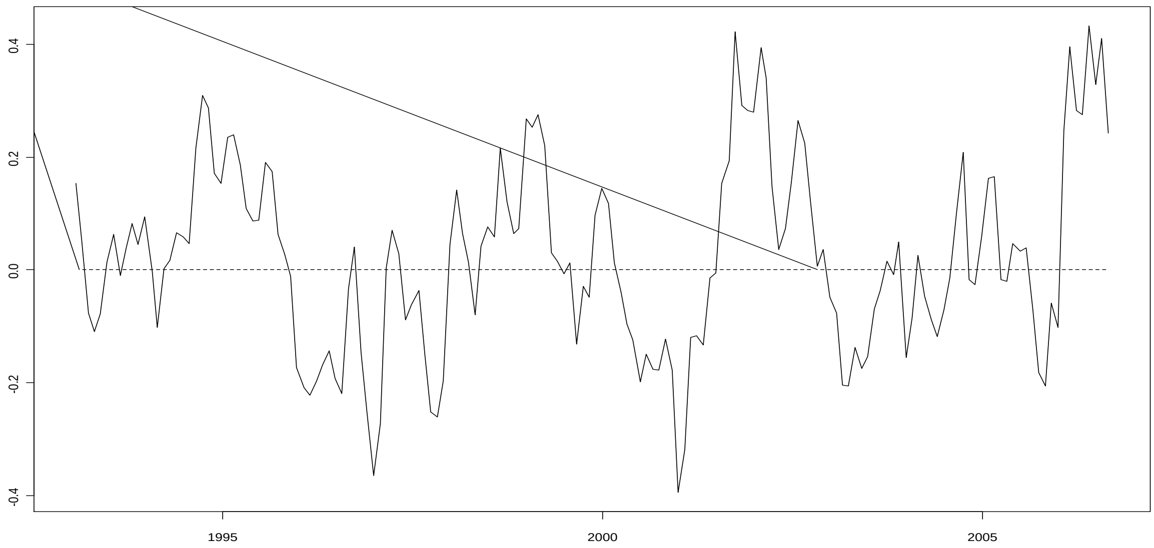

Fig 3: *Monthly Natural Gas adjusted spread*

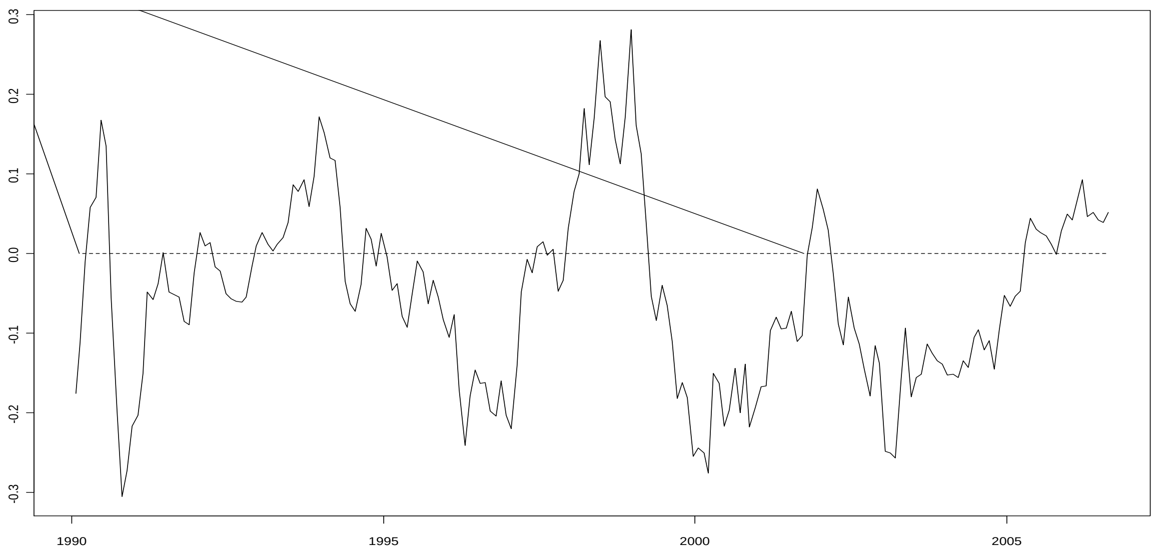

Fig 4: *Monthly Crude Oil adjusted spread*

ii) Turning to inventory, data were taken from the Department of Energy (DoE) Energy Information Administration website (www.eia.doc.gov) :

a) For natural gas, we collected the volume of natural gas stocks in the United States at the end of each month during the period December 31, 1992 to July 31, 2006. The inventory data exhibit a strong seasonality - as could be expected from the seasonal use of natural gas. To deseasonalize natural gas inventory data, we regress inventory on trigonometric functions of time and obtain the following decomposition (the t-values are reported in parentheses under each estimated coefficient):

$$I_t = \underset{(100.82)}{2.11} + \underset{(21.64)}{0.63}\cos(2\pi t/12) - \underset{(-21.28)}{0.64}\sin(2\pi t/12) + \underset{(5.74)}{0.17}\cos(2\pi t/6) + \tilde{I}_t$$

where I_t refers to the original and $\tilde{I}_t$ deseasonalized inventory. The trigonometric fit is illustrated in Figure 5.

b) For the oil inventory, we gathered the volumes of all petroleum products stored in OECD countries at the end of each month from the end of December 1989 to the end of July 2006. The inventory data exhibit a positive drift, translating the growth of the world oil consumption. Over the past 30 years, daily oil consumption has risen by approximately 30 million barrels: Asia has represented half of this growth in demand, the rest being accounted for by developed countries in particular. To detrend crude oil inventory data, we regress inventory on time, obtaining the following trend for the petroleum products inventory (the t-values are reported in parenthesis under each estimated coefficient):

$$I_t = \underset{(286.83)}{3.70} + \underset{(14.74)}{0.0017}\, .t + \tilde{I}_t$$

where I_t refers to the original and $\tilde{I}_t$ to the detrended petroleum products inventory. The linear fit is illustrated in Figure 6.

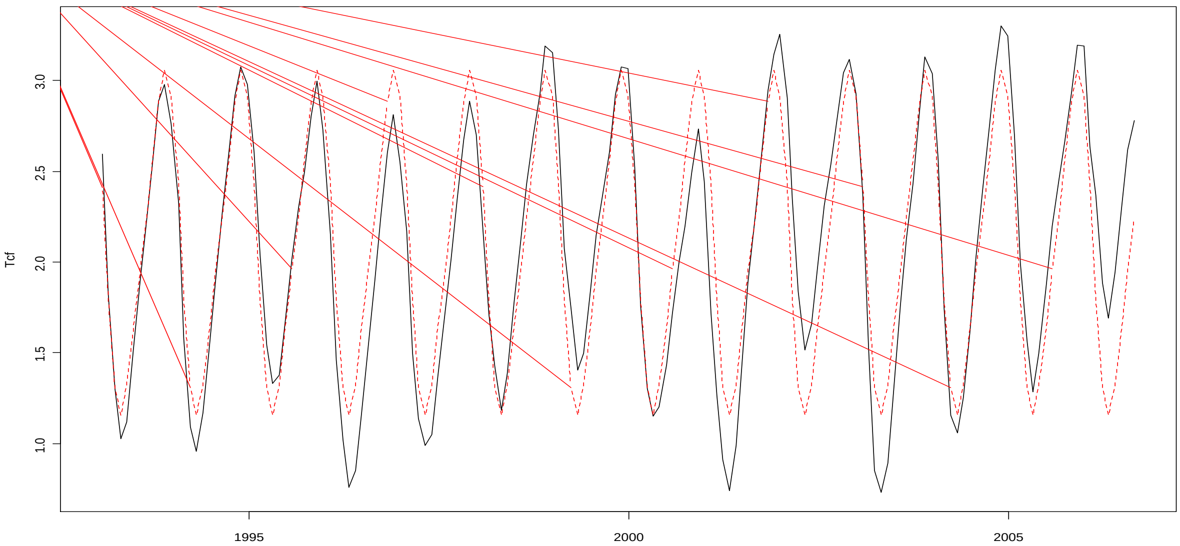

Fig 5: *US Natural Gas inventory at the end of each month (in Trillion Cubic Feet) and trigonometric fit (dotted line)*

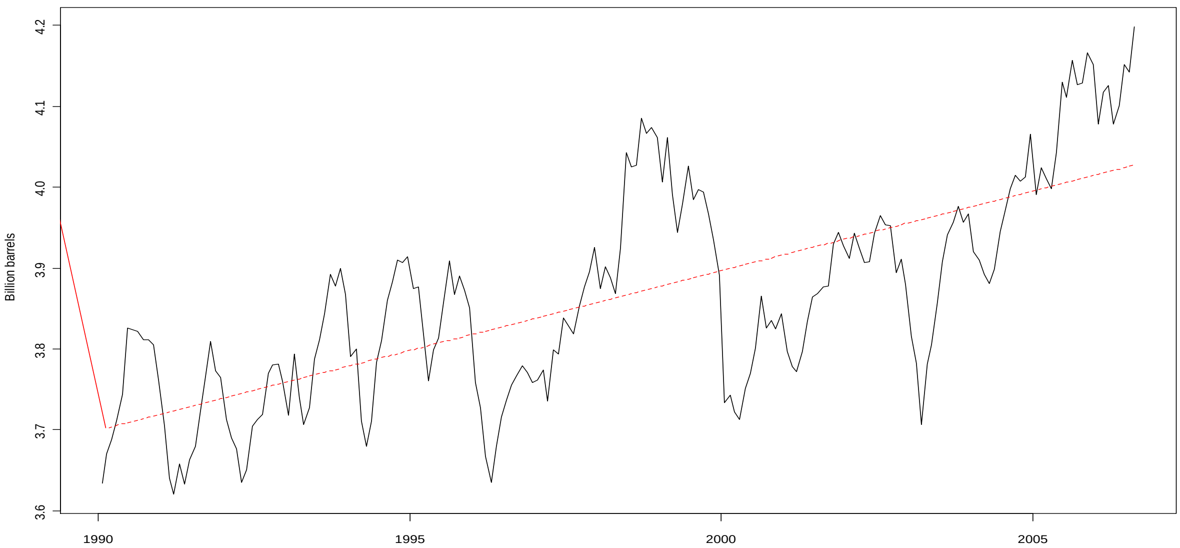

Fig 6: *Petroleum products inventory in OECD countries at the end of each month (in Billion barrels) and linear fit (dotted line)*

Stationarity tests:

ADF stationarity tests[3] on the gas (resp. oil) adjusted spreads and deseasonalized (resp. detrended) inventories reported on Table 2 reject the hypothesis Ho of a unit root with 95% confidence:

	Spread	inventory
Gas	-3.33	-2.93
Oil	-2.96	-3.04

Tab 1: *Augmented-Dickey-Fuller unit root tests (using 5 lags and including a constant but no linear time trend in the regression) performed on gas (resp. oil) adjusted spreads and deseasonalized (resp. detrended) inventory: the statistics of the tests are reported in the two right columns; the 5% (resp. 1%) critical value is -2.88 (resp. -3.46)*

Results of the regression of adjusted spread on inventory

1) For natural gas, we obtain the following regression of the gas monthly adjusted spread (here denoted $spread_t$) during month t on the deseasonalized inventory at the end of month t-1 (the t-values are reported in parentheses under each estimated coefficient):

$$spread_t = +\underset{(2.54)}{0.022} + \underset{(14.08)}{0.47}\,\tilde{I}_{t-1} + \varepsilon_t \qquad (1)$$

where the R^2 of the regression is 54.76 %

2) For oil, we regress the crude oil monthly adjusted spread on the one-month-lagged original inventory (denoted I_{t-1}), on the one hand, and the one-month-lagged *detrended* inventory on the other hand. The results go as follows (the t-values are reported in parentheses under each estimated coefficient):

a) regression of the adjusted spread on the original inventory:

$$spread_t = -\underset{(-5.47)}{1.21} + \underset{(5.25)}{0.30}\,I_{t-1} + \varepsilon_t \qquad (2)$$

R^2 of the regression: 11.76 %

b) regression of the adjusted spread on the detrended inventory:

$$spread_t = -\underset{(-8.12)}{0.051} + \underset{(11.28)}{0.78}\,\tilde{I}_{t-1} + \varepsilon_t \qquad (2\text{-bis})$$

[3] The Augmented-Dickey-Fuller test with constant and time trend and p lags tests the significance of the coefficient α in the linear model:

$\Delta x_t = \mu + \lambda t + \alpha x_{t-1} + \sum_{i=1}^{p} \beta_i \Delta x_{t-i} + \varepsilon_t$; the statistics of the test is the t-value of the coefficient α, which has a documented distribution under the hypothesis H0 that $\alpha = 0$ (presence of a unit root).

R^2 of the regression: 38.82 %

As could be expected from the clear upward trend in oil inventory over the period 1990-2006, the R^2 is significantly higher after detrending.

As a conclusion, we can state that for both oil and natural gas, inventory is a very good explanatory factor of the (adjusted) slope of the forward curve. Figures 7 to 10 illustrate the goodness-of-fit for the two energy commodities.

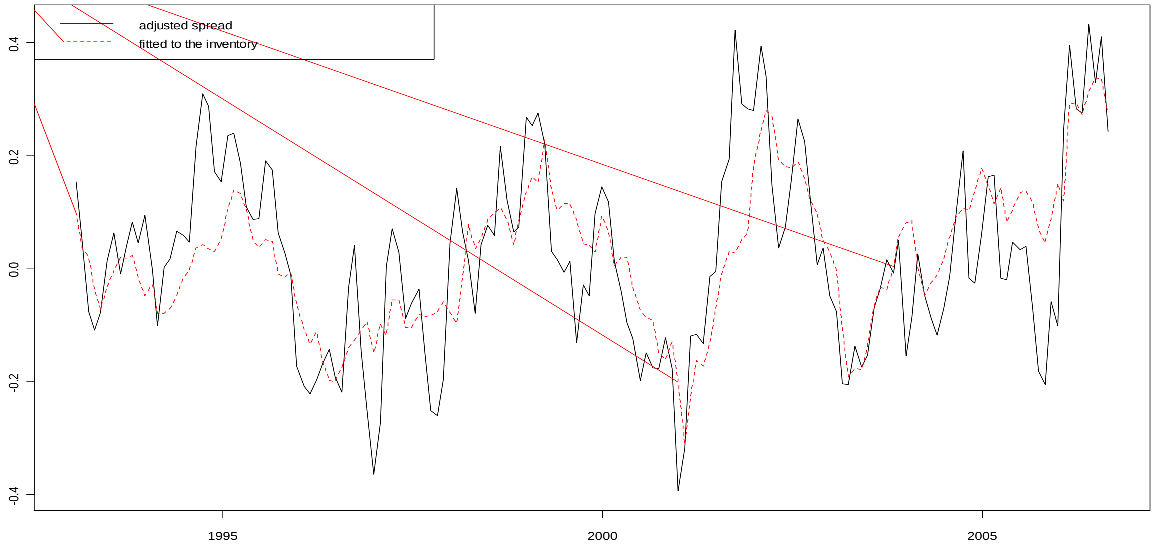

Fig 7: *Natural Gas adjusted spread (full line) and fitted to the deseasonalized inventory (dotted line)*

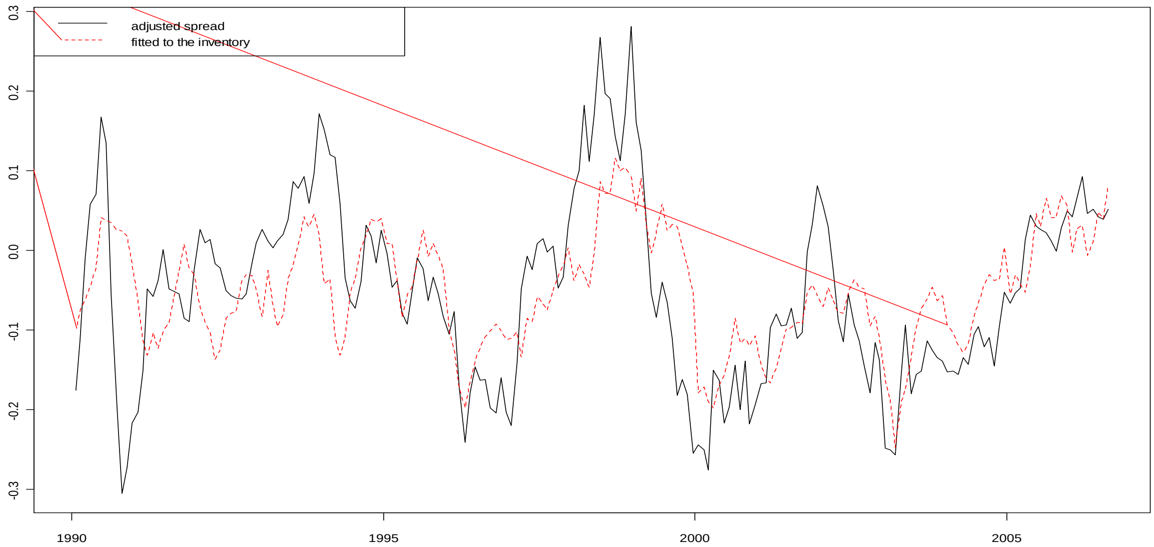

Fig 8: *Crude Oil adjusted spread (full line) and fitted to the detrended inventory (dotted line)*

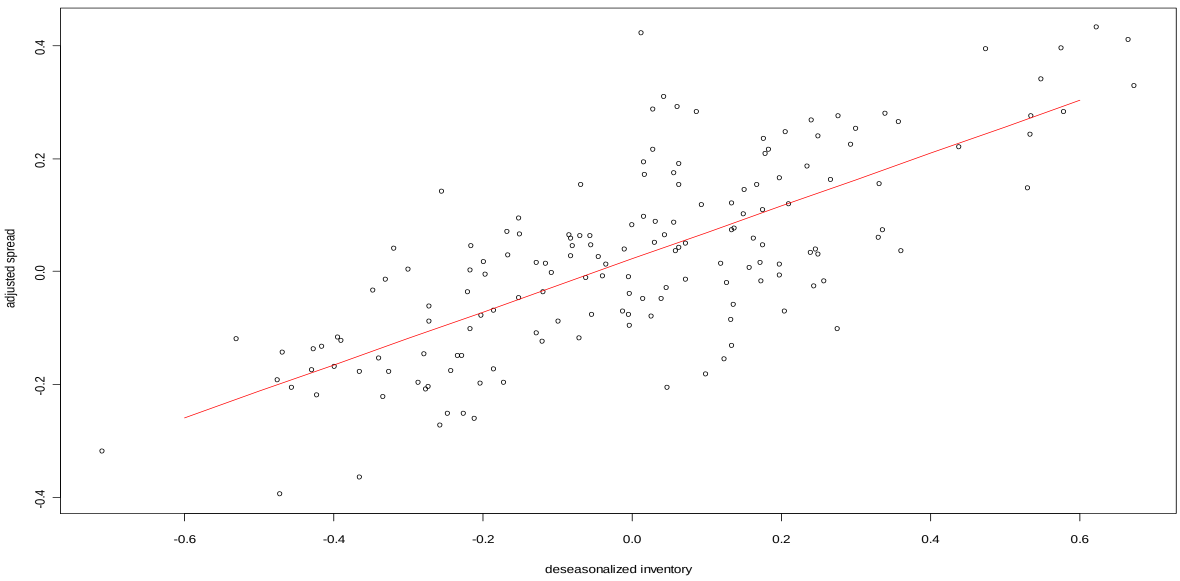

Fig 9: *Natural Gas adjusted spread in terms of the deseasonalized inventory and best linear fit*

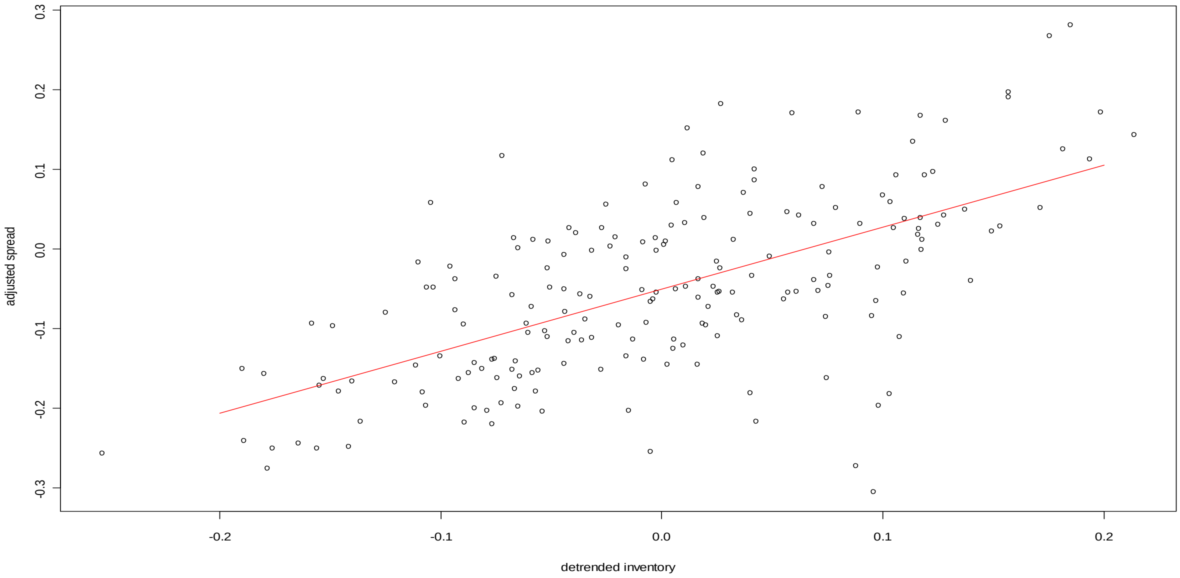

Fig 10: *Crude Oil adjusted spread in terms of the detrended inventory and best linear fit*

Analysis of the causality between inventory and adjusted spread

As a complement to the previous regressions, our objective here is to study the dynamics of the pair (inventory, adjusted spread)[4], and in particular the causality relations existing between inventory and adjusted spread.

We calibrate the following VAR(1) model for natural gas and crude oil:

$$\begin{pmatrix} \tilde{I}_t \\ spread_t \end{pmatrix} = \begin{pmatrix} C^1 \\ C_2 \end{pmatrix} + \Gamma \begin{pmatrix} \tilde{I}_{t-1} \\ spread_{t-1} \end{pmatrix} + \begin{pmatrix} \varepsilon_t^1 \\ \varepsilon_t^2 \end{pmatrix}$$

where:

- $\begin{pmatrix} C^1 \\ C_2 \end{pmatrix}$ is a vector of constants
- Γ is a 2*2 matrix expressing dependence with respect to lagged detrended inventory and spread
- $\begin{pmatrix} \varepsilon_t^1 \\ \varepsilon_t^2 \end{pmatrix}$ are error terms

The calibration of the model by Ordinary Least Squares leads to the following results (the t-values are reported in parentheses under each estimated coefficient):

- Natural Gas:

$$\tilde{I}_t = \underset{(0.663)}{0.00317} + \underset{(22.758)}{0.959}.\tilde{I}_{t-1} - \underset{(-0.195)}{0.0131}.spread_{t-1} + \varepsilon_t^1$$

$$R^2 = 88.31$$

$$spread_t = \underset{(1.247)}{0.00910} + \underset{(3.920)}{0.166}.\tilde{I}_{t-1} + \underset{(9.401)}{0.634}.spread_{t-1} + \varepsilon_t^2$$

$$R^2 = 70.6$$

- Oil:

$$\tilde{I}_t = \underset{(2.217)}{0.00685} + \underset{(21.247)}{0.821}.\tilde{I}_{t-1} + \underset{(3.715)}{0.115}.spread_{t-1} + \varepsilon_t^1$$

$$R^2 = 83.06$$

$$spread_t = -\underset{(-1.475)}{0.00577} + \underset{(1.579)}{0.077}.\tilde{I}_{t-1} + \underset{(22.166)}{0.866}.spread_{t-1} + \varepsilon_t^2$$

$$R^2 = 85.3$$

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[4] $\tilde{I}_t$ is defined as the detrended (resp. deseasonalized) oil (resp. gas) inventory at the end of month t and $spread_t$ is taken to be the average adjusted spread of month t

We first remark that the inclusion of serial auto-correlation leads to much higher values of R^2 than those derived from the simple linear models (1)-(2). In addition, we observe a difference in causality between gas and oil: for the first energy, causality runs essentially from inventory to adjusted spread whereas for the latter, the causality runs both ways and the impact of the lagged spread on inventory is even more pronounced than the impact of the lagged inventory on the spread.

A likely interpretation is that, in the case of natural gas, seasonality is the dominant feature of the forward curve (as documented in Borovkova and Geman (2007)). In the case of oil, there is no seasonality, since the oil market is a world market; hence, market participants exploit the shape of the oil forward curve to implement both carry and reverse carry strategies.

II. Inventory and price volatility

As documented by many authors (Pindyck (2004), Geman and Nguyen (2005)), commodity prices are volatile, and volatility itself varies over time. In the case of energy commodities (and some metals for which the issue of exhaustibility has come in the forefront of actuality like copper and zinc), price volatility has been consistently at a high level over the last two years.

A vast body of the financial literature on equity markets has been dedicated to the relationship between news arrival, trading activity, price changes and volatility (see Ané – Geman (2000)), Jones, Kaul & Lipton (1995)). In the case of commodities, a number of authors have argued that it is the knowledge of quantities produced and existing inventories which are the key elements in the derivation of testable predictions about prices and price volatility (Williams and Wright (1991); Ng and Pirrong (1994)). Building on this literature, our goal in this section is to analyze the relationship between inventory and volatility in the US oil and natural gas markets.

The monthly volatilities are estimated as the annualized standard deviations of the returns of the front-month futures prices over two consecutive rolling days. The trajectories of the monthly volatilities of gas and crude oil are plotted in Figures 11 and 12.

We observe a clear seasonal pattern for natural gas volatility (see Figure 11). This feature is related to a greater demand volatility and a higher sensitivity to demand shocks during winter periods. To deseasonalize natural gas volatility, we use again trigonometric functions of time, obtaining the following decomposition (t-values in parentheses):

$$V_t = \underset{(35.47)}{49.97} + \underset{(6.37)}{12.68}\cos(2\pi t/12) + \underset{(1.88)}{3.75}\cos(2\pi t/6) + \underset{(3.05)}{6.06}\sin(2\pi t/6) + \tilde{V}_t$$

where V_t is the original front-month and $\tilde{V}_t$ the deseasonalized gas volatility.

We plot in Figures 13-14 the gas (resp. crude) front-month deseasonalized (resp. original) volatility in terms of the one-month lagged deseasonalized (resp. detrended) inventory. Note that both detrended or deseasonalized inventory and deseasonalized volatility can take negative values.

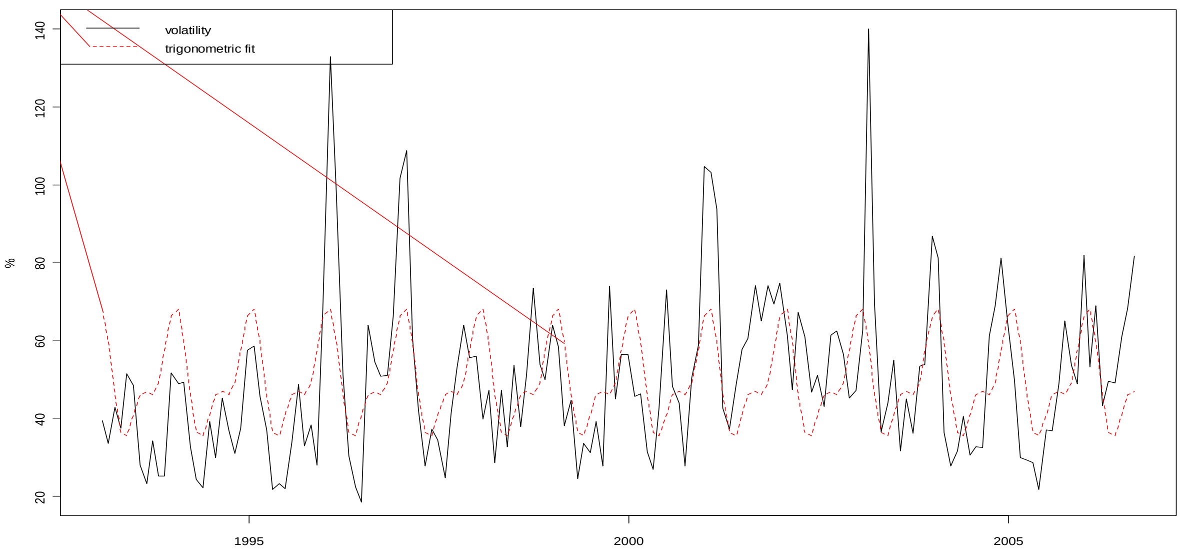

Fig 11: *Natural Gas front-month volatility and trigonometric fit in %*

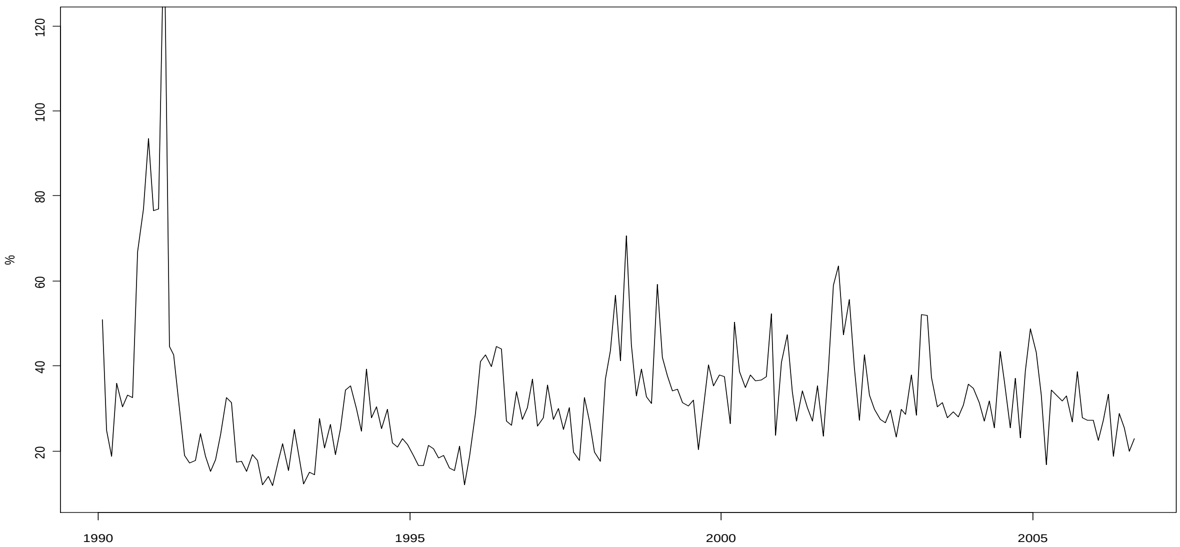

Fig 12: *Crude Oil front-month volatility in %*

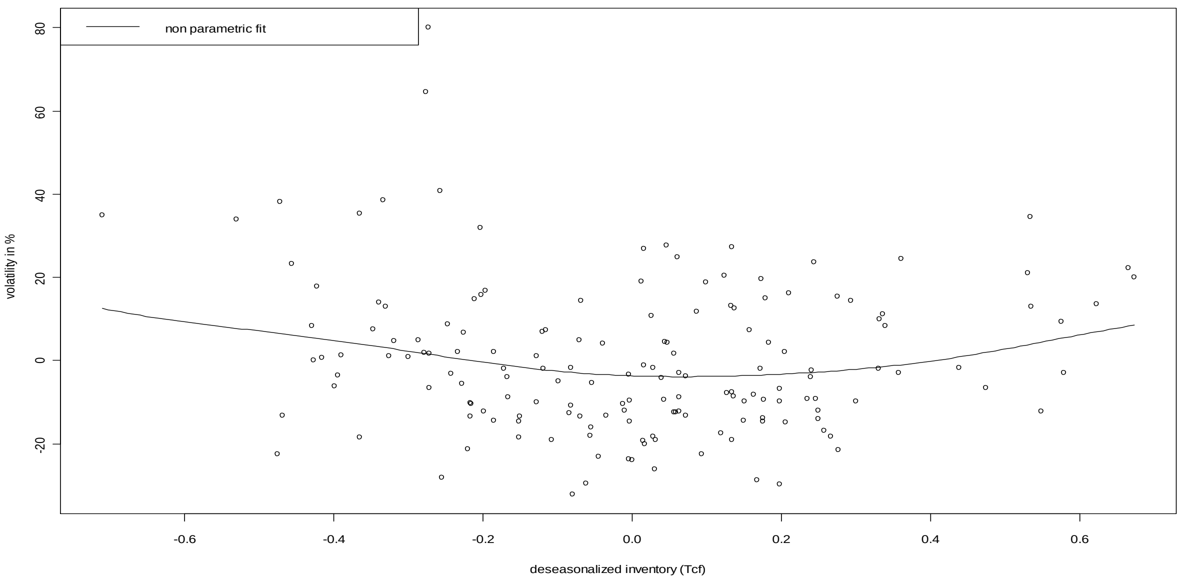

Fig 13: *Natural Gas deseasonalized volatility in terms of deseasonalized inventory and Nadaraya-Watson regression estimate with Gaussian kernel*

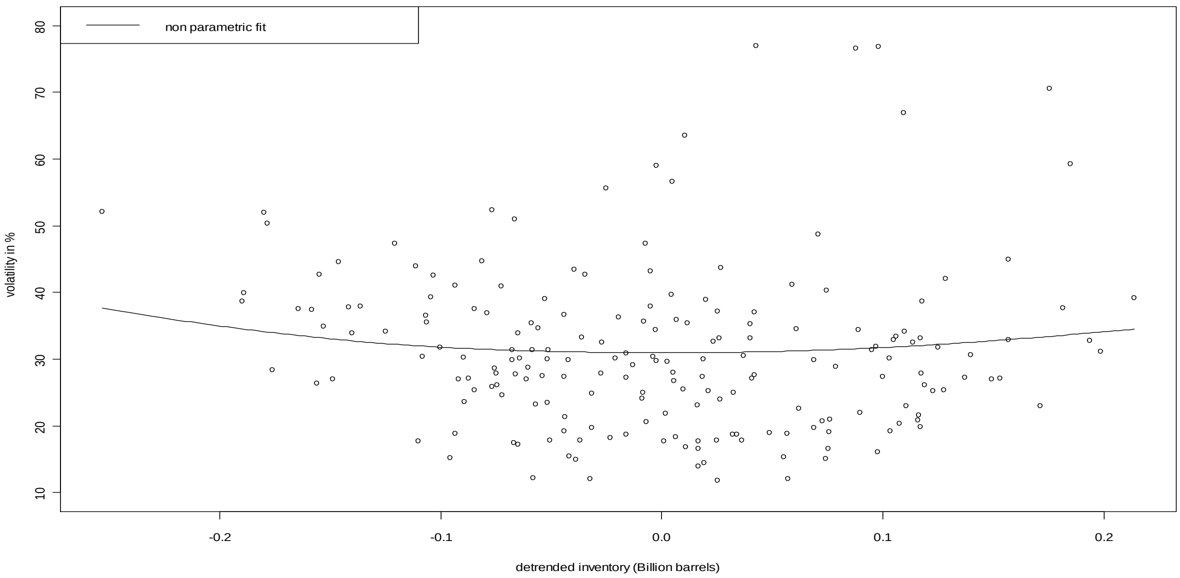

Fig 14: *Crude Oil volatility in terms of detrended inventory and Nadaraya-Watson regression estimate with Gaussian kernel*

Correlation tests:

Our purpose here is to study whether there is a significant negative correlation between volatility and inventory: we test the hypothesis H0 that the correlation between volatility and detrended/deseasonalized inventory is null; the alternative hypothesis is a negative correlation. For crude oil, we test the correlation between the detrended inventory and the original front-month volatility. For natural gas, we test successively the correlation between the deseasonalized inventory and:

- the original front-month volatility
- the deseasonalized front-month volatility

The test uses the Spearman rank correlation[5] to account for possible non linear dependence and to minimize the impact of extreme values of volatility (see for instance the Gulf War period for crude oil and the winters 1996 and 2003 for natural gas).

For each energy commodity, two tests are performed:

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[5] Given n pairs of observations (x_i, y_i), the (x_i) and (y_i) are separately assigned rank values. For each pair (x_i, y_i), the corresponding difference d_i between the ranks of x_i and y_i is found. The value R is defined by $R = \sum_{i=1}^{n} d_i^2$. For large samples, the test-statistic is then: $Z = \frac{6R - n(n^2 - 1)}{n(n+1)\sqrt{n-1}}$, which is approximately normally distributed under H0.

1) one for the whole period
2) the other restricted to the ***scarcity periods***, defined as those periods where the detrended/deseasonalized inventory is negative

In addition, for crude oil, we perform the correlation tests on the period Jan 1990-Aug 2006 and on the period May 1991-Aug 2006 (after the Gulf Warf episode), as the period Jan 1990-July 1991 experienced an abnormally high volatility due to high political tensions in major oil producing countries.

The results are displayed in Table 2 below:

	rank correlation	p-value
Gas original volatility		
Whole period	0.023	0.62
Scarcity periods	-0.38	0.000029
Gas deseasonalized volatility		
Whole period	-0.056	0.24
Scarcity periods	-0.49	2.71.10^-6
Oil January 1990/August 2006		
Whole period	-0.12	0.05
Scarcity periods	-0.22	0.01
Oil May 1991/August 2006		
Whole period	-0.16	0.01
Scarcity periods	-0.27	0.004

Tab 2: *Rank correlation tests between volatility and inventory: we test the hypothesis Ho that the correlation between original/deseasonalized volatility and detrended/deseasonalized inventory is null; the alternative hypothesis is a negative correlation. The Spearman's rank correlation and p-value of the tests are reported.*

The non-parametric fits in Figures 13 and 14 and the correlation tests exhibit a slightly negative correlation between the two variables over the whole period for crude oil only and a strong negative correlation for lower than average inventory (situation of "scarcity") for the two energy commodities. In addition, using one-month lagged or contemporaneous inventory does not change any of the results, conclusive or not, exhibited for both oil and natural gas (analysis available from the authors upon request).

We observe that the negative correlation during periods of scarcity is much higher in the case of natural gas. Apart from geopolitical events affecting the oil supply worldwide, this property may be explained by the fact that crude oil reserves have an estimated average lifetime of 30 to 35 years, roughly half of the 60 years of current consumption-based natural gas reserves. Hence, any information release on underground reserves' estimates has a major impact on price volatility.

Conclusion

We have analyzed in this paper the relationship between three quantities which are of crucial importance for all commodities, namely the spread of the forward curve, the available inventory and the spot price volatility. We have documented that for both crude oil and natural gas, inventory is indeed a good proxy for the adjusted spread, confirming and extending to energy commodities the conjecture made by Fama and French (1987) in the case of metals. Regarding the correlation between spot price volatility and inventory, we have exhibited that it is significant (and negative) only in those periods of scarcity when inventory is below its long run average. Lastly, this negative correlation is much higher for natural gas, suggesting that in the case of oil, geopolitical factors also play an important role in explaining price volatility.

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